

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING
(Railway Engineering Program)



**DESIGN OF SIMPLE TO ASSEMBLE STEEL TRUSS
BRIDGE FOR PEDESTRIAN CROSSING IN ADDIS ABABA
LRT**

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Thesis Submitted To The School Of Graduate Studies Of Addis Ababa University
In Partial Fulfillment Of The Requirements For The Degree Of Master Of Science
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ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATED STUDIES
POSTGRADUATE PROGRAM IN RAILWAY ENGINEERING
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**Design of Simple to Assemble Steel Truss Bridge for
Pedestrian Crossing in Addis Ababa LRT**

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “Design of Simple to Assemble Steel Truss Bridge for Pedestrian Crossing in Addis Ababa LRT” is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis been duly acknowledged.

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This is to certify that the above declared made by the candidate is correct to the best of my knowledge.

Dr.Ing Demiss Alemu (Advisor)

Date

Melaku Desalegn

Addis Ababa
June /2015

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Abstract

Road traffic accident is becoming the major problem globally. Our country is also facing the problem currently with increasing trend of the magnitude of the problem from time to time. Addis Ababa, the capital of the nation is the major area where traffic accident is occurring in the country. One of the main reasons for road traffic accident is thought to be due to the absence of separate way for pedestrian crossing and imbalance between the number of pedestrians, vehicle number and size of the road. Considering the new railway line of Addis Ababa if it continuous this way the traffic accident will increase. To minimize this and facilitate the movement of rail vehicle its vital to provide a separate way for the pedestrians from the railway track. And this thesis facilitate and smoothies the flow of rail vehicles by designing pedestrian crossing truss bridge in the roads congested with pedestrians, vehicles and railway track by the methods of Finite Element analysis, modeling and simulating software's such as CATIA, SOLIDWORK and ANSYS.

This Design permits rail vehicles to have smooth and safe way by avoiding pedestrian's interference since it allows them a separate crossing way.

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List of Symbols and Abbreviation

- A = Cross-sectional area
- A_{bm} = Cross sectional area of the base material
- A_v = Shear area
- A_w = Cross sectional area of the weld
- A_b = Cross sectional area of bolt
- d = Diameter of bolt
- E = Modulus of elasticity
- F_{bm} = Nominal strength of the base material
- $F_{b,RD}$ = Bearing capacity of bolt
- F_{EXX} = Nominal tensile strength of the weld metal
- F_w = Nominal strength of the weld electrode
- F_y = yield strength
- L = length
- $N_{pl,Rd}$ = Design plastic resistance
- $N_{t,Rd}$ = Design tension resistance capacity of the cross section
- $N_{t,sd}$ = Design value of the axial tension force at each cross section
- Q_i = Force effect
- R_f = Factored resistance
- $F_{V,RD}$ = Specified minimum ultimate strength of bolt
- σ_v = shear stress
- t = Plate thickness
- γ_m = partial safety factor
- F_y = Minimum Yield Strength
- P_w = Factored pedestrian load
- ρ = Density,
- V_{10} = wind velocity at 10 m above low ground
- V_B = base wind velocity of at 10 m height
- Z = height of structure
- V_o = friction velocity, a meteorological wind characteristic
- Z_o = Friction length of upstream fetch, a meteorological wind characteristic

I_r = Wind Importance Factor

η_i = Load modifier: a factor relating to ductility, redundancy, and operational importance

γ_i = Load factor

Q_i = Force effect by pedestrian

μ = Resistance factor

R_n = Nominal resistance

F_l = Line load

F_n = Nodal load

F_{bm} = Nominal strength of the base material

F_w = Nominal strength of the weld electrode

ϕ = resistance factor

F_y = lower of the nominal yield strength of bolt and the connected part.

ERA =Ethiopian Roads Authority

LRFD = Load resistance Factor Design

ASTM = American society for testing and materials

AASHTO = American Association of state highway and transportation

FEM= finite element method

PA= left end panel

PB = second panel next to right end panel

PC = third panel

PD = right end panel

SB = Bottom chord

ST = Top chord

STM = Top chord for module A and B

SV = Verticals members

SDM = Diagonals members for module A and B

SD = Diagonals members

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CHAPTER ONE: INTRODUCTION

1.1 Background

Addis Ababa light rail transit project is one of the mega projects under construction in Ethiopia, and such big infrastructures have a great role in facilitating the economy growth of the country when it comes to finish.

However, considering the traffic congestion of Addis Ababa such infrastructures has effects in the movement of pedestrians (no motorist). Since pedestrians are part of every roadway environment, their interaction with traffic should be a major consideration in railway planning and design. Pedestrians have also some feature's which can make them vulnerable to traffic accidents include their less predictable action than a motorist; many consider themselves outside the law in traffic matters, have a basic resistance to changes in grade or elevation when crossing roadways (avoid over pass pedestrian facilities), and they walk in a path representing the shortest distance between two points. Also driving speed of the trains and vehicles also has crucial effects on the pedestrian crossing safety. Because of the demands of vehicular traffic in congested urban areas, it is often very difficult to make adequate provisions for pedestrians. Yet provisions should be made, because pedestrians are the lifeblood of our urban areas, especially in the downtown and other retail areas. In general, the most successful shopping sections are those that provide the most comfort and pleasure for pedestrians.

