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ANALYSIS OF UNDER-DECK CABLE STAYED BRIDGE AND COMBINED CABLE STAYED BRIDGE

AHMAD ZAKWAN BIN ZULKEFLY

Report submitted in partial fulfillment of the requirements for the awards of the degree of B.Eng (Hons) Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JULY 2015

SUPERVISOR'S DECLARATION

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of the degree of Bachelor of Civil Engineering.

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STUDENT'S DECLARATION

I declare that this thesis entitled "ANALYSIS OF UNDER-DECK CABLE STAYED BRIDGE AND COMBINED CABLE STAYED BRIDGE" is the result of my own research except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

This project report I dedicated to the most sincere,
Encik Khairul Anuar Bin Shahid (Supervisor)

To my beloved parents and family:
ZULKEFLY BIN HASSAN
ZAINOL BINTI TEH
NURUL DIYANAH BINTI ZULKEFLY
For their loving and never ending encouragement and support towards the success of this study.

Also, special thanks to all my beloved friends, course mates and faculty members

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Thanks to both of my parents on love, encouragement and support given to me during this research. Also do not forget all lecturers Faculty of Civil and Engineering and Earth Resources and others faculty for their guidance during my studies here.

Finally, an honorable mention goes to my fellow friend for their understanding and support on me in completing this research. Without their helps I wouldn't be able to finish this research.

ABSTRACT

Under-deck cable stayed bridge and combined cable stayed bridge is an unconventional cable bridge system which is instead of having cable stay above the deck like the conventional cable stayed system, the stays locates below the deck connected with the struts that as a pylon to the cable. In combined cable stayed system cable are both above and below the deck which like a mixing of conventional and unconventional design. The Purpose of this research is to study the principal theory of under-deck cable stayed and combined cable stayed system and analyses the behavior of the system and compared with the conventional cable stayed system. In this research 2D static analysis of highway bridge have been investigated to determine the maximum and minimum stress on cable and deck, resultant moment and deflection of the bridge. Five model of the bridge with single and multiple spans are considered in this research which are the conventional design, Under-deck cable stayed, Intradosed, Combined cable stayed and Extradosed-intradosed design. The research intended to analyses the effect of the location of the cable stays to the overall behavior of the bridge. The manipulated variable in this analysis shows that cable stay above the deck produced better result than below the deck. But under-deck cable stayed system still produce an acceptable result that gives an option to the engineer. The analysis is successfully done using finite element software, LUSAS.

ABSTRAK

"Under-deck cable stayed bridge" ialah sejenis jambatan kabel yang luar kebiasaan yang di mana tidak seperti jambatan kabel yang biasa yang ia mempunyai kabel yang terletak di atas dek, kabel terletak di bawah yangg disambung mengunakan batang besi yang bertindak sebagai menara sepertimana jambatan kabel biasa. "*combined cable stayed bridge"* pula mempunyai kabel yang terletak di atas dan di bawah dek seperti gabungan antara jambatan kabel biasa dan jambatan kabel luar biasa. Tujuan kajian ini adalah untuk menkaji prinsip theory *"Under-deck cable stayed bridge and combined cable stayed bridge"* dan menganalisa tidak balas system ini dan membandingkannya dengan jambatan kabel yang biasa. Dalam kajian ini, jambatan 2D static analisa telah dikaji untuk menentukan maksima dan minima tekanan di kabel jambatan dan dek, momen lentur, dan sesaran jambatan. Lima model jambatan dengan satu rentang, dan tiga rentang telah dikaji iaitu, '*conventional design', "Under-deck cable stayed", "Intradosed, Combined cable stayed"* dan *"Extradosed-intradosed bridge".* Kajian bertujuan untuk menentukan kesan lokasi kabel terhadap tindak balas keseluruhan jambatan. Pemalar yang berubah-ubah dalam analisa ini menunjukan kabel di atas dek memhasilkan keputusan yang lebih baik daripada kabel di bawah. Namun tetapi,*"Under-deck cable stayed bridge"* masih menghasilkan keputusan yang boleh diterima yang boleh memberi pilihan kepada jurutera. Analisis ini Berjaya dijalankan mengunakan perisian unsur terhingga, LUSAS.

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LIST OF SYMBOLS

Q_k	Live Load
G_k	Dead Load
w_r	Residual Area Width
E	Young's modulus of Elasticity
μ	Poisson's ratio
σ	Shear Stress
ε	Strain
A	Area
I	Moment of Inertia
F	Force

LIST OF ABBREVIATIONS

Al	Alluminium
AASHTO	American Association of State Highway and Transportation Officials
BS	British Standard Code
2D	Two Dimensions
FEM	Finite Element Methods

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Bridge is structure build carrying a road, railway, valley with a purpose of providing passage to cross over the obstacle. The structure spans horizontally between supports, whose function to carry vertical load with two supports holding up a beam. There are many different bridge design which all serve a different purpose and applicable in different situation. Bridge design different depend on the function of the bridge, the condition of the nature where bridge to be constructed, material used, and funds available to build it.

Bridges categorized in several different ways. Bridge classified by how the tension, compression, shear, bending and torsion are distributed through the structure. There are five common type of bridge. The first type of bridge is beam and girder type. Beam bridges are horizontal beams supported at each end by pier or abutment. The beam is simply supported when the beams only connect with a single spans, and continuous when the beams are connected with two or more spans. The bridge must be capable to resist twisting and bending under load. Under load, the beam's top surface is under compression while the bottom edge is stretched or placed under tension. The main beam could be I-section beam, trusses or box-girder. Box girder beam gives better resistance to torsion compared to I-section beam.

The second type of bridge is arch bridge. Arch bridges are characterized by their elegant forms that are supported by the abutment at each end as a curved arch. The load of an arch bridge is carried along the curve of the arch to the supports at each end.

Supports called abutment at either end transferred the weight and carried the load and hold the end of the bridge. These supports carry the load of entire bridge and responsible on holding the arch in the unmoving position. The structure is rigid and strong because of the weight pushes the surrounding rocks down and outward. The greater the degree of curvature, the greater the tension act at the bottom of the bridge. Arch bridges are commonly built with reinforced concrete that lowers the construction cost. A disadvantage of arch bridges is that number of materials required is higher than other type of bridge, even if the span is short.

Next is truss bridge. Truss is a configuration of triangular units composed structure connected at joints called the nodes. Slender and straight triangular unit form a truss. There are two structure design of truss that is space frame and planar frame. Space frame are truss attain 3-dimensional form while planar frame has a 2-dimensional design. Truss bridge is a load-bearing bridge superstructure that consists of truss. The triangular webs located between the long horizontal chords prevent the chords from flexing and bending. Truss can be analysis using the application of Newton's laws of motion according to the branch of physics known as static. Pin joint are point where the truss straight component meet. Truss bridge supported by the abutments at either end. There are many design used for truss bridge construction. The design is different on the configuration of the truss such a Howe truss, Pratt Truss, and Bailey truss. The disadvantages of the truss bridges are lack of aesthetic appeal and high construction cost.

Another type of bridge is suspension bridge. Suspension bridge consists of deck that is suspended from a steel wire cable that connected between the towers. The strength of the suspension bridge is very strong because of the cable. Their design is pleasing to the eye, and because of its suspension, the bridge is suitable for use in a range of lengths. Bridges that are more complex in design than the other types of bridges are the same and are more expensive to build. When built in soft ground, suspension bridges require extensive and expensive foundation work to combat the effects of the heavy load on foundation towers. The disadvantage is when suspension bridge is heavy, concentrated loads are involved.

The last common type of bridge is cable bridges. A cable-stayed bridge is a bridge design that uses large steel cables suspended from high towers or poles to support the bridge deck. The towers are the primary load-bearing structures that transmit the bridge loads to the ground. The tower of a cable-stayed bridge is responsible for reacting to the compressional forces. The cables attach to the roadway to support the span of the bridge. The cables are in tension while the deck is in compression. The advantage of cable bridges is the spans are self-anchoring therefore no need for anchorages to support strong horizontal forces. The construction cost is less than suspension bridges for a given span. Less steel cable required and they are faster to build.

Cable stayed bridge can be classified into two categories that is conventional and unconventional. Conventional cable stayed bridge is describe as the common type of cable stayed bridge used. Standard cable stayed and extradosed bridges are the conventional design used on the cable bridges construction. Extradosed bridges describe as the mix of the girder bridge and the cable-stayed bridge. The decks are supported by the tower of the deck act as a continuous beam. The cable stays act as pre-stressing cables for a concrete deck, whether made with I-beam or box girder. Extradosed bridges are very expensive and material not very efficient. Extradosed bridges show that more variation of cable bridges can be design with more efficiency.

The used of tendon are basic on the cable bridge design with conventional type bridge tendon are located above the deck. When the tendons are situated within the deck and inside the concrete cross-section, the case is referred as the bridge with internal pre-stressing. When tendons are within the deck but outside cross-section, the case describe as bridge with external pre-stressing. Conventional bridges are when the tendon are outside the cross section and above the deck. From this classification, there are new alternatives to the two types of conventional bridge emerge that is when new configuration of tendon location are propose. The tendon may locate below the deck, or both above and below the deck. This new classification scheme is categories as the unconventional bridges.

Unconventional bridges are separated into two types that is under-deck cable-stayed bridges and combined cable-stayed bridges. Under-deck cable stayed bridges are bridges in which the tendons are located below the intrados of the deck. They are distinguish into two different classes, which is under-deck cable stayed bridge that has high contribution response to traffic live load and intradosed bridge that is low contribution to traffic live load. In under-deck cable stayed bridge, the stay cables shape is polygonal layout under the intrados of the deck and anchored to the deck at the support section. Combined cable-stayed are bridges in which the tendons are located both above the extrados and below the intrados of the deck. They are also distinguish into two classes that are, combined cable-stayed bridges that has high contribution to the traffic live load and extradosed-intradosed pre-stressing bridge with low contribution to live load. In combined, the stay cable located both above extradosed and below intradosed of the deck.

As the bridge structure that to be analysis includes the different type of design, the best possible way to analyses the many different type of bridge with efficiency is by using engineering software. In general, the process of analysis and design is a long process and required a lot of time and oversights may apply if the process is not executed properly. In the modern era, the use of computers in engineering is increasingly widespread. with the help of computer software LUSAS, the time and cost of analysis and design can be saved. Moreover, analysis using computer software is more accurate and easy to use. Six different type of conventional and unconventional bridge will be analyses and compared. The loading being applied is considering dead load and live load. The analyses are including checking off the resultant moment, and resultant shear, deflection, at the mid-span of the bridges.

1.2 PROBLEM STATEMENT

The purpose of design in bridge engineering focuses on four areas of concern, which are safety, serviceability, economy and aesthetics. Every bridge design presents complicated factors to consider, such as the geology of the surrounding area, the amount of traffic, weather and construction materials. Sometimes these factors are miscalculated, or something happens that bridge designer did not expect. The failure of bridges is of special concern for structural engineers in trying to learn lessons important to bridge design, construction and maintenance.

Cable bridges are one the best and excellent bridges structure design in bridges engineering when comes to a bridge with significance length. The bridge, archive the perfection because of the pre-stressing. Pre-stressing using the tendons are one of the powerful tools that allow structural engineers to apply stresses to a structure. The cable supported by the tower called pylons located at the middle span of the bridge that transfers the load to the foundation. The problems occur when there is no possible way to construct a pylon because of the obstacle below the bridge such road and etc. Therefore the new types of bridge such as under-deck cable stayed bridge are designed.

The location to build the abutments or piers needed a strong type of soil to hold up the foundation. The problem occurs when there is the presence of the creeping soil at the abutment or piers location. Laying the foundation for the piers near the abutment would have been very complicated and expensive. The problem can be solved when the end piers were replaced by the under-deck cable stayed bridge system. When propose the design of the bridge, the aesthetic value must be considered. The unconventional bridge design can solve the problem. Sometimes, the bridge location has a beautifully scenery but blocked by the pylon and cable of the bridge. Under-deck cable stayed bridge will solve the problem because the cable of the bridges located under the bridge.

1.3 OBJECTIVES

The main objectives of this research are:

i. To study the principle component of under-deck cable stayed bridge and combined cable stayed bridge.

ii. To analyze the behavior of the under-deck cable stayed bridge and combined cable stayed bridge.

iii. Compared the behavior of the conventional bridges and unconventional bridges.

1.4 SCOPE OF STUDY

Before carried out the research, a few scope of the research are determined:-

i. The modeling and analysis of the bridge will be using a Finite Element Analysis Methods (FEM) which is LUSAS.
ii. Geometric parameters of the bridge determined, the length of the span are 150m, with a width 10mm.
iii. Six model of bridge are will be analyses including both conventional and unconventional.

Conventional Bridges:-

1. Cable Stayed Bridge
2. Extradosed Bridge

Unconventional Bridges:-

1. Under-deck Cable Stayed Bridges
2. Intradosed Bridges
3. Combined Cable stayed Bridge
4. Bridge with Combine Pre-stressing

iv. Shear, resultant moment, and deflection will be check.
v. Types of loading applied are dead load and live load only that are applied along the bridge deck
vi. The wind load will be neglected.

1.5 SIGNIFICANCE OF RESEARCH

Commonly, this type of analysis is always being conducted using numerical method or manual calculation. Lacks of research are done by using computer software such as ANSYS, LUSAS, and etc. that happened because of lacks of expertise in this field that capable on using this software. The limited experts lead to the lack of exposure of this software in engineering field. By conducting this research, the knowledge of the capability of the software will be exposed. By using the software to perform the analysis of the structure, we can save a lot of time.

This research is about the study of tendons arrangement and configuration that are covered two new types of cable stayed bridges, which is under-deck cable stayed bridge and combined cable stayed bridge. If the research are proves to be successful, engineer will take advantage to solve their problems. This research will help the engineer in determining the type of tendons arrangement to be used for the specific length of the span. Result on shear, moment and deflection will give the engineer more option on determine the best possible design for the specific condition of the bridges.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Bridge is very important structure in our life because the functionalities of the bridge which is to connecting one point to the other across over obstacle such as river, sea, or roadway. There are many type of bridge design by the engineer with their own advantages. This research will be specifically studies on the cable stayed bridge that are very economical and suitable for a long span bridge. There are a few type of bridge that capable of having a long span which is suspension bridge and cable stayed bridge. However, cable stayed bridges are far more economical and provide more aesthetic view of the bridge.

Nowadays, engineers are trying to improve the cable stayed to be more efficient and economical while keeping the aesthetic view of the bridge. Then unconventional bridge design is produced called under-deck cable stayed where the arrangement and location of the cable stayed are below the deck. The purpose of this chapter is to discuss about the previous studies of the unconventional cable stayed bridge by the engineer with comparison to the conventional designs that cover the linear static analysis, the main component for each design, compression, and tension.

2.2 HIGHWAY BRIDGE

The bridge also can be classified in the aspect of use and functionalities. The group can be different in load distribution, design and construction cost. There are four types of bridge that have different function. There are pedestrian bridges, highway bridges, railroad bridges, and pipelines bridges.

Pedestrian bridge is a type bridge design for pedestrian used only. The load of the bridge might be different because the bridge only supported smaller load such people and cyclist. Different with highway bridges, where greater load such car, lorry or truck must be supported by the bridges. The, most commonly constructed highway bridges are slab and girder bridges. The girders made of either steel or prestressed concrete while the slabs are cast-in-situ reinforced concrete slabs to avoid structure failure. (A.Y.C Wong 2006)

Railroad bridge are bridge specifically design for train usage. Railroad Bridge in the modern world commonly transports a high speeds train. The engineer must ensure that bridge able to support the high velocity bridges. Other bridge that have a specifically task is pipelines bridges. The bridges are usually used only to carry the pipeline across water or terrain. The load for Pipelines Bridge usually smaller than other type bridge whether it carry water, air or gas.

2.3 GENERAL BEHAVIORS OF CABLE STAYED BRIDGE

Conventionally, cable stayed bridge is a bridge that the deck support by pylons erected above the piers in the middle of the span. The cables are attached to the girder to provide additional supports to the deck. A cable-stay bridge is supported by steel cords running directly between the roadway and the towers.

Bridges must be able to confront several types of forces. The two most common forces to model bridges are compression and tension, which are pushing and pulling respectively.

2.3.1 Compression

Compression is a pushing or compressing force. The shorter an object is, the more compression it can hold or otherwise. When a slender object is being compressed, the object starts to bend. When a piece of wood breaks because of compression, it is called buckling failure. Typically the deck of a bridge will be in compression

2.3.2 Tension

Tension is describes as the pulling force exerted by each end of the object. Tension is when we are pulling something apart from each end, and thus stretching it longer. Tension is the opposite of compression. Normally in the bridge structures, the cable will be in tension mode.

Bridges were built for a reason to cross waterways to get to the other side. These structures must capable of supporting their own weight and live weight such as people or vehicle. Compression and tension are force that helps to fulfill this goal. Compression is a force acts to compress or shorten. Tension is the force that stretches or longer objects apart. Compression and tension cause objects to become shorter or longer. Together, tension and compression help bridges remain standing and balanced. The roadway of a bridge is in compressions. And the underside of that roadway is in tension. These forces must be balance to prevent structure failure.

Bridges are designed to remain standing on whatever condition or force acting on the structure. The force such as winds, ocean wave, river currents, and earthquakes is the type of force that the bridge can handle. Bridges have a horizontal component that stretches across a stream or road. Live loads that are the weight of the vehicles or people traveling on the bridge's deck compresses or pushes down vertically on the beam of the bridge. While the bottom of the beams are in tensioned.

The picture below has shown the mechanism on how the tension and compression force act to each other to stabilize the bridges.

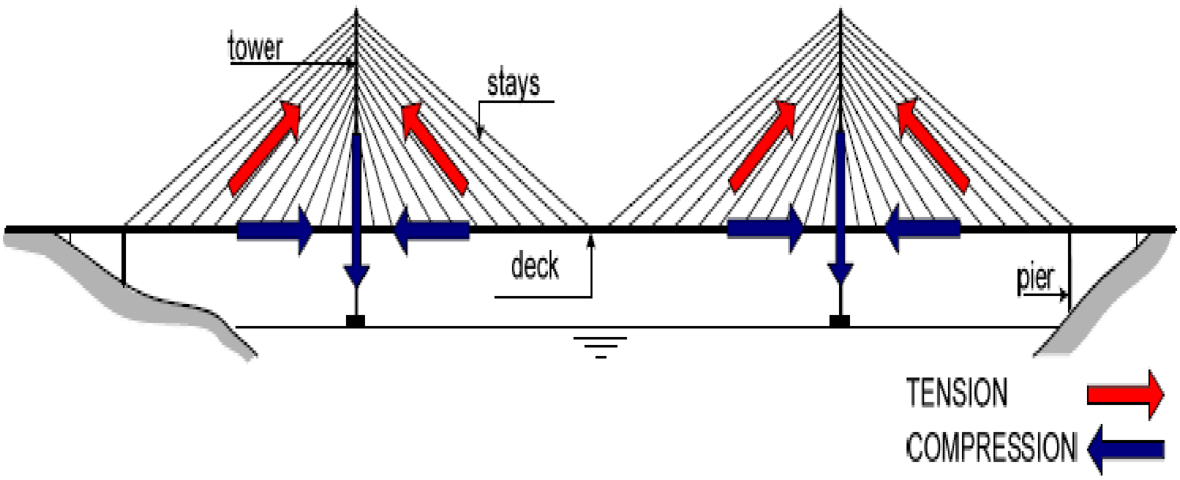

Figure 2.1: Tension and Compression of the Cable Stayed Bridge

Source: C.M.C Calado, 2011

2.4 LOADS

A structure are designed to resist gravity loads, it includes live load (Q_k) and dead loads (G_k). In general, the principal loading for highway bridges is designed by the truck loading.

2.4.1 Dead Load

Dead load is a load that defined as the load that not considered changing during the lifetime of the structure. This load can also be considered as existing load. Dead loads always remain and act on a bridge throughout its life. Dead load is the gravity load due to the self-weight of the structural and non-structural element permanently connected to the bridge. Examples of dead loads are the weight of the concrete slab, walls and finishes on floors or walls. Dead load easier because the size is determined by the thickness and volume of each component can be determined.

Superimposed dead loads are load that placed on the superstructure after the deck has cured and began to work with the primary member in resisting loads. Different from the dead load, superimposed dead load is resisted by a composite section, therefore cause less deflection and stress in the stringer that other dead load. (JJ Zhao, 2007).

2.4.2 Live Load

Live load is defined as the load that not considered fixed and the variable depends on the time and usefulness space that designed. Due to the use of space are different, the load determination are more difficult. Therefore, the designer usually refers to a specific design code. Codes of practice are frequently used in Malaysia country is the code of practice BS6399 - British Standard for Building Design Loading Part 1 (Code of Practice for Dead and Imposed load). Examples of live load commonly used in residential, office, hospital, shops and other.

In addition, there is also live load is considered a special case of live load. This is because the load can be defined as a dynamic load which the strength is variable according to time. The load are wind load and the earthquake load.

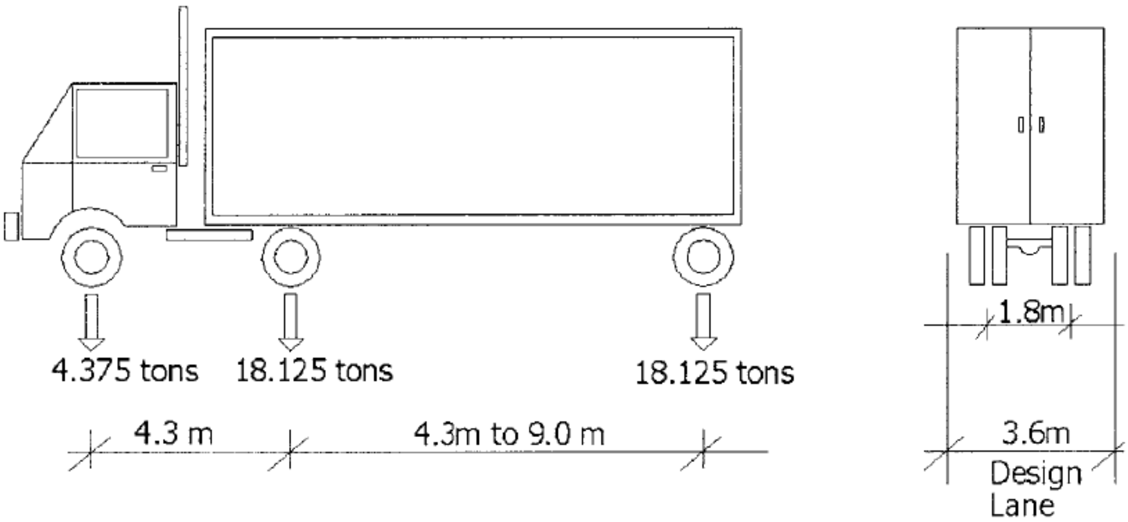

Figure 2.2: AASHTO Live Load Truck Loading

Source: E. Davalos, 2000

2.5 CONVENTIONAL CABLE STAYED BRIDGE

Conventional cable stayed bridge is a standard design of the bridge where the cable of the bridge is located above the deck. The bridge has a single continuous span suspended by cable connect at the two tower called pylon that bearing the bridge span at the central pier.