Due to these reasons truss bridge is preferable for safe crossing of pedestrians over a road congested by vehicles and railway track as shown in figure 1 and 2.

The ease of assembling and erecting panelized steel truss bridge makes it a good alternative for use in remote areas. But these are usually imported from abroad. The high cost of importing it is one of the reasons that prohibit its widespread application in inaccessible areas and for temporary works. The design and fabrication of this panelized steel bridge with locally produced steel sections is a possible solution for the problem. This research explores this possibility. It gives analysis and design procedures of a simple to assemble overhead steel truss bridge

Using Steel truss bridges have many advantages, some of them are:

- Less cost(economical)
- Simple to assemble
- Flexibility in design
- Resistance to dynamic loads
- Easy maintenance
- Safe



Figure 1.1: Train passing under pedestrian truss bridge



Figure 1.2: steel bridge for pedestrian around Arat killo

1.2 Problem statement

Road traffic accident is becoming the main problem of Addis Ababa city. Every day a number of pedestrians are dying because of road traffic accident. Also each year the city is losing millions of dollars as a result of traffic accident.

One of the reasons that contribute to the problem is lack of appropriate pathways for pedestrians beside the speed of vehicle, road design, road environment, and driver skill and behavior. Because of the absence of safe path ways for pedestrians in the city, they are forced to cross streets through inappropriate way risking themselves to traffic accident. It is everyone's responsibility to look for a solution to alleviate such a big problem of the city.



Figure 1.3: unsafe crossing of pedestrian around lancha.

A solution to protect pedestrian safety during crossing is to design and build safe and simple to assemble pedestrian steel truss bridge which will eliminate traffic congestion and delay, as well as eliminate conflicts between pedestrians and motorists.

1.3 Objective

1.3.1 General objective

In Ethiopia most of the permanent bridges are made from reinforced concrete and imported steel bridges being used mainly as temporary replacement for failed bridges and in locations where access is not easy.

The main objective of this research is to promote the use of locally available steel profiles to provide a safe walk for pedestrians during crossing on busy roads (sites with extremely high traffic) with a railway track, by designing safe and simple to assemble steel truss bridge.

1.3.2 Specific objective

- To Design economical, safe and simple to assemble steel truss bridge for pedestrian crossing purpose.
- Design locally available steel truss bridge
- To develop analysis and design procedure for steel truss bridge.
- To make a design to separate train and pedestrians to avoid road traffic accidents
- To avoid pedestrian trapping in railway track
- Simulating steel truss bridge using Ansys software
- Model 3D of steel truss using software like ANSYS and CATIA

1.4 Scope of This Paper

The scope of the study has been limited to design and assemble of simple steel truss Pedestrian bridge for Addis Ababa light rail transit using locally available materials by the method of finite element software. Main components of the steel truss were analyzed using ANSYS workbench software. Assembly and maintenance procedures are prepared considering the relevant conditions.

This research may be used as a basis for future study to include the design of other parts of the bridge so that the whole bridge could be designed and manufactured using local steel profiles.

This design did not consider disabled pedestrians.

1.5 Report Organization

The report is made up of six chapters. Chapter one deals with introduction such as background information, problem statement that lead to the formulation of the project, brief discussion on study methodology, and scope of the study.

Chapter two scoops the literature to solicit information relevant to pedestrian steel truss bridge. Chapter three presents study methodology and data collection, while chapter four presents analyzing the loading system of pedestrian steel truss bridge. Chapter five and chapter six discuss the detail designing of modular steel truss pedestrian bridge and assembly techniques of the steel truss bridge respectively.

Chapter seven caps the report with conclusions and recommendation drawn from the study and suggestions to improve pedestrian safety at these crossings.

1.6 Selecting Bridge Location

The Addis Ababa light rail transit includes both the north –south and east –west line with double track rail and highway line. In this thesis the steel truss bridge is selected for north –south line since the east west line is less dense than that of north south. Therefore this can be implemented in the whole root of the north –south line. To make the design selecting a specific location was mandatory. And the proposed site is around saris in lafto sub city was selected.

Hence the necessary geometry data for the design is taken from this site.

During multiple site visits to the proposed pedestrian bridge location, pedestrian and vehicular traffic data was observed.

The site selection was evaluated based on the following criteria:

- Bridge Geometry
- Traffic density and Safety
- Aesthetics



Figure 1.4: Google map location of the truss bridge

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A bridge is a structure that crosses over a gorge, road, river, railway, or other obstructions, permitting smooth and safe passage of vehicles, trains and pedestrians.

A pedestrian bridge is a bridge designed for pedestrians and in some cases cyclists, animal traffic and horse riders, rather than vehicular traffic. Pedestrian bridges complement the landscape and can be used decoratively to visually link two distinct areas or to signal a transaction. In many developed countries, pedestrian bridges are both functional and can be beautiful works of art and sculpture. For poor rural communities in the developing world, a footbridge may be a community's only access to medical clinics, schools and markets, which would otherwise be unreachable when rivers are too high to cross. Simple suspension bridge designs have been developed to be sustainable and easily constructible in such rural areas using only local materials and labor. The record for the longest footbridge in the world is claimed by the Poughkeepsie Bridge across the Hudson River at Poughkeepsie, New York [2]. Originally built for trains, it was recently restored as a pedestrian walkway. The footbridge has a total length of 2082.15 meters (6,767 feet). Before it was demolished in 2011, the Hornbook Bridge which crossed Bramble Bay in Queensland, Australia was longer than the Poughkeepsie Bridge at 2.8 km [3].



Figure 2.1: pedestrian steel truss bridge for crossing railway track

Truss Bridge: Truss structures are composed of members that are connected to form a rigid frame of steel. This broad application can be used in many areas, such as pedestrian crossing bridge, rail road and other transportation bridges. The individual members of a truss bridge are the load carrying components of the structure, they are arranged in a triangular manner resulting in the loads carried to become either in tension or compression. Today bridge are used for many purposes, since they are simple to assemble and economical.

2.2 Steel Truss

Steel is widely used around the world for the construction of bridges of different size. It is a versatile and effective material that provides efficient and sustainable solutions. Steel has long been recognized as the economic option for a range of bridges. It dominates the markets for long span bridges, railway bridges, footbridges, and medium span highway bridges. It is now increasingly the choice for shorter span highway structures as well. Society gains in many ways from the benefits delivered by steel bridge solutions. Landmark steel bridges embody good design, they are fast to build, and have stimulated the regeneration of many former industrial, dock and canal side areas.

The connected elements (typically straight) may be stressed from tension, compression, or sometimes both in response to dynamic loads [4]. These trusses can be made of timber, steel or can be composite structure. In this thesis, steel trusses used for building bridges are considered. Steel has higher strength, ductility and toughness than many other structural materials such as concrete or wood. However steel must be painted to prevent rusting [10].

Like other bridge types, there are both simple and continuous truss bridges. The members of a truss can be arranged in an almost unlimited number of ways, but the vast majority of trusses encountered in bridge belong to one of the common types listed below. Some of these common types of trusses are the Baily truss, Warren truss, Warren truss with verticals, subdivided Warren truss, the Pratt truss, subdivided Pratt (Baltimore) truss, K truss, and the Howe truss. The integral members of a steel truss bridge are shown in figure2.2.

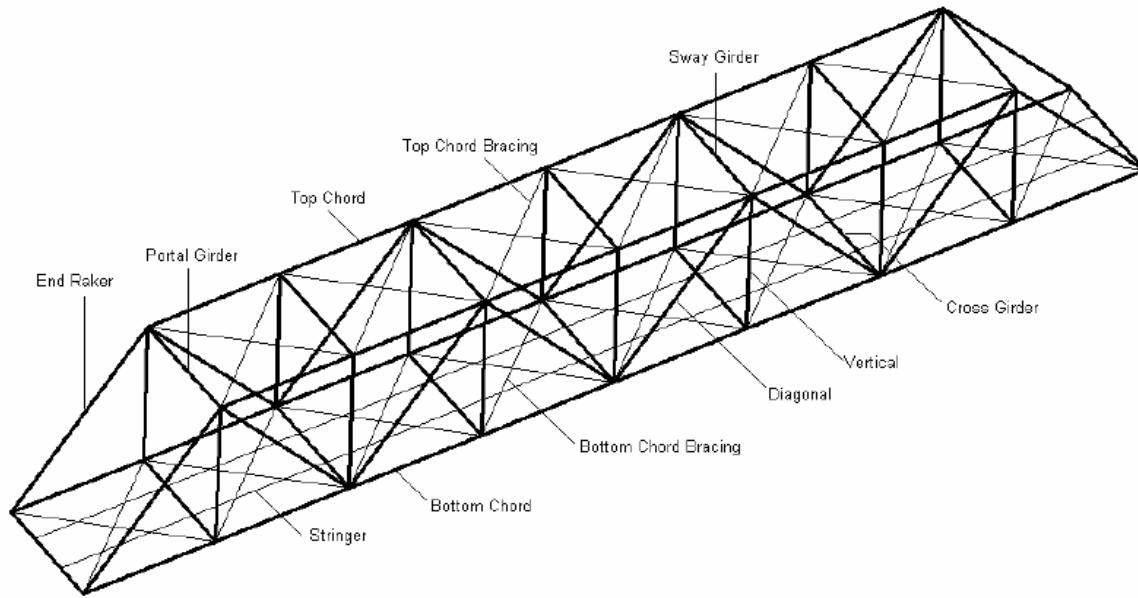


Figure 2.2: Skeleton of a typical steel truss bridge

A) Members of steel truss

The members are generally arranged to form a series of triangles that act together to form the structural system. The chords are the top and bottom members that behave as the flanges of a girder. Diagonals and verticals function in a manner similar to the web in a plate girder. Diagonals generally provide the necessary shear capacity. Verticals carry shear and provide additional panel points through which deck and vehicle loads can be applied to the truss. Tension verticals are commonly called hangers, and compression verticals are often called posts.

They also serve to limit the dead load bending stresses in the chord members by reducing the unsupported member length. Joints are the locations where truss members intersect and are referred to as panel points.

The deck is the structural element that directly supports applied pedestrian loads. Stringers are longitudinal beams, generally placed parallel to traffic, that carry deck loads to the floor beams.