Pietro Pedrozzi (2004) stated that the main advantages of cable-stayed bridges is that they can be built with very large spans (today with a central span of up to 900 meters) by free cantilevering provide a large stiffness, need little material and can look quite elegant.

2.5.1 Deck

The deck is the main component of the bridge that carried the functionality of the bridge which is for crossing from one point to the other point. The main objective of others component of the bridge such as pier, cable, abutment, and pylon are to support the deck. The main loads of the bridges are located mostly on the deck. The decks carried longitudinal and transverse bending moment and distribute point loads to cables. Deck properties or material depend on the longitudinal and transverse layout of the stay cables. (J. Juvani et al 2012). The deck can be made from different material such as steel, concrete or composite deck.

The main reason extradosed bridges describe as the combination of girder bridges and cable stayed bridge is because the bridge's deck used is a box girder beam. The box girder shape beam used because to accommodate the external pre-stressing of the bridge. The deck of the bridge must be slender to be more sensitive to live load. (Chio 2000). And the results obtained by Ruiz-Terán (2005) show that if the slenderness ratio decrease due to decrease of deck depth, the stressing effectiveness also increase thus making the bridge most sensitive to over loads. The deck must be supported by the pier and not fixed to the pier to produces deflection downwards and upwards in side spans.

2.5.2 Pylon

Tower or pylon for cable stayed bridge functionality is to support the axial force of the vertical component of the bridge through the cables attached to the pylon. There is various design of pylon for conventional cable stayed bridge such as single, twin, portal and A-shaped towers.

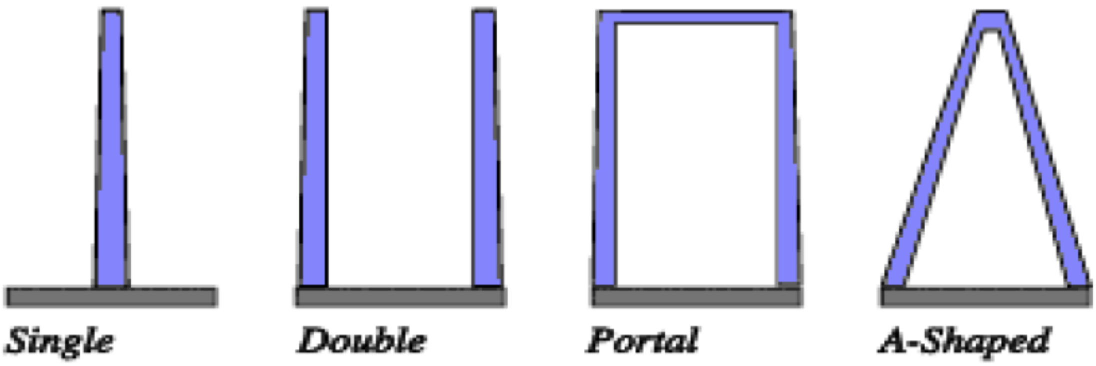

Figure 2.3: Tower Types

Source: J. Juvani et al, 2012

Portal shape is consider the best type at the earliest stage of cable stayed bridge construction to overcome the strong wind load acting at the pylon. Latest investigation indicated that the horizontal forces of the cables were very small so that free standing towers could be used without a major problem. (J. Juvani et al 2012).

2.5.3 Cable

The cable is a basic component in all cable-stayed bridges. Cables use in cable bridge engineering are made from high quality steel that have high tensile strength and high elastic modulus. Cable also must have a satisfactory fatigue strength that makes them extremely strong and flexible against axial tension. However cable are weak with bending forces and compression that make long span bridge vulnerable to the wind load.

It is important that the cables have a good corrosion resistance. The used of steel cable are very popular because they are very economical as they allow a slender and lighter structure capable of bearing a long span bridges.

The arrangement of cable at the pylon also influences the performance of conventional cable stayed bridges. There are three major types of cable stayed arrangement that are Harp arrangement, fan arrangement and semi-fan arrangement. The choice of cables arrangement depends mainly on the mechanical properties, structural properties and economic criteria. (Olfat Sarhang Zadeh, 2012)

a) Harp Arrangement

Harp arrangement is where the cable position are made nearly parallel to each other by attaching them to different point on the pylon. From economical view, the cable are not efficient for a long span bridges because it requires more steel for the cable, more compression acting on the deck and also produces bending moment in the pylon. However, parallel cable gives more pleasant appearance from the aesthetic perspective. (O.S. Zadeh,2012)

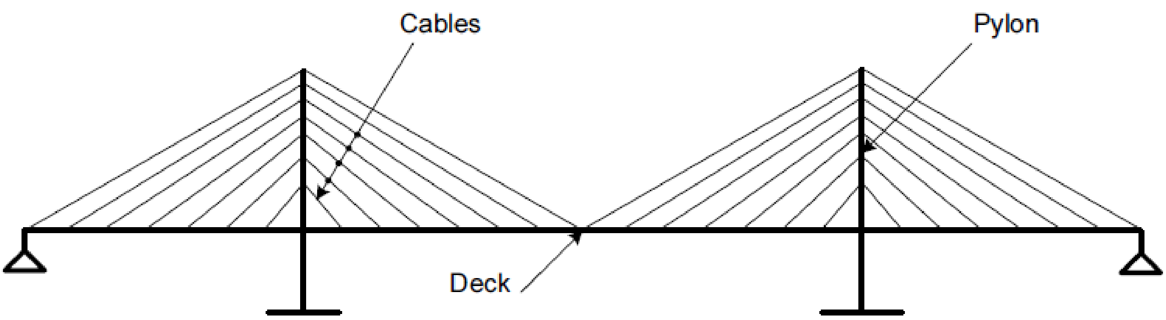

Figure 2.4: Harp Arrangement

Source: O.S. Zadeh, 2012

b) Fan arrangement

For fan arrangement, cable are attach to a single point on the pylon. Steep slope of the cable stayed bridge result a smaller cable cross-section compare to harp type. By increasing the number of the stay cables, the weight of the anchorages also increase but the construction process will be difficult. (O.S. Zadeh, 2012)

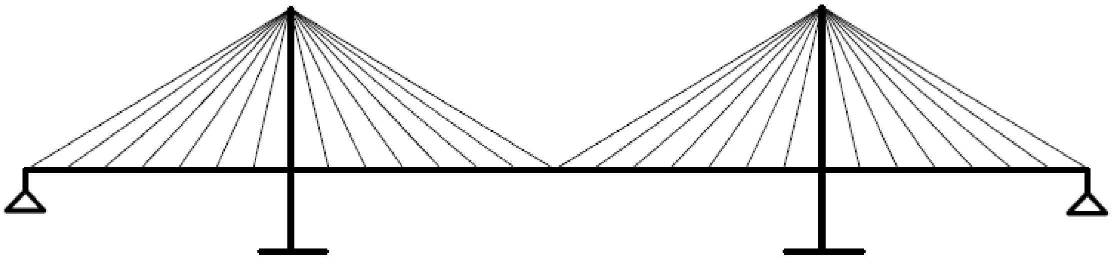

Figure 2.5: Fan arrangement

Source: O.S. Zadeh, 2012

c) Semi-fan

The semi-fan arrangement has better aesthetic appearance in comparison to the fan arrangement. The cable have more steeply inclined close to the pylon and distributed over the upper part of the pylons.

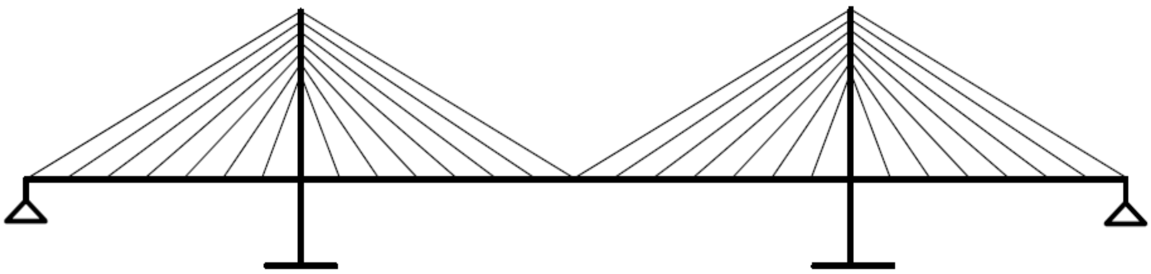

Figure 2.6: Semi-Fan Arrangement

Source: O.S. Zadeh, 2012

2.6 UNDER-DECK CABLE STAYED BRIDGE

Under-deck cable-stayed bridges are innovative bridge with different configurations than conventional design in which stays cable are located underneath the deck. The major different between the standard cable stayed bridge and under-deck cable stayed bridge is the location of the tendon anchor to the deck of the bridges which is at the top and bottom of the bridge respectively. Unlike the conventional design, the under-deck cable stayed bridge cable not anchored by the pylon to transfer the force from the cable to the substructure of the bridge. The steel struts are used and act as the pylon of the bridge to anchor the cable. The cable is considered self-anchor to the deck of the bridges.

This new type of cable stayed bridge purposely design to overcome the standard cable stayed bridges weaknesses. Bridge engineers proposed this new design to make the construction of the cable stayed bridge is more economical, more stable structure, reduce the maintenance and also comfort to the user. (Ruiz Teran, 2010)

2.6.1 Deck

Design of the deck of under-deck cable stayed bridges is basically the same as any other cable stayed bridges. The different of this system is the strut is connected at the bottom of the deck. The deck is connected with bolt and rivet to the strut to hold the polygonal arrangement cable at the bottom of the cable.

Ruiz-Teran (2010) stated that steel-concrete composite deck studied to be the best suitable material for under-deck cable systems because the flexibility of the systems response with the axial load. Furthermore, apart from being lightweight solutions with high durability, composite decks allow for a high proportion of prefabrication with its obvious advantages which is quality, precision, safety and construction speed.

The span of the bridge can be either single or multi-span. Under-deck cable systems are very appropriate for single-span bridges. The used of under deck cable staying systems in viaducts allows the elimination of certain piers to the deck of the bridge. Despite the particular span in the viaduct being double the length of the other spans, the characteristics of the deck such as depth, concrete strength, amount of reinforcement, and amount of steel still can be maintained.

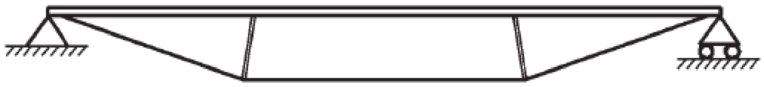

Figure 2.7: Single Span Under-Deck Cable Stayed Bridge

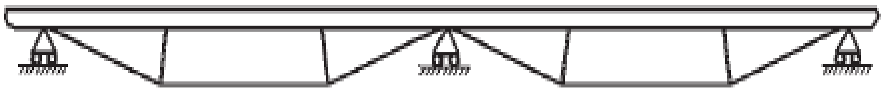

Figure 2.8: Multi-Span Under-Deck Cable Stayed Bridge

Source: A.M. Ruiz Teran, 2010

2.6.2 Strut

Strut function at the under deck cable system is the same as pylon on the conventional system that is to hold the cable. The strut is connected at the bottom of the deck. The system is considered self-anchor because of the elimination of pier and pylon of the bridges. Engineers have proposed several design of the strut. The design majorly different on the number of the struts implement on the system.

The number of the strut depends on the type and condition of the bridge to be constructed. The number of strut can be either single, double or multiple. Javier Manterola was the first engineer designs the under-deck system implement the single strut on the Osormort viaduct. If number of struts increase, the efficiency of the stay cables also increase. Pin connection between the struts and the deck are more effective for the bending moments in the slender deck (Ruiz-Teran and Aparicio, 2008a).

Tobu Recreation Resort footbridge in Japan was the first under-deck cable-stayed bridge designed with multiple struts. The bridges are design by Toyo Ito & Associates in 1998. The connection between the deck and all strut are pinned with the exception of a fixed connection at the mid-span. The design highlighted the capabilities of bearing the vibration due to live load. (Tsunomoto and Ohnuma, 2002)

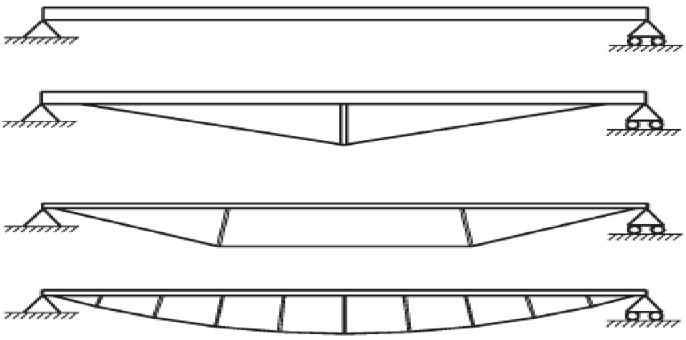

Figure 2.9: Strut Arrangement

Source: A.M. Ruiz Teran, 2010

2.6.3 Cable

The different between the under-deck cable stayed systems with the conventional system is the location of the stay cable with bottom and top respectively. Cables properties in this system are made from high quality steel that have high tensile strength and high elastic modulus. The cable is self-anchored in the deck provide elastic supports to the deck through the struts, reducing the bending moments acting on the bridge as a consequence.

There are two cable arrangements for under-deck cable stayed system which is concentrated and expanded transverse cable arrangements. As the figure shown, the strut is pinned to the deck of the cable. The connection between the struts and the deck completely release the rotation at the transverse Y-axis. The axial load introduces at the centroid of the deck exerted by the cable through the compressed struts to avoid local buckling.

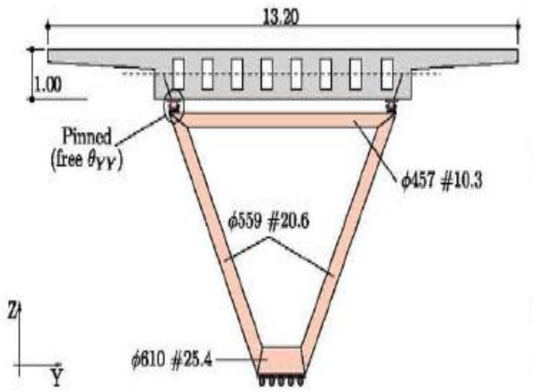

Figure 2.10: Concentrated Cable arrangement

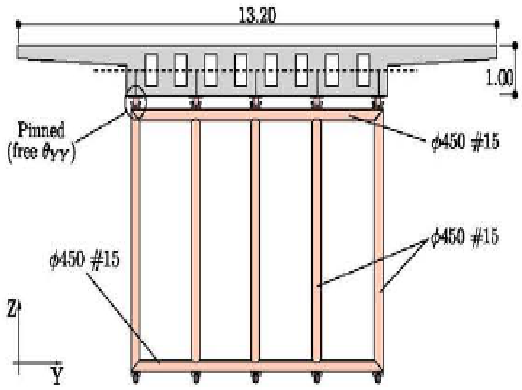

Figure 2.11: Expended cable arrangement

Source: A. Camara et al, 2013

2.7 COMBINED CABLE STAYED BRIDGE

Combined cable stayed bridge is the combination of conventional cable system and unconventional cable system which mean the bridge have both cable stay at the top and bottom of the deck. In having both cable at top and bottom, mean that this system will have both pylons and struts on the same system. For the stay cables are above the deck, they are deflected by the pylons that take the cable downward deviation forces directly to the supports and for the stay cables are below the intrados of the deck, they have a polygonal layout and are deflected by struts that, under compression, introduce the cable upward deviation forces into the deck.

The first combined cable stayed system used is Obere Argen viaduct in Germany designed by Jorg Schlaich in 1991. The unconventional cable stayed system is introduced to the conventional system to avoid construction at the end of the pier viaducts. The elimination of the end piers is possible by prestressing the stay cables.

This system is suitable for area that have creeping soil at both end because the used of abutment will be more costly. (Ruiz-Teran, 2010)

2.7.1 Deck

The deck of combined cable stayed bridge is connected to both pylons and struts. The deck is under compression force against the tension from the cable stayed. The material of the deck can be steel, concrete or composite steel-concrete. In the construction of the Obere Argen viaduct in Germany, Jorg Schlaich chose a steel box-girder with angled struts supporting the transverse cantilever for the deck.

Under-deck cable systems and combined cable stayed system are very appropriate for single-span bridges. For continuous bridges, only combined cable-staying systems have a high efficiency under traffic live load (Ruiz-Teran and Aparicio, 2007b). Combined cable-stayed bridges required about half the cross sectional area for the cables compared with under-deck cable stayed systems because of the higher effective eccentricity of the combined cable-staying systems.

Figure 2.12: Single Span Combined Cable Stayed Bridge

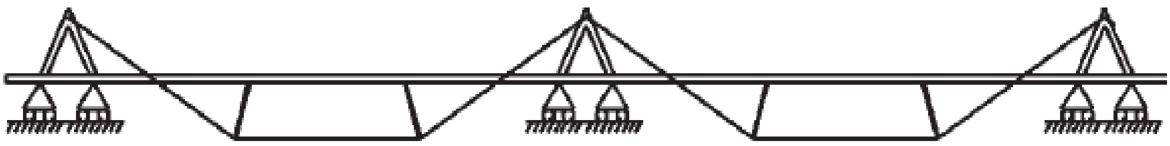

Figure 2.13: Multi-span Combined Cable Stayed Bridge

Source: A.M. Ruiz Teran, 2010

2.7.2 Pylon and strut

The combined cable stayed systems have both pylon and struts. Both pylons and struts are under compression**.** The pylon and struts function is to hold the cable and support the axial force of the vertical component. The pylon shape the same as conventional cable stayed bridge can be single, twin, portal and A-shaped and the struts can be single, double or multiple.

The combined cable stayed bridges system proved to be more costly because of the existence of pylons but, the used of slender deck shown that the combined system will be more economical than conventional bridge.

2.7.3 Cable

The cables of the combined system are connected at both pylons and struts using the same cable. The cables are connected at top of the pylons and at the bottom of the struts. Cable must have high fatigue strength, tensile strength and elastic modulus that capable of handling the extremely strong axial tension. Cables use in this systems are made from high quality steel to prevent any failure happened on the bridges.

The stay cables are deflected by the pylons that take the cable downward deviation forces directly to the supports. The struts deflected the cable the stay cables introduce the cable upward deviation forces into the deck.

2.8 GLOBAL ANALYSIS ON CONVENTIONAL CABLE STAYED BRIDGE

Elizabeth Devalos (2006) had done a research to study the behavior of the cable stayed bridges. The main focus is to studies the basic structural behavior of each of the component of cable-stayed bridges and to presenting the analysis of a specific cable-stayed bridge which was proposed on the Charles River Crossing. The bridge has a single tower with a fan longitudinal cable stayed system and two plane inclined transverse system. The cable anchored to back span piers provides support for the tower. The studies showed that for the effective modulus of elasticity, the stiffness of the cable decrease as the sag increase. The tower behavior is governed by the axial force from the vertical reaction of the cables and weight of the tower. The tower is subjected to deformation due to live load.

Cabeçadas Calado (2011) also conducted a research regarding the structure behavior of the cable stayed bridges. The research describes the structural behavior of cable-stayed bridges, identifies cable-stayed bridge elements, and discusses the cable role in supporting the structure. He presents methods of pre-sizing the stays and describes a mathematical procedure that allows optimal tensioning of forces in the cable stays, so that the structure complies with the design criteria. A parametric study of a bridge structure similar to the Vasco da Gama Bridge in Portugal was carried out to understand the suspension, static and longitudinal system. The main focused is to analyze the deformation and stresses in the bridge deck. Various arrangements of stay are subjected to the research with pier in the side span and without. The research concludes that the existence of piers in the side span will decrease the displacement of the bridge deck and will also decrease the tower displacements.

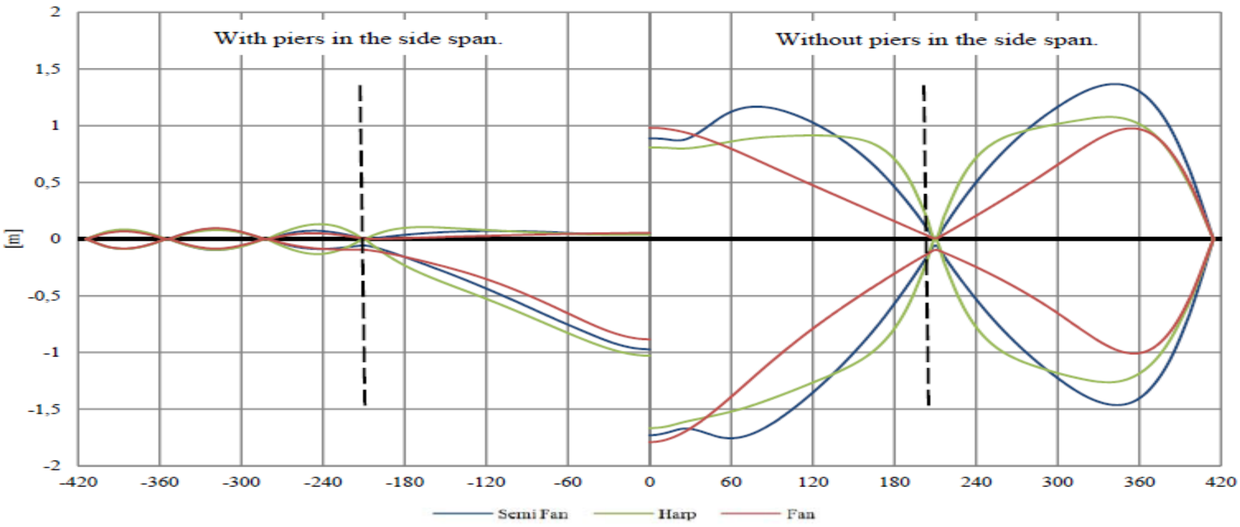

Figure 2.14: Bridge deck displacement under live load for three different cable arrangements

Source : C.M.C. Calado, 2011

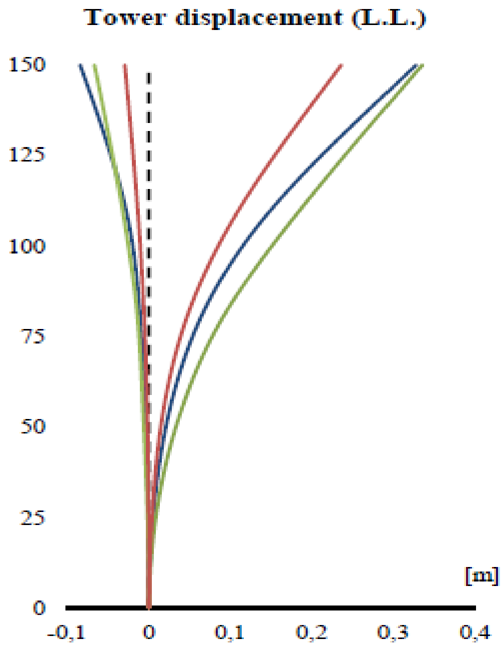

Figure 2.15: Tower Displacement under live load

Source: C.M.C. Calado 2011

2.8.1 GLOBAL ANALYSIS ON UNCONVENTIONAL CABLE STAYED BRIDGE

Ruiz-Teran (2007) has conducted a research about two new types of bridges that is under-deck cable stayed bridge and combined cable stayed bridge. Four new designs are considered that are under-deck cable bridges, intradosed bridges, combined cable stayed bridge and combined extradosed-intradosed bridge. 80 m single-span under-deck cable stayed bridge were considered with two or multiple (15) diverting struts along the Deck. Three different types of loading have been considered that are uniform live load, point load that applied at the mid-span, and two bending moments applied at the supports. The response of the structure in forces and deflections has been obtained, resolving the structure using the flexibility method.