Floor beams are usually set normal to the direction of traffic and are designed to transmit loads from the bridge deck to the trusses. Some trusses in the past have been designed without stringers, relying on the deck to transmit the loads directly to the floor beams. This requires the joint spacing along the chords to be relatively small, and as a result is not economical in the current market.

Lateral bracing is normally provided in the plane of both the top and bottom chords of the trusses. Its purpose is to stiffen the trusses laterally and to carry wind loads and other applied lateral loads back to the support locations.

B) Design

The nature of design truss allows the analysis of the structure using a few assumptions and the application of Newton's laws of motion according to the branch of physics known as statics. For purposes of analysis, trusses are assumed to be pin jointed where the straight components meet. This assumption means that members of the truss (chords, verticals and diagonals) will act only in tension or compression. A more complex analysis is required where rigid joints impose significant bending loads upon the elements [3].

C) Analysis of trusses

Because the forces in each of its two main girders are essentially planar, a truss is usually modelled as a two-dimensional plane frame. If there are significant out-of-plane forces, the structure must be modelled as a three-dimensional space.

The analysis of trusses often assumes that loads are applied to joints only and not at intermediate points along the members. The weight of the members is often insignificant compared to the applied loads and so is often omitted. If required, half of the weight of each member may be applied to its two end joints. Provided the members are long and slender, the moments transmitted through the joints are negligible and they can be treated as "hinges" or 'pin-joints'. Every member of the truss is then in pure compression or pure tension – shear, bending moment, and other more complex stresses are all practically zero. This makes trusses easier to analyze. This also makes trusses physically stronger than other ways of arranging material – because nearly every material can hold a much larger load in tension and compression than in shear, bending, torsion, or other kinds of force.

Structural analysis of trusses of any type can readily be carried out using a matrix method such as the direct stiffness method, the flexibility method or the finite element method [3].

2.3 Types of truss bridge

According to the configuration of members a truss can be classified in to different types and in this paper the Bailey truss configuration type was selected. Classifications of truss type according to their member configuration are listed below [4].

- Bailey truss
- Boll man truss
- Bowstring arch truss
- Brown truss
- Howe truss
- Long truss
- Warren truss
- Pratt truss etc.

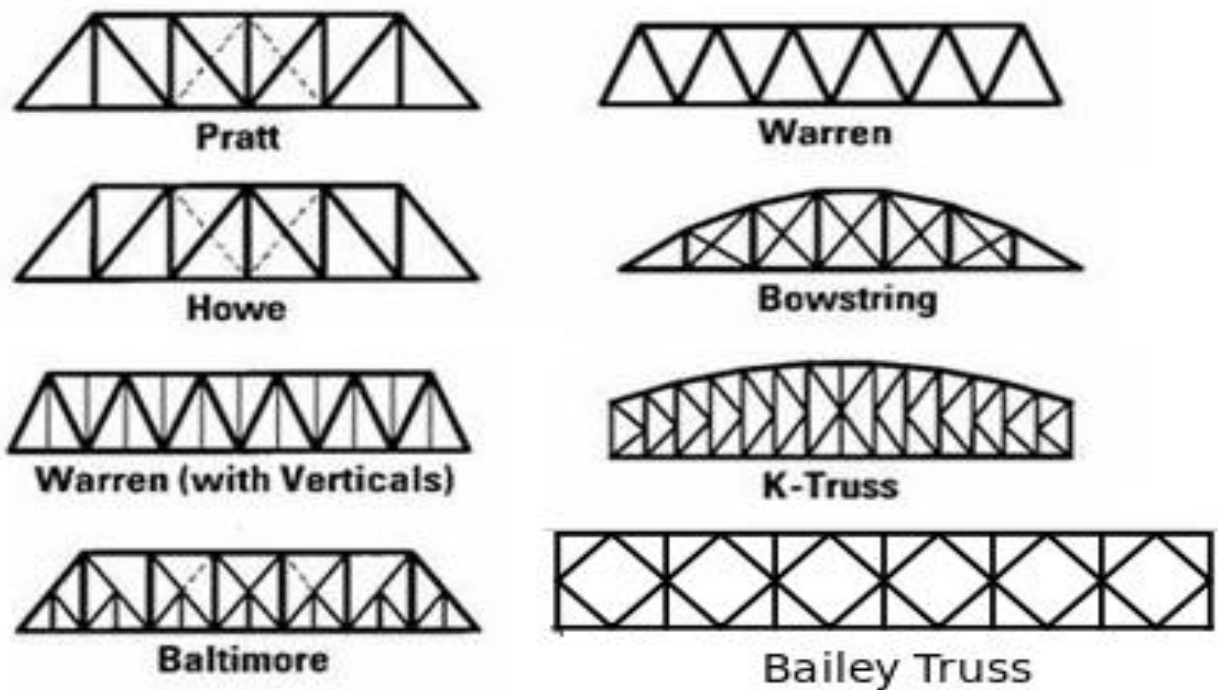


Figure 2.3: Example of Common truss configuration

Bailey truss type: Bailey truss bridge is standard bridge equipment, adopted extensively and the most popular in the world. Prefabricated and standardized truss elements may be easily combined in various configurations to adapt to the needs at the site.