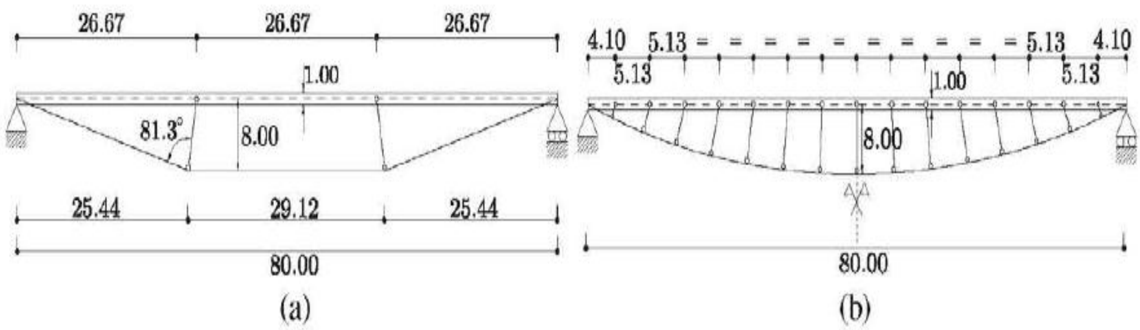

Figure 2.16: Parameter of the bridges

Source: A. Camara et al, 2013

To design the stay cable layouts with large eccentricities at the critical sections of the deck is necessary, in order to design cable-staying systems that are efficient under live load. The bridge also must be design with a small rigidity of the deck to the cable-staying system. Both conditions make cable-stayed bridges capable to resist the traffic live load by axial response rather than by flexural response. The bending moment due to traffic load are significantly different to the conventional bridges without stay cables. High efficiencies can be easily achieved in these types of bridges.

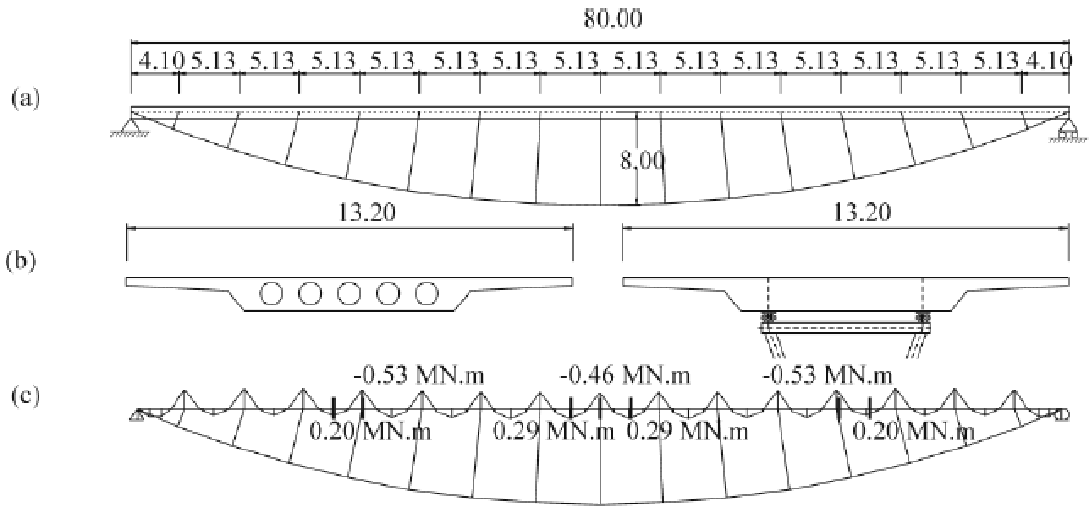

Figure 2.17: Bending Moment

Source: A.M. Ruiz Teran, 2010

Ieva Misiunaite (2013) also had done a research on this new morphology of a cable-staying system for an under-deck cable-stayed bridge. The research is proposed about computational method that been derived for a one-strut conventional cable staying system and unconventional double-level cable-staying system. An analysis of the non-linear analysis of simply supported and additionally restrained beam-column using finite element software ANSYS was carried out to present the accuracy of the proposed method. The paper also demonstrates comparison analysis between the conventional and unconventional structural schemes for the under-deck cable-stayed bridge under symmetric and asymmetric loading. The research noted that continuous main beam in under-deck cable stayed system structures is sensible to the deformations of cable-staying system and asymmetric loading. The inappropriate adoption of structural rigidities of the elements refers to the irrational bending moment's distribution of the main girder.

Table 2.1: Result From the Research (I. *Misiūnaitė, 2013*)

	Symmetric Loading		
	Simplified Analysis	**FE analyse with ANSYS**	**Errors**
Bending moments	**Distributed transfer load on the span: q = 20kN/m**		
***M(z=l/4)* (kNm)**	**278.3**	**277.9**	**-0.12%**
***M(z=3l/4)*(kNm)**	**278.3**	**277.9**	**-0.12%**
Displacement			
***v(z=l/4)* (mm)**	**76.6**	**76.3**	**-0.34%**
***v(z=3l/4)* (mm)**	**118.8**	**118.5**	**-0.30%**
	Asymmetric loading		
Bending moments	**Distributed transfer load on the sub-span: q=20kN/m**		
***M(z=l/4)* (kNm)**	**261.7**	**261.6**	**-0.03%**
***M(z=3l/4)*(kNm)**	**261.7**	**261.3**	**-0.13%**
Displacement			
***v(z=l/4)* (mm)**	**67.2**	**67.5**	**0.48%**
***v(z=3l/4)* (mm)**	**98.3**	**98.0**	**-0.23%**
	Asymmetric loading		
Bending moments	**Distributed transverse load on the sub-span: q=10kN/m**		
***M(z=l/4)* (kNm)**	**135.7**	**135.6**	**-0.09%**
***M(z=3l/4)*(kNm)**	**135.7**	**135.8**	**0.01%**
Displacement			
***v(z=l/4)* (mm)**	**43.4**	**43.7**	**0.69%**
***v(z=3l/4)* (mm)**	**74.4**	**74.4**	**-0.05%**

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter is prepared to provide a methodology to get static measurement of under-deck cable stayed bridges and combined cable stayed bridges by using finite element method then compared with numerical calculation. The bridges structure with dimensions that have been determined had been built as a model and then analyzed using the software LUSAS. In this software, the finite element method was used to analyze the structure of this bridge.

In this thesis study, several stages of the procedure should be done as an understanding of the software LUSAS, collecting information related to the study as well as process modeling and analysis.

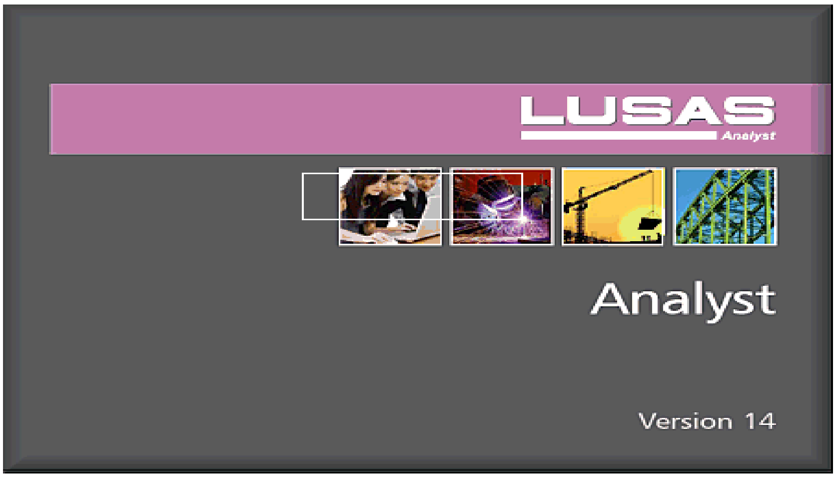

Figure 3.1: Lusas Analysis Software

3.2 PROJECT FLOW CHART

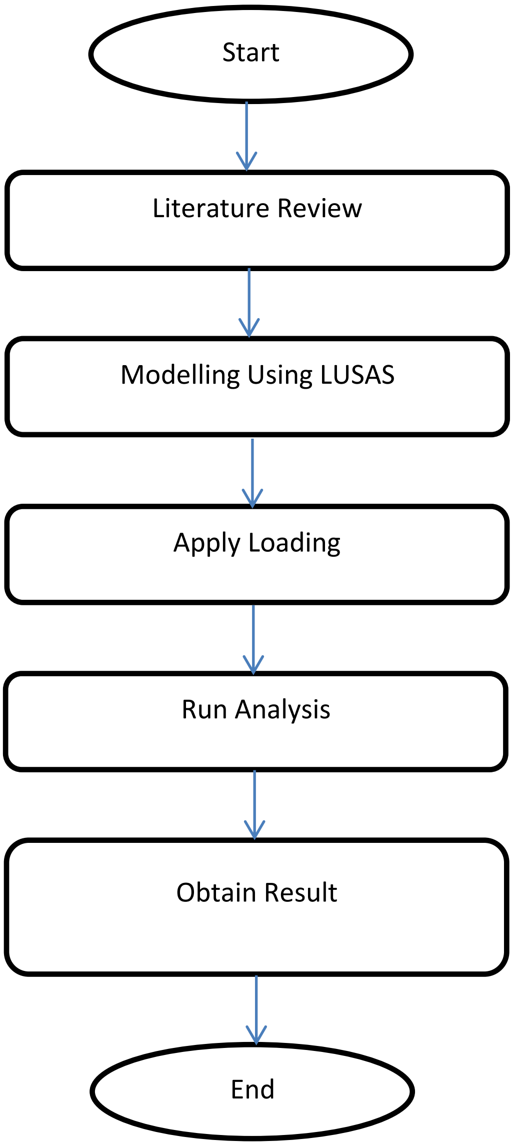

Figure 3.2: Project Flow Chart

The flow chart represents the methodology of this research. The first step is doing the literature review. Main point for literature review is to come out with the problem statement. This study is being done because of some bridge failure are because of failure in static measurement whether because of the overloading or cannot with stand their own load. Review of past research can provide us the idea on how to conduct the research. Also provide us with a brief idea including determination of material, code, load and others which can be obtain from journal, book or others.

Second step on this methodology is modeling the structure using the finite element software with in this case is LUSAS. The description or parameter of the bridges needs to be sketch up first before modeled in the LUSAS software. The modeling part is includes the modeled out the deck, pylon, tower and cable arrangement of both types of bridges. The properties and material of the bridges element also needs to be assign before applying the load. After that the load will be placed at the deck of the bridge. The analysis will be run to determine the global behavior of the bridges such as deflection, resultant moment, and shear of the bridges. All both model of the bridges which is conventional and unconventional will be analyzed and compared to achieved and determine the objective of the study.

3.3 LUSAS SOFTWARE

In this research, modeling and analysis for the bridges structure was performed using the software LUSAS. With today's technological advances, modeling and analyzing of a structure using computer software is more appropriate to use than the manual method. This is because with the use of computers, the problem of static analysis that cannot be done before can be done easily with the use of computers.

LUSAS is software for analyzing and designing a structure. This software is equipped with various design codes worldwide. In this software, there is a finite element analysis method that can be done to analyze the structure. The finite element method is a numerical procedure for solving many problems in engineering analysis. This method has become so important to solve problems in engineering such as structural analysis, continuum mechanics and fluid flow.

The basic concept of the finite element method is to divide the modeled structure to a number of sub domain or finite elements, and the solution for a domain with matrix solution techniques. The accuracy of the results to be obtained from the analysis also depends on the number of pre-defined sub domain. The more the number of sub domains or elements which are divided into a structure that is analyzed, we have the more accurate the results to be obtained.

3.4 STRUCTURE MODELLING

In the bridges structure modeling process, the input stage is very important in any dimension is important for the structure of the bridges should be given attention. The load to be imposed on the bridges structure should also be calculated and recorded. In addition, the characteristics and constants of the materials used in the design of this structure must also be taken into account.

3.4.1 Model Description

Before the bridges model been draw in the LUSAS software, a rough idea of the structure are sketched on paper, taking into account the geometric parameters involved such as deck and pylons height, and number of cables.

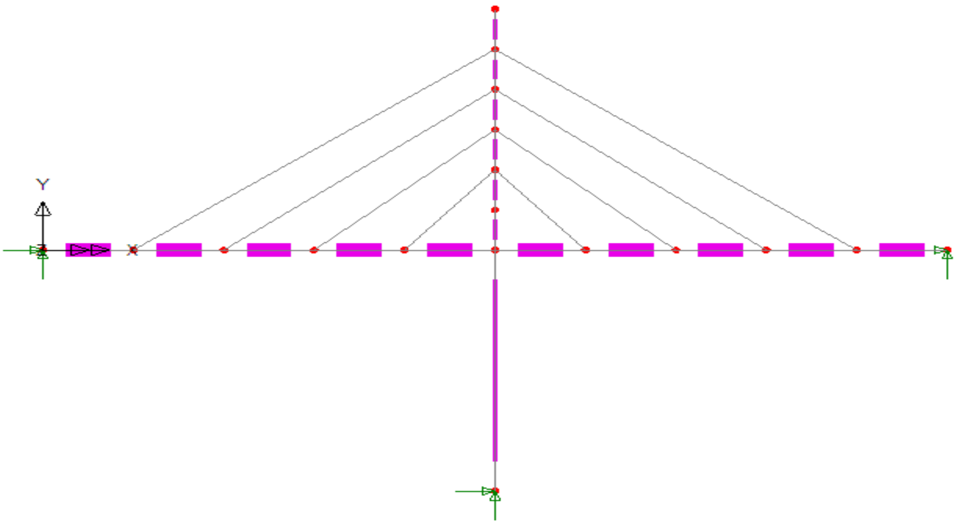

Figure 3.3: Conventional Cable Stayed Bridge

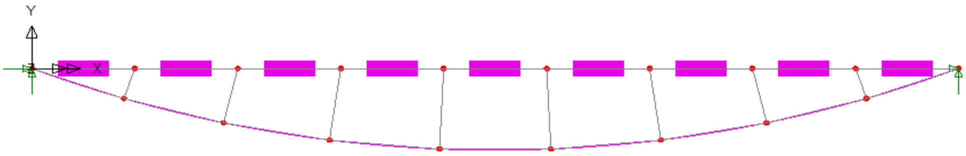

Figure 3.4: Under-Deck Cable Stayed Bridge

Figure 3.5: Intradosed Bridge

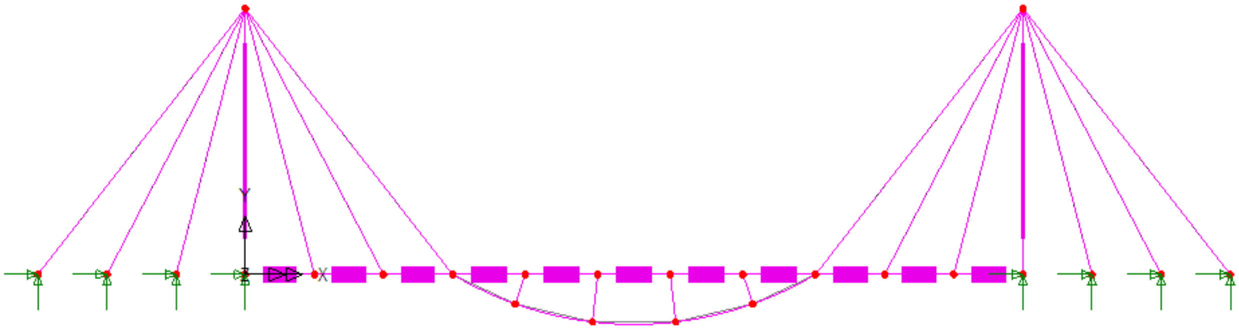

Figure 3.6: Combined Cable Stayed Bridge

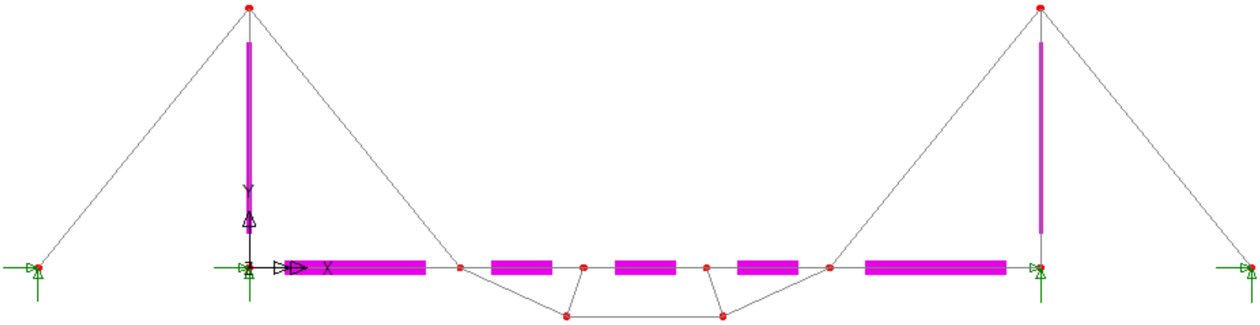

Figure 3.7: Extradosed-Intradosed Bridge

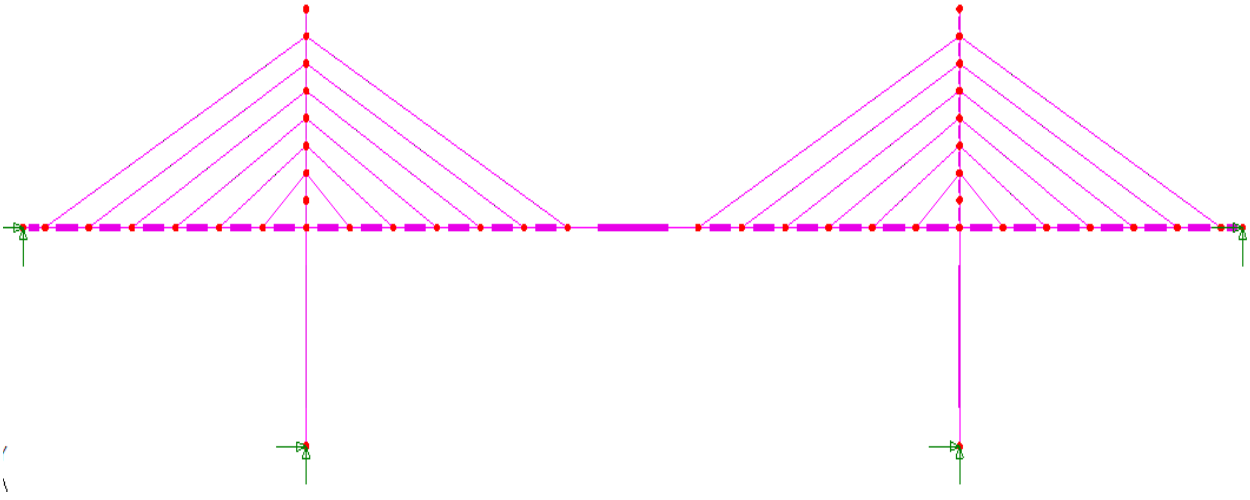

Figure 3.8: Multiple Spans Conventional Cable Stayed Bridge

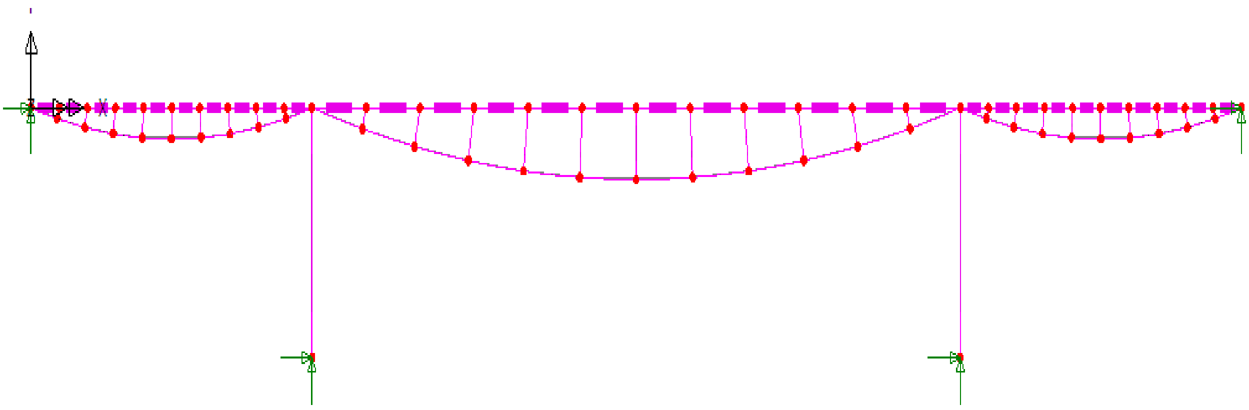

Figure 3.9: Multiple Spans Under-Deck Cable Stayed Bridge

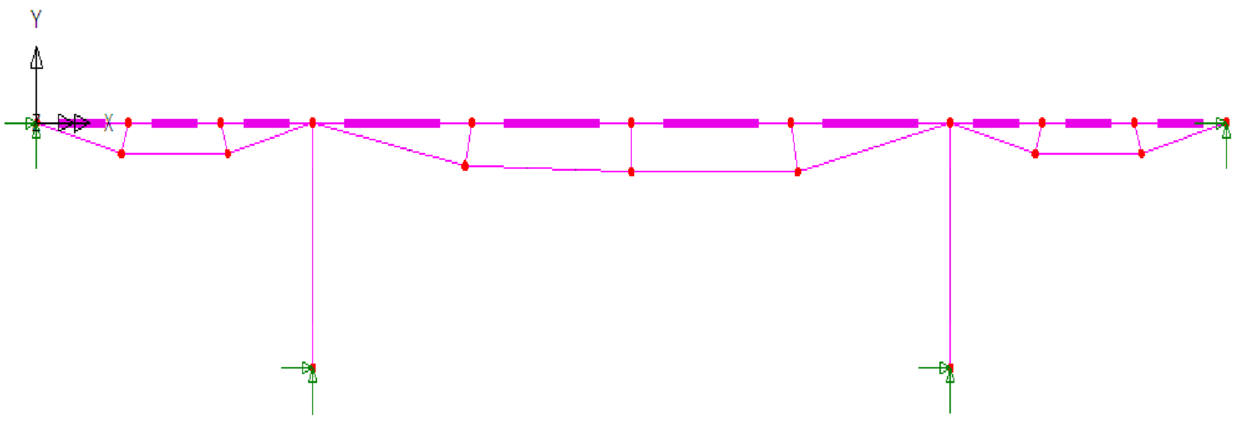

Figure 3.10: Multiple Spans Intradosed Bridge

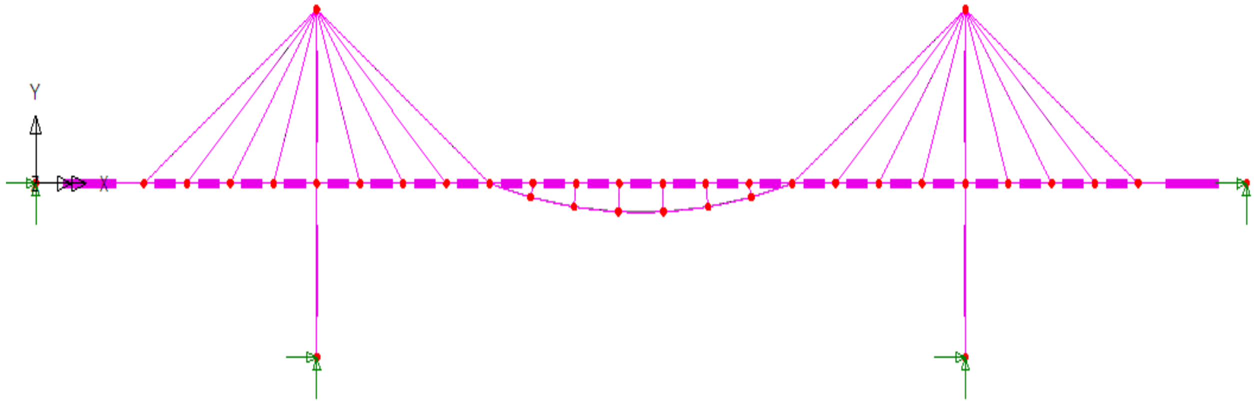

Figure 3.11: Multiple Spans Combined Cable Stayed Bridge

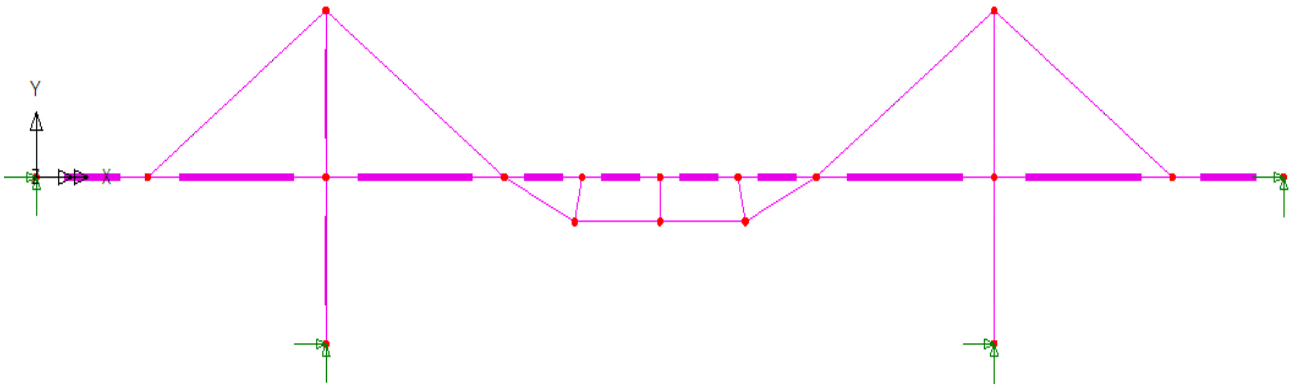

Figure 3.12: Multiple Spans Extradosed-Intradosed Bridge

3.4.2 Modeling Using LUSAS

The template used in this research is default template from the LUSAS software which is Y-template. Y-direction template use because the research is to study the 2D static analysis on the y-direction. The first step on creating a new project is to set up the unit used for the analysis as shown in Figure 3.13 below. The unit for LUSAS is consistent which mean it is fixed to the equation F=ma.

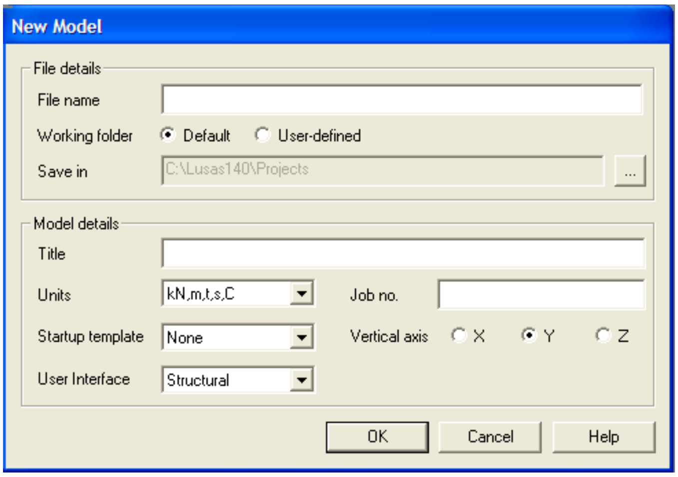

Figure 3.13: First Step to Create a Project

New point of the bridge is determined which is representing the coordinates of the bridge element. Deck of the bridge will be conducted first so that x coordinate of the bridge can be determined and conducted. Start by drawing the point and the line of the bridge. Firstly, the coordinates of the x, y, and z must be (0,0,0) coordinates for the origin. Click the geometry tab and select the point and coordinates to create the point as shown in Figure 3.14 below. Three box columns will appear for the coordinates of the point. Then, the coordinates for the deck, pylon, struts, and cables are all created. After all the point is create, the point is connected using the line. Click the geometry tab and select the line and coordinates to connect the point using the line.

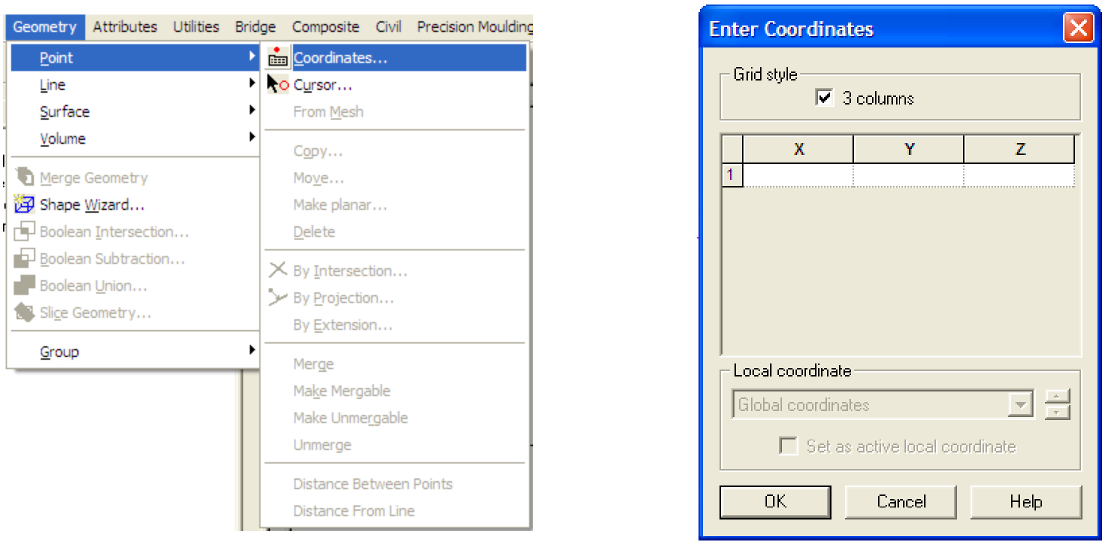

Figure 3.14: Determination of the Coordinates for the Structure

Next step is to specify the mesh attributes for all the line created shown as the Figure 3.15 below. To select a mesh for each element, select attributes tab, choose mesh and line. Line mesh tab will appear. For the deck, pylons and struts two dimensional thick beam with fourdivisions are used and the interpolation order is linear. For the cable stays the structural element type used is one divisions two dimensional bar element with also linear interpolation order.

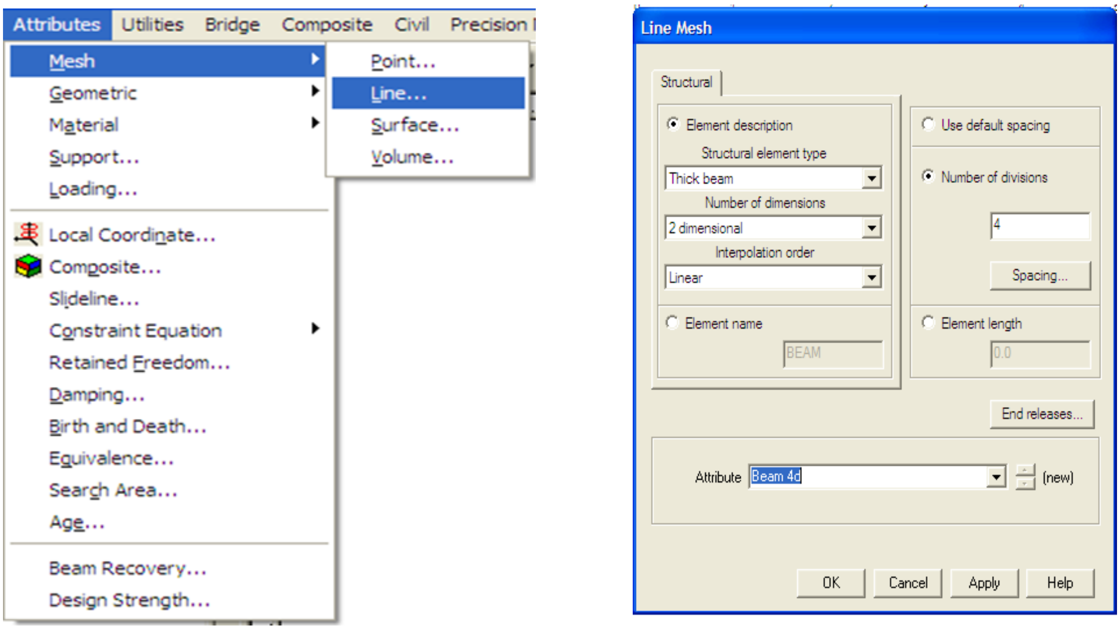

Figure 3.15: Mesh Attributes for the Structure

All the element must be mesh first before the geometric section is assigned. To assign the geometric section, select attribute tab, and choose section library as shown in Figure 3.16. Geometric section also can be create with the user own dimension. To create a new geometric section, select utilities and choose section calculator. Pylons used in this project are 450 x 450 x 32 square hollow section with cross-sectional area of 0.051. For cable stays, 25mm diameter circular solid section is used.

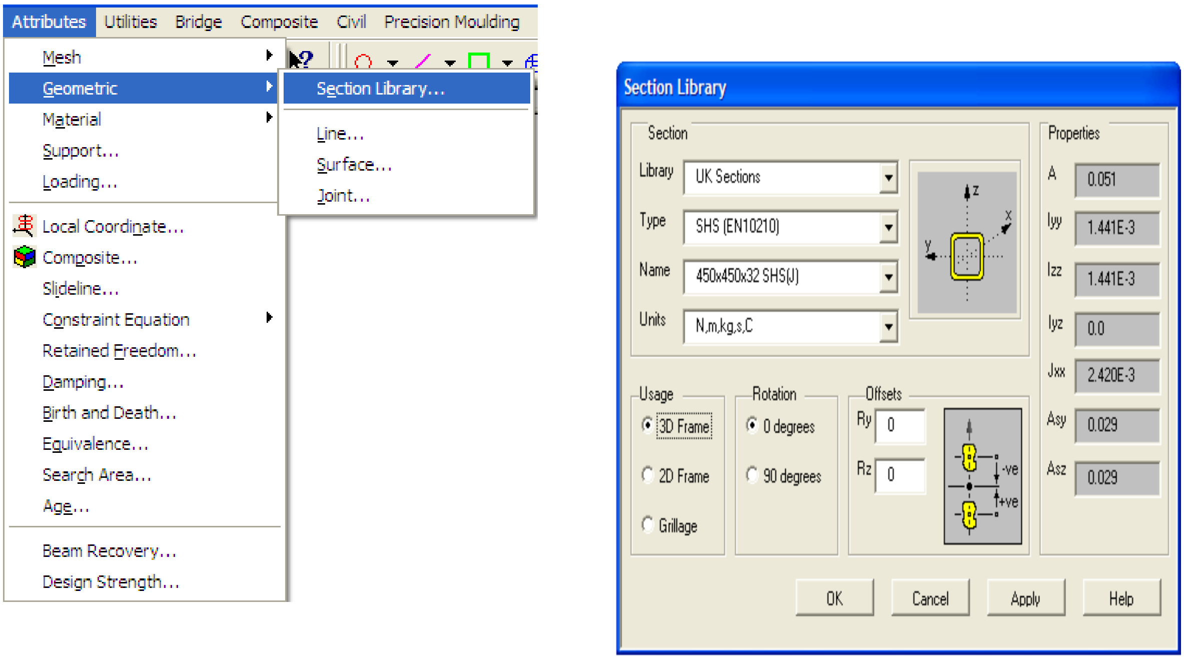

Figure 3.16: Selection of Geometric Section

After that, material attributes is specify for all whole bridge elements. Material used in this project is ungraded mild steel with density of 80kN/m^{3}shown in Figure 3.17. Next, supports are assigned to the model. Select attributes, and choose support to determine the support as shown in Figure 3.18 below. Pinned supports are used on this research for the pier and abutment of the bridge. All translation on x, y, and z are considered fixed.

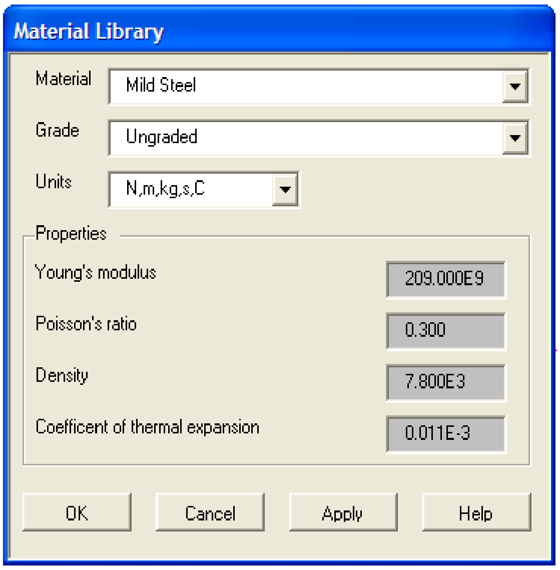

Figure 3.17: Determination of Material for the Structure

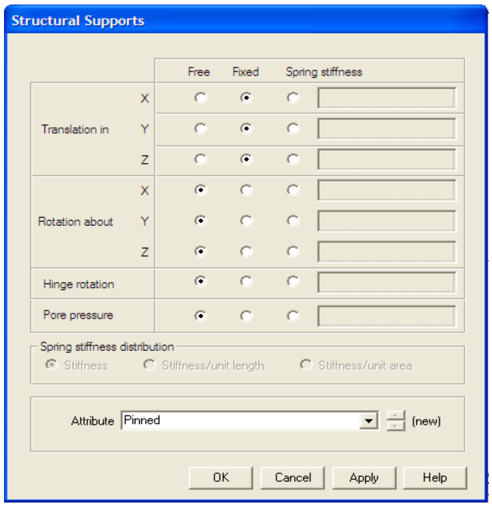

Figure 3.18: Determination of Support for the Structure

And lastly, loading attributes need to be specified. To applied load, select attribute, and choose load shown in Figure 3.19. Local distributed load is applied to the deck of the models. This research is study for highway bridges therefore dead load and live load are considered. Dead load applied is 319kn/m. Live load applied is 39kn/m. After the load is applied the models is solve.

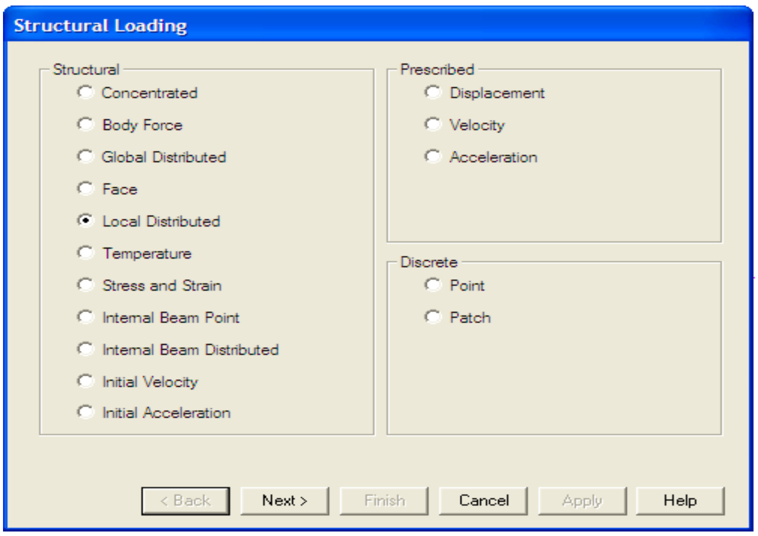

Figure 3.19: Specify the loading for the Structure

3.4.3 Load

To analyze a structure, the loading should be done. With this, decisions regarding the behavior of the structure due to the imposition can be identified. Loading consists of two conditions, namely dead load,$G_k$and live load,Q_k. Dead Load value, $G_k$modeled for the bridges structure used in this research is as follows: -

Dead Load

For dead load, beam selfweight, diaphragm, deck slab, parapet, railing and premix are considered.

1) **Beam Selfweight**

Density of steel = 80kN/m^3

Beam cross-section area = 0.360 m^2

Beam selfweight = 28.8kN/m

2 Number of beam = 2 x 28.8kN/m = 57.6kN/m

2) Diaphragms

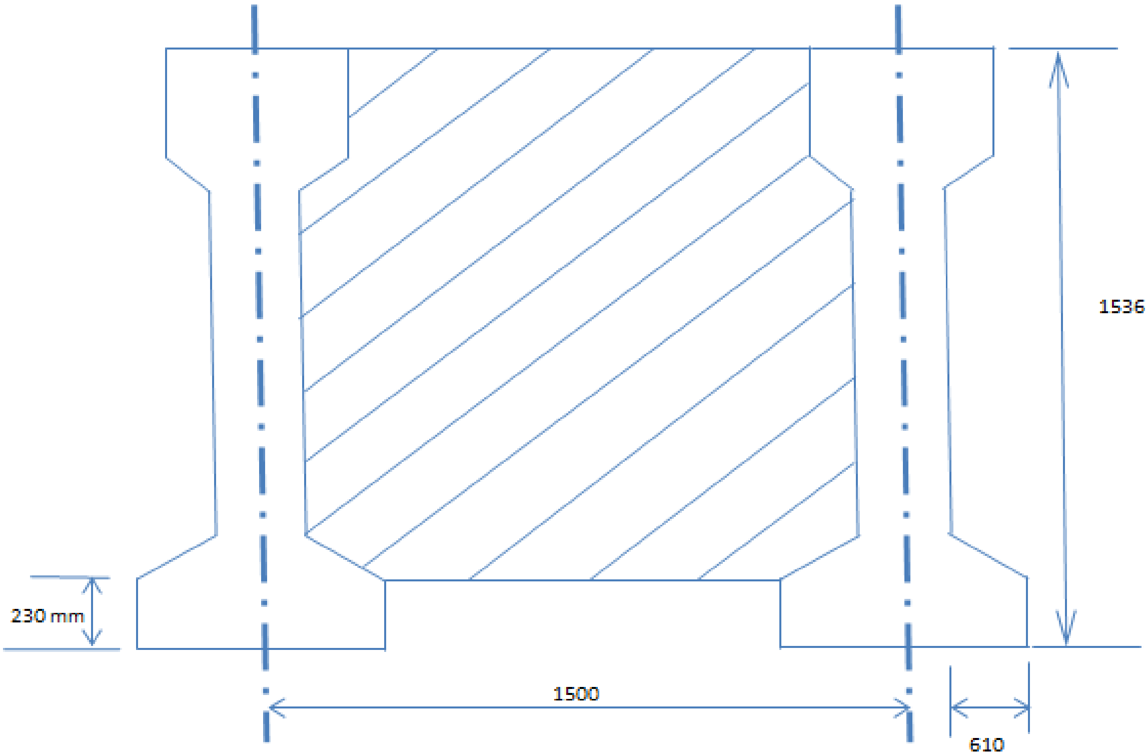

Figure 3.20: Dimensions of Diaphragm

Diaphragm cross section area

[(1.5 x 1.536) – 0.467 – (15 – 0.61)] x 0.23

= 1.63m^2

Density of steel = 80kN/m^3

Weight of diaphragm = 80kn/m^3 x 1.63 m^2 = 130.4kN/m

3) Deck slab

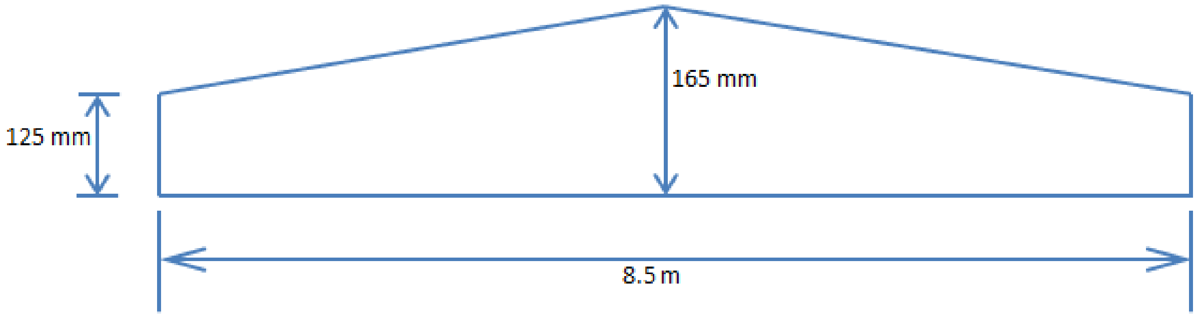

Figure 3.21: Dimensions of Deck Slab

Cross section area

= ½ (0.125 + 0.165) x 8.5

= 1.28m^2

Total deck slab load = 1.28 m^2 x 80kN/m^3

= 102.4kN/m

4) Parapet and Railing

Weight per meter run = 7.315kN/m

Total weight of 2 parapet = 2 x 7.315kN/m = 14.63kN/m

Superimposed Dead Load

1) Premix

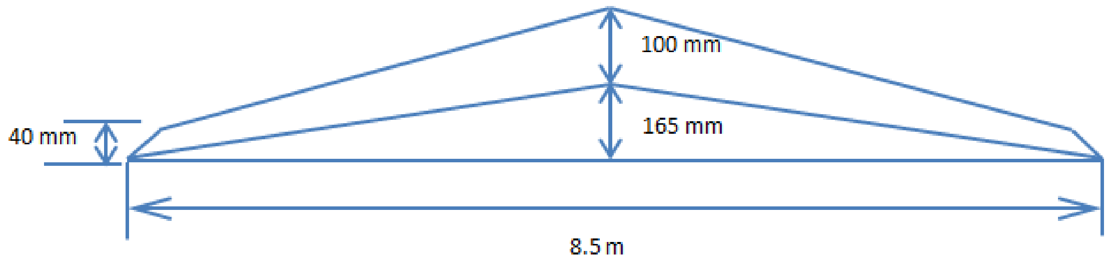

Figure 3.22: Dimensions of Premix

Density of premix = 22.6kN/m^3

Cross section area

=½ (0.04 + 0.1) x 8.5

= 0.595m^2

Total weight = 0.595m^2 x 22.6kN/m^3

=13.447kN/m

Summary of Dead Load

1.	Beams	= 57.6kN/m
2.	Diaphragm	= 130.4kN/m
3.	Deck slab	= 102.4kN/m
4.	Parapet and Railing	= 14.63kN/m
5.	Premix	= 13.447kN/m
	Total Dead Load	319.00kN/m

Live load

For live load, Eurocode load model one are considered.