Bailey Bridges which are portable steel bridge have been widely used in various fields, its most important feature is to achieve a variety of spans, bear carrying capacity, light and handy components, easy to dismantle and strong adaptability can be quickly completed with simple tools and manpower[11].

Advantage:

- Possessing the features of simple structure
- convenient transport, speedy erection
- easy disassembling
- High capable to support loads for long span bridges when intermediate support is not possible
- heavy loading capacity
- great stability and long fatigue life

Features

- High strength and big stiffness, relative to the concrete bridge can be reduced trabecular high and self-respect
- Due to the steel isotropic, quality of a material is uniform and modulus of elasticity, that make steel bridge in the working condition and calculation compared with the assumption
- Steel bridge generally uses factory, site splicing, the construction period is short, processing convenient and not affected by seasonal effect.
- Steel bridge is suitable for industrialized manufacture and very convenient to transport.
- Steel bridge is easy to repair and replace, long lifetime, material can be recycled.

2.4 Why Use Steel Truss Bridges

Steel truss bridges are made of panels that are pin connected or fixed type to form the bridge. Fabrication of panels by welding is conducted in the shop (at production site) where the bridge components are prepared before being assembled on the construction site.

The relatively small size of individual parts makes it the ideal bridge for places where it is difficult to transport large parts or where large cranes and heavy equipment cannot be used during erection or at remote places where it becomes very expensive to build reinforced concrete bridges.

In this thesis, steel trusses used for constructing bridges are considered. Steel has higher strength, ductility and toughness than many other structural materials such as concrete or wood. However steel must be painted to prevent rusting.

2.5 Steel Bridges in Ethiopia

According to information gathered from Ethiopian Roads Authority, steel bridges were in use as early as 1945. The types of steel bridges used in Ethiopia are steel truss bridges, steel girder bridges and temporary steel panel bridges. Currently the federal road network has 50 temporary panel bridges, 7 permanent steel bridges and 11 steel girder bridges under it. Some of these bridges have reinforced concrete deck, others timber deck and some are of steel deck. Temporary steel bridges imported as close as 10 years back were with timber deck. Usually such kind of deck serves only for short time depending on volume of traffic. When it wears out it is replaced by local timber made from Eucalyptus tree, which brings about undesired dynamic effect and movement of the span while vehicles are passing. Thus overload plus over speed coupled with irregular driving sometimes brings about failure of these bridges. Rohalomi bridge is an example of such a failure. It was a 20mt long, single span steel truss bridge (Bailey type) with timber deck located in Gonder on the Gonder-Humera road.



Figure 2.4: Baily truss bridge at the entrance to the Addis Ababa Tennis Club

CHAPTER THREE: METHODOLOGY

To achieve the objectives of the research, quantitative and qualitative research methods were used.

3.1 Quantitative Data collection

Quantitative data was collected from Ethiopian Road Authority, Akaki Kality Steel Manufacturing Factory and by taking manual measurement's at the selected sites. The measurements include width of railway track, width of road, width of pedestrian walkway and height of railway electric pole. These were the basic inputs for the design of the steel truss bridge.

Load system and load related data was collected from the Ethiopian road Authority Bridge Design manual and from ASSHTO load and resistance factor design manual.

Material data for the steel truss bridge members were collected from Akaki Kality Steel Manufacturing Factory. Some of the data includes mechanical property of the steel and cross sectional size and shape of the members.

Numerical data was collected from exiting steel truss bridges listed below:

- Steel Truss Pedestrian bridge in 4 kilo
- Baily bridge at the entrance to the Addis Ababa Tennis Club
- Panel Bridge parts at ERA's store in Alemgena District.

a) Assessment of Locally Built Steel Truss Bridges

Site visit was conducted on existing Baily bridges in Addis Ababa and on different parts of steel truss Bridge outside of Addis Ababa to appreciate the design problem. Site visits were made at 4 kilo pedestrian truss bridge near to ministry of education and at Alemgena Panel Bridge parts store of Ethiopian Roads Authority in Alemgena district and the visit area within Addis Ababa was the Baily Bridge at the entrance of Addis Ababa Tennis Club (see Figure 2.4 and figure 3.1).

Bridge Location: At the entrance to the Addis Ababa Tennis Club (see Figure 2.4)

Crossing: Filwoha River

Bridge Type: Baily steel truss bridge with timber deck

Number of spans: 1

Span Length: 15.20m

Roadway width: 3.35m

Foundation: Stone masonry head wall and wing wall

During the site visit at Alemgena, pictures and measurements of different parts were taken for the accompanying study. The measurements are listed below.



Figure 3.1: Panel steel truss parts at ERA's store in Alemgena District.

Panel: - made of top chord, bottom chord, verticals, diagonals and connection plates with the following measured dimensions (see Fig. 3.2).