Width = (3.5 x 2) = 7m > 6m

n_i= int [$\frac{w}{3}$] = int [$\frac{7}{3}$] = 1.83

Residual area width given by;

w_r = 7-3(1.83) = 1.50

Total width of the bridge = (3.5 x 2) + 1.5 = 8.5

Table 3.1: Distributed and Concentrated Loads on the Bridge

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
Residual area	0	2.5

Eurocode 1 allows for assuming a value alpha = 0.8 for the first conventional lane (1.0 for the others), for both the concentrated loads and the uniform load. We thus have;

Lane 1: Q = 0.8 x 300kn = 240kN   q = 0.8 x 9.0kN/m

Lane 2: Q = 1.0 x 200kn = 200kN   q = 1.0 x 2.5kN/m

Lane 3: Q = 1.0 x 200kn = 200kN   q = 1.0 x 2.5kN/m

For the this project, two lane are considered;

Lane 1: 0.8 x 9 = 7.2kN/m

Lane 2: 1 x 2.5 = 2.5kN/m

Distributed live load, q = [lane (1 + 2) x lane width] + [(residue area) x residue]

= [(7.2 + 2.5) x 3.5m] + [2.5 x 2]

= 38.95kN/m

3.4.4 Constant

Bridges analyzed in this research is ungraded mild steel structure. Each of the material used to make a structure has its own characteristics and constants such as the density of the material, young modulus and Poisson's ratio.

Material	Ungraded Mild steel
Young Modulus	209.000E9
Poisson's ratio	0.300
Density	7.800E3
Coefficient of thermal expansion	0.011E-3

After the stage where the parameter input geometry, loading on the structure and characteristics of the bridge and constants of the material used has been determined, the process of structural modeling was done using the LUSAS software.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter will elaborate more on the findings of this project. All the data and result from the research will be analyzed to check whether the research fulfilled the objective of the project. Based on the result obtain, the performance of the Under-deck cable stayed system will be discuss and compare with the conventional cable stayed system.

One of the objectives of this research is to study the performance and behavior of the under-deck cable stayed system and combined cable stayed bridge. In order to achieve the objective, as stated in chapter three, the research will be carried out with five different cable stay arrangement and in each of the arrangement will be test with a single and multiple span. After both of single and multiple spans analyzed using LUSAS software, the result such as displacement, bending moment, shear stress, normal stress obtain is tabulated. The result is shown in table and graph for comparison.

4.2 RESULTS

4.2.1 Single Span Analysis

Table 4.1: 2D Static Analysis for Single Span

2D Static Analysis	**Conventional Design**		**Under Deck Cable Stayed**		**Intradosed**		**Combined Cable Stayed**		**Extradosed-Intradosed**	
	Fx	**Fy**	**Fx**	**Fy**	**Fx**	**Fy**	**Fx**	**Fy**	**Fx**	**Fy**
Maximum Stress on Cable (kN/m^2)	1.24	0	14.41	0	14.53	0	6.40	0	9.89	0
Minimum Stress on Cable (kN/m^2)	0.287	0	14.40	0	14.53	0	2.44	0	5.43	0
Maximum Stress on Deck (kN/m^2)	1.096	6.31	0.52	9.32	0.303	9.96	1.14	4.90	0.75	6.66
Minimum Stress on Deck (kN/m^2)	-17.28	-6.31	-1.32	-9.32	-4.454	-9.96	-23.89	-4.90	-15.38	-6.66
Bending Moment (kNm)	42.30		0.012		0.0021		36.59		1.61	
Displacement (m)	0.00012		0.0040		0.0038		0.0014		0.0021	

i. Displacement

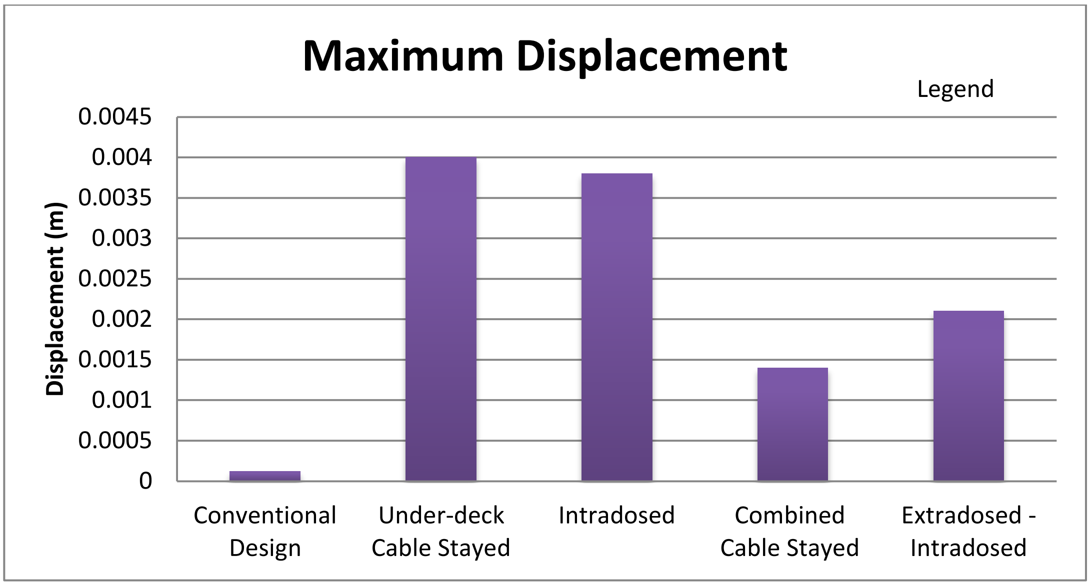

Figure 4.1: Maximum Displacement for Single Span Analysis

For a single span analysis, the maximum displacement occurs on the under-deck cable stayed system 0.004m displacement at node 20. From Figure 4.1, the intradosed bridge performs slightly better with 0.0038m of displacement. The conventional cable stayed bridges recorded the lowest maximum displacement with 0.00012m of displacement. With the combination of both under-deck system and conventional system on combined cable stayed bridge and Extradosed-intradosed Bridge produced a better result than the under-deck system with combined cable stayed bridge produced lower maximum displacement than Extradosed-intradosed Bridge.

ii. Resultant Moment

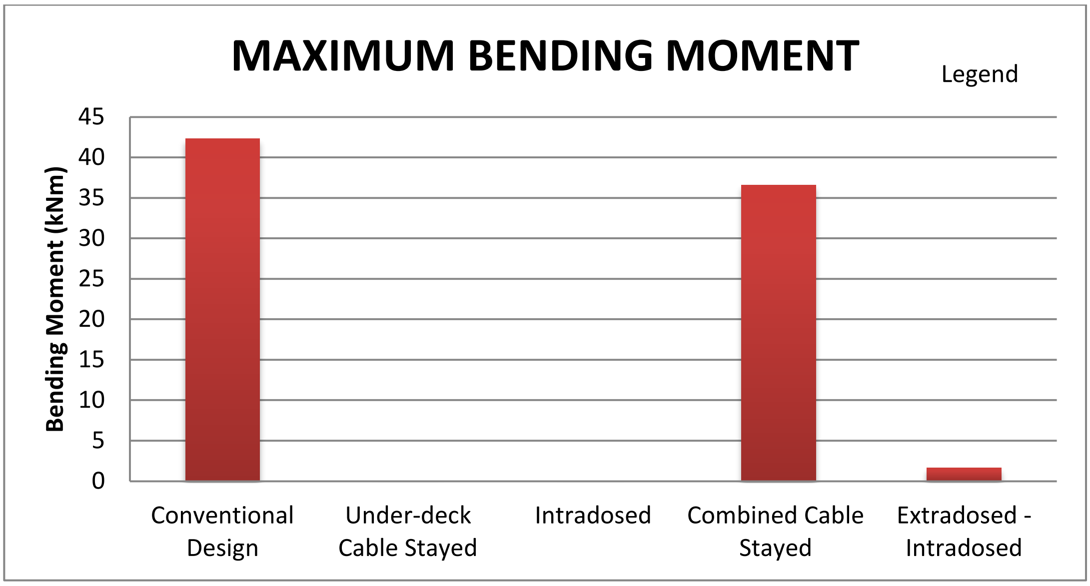

Figure 4.2: Maximum Bending Moment for Single Span Analysis

Different with the maximum displacement, under-deck cable stayed system and combined cable stayed system produced lower maximum bending moment than the conventional system. The lowest Maximum Bending moment occurred on Under-deck cable stayed bridge with 0.012kNm while the conventional Bridges are the highest with 42.3kNm shown in Figure 4.2.

iii. Normal stress

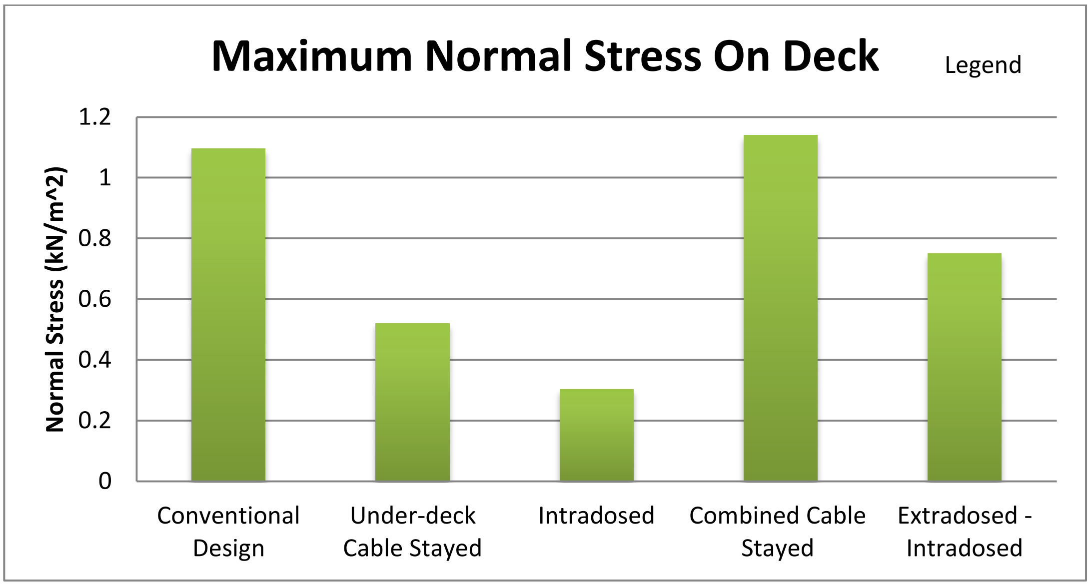

Figure 4.3: Maximum Normal Stress on Deck for Single Span Analysis

For single span analysis, the maximum normal stress occurs on the combined cable stayed bridge with 1.14kN/m^2 as shown in Figure 4.3 above. Intradosed bridge recorded the lowest normal stress with 0.303kN/m^2. The figure shows that both of the under-deck system performed better against the normal stress while the conventional and combined cable stayed bridge are not for the single span analysis.

The performance of the pylon of the bridge could be the factor for the higher normal stress on deck of the conventional and combined cable stayed bridge. The displacement of the pylon happened on the x-axis and encouraged higher stress on the deck of the bridge.

iv. Shear Stress

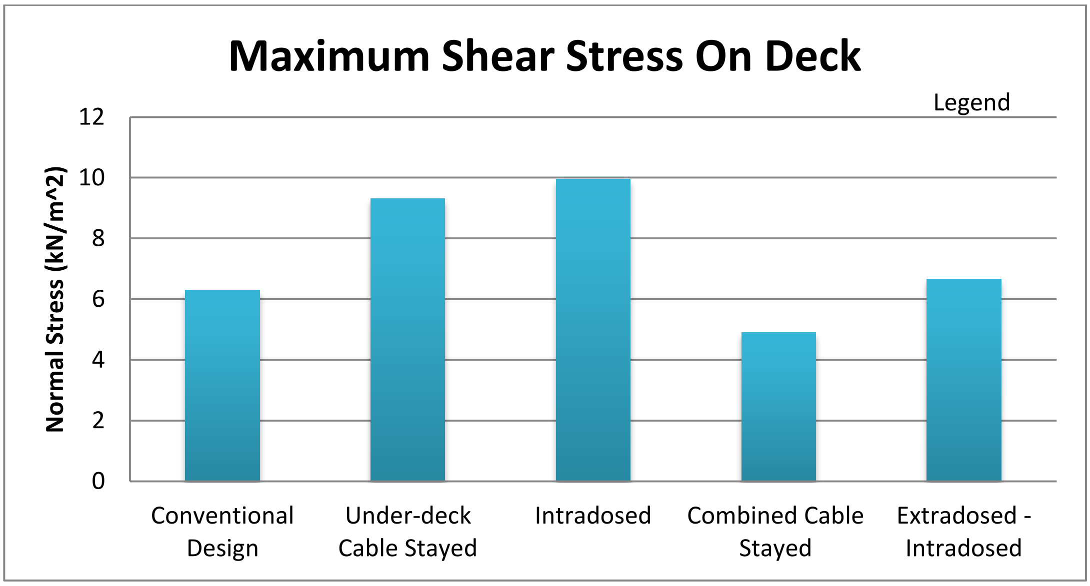

Figure 4.4: Maximum Shear Stress on Deck for Single Span Analysis

For the shear stress acting on the deck of the bridge, parallel to the normal stress, under-deck cable stayed system recorded the highest shear stress followed by conventional system and combined cable stayed system. The Intradosed bridge recorded 9.96kN/m^2 of shear stress and combined cable stayed bridge are the lowest with 4.9kN/m^2 as shown in Figure 4.4 above.

The pylons of the bridge are good against the compressive stress of the bridge produce from the tension acting on the stay that connected to the pylon of the bridges. The combination of the pylons and struts on combined cable stayed bridge prove to be a good option.

v. Stress on cable

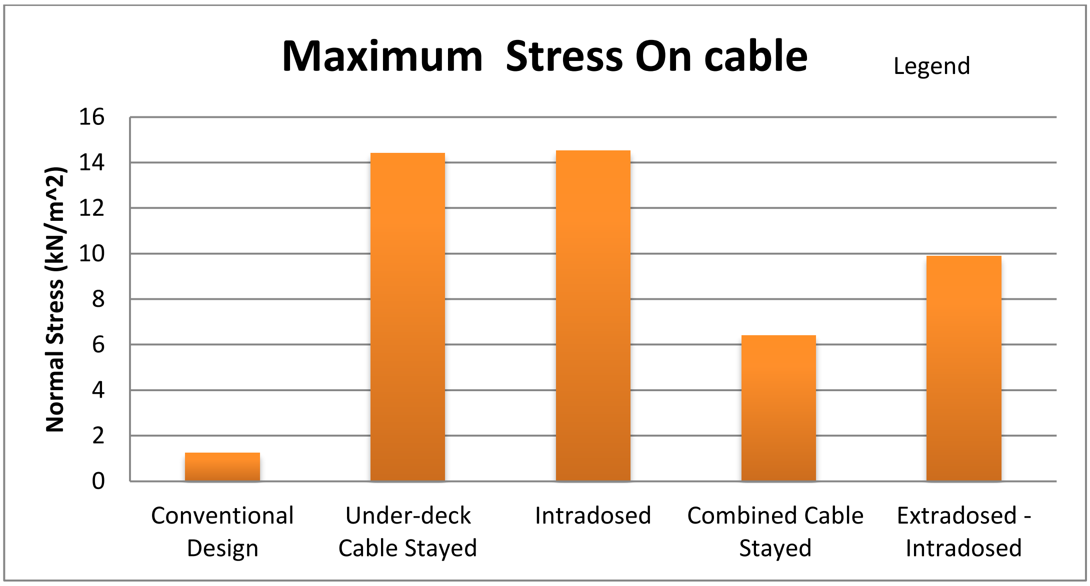

Figure 4.5: Maximum Stress on Cable for Single Span Analysis

For stress occurs on the stay cable for single span analysis, From Figure 4.5 both of the under-deck cable stay system recorded the highest with 14.53kN/m^2 occurs on the intradosed bridge. The lowest is on the conventional design with 1.24kN/m^2.

The combination of the conventional and under-deck system produced smaller stress on the stay cable than the under-deck system. The stay cable are connected to the struts that self-anchored to the deck of the bridge stress the cable more than stay cable that connected to the pylons.

4.2.2 Multiple Spans Analysis

Table 4.2: 2D Static Analysis for Multiple Spans

2D Static Analysis	Conventional Design		Under Deck Cable Stay		Intradosed		Combined Cable Stayed		Extradosed-Intradosed	
	Fx	**Fy**	**Fx**	**Fy**	**Fx**	**Fy**	**Fx**	**Fy**	**Fx**	**Fy**
Maximum Stress on Cable (kN/m^2)	10.21	0	24.42	0	21.67	0	15.47	0	20.01	0
Minimum Stress on Cable (kN/m^2)	2.53	0	-2.95	0	-4.97	0	455.05	0	15.78	0
Maximum Stress on Deck (kN/m^2)	20.60	5.37	14.51	20.11	14.21	22.15	13.32	9.96	12.96	14.85
Minimum Stress on Deck (kN/m^2)	-52.85	-5.37	-44.94	-20.11	-45.21	-22.86	-50.13	-9.96	-49.3	-14.85
Bending Moment (kNm)	43.24		423.45		473.84		126.95		227.58	
Displacement (m)	0.0061		0.017		0.021		0.009		0.010	

i. Displacement

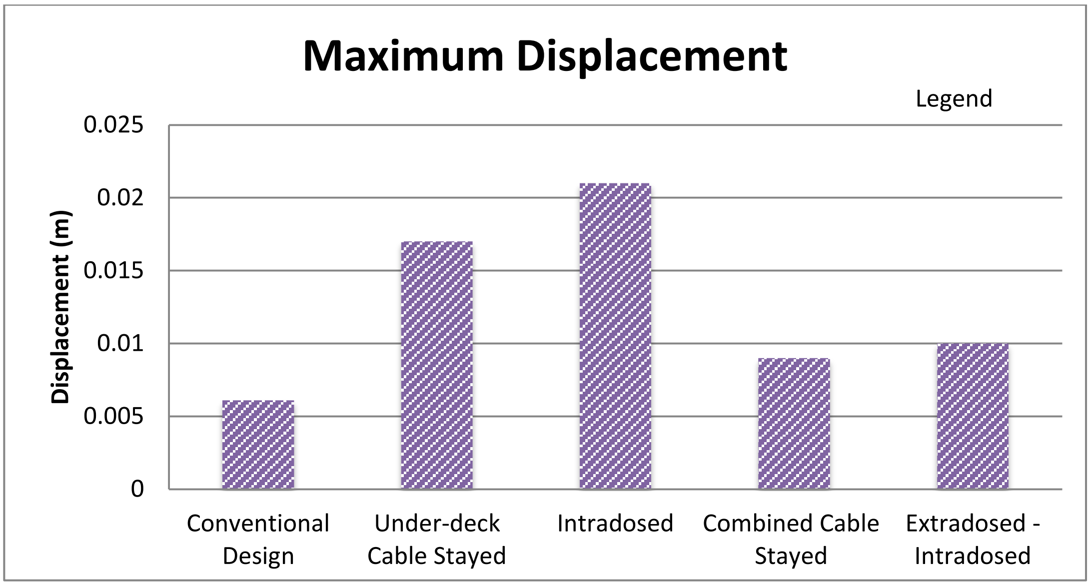

Figure 4.6: Maximum Displacement for Multiple Spans Analysis

From the multiple analysis result shown on Figure 4.6, maximum displacement occurs on the under-deck system at intradosed bridge with 0.021m. Meanwhile the lowest displacements are recoded at the deck of the conventional system with 0.0061m of displacement. The conventional system proved to be the best on the multiple span bridge construction.