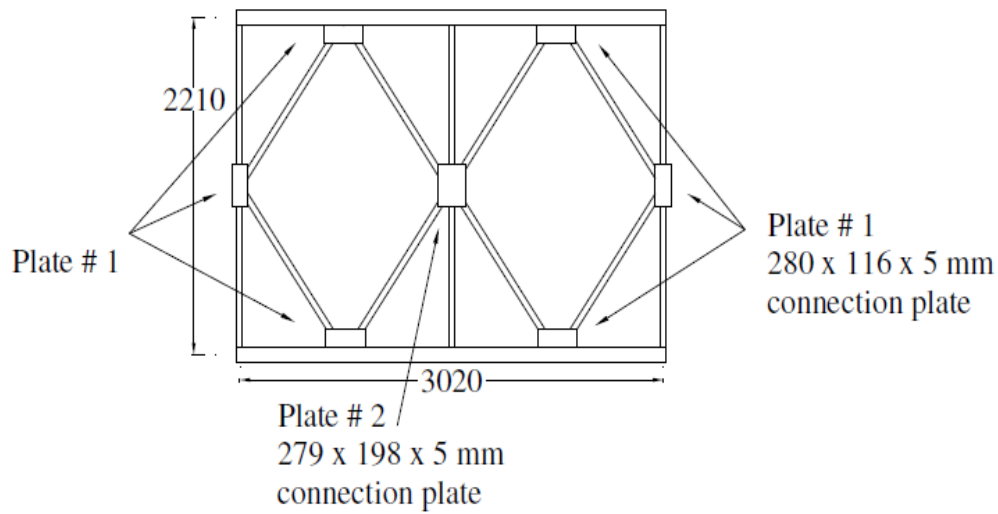


Figure 3.2: Measured dimensions of locally available panel truss part at ERA's store Alemgena District

Bottom/top chord: made of two channels with the following measured dimensions

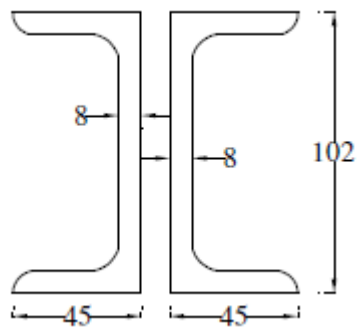


Figure 3.3: Measured dimensions in mm of bottom /top channel

Cross-sectional area = 1368 mm²

Vertical/diagonal members: made of single channel with the following measured dimensions

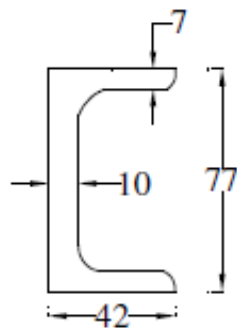


Figure 3.4: Measured dimensions in mm of vertical / diagonal channel

Cross-sectional area = 1129.00 mm²

Using the above data as a starting point a local panel section is chosen. The panel members, stringers and floor beams are made of channel sections chosen from Kality Metal Products Factory products.

Steel deck section is assumed and standard ERA specification loading conditions are applied on it. These loads are transferred to the stringers and floor beams, which are lattice girders, and then Analyzed. The section capacities of the stringers and floor beams are checked for the applied loading and the load is transferred to the truss.

3.2 Qualitative Data Gathering

The data were gathered by making face to face interview with the pedestrians and drivers at selected sites. Three sites, Saris, Richea and around Lideta were selected for interviewing the pedestrians. These three sites are crowded and highly exposed to pedestrian accident areas of the south – north line of the Addis Ababa light rail transit. In addition to this the following methods are also used.

- Site visits and observation
- Pictures and site survey
- Study of previous relevant works, articles or journals and other documents

The Qualitative data's, like interviews and visual observations are useful to identify and analyze the existing problems that should have to be solved.

The Quantitative data's are useful inputs for designing safe, reliable, economical, and simple in construction pedestrian steel truss bridge.

a) Field visits and Pedestrian survey

Field visit to priority pedestrian crossings was intended to gain personal experience about the crossings and their usage. The survey was done through personal interviews to some pedestrians who used the crossings. They include school principals and pedestrian passing-by the crossings that showed interest. Principals of schools that were in the vicinity of some of these crossings were interviewed. They were considered to represent views of school children who use those crossings.

b) Estimate of pedestrian crossing problem

Four questions intended to estimate subjectively the magnitude of the pedestrian safety problem in the country. In these questions respondents were asked:-

- How often do they not yield to pedestrians;
- The frequency the respondent sees other drivers not yielding to pedestrians;
- If they know any pedestrian who was a victim of “crossing the road” phenomena.
- Drivers were asked, their responsibility at zebra crossings when a pedestrian is waiting to cross the roadway

3.3 Design Method

Generally AASHTO load and resistance factor design approach was used to design the pedestrian steel truss bridge for this research. Ethiopian Road Authority manual was used to design loading system of members in the pedestrian steel truss Bridge. Based on ASTM standard, Hot rolled structural steel channel sections of Kality Metal Products Factory was used for the members to design.

a) Material used

The basic materials used during the study were listed below:

- Internet
- Books
- Journals
- Software

b) Procedure

Main procedures used are:

- Collecting data
- Mathematical Analyzing the data
- Load design calculation
- Modeling of the steel truss bridge using software(CATIA and SOLIDWORK)
- Analysis using ANSYS workbench software
- Result analyzing and discussion
- Assembly of the steel truss using SOLID WORKR
- Recommendation and conclusion

CHAPTER FOUR: DESIGN AND ANALYSIS OF STEEL TRUSS

4.1 Design Considerations:

a) Design data

Dimensions measured from the site and considered for the design of the steel truss pedestrian bridge are listed in the table below.