The self-anchored struts performances against the displacement of the bridge are nowhere close to the pylons. The result of the under-deck cable stayed bridge is still acceptable for the bridge construction. The combination of both systems on combined cable stayed system managed to reduce the displacement of the deck.

ii. Resultant moment

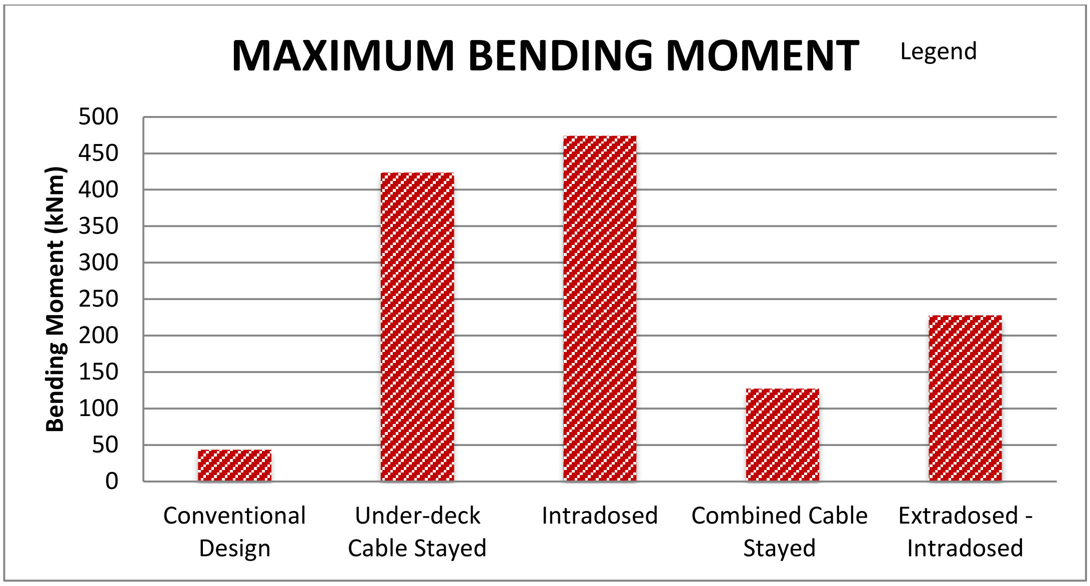

Figure 4.7: Maximum Bending Moments for Multiple Spans Analysis

Opposite to the result on single span analysis on Figure 4.7, figure shows that maximum bending moment occurs on the under-deck cable stayed system. Intradosed recorded the highest resultant moment with 473.84kNm while conventional designs are the lowest with 43.24kNm. Based on the result we can proved that under-deck cable stayed system are better for a single span bridges construction rather that multiple span bridge.

The result for under-deck still acceptable but not very economical for construction compare to conventional system because the higher the bending moment value, the bigger cross-sectional area needed when designing the bridge.

iii. Normal Stress

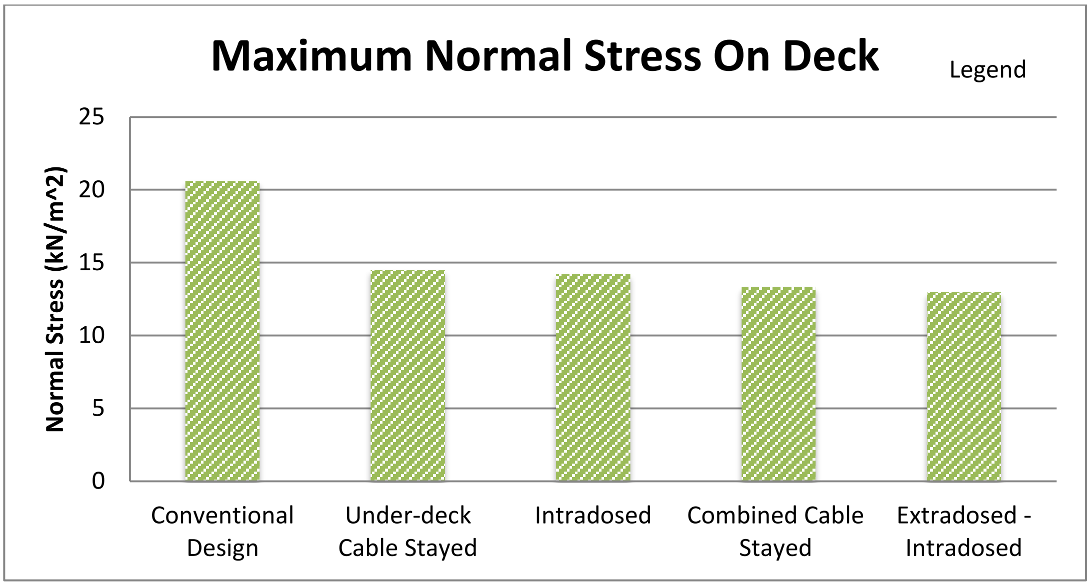

Figure 4.8: Maximum Normal Stress on Deck for Multiple Spans Analysis

For the normal stress on deck on multiple analysis, conventional cable stayed bridge produced the highest value among the system analyzed with 20.6kN/m^2 as shown on Figure 4.8. The under-deck system and combined cable stayed system produced almost identical result with 14.51kN/m^2, 14.21kN/m^2, 13.32kN/m^2, and 12.96kN/m^2 respectively with combined cable stayed bridge produce slightly lower value.

The value that recorded at the conventional cable stayed bridge is affected by the pier at the center of the bridge that produced horizontal movement to the deck of the bridge.

iv. Shear Stress

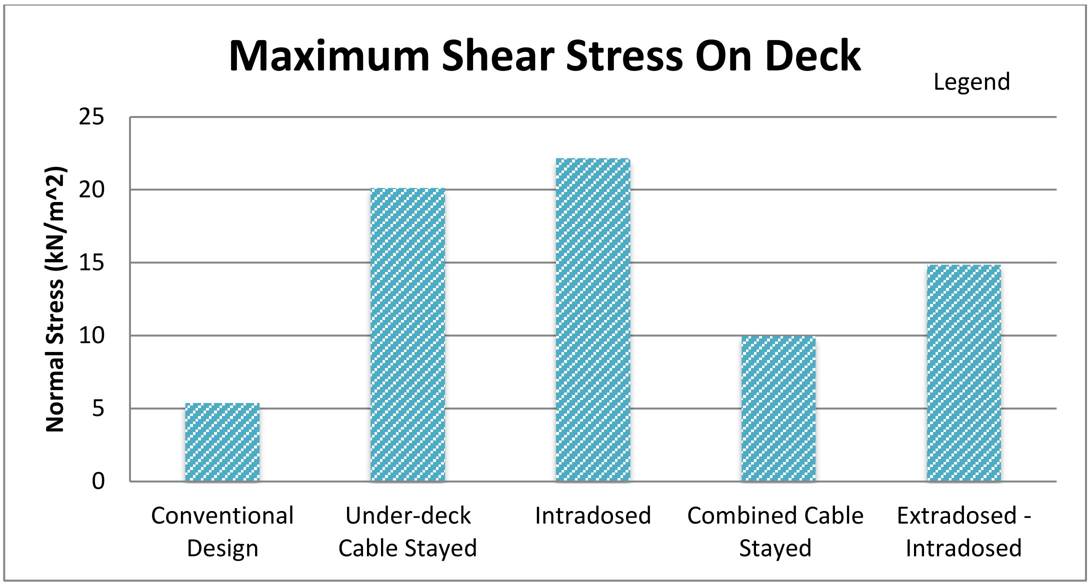

Figure 4.9: Maximum Shear Stress on Deck for Multiple Spans Analysis

Figure 4.9 shows the maximum shear stress on deck for multiple span analysis with both under-deck cable stayed system produced the highest y-direction stress. Intradosed bridge produced the highest shear stress with 5.37kN/m^2. The lowest shear stress occurs at the conventional cable stayed bridge with 5.37kN/m^2.

The same with single span analysis, compressive force on the pylons once again is the major factor of the shear stress recorded on conventional cable stayed bridge and combined cable stayed bridge.

v. Stress on Cable

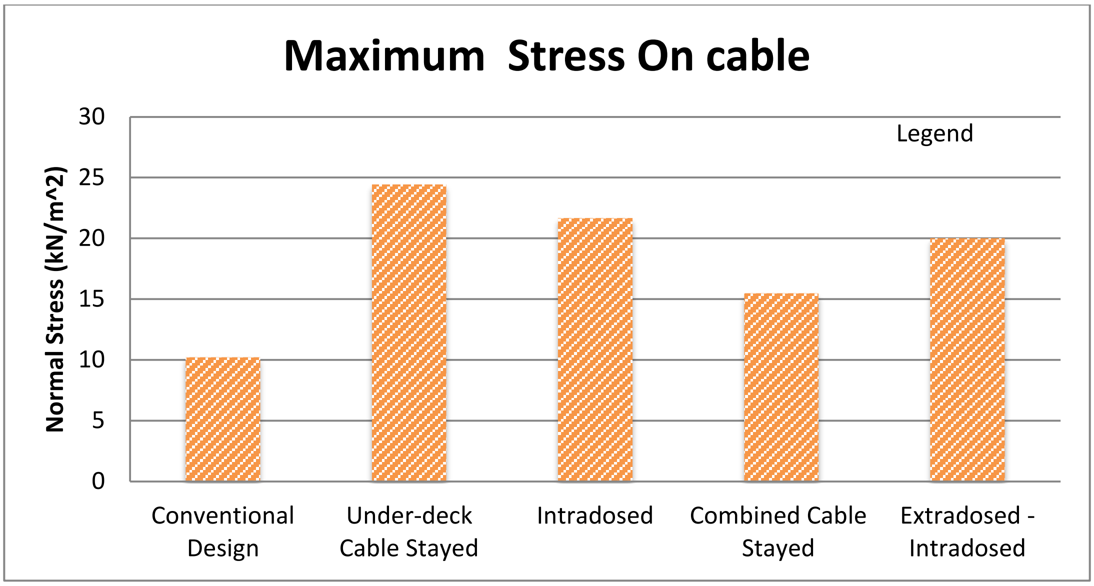

Figure 4.10: Maximum Stress on Cable for Multiple Spans Analysis

For the maximum stress on cable on multiple span analysis, the results as the Figure 4.10 above. The highest are result recorded on the under-deck cable stayed bridge with 24.42kN/m^2. Maximum stresses on cable on the conventional cable stayed bridge are the lowest with 10.21kN/m^2.

4.3 SUMMARY OF THE RESULTS

For single span analysis, cable stayed bridge which has pylons is more stable in term of deflection on deck, shear stress on deck and cable stress. While under-deck cable stayed bridges and intradosed bridge are more stable against the resultant moment and normal stress. In term of deflection, under-deck cable stayed bridge still produced small deflection and the displacement is still acceptable for bridges construction. The bridges that have pylons, have more stay cable than both of the under-deck cable stayed system, therefore producing lower stress on cable.

The number of stay cable also produced better upward deviation force on the deck of the bridge that will generate lower shear stress on deck of the bridge. Single span under-deck cable stayed system are much lower in term of bending moment and normal stress due to cable stay that connected to the struts are self-anchored to the deck of the bridge. Under-deck cable stayed system is the best in economic view because of no pylons need be constructing and produced lower bending moment that reduced the sectional area of the bridge.

For Multiple spans analysis, cable stayed that has pylons which are conventional and combined cable stayed system is more stable in term of all behavior investigated. Under-deck cable stayed bridge proves to be more stable for single span bridges that multiple span analysis. The result interrogated is still acceptable for bridge construction. Pylons are needed for multiple and longer span to be more stable.

The increase number of strut on under-deck cable stayed system can also generates a more stable bridge. In conclusion, the under-deck cable stayed system is not the best from static and economic point of view, but still useful if creeping soil problem occurs.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter finalized all the analysis and made up into a conclusion based on the objective of the research and possible recommendation would also be included. The conclusion made will indicate either the objectives of the research are successfully satisfied or not.

5.2 CONCLUSION

5.2.1 Objective 1:

To study the principle component of under-deck cable stayed bridge and combined cable stayed bridge

The principle of Under-deck cable stayed bridges and combined cable stayed bridge has been discussed in literature review on Chapter 2 of this thesis. Under-deck cable-stayed bridges are innovative bridge with different configurations than conventional design in which stays cable are located underneath the deck. The different between the conventional cable stayed bridge and under-deck cable stayed bridge is the location of the cable anchor to the deck of the bridges which is at the top and bottom of the bridge respectively. The cable is connected to the steel struts that anchor to the deck of the bridge.

Combined cable stayed bridge is the combination of conventional cable system and unconventional cable system which mean the bridge have both cable stay at the top and bottom of the deck. This system will have both pylons and struts on the same system. The stay cable is connected to the pylons and the struts of the bridge that will give upward deviation force to the deck of the bridge. For a single span combined cable stayed bridge, the design proposed by Ruiz Teran doesn't have pier under the pylons and which the pylons must be located at each end of the bridge. The stay cable at each end of the bridge will be connected outside the deck of bridge

Both under-decks cable stayed system and combined cable stayed system is design by the engineers to solve their problem on constructing the bridge. Bridge engineers also proposed this new design to make the construction of the cable stayed bridge to be more economical, more stable structure, reduce the maintenance and also comfort to the user.

5.2.2 Objective 2:

To analyze the behavior of the under-deck cable stayed bridge and combined cable stayed bridge

Based on the result obtain from the single span and multiple span analysis, all four design of two under-deck cable stayed system and combined cable system produced different result on displacement, resultant moment, shear stress and normal stress of the bridge. The number of span analyze on single span and multiple span analysis also affect the result obtain. For a single span, maximum displacement on deck of under-deck cable stayed bridge and intradosed bridge are higher than displacement at the deck of the combined cable stayed bridge and Extradosed-intradosed Bridge. It can be conclude that combined cable stayed system is more stable than under-deck cable stayed system.

For bending moment and normal stress on single span analysis, Under-deck Cable Bridge and intradosed bridge interrogate lower result than combined cable stayed bridge. From this result, we can concluded that under-deck cable stayed system is more economical than combined cable stayed system because sectional area of the bridge design will be lower with smaller resultan moment and normal stress. For shear stress and stress on cable, combined cable stayed system recorded lower result than under-deck system.

For multiple spans analysis, under-deck cable stayed bridge and intradosed bridge obtains higher result on all behavior investigated in this research than combined cable stayed bridge. This can be concluded that combined cable stayed bridge is more stable than under-deck cable stayed bridge.

5.2.3 Objective 3:

Compared the behavior of the conventional bridges and unconventional bridges

For a single span analysis, the result shown that conventional bridge slightly tends to be more stable than under-deck cable stayed bridge and combined cable stayed bridge in term of displacement, stress on cable and shear stress. In term of displacement, only small maximum displacement occurs at the deck of the conventional cable stayed bridge. Displacement on unconventional bridges still consider small and acceptable for construction. Therefore, the tensile strength is considered to be higher in conventional cable stayed bridges than unconventional cable stayed bridge. For resultant moment, unconventional cable stayed bridge generate lowest value than conventional cable stayed bridge that will indicate smaller cross-sectional area needed to design the bridge. Therefore, we can conclude that both of the systems are good at different perspective on single span.

For multiple span analysis, conventional cable stayed system also more stable than unconventional system in term of displacement, resultant moment, normal stress, shear stress and stress on cable. The displacement of the conventional slightly increases from the single span analysis. Therefore, the tensile strength is also considered be much higher in conventional cable stayed bridge than unconventional cable stayed bridge studied in this research. In terms of resultant moment and shear, lowest value on conventional cable stayed bridge indicates that the bridge is more stable on resisting buckling failure. In conclusion, the unconventional cable stayed bridge is more suitable on single span bridge than multiple span bridges.

5.3 RECOMMENDATIONS

1. Under-deck cable stayed and combined cable stayed bridge will produce much accurate result with detail parameter on 3D analysis

2. More accurate result if moving load are considered on dynamic analysis on Unconventional bridges

3. Considered another factor for analysis, such as wind load, temperature effect, earthquake and etc.

4. Analysis using other finite element software such as ANSYS, STAADPro, SAP2000 and etc.

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APPENDIX A1

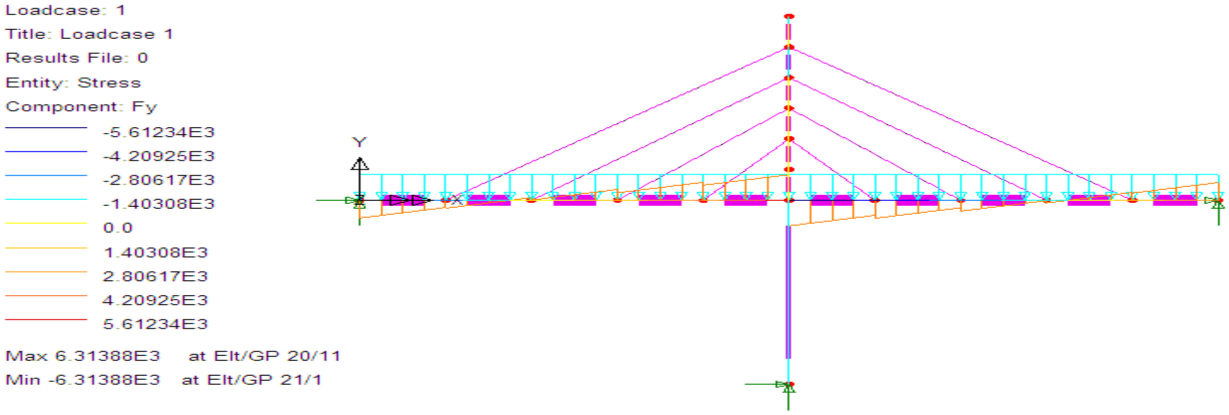

Figure 4.1(a): Shear stress on conventional cable stayed bridge

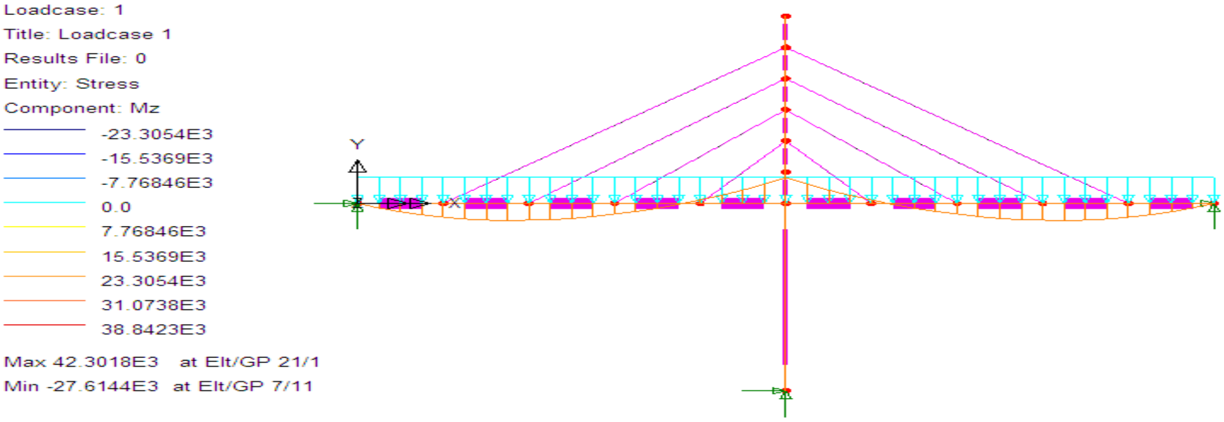

Figure 4.1(b): Bending moment on single span conventional cable stayed bridge

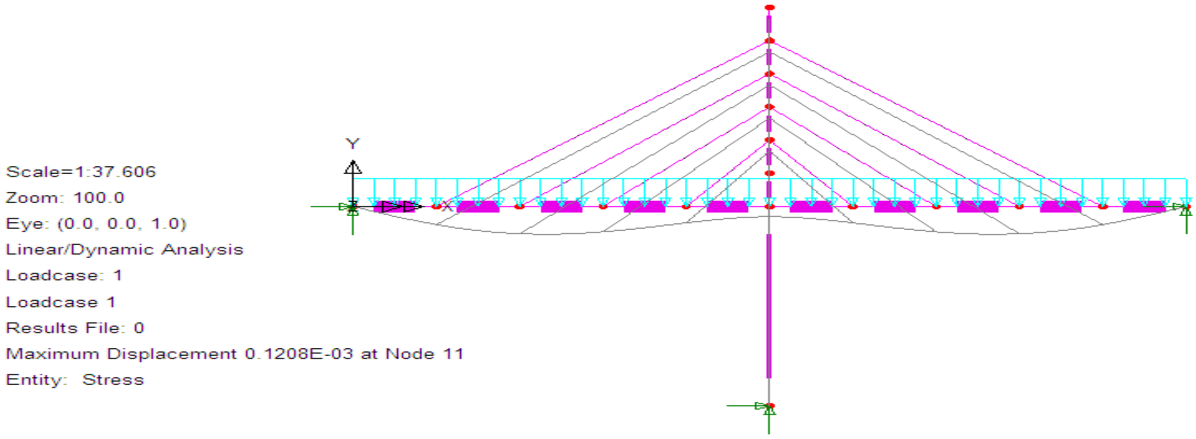

Figure 4.1(c): Displacement on single span conventional cable stayed bridge

APPENDIX A2

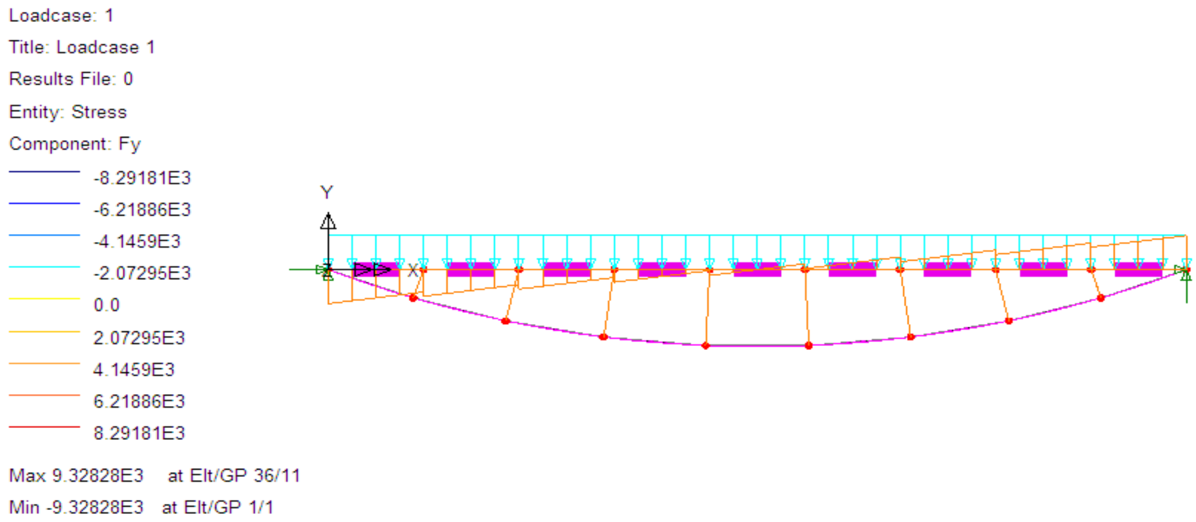

Figure 4.2(a): Shear stress on Under-deck cable stayed bridge

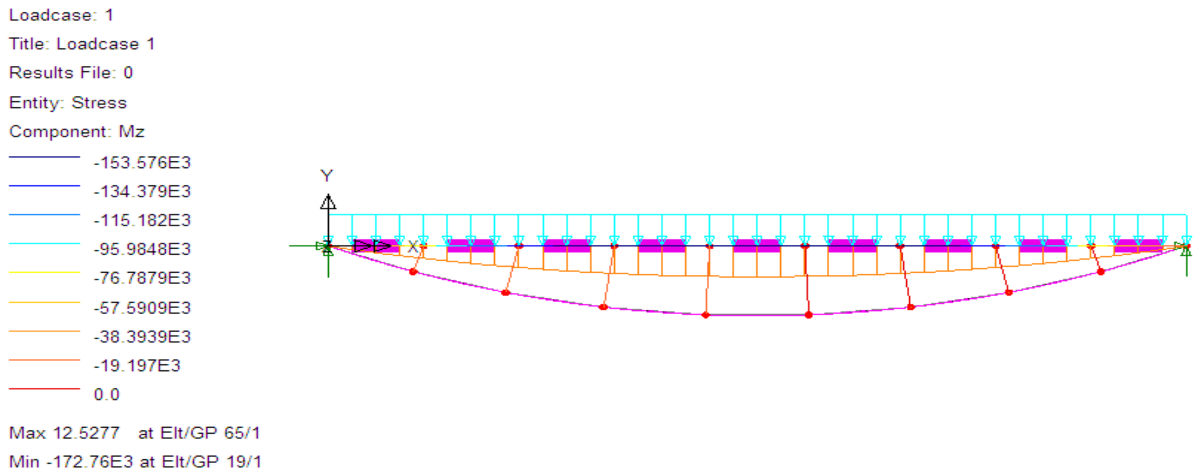

Figure 4.2(b): Bending moment on single span Under-deck cable stayed bridge

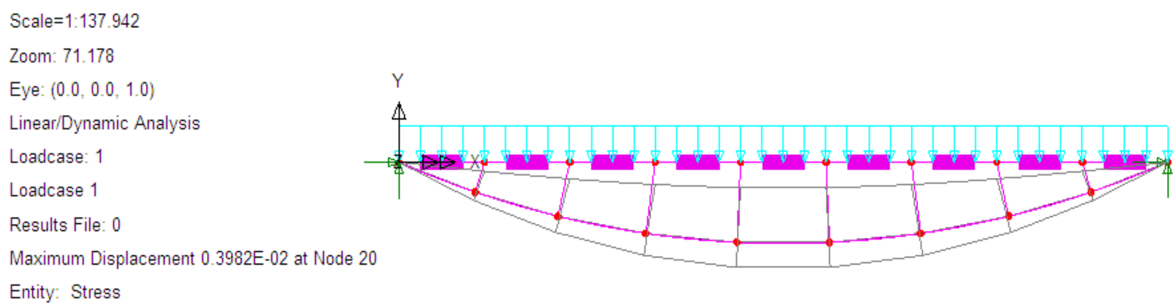

Figure 4.2(c): Displacement on single span conventional Under-deck cable stayed bridge