Table 4.1: Dimensions used to design the pedestrian steel truss

Railway track width	12m
Roadway width	18m
Total length of the span	30m
Height	8m
Width of the span	25m
Truss depth	2.5 m
Number of spans	1
Types of truss configuration	Bailey steel truss
Material	Structural steel

Hot rolled structural steel channel sections of Kality Metal Products Factory with yield strength of 345MPa, ultimate tensile strength of 450MPa and young's modules of 20 GPa are used to construct the trusses members.

- It has been considered that all members are channel bars except the support members which is I beams with cross section of 250 mm x 200 mm, as it is structurally strong enough to carry the design load and locally available material.
- The properties of the steel used as input value in finite element analysis are given below. The material data is obtained from the AASHTO and ERA bridge design manuals specification [5].

Table 4.2: Minimum Mechanical Properties of Structural Steel by shape, strength, and thickness

AASHTO Designation	M270MGrade 250	Remark
Equivalent ASTM Designation	A 709M Grade 250	AASHTO, section 6.4.1, table 1
Thickness of plate, t, mm	$t \leq 100$	AASHTO, section 6.4.1, table 1
Shapes	All groups	AASHTO, section 6.4.1, table 1
Minimum tensile strength, F_u , MPa	343	AASHTO, section 6.4.1, table 1
Minimum Yield Strength, F_y , MPa	250	AASHTO, section 6.4.1, table 1
Density, ρ_c , kg / m ³	7850	AASHTO, section 3.5.1, table 1
Modulus of Elasticity, E_c , MPa	200,000	AASHTO, section 6.4.1
Thermal Coefficient of expansion, mm/ ⁰ c	11.7×10^{-6}	AASHTO, section 6.4.1
Poisson's ratio, ν_c	0.3	

b) Material type

The pedestrian truss is modeled for analysis using ANSYS workbench version 14 software. Four ASTM A656 grade 100 sections namely RT128, RT106, ST100 and ST80 are chosen and checked for carrying capacity and the two with better capacity are used as members of the panel. The top and bottom chords are modeled using RT128 and the vertical and diagonal members using ST100. The design load is applied to all panel points, which are located on the bottom chord.

c) Member Cross section

- Top Chord = 150 mm x 100mm x 15 mm I- Beam
- Bottom Chord = 150 mm x 100mm x 15 mm I- Beam
- Vertical = 100mm x 45 mm x 8mm C-Chanel
- Diagonal = 100mm x 45 mm x 6mm C-Chanel
- Top Bracing = 50mm x 50 mm x 6mm Angle iron

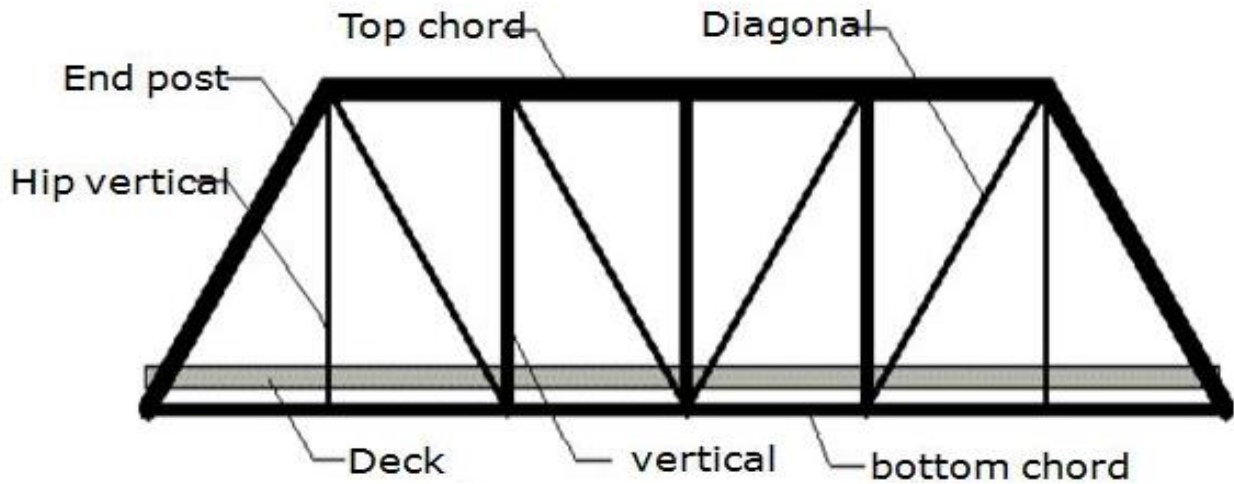


Figure 4.1: Components of steel truss bridge

d) Loadings

- Dead Load = the self-weight of the steel members is accounted for in ANSYSWORKBENCH

- Pedestrian Load = **4.0 kPa** (kN/m²) according to Ethiopian roads authority [5]

- Wind Load = **1.5 kpa** according to Ethiopian roads authority [5]

The Pedestrian Load of the steel is multiplied by a factor of 1.75 to account for any mechanical, electrical system and any supplementary dead loading.