APPENDIX A3

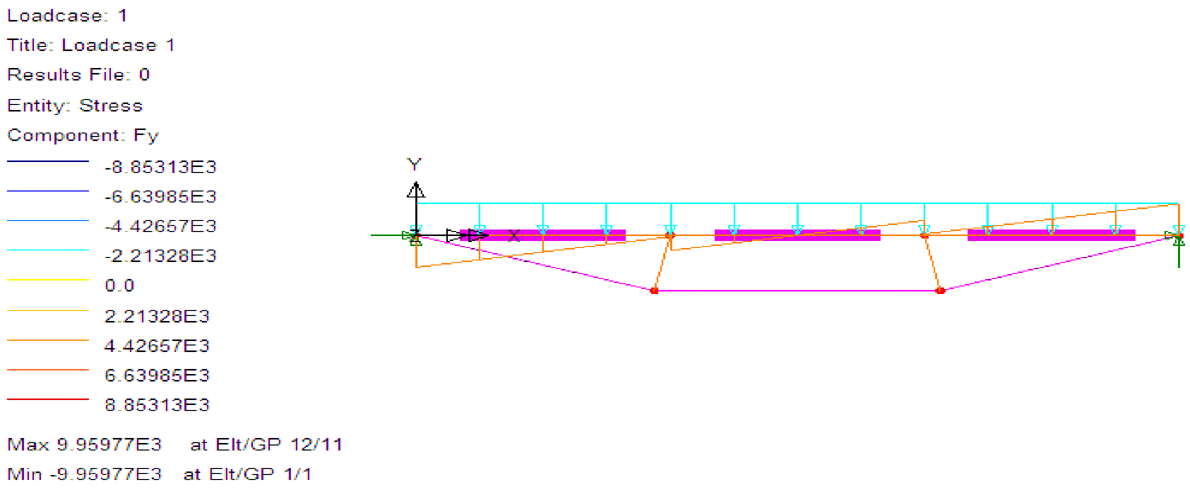

Figure 4.3(a): Shear stress on Intradosed Bridge

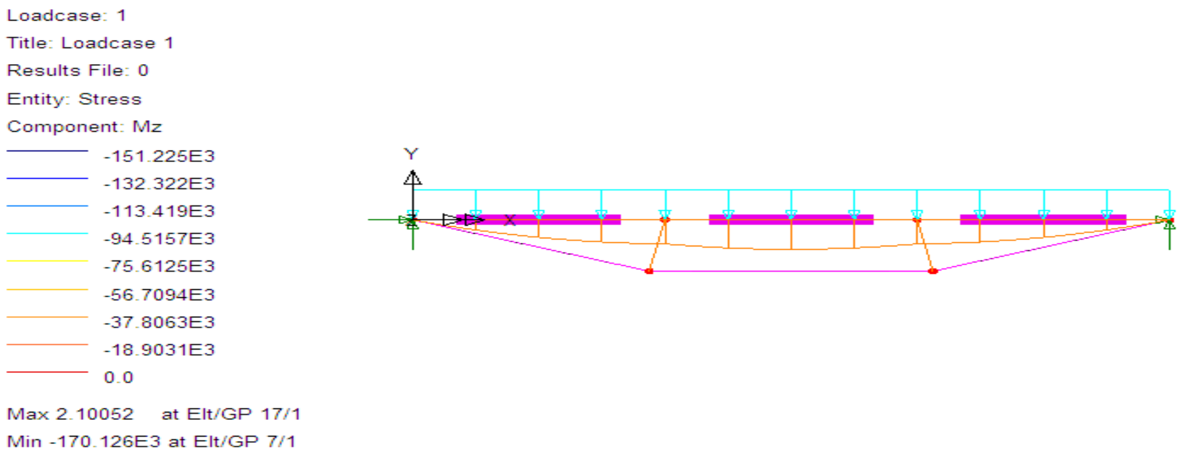

Figure 4.3(b): Bending moment on single span Intradosed Bridge

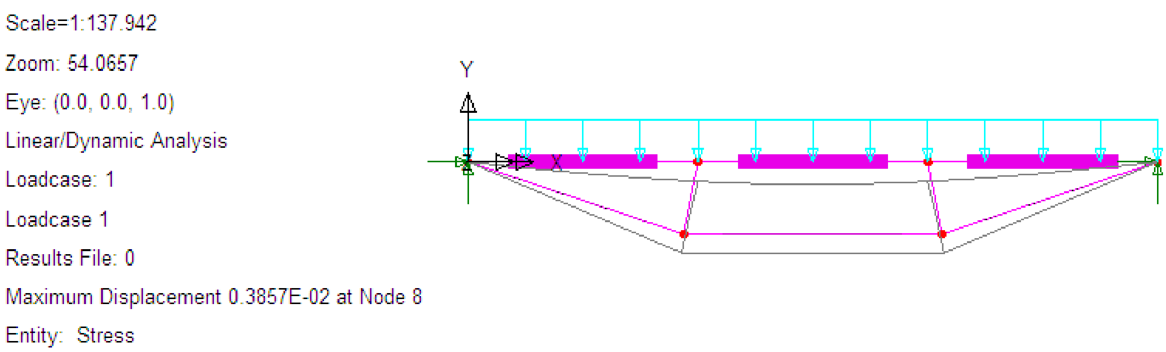

Figure 4.3(c): Displacement on single span Intradosed bridge

APPENDIX A4

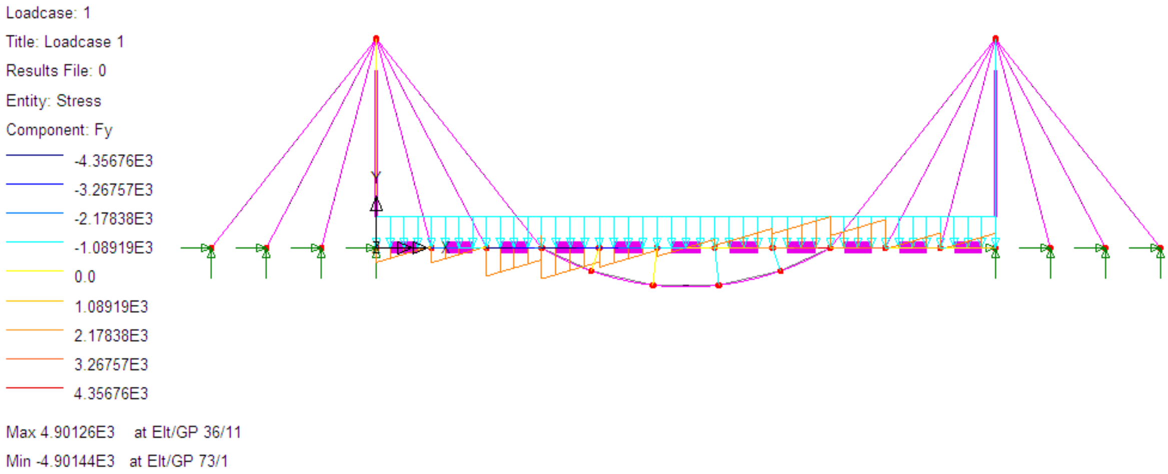

Figure 4.4(a): Shear stress on Combined Cable Stayed Bridge

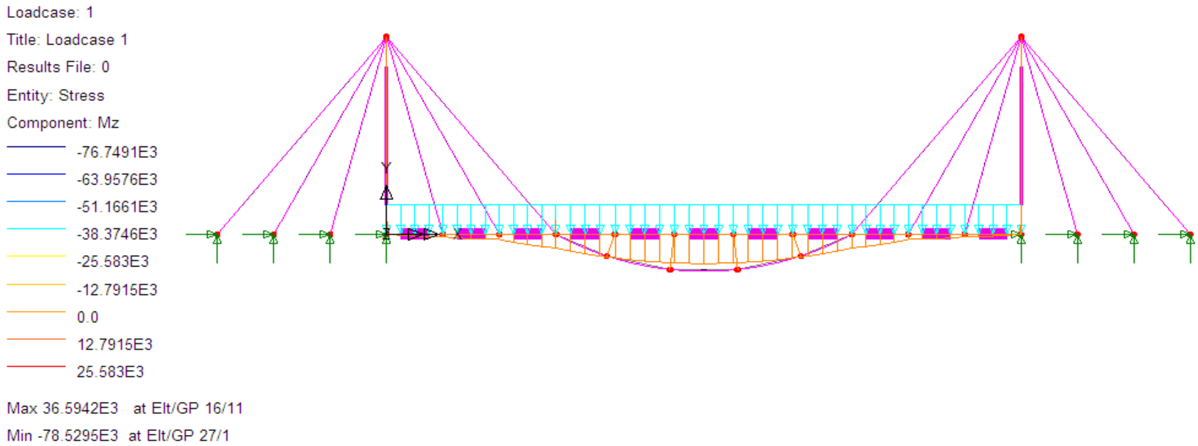

Figure 4.4(b): Bending moment on single span Combined Cable Stayed Bridge

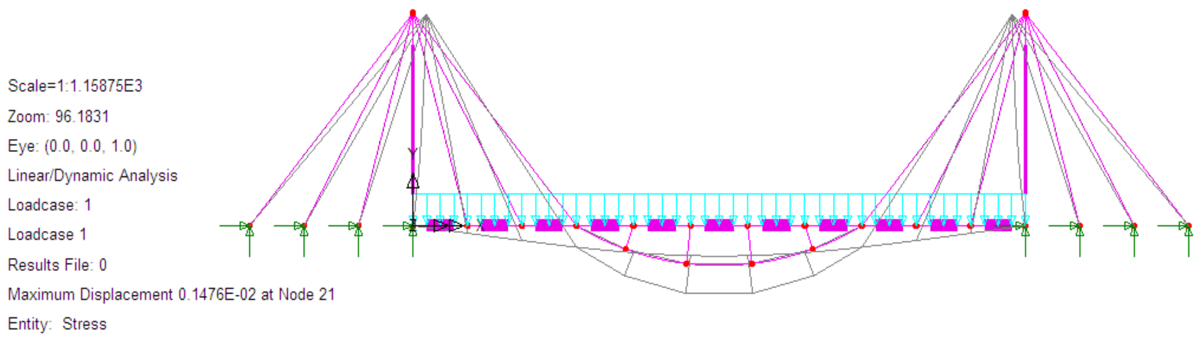

Figure 4.4(c): Displacement on single span Combined Cable Stayed Bridge

APPENDIX A5

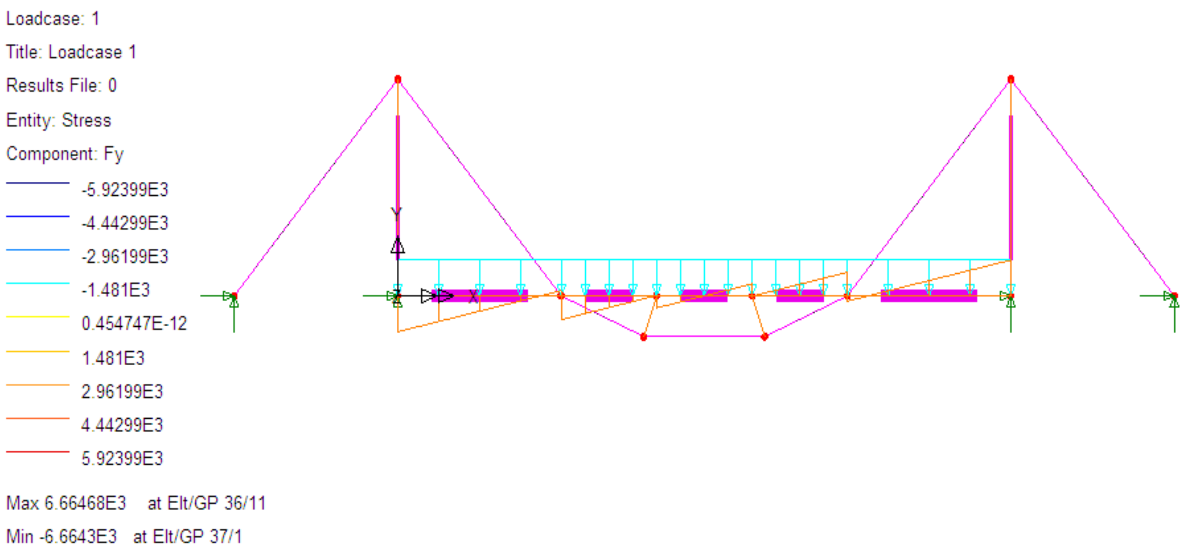

Figure 4.5(a): Shear stress on Extradosed-intradosed Bridge

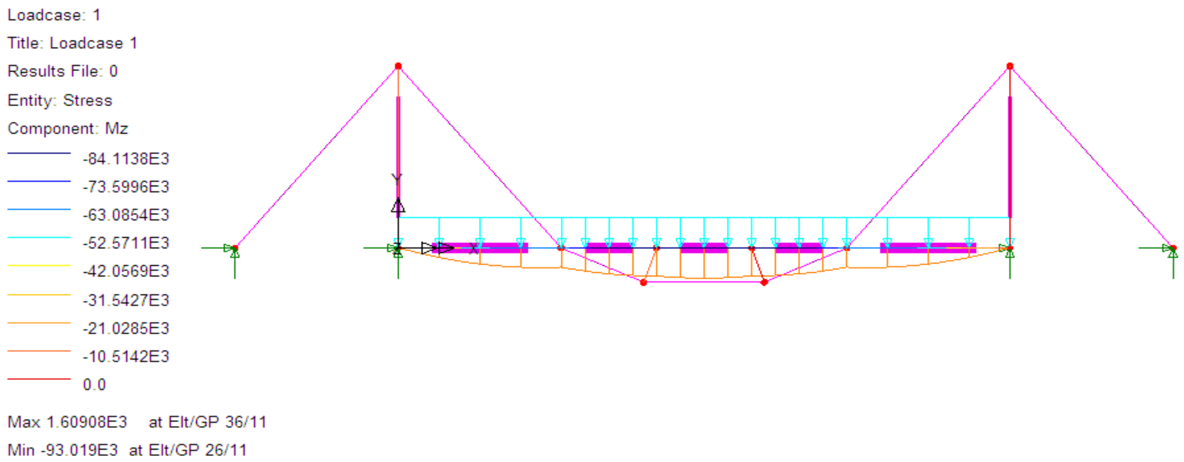

Figure 4.5(b): Bending moment on single span Extradosed-intradosed Bridge

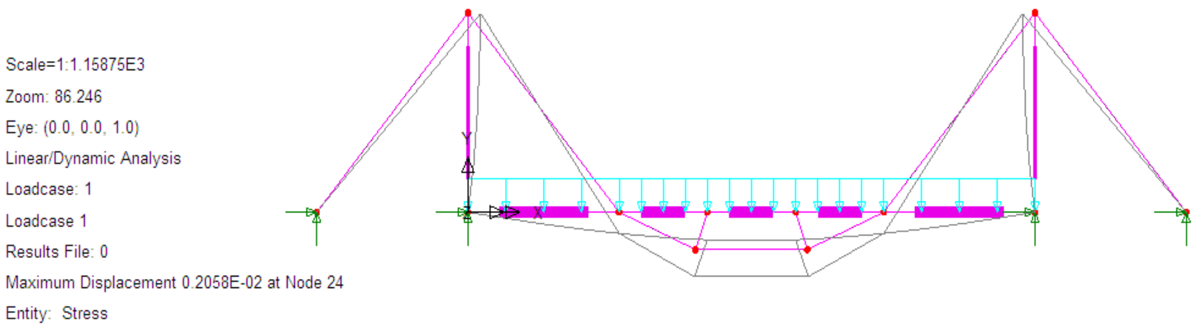

Figure 4.5(c): Displacement on single span Extradosed-intradosed Bridge

APPENDIX B1

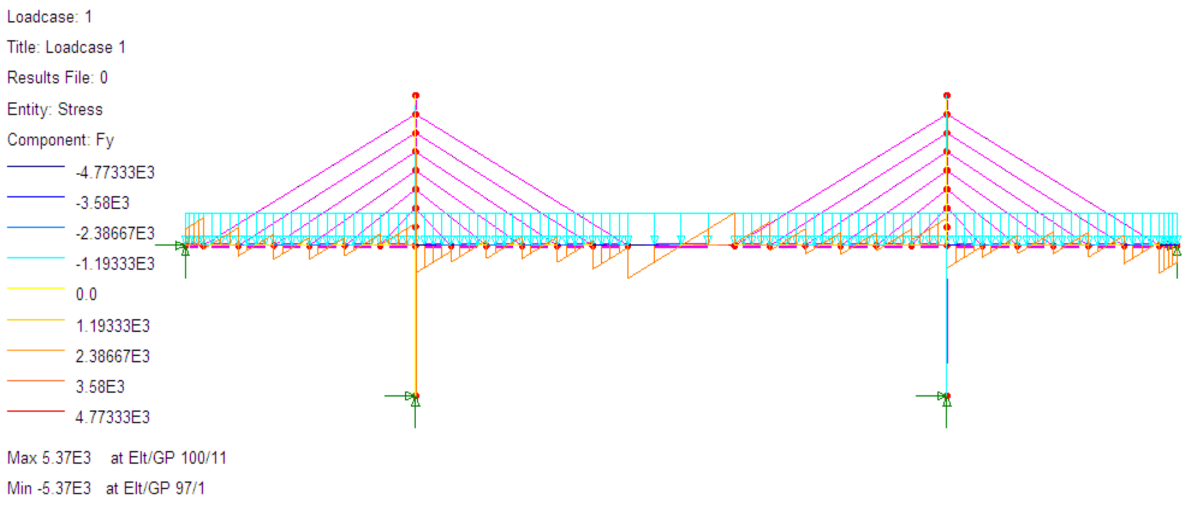

Figure 4.6(a): Shear stress on multiple span conventional cable stayed bridge

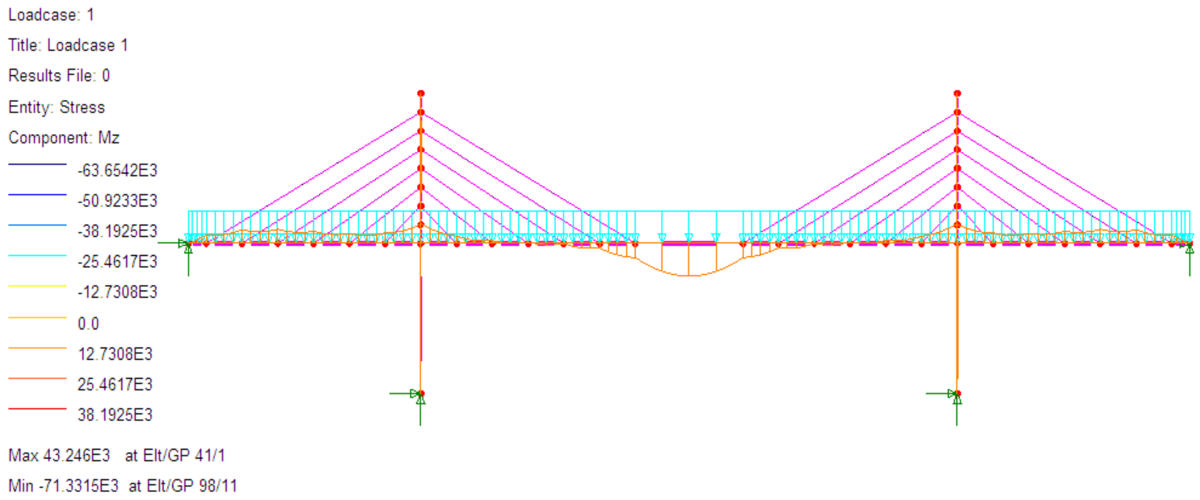

Figure 4.6(b): Bending moment on multiple span conventional cable stayed bridge

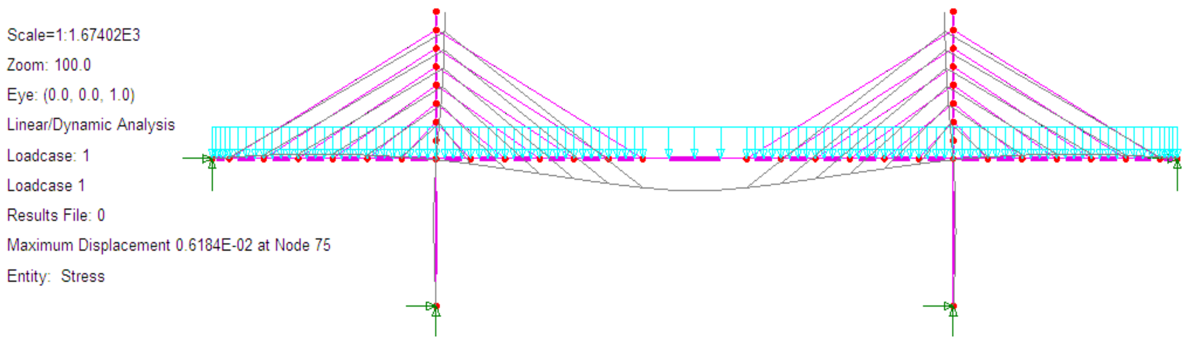

Figure 4.6(c): Displacement on multiple span conventional cable stayed bridge

APPENDIX B2

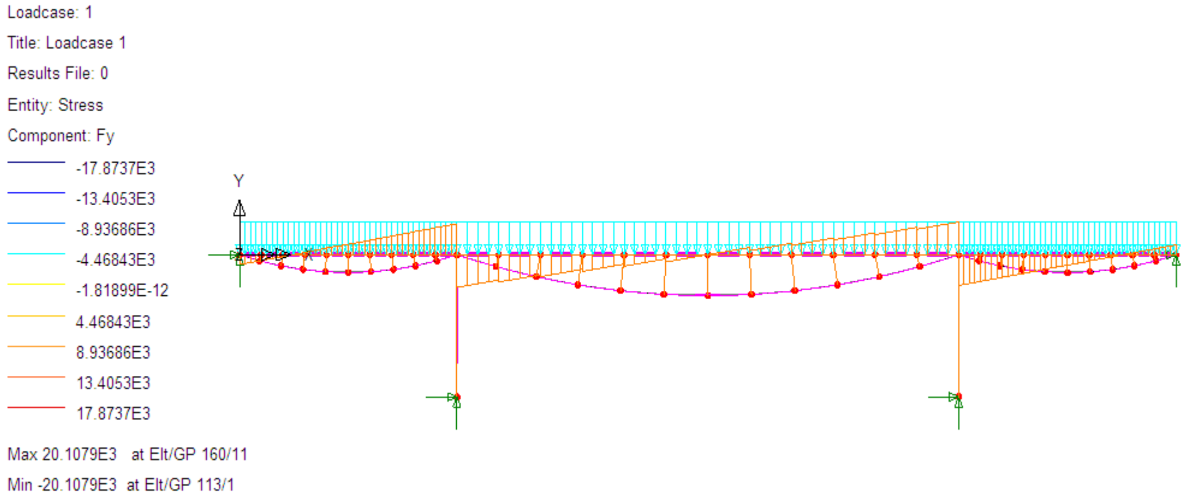

Figure 4.7(a): Shear stress on multiple span Under-deck cable stayed bridge

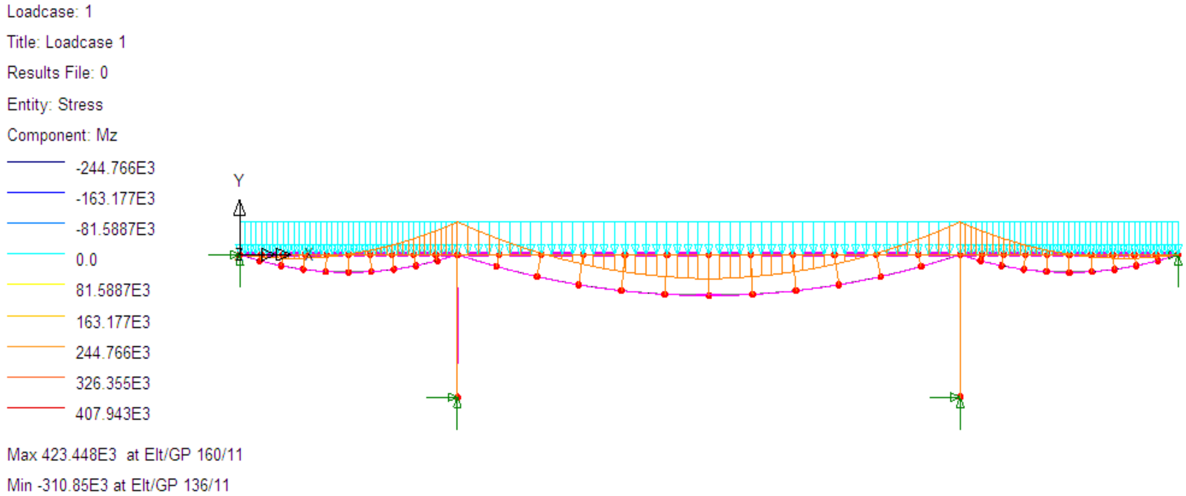

Figure 4.7(b): Bending moment on multiple span Under-deck cable stayed bridge

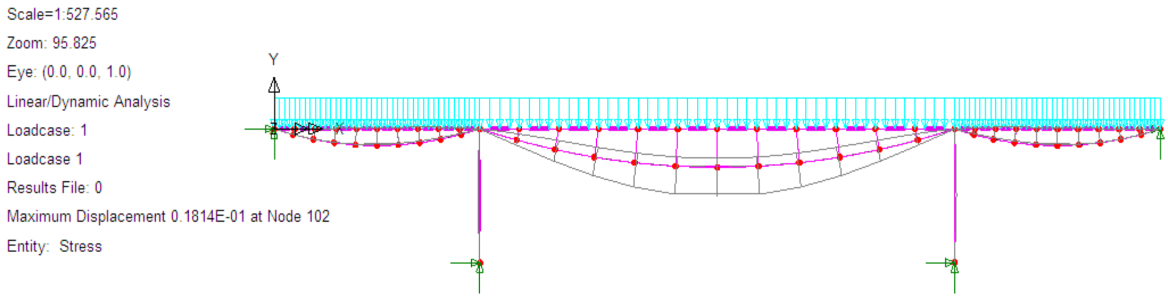

Figure 4.7(c): Displacement on multiple span Under-deck cable stayed bridge

APPENDIX B3

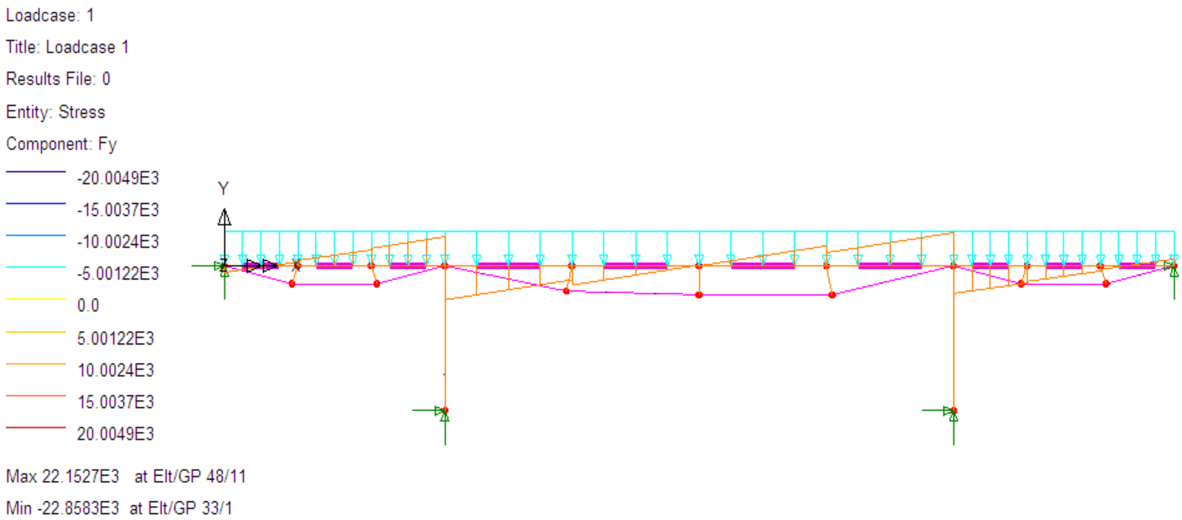

Figure 4.8(a): Shear stress on multiple span Intradosed Bridge

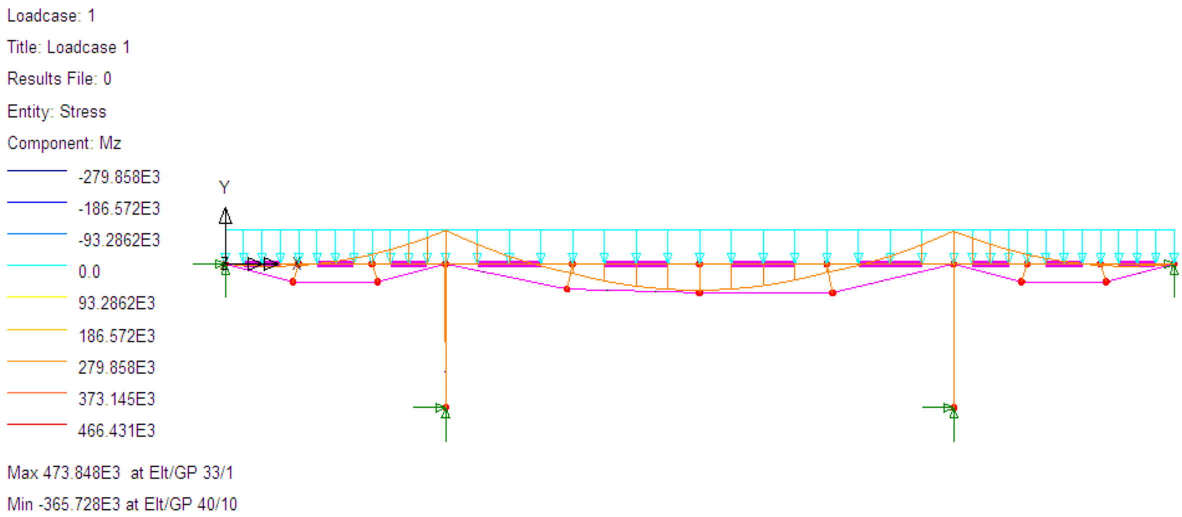

Figure 4.8(b): Bending moment on multiple span Intradosed Bridge

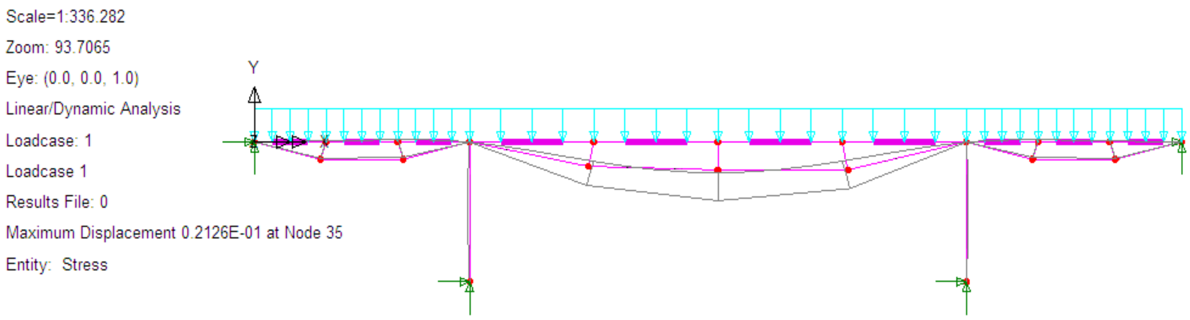

Figure 4.8(c): Displacement on multiple span Intradosed Bridge

APPENDIX B4

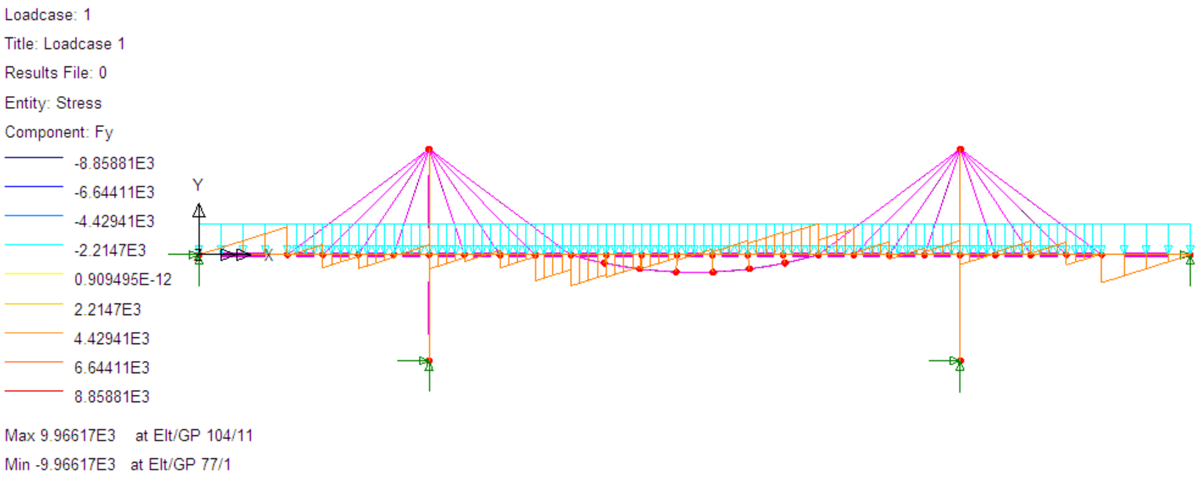

Figure 4.9(a): Shear stress on multiple span Combined Cable Stayed Bridge

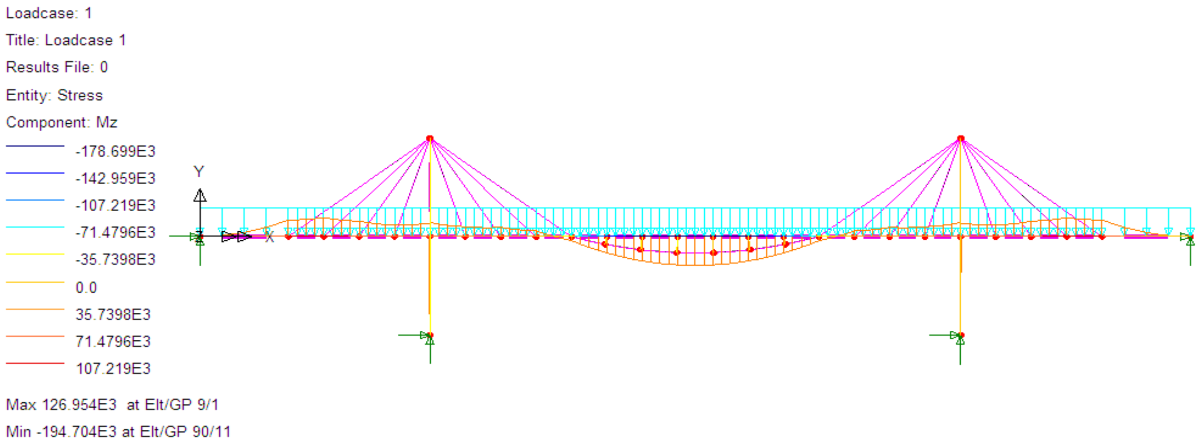

Figure 4.9(b): Bending moment on multiple span Combined Cable Stayed Bridge

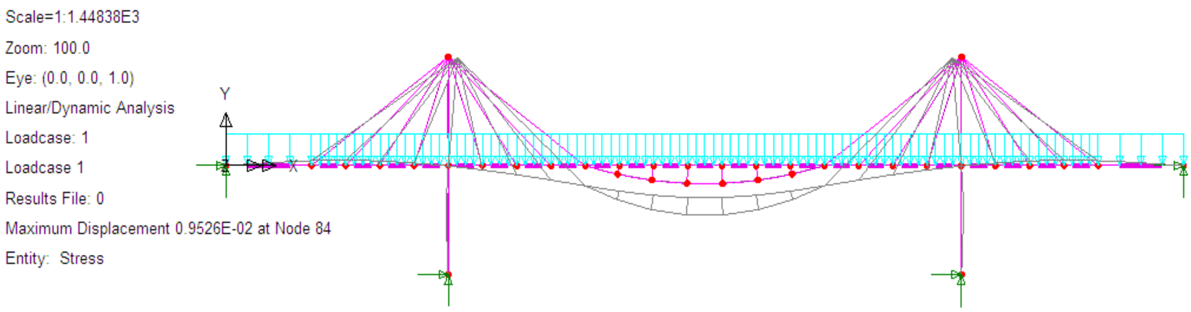

Figure 4.9(c): Displacement on multiple span Combined Cable Stayed Bridge

APPENDIX B5

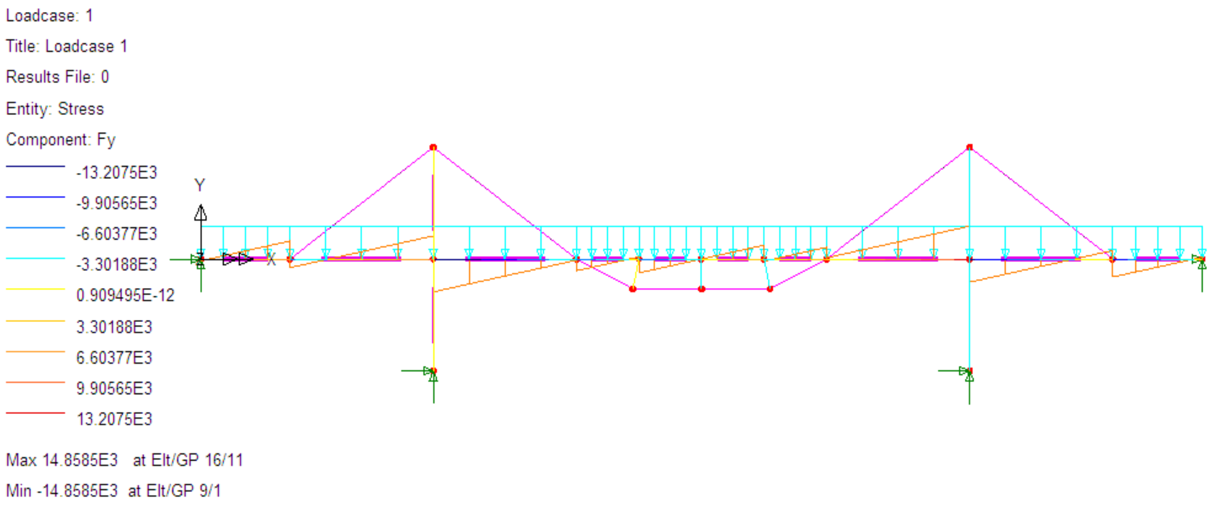

Figure 4.10(a): Shear stress on multiple span Extradosed-intradosed Bridge

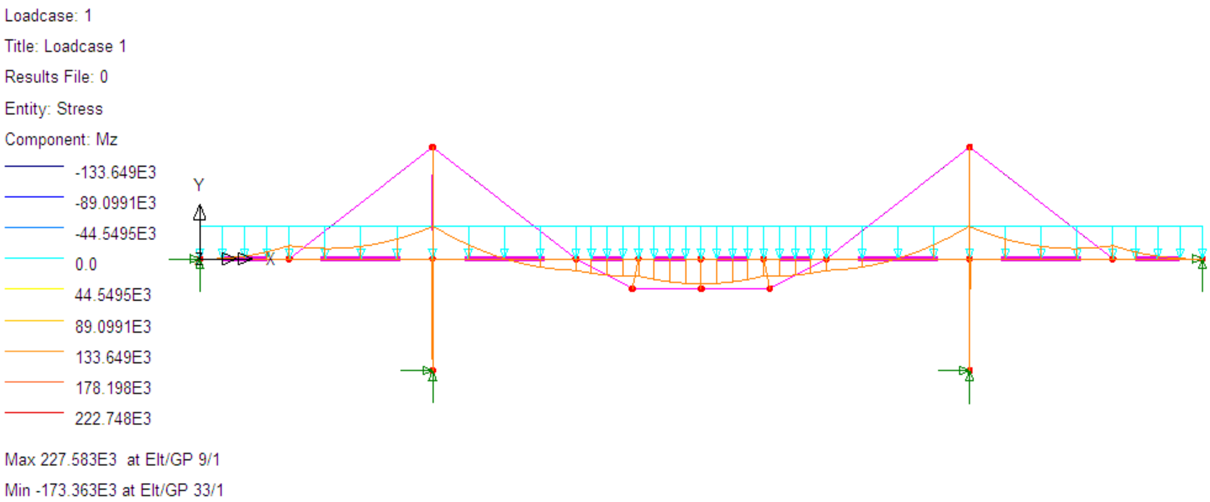

Figure 4.10(b): Bending moment on multiple span Extradosed-intradosed Bridge

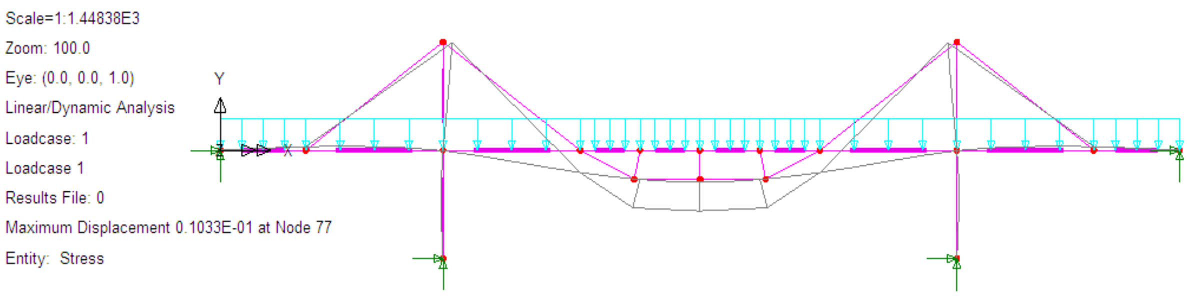

Figure 4.10(c): Displacement on multiple span Extradosed-intradosed Bridge