e) Deflection of steel truss bridge

Excessive deformation can cause premature deterioration of the wearing surface and Affect the performance of fasteners and welded joints. According to ERA design manual chapter 2, in the absence of other criteria, the deflection limits for pedestrian steel truss structure shall not exceed 1/500 of span in mm. [5]

4.2 Steel Truss Bridge Loading System

The various types of loading which need to be considered can be broadly classified as permanent, or transient (variable). Permanent loads are those due to the weight of the structure itself and of any other immovable loads that are constant in magnitude and permanently attached to the structure. They act on the bridge throughout its life. Transient loads are those loads that vary in position and magnitude and act on the bridge for short period of time such as live loads, wind loads etc. some of these are

- a. Permanent loads
 - Dead load of structure
 - Superimposed dead loads
- b. Transient loads
 - Pedestrian live loads
 - Wind loads etc.

4.2.1 Permanent loads

Dead load shall include the weight of all components of the truss structure. Thus, the density of the structural steel (given as 7850 kg/m^3) must be converted to force unit (N/m^3) by multiplying the gravitational at constant $g = 9.81 \text{ m/sec}^2$.

4.2.2 Transient loads

The Transient loads for the truss bridge consists of the weight of the applied moving load of pedestrians. To form a consistent basis for design, standard loading conditions are applied to the design model of structure. The standard load is specified both in AASHTO bridge design specification, 2007. Accordingly, Article 6.6.1.6, and ERA bridge design manual (2002), section 3.12, Bridges for only pedestrian and/or bicycle bridges traffic shall be designed for a live load of 4.0 kPa [5].

These loads are factored and combined to produce extreme adverse effect on the member being designed.

a) Pedestrian Loads

According to Ethiopian roads authority bridge design manual, A pedestrian load of **4.0 kPa** (kN/m²) shall be applied to all pedestrian bridges wider than 0.6 m. Dynamic load allowance is not applied to pedestrian live loads [5]

b) Wind Loading

For any structure, the force applied to it by the wind is a major concern in the design of the structure. Unlike the loads previously discussed, the wind loading is applied perpendicular to the structure, and not in the direction of the force of gravity. To determine the force from the wind, first had to find out what the maximum wind speed that the bridge should be designed for. According to the Ethiopian road authority manual there are two conditions that need to be considered [5].

- For truss bridges having height of less than 10 m above the ground, design wind velocity shall be designed with a minimum wind load of 1.5 kpa on the full vertical projected area of the bridge.
- For truss bridges greater than 10 m above low ground or water level, the design wind velocity, V_{DZ} (km/h), at design elevation, z , should be adjusted according to:

$$V_{DZ} = 2.5 * V_o \left[\frac{V_{10}}{V_B} \right] \ln \left[\frac{Z}{z_o} \right] \quad (4.1)$$

Where: V_{10} = wind velocity at 10 m above low ground or above design water level (km/h)

V_B = base wind velocity of 160 km/h (45 m/s) at 10 m height

Z = height of structure at which wind loads are being calculated as measured from low ground

V_o = friction velocity, a meteorological wind characteristic

Z_o = friction length of upstream fetch, a meteorological wind characteristic

There for in this design the truss bridge height is 8 m which is less than 10 m the first condition is applied.

$$P_w = 1.5 \text{ kpa}$$

Wind Importance Factor (I_r) shall be taken as 1.15 and Wind load on signs supported by the pedestrian truss bridge shall be included [5].

4.2.3 Load Factors and Combinations

The LRFD (Load and Resistance Factor Design) design method as per the provision of ERA 2002 Bridge Design Manual is used. Load factors are applied to the loads and resistance factors to the internal resistances or capacities of sections. The load combinations, load factors and force effects are considered according to ERA 2002 Bridge Design Manual clause 3.3 and shall satisfy Eq. (4.2).

$$R_f = \sum \eta_i \gamma_i Q_i < \mu R_n \quad (4.2)$$

Where:

η_i = load modifier: a factor relating to ductility, redundancy, and operational importance

γ_i = load factor: a statistically based multiplier applied to force effects

Q_i = force effect by pedestrian

μ = resistance factor: a statistically based multiplier applied to nominal resistance

R_n = nominal resistance

R_f = factored resistance

a) Factored force effect of pedestrian load

The total factored force effect shall be taken as:

$$Q = \sum \eta_i \gamma_i Q_i \quad (4.3)$$

Note: from ERA design manual of 2002, according to Tables 3-2 and 3-3 the values for [5]

$$\gamma_i = 1 \quad \text{And} \quad \eta_i = 1.75$$

$$Q = 1.75 \times 1 \times 4.0 \text{ (kN/m}^2\text{)} = \underline{\underline{7 \text{ (kN/m}^2\text{)}}}$$

b) Factored effect of wind load

For truss bridges having height of less than 10 m above the ground, it shall be designed with a minimum wind load of 1.5 kPa on the full vertical projected area of the bridge. Wind Importance Factor (I_r) shall be taken as 1.15 and Wind load on signs supported by the pedestrian truss bridge shall be included.

The total factored wind effect shall be taken as:

$$\begin{aligned} Q_w &= I_r * P_w \\ &= 1.15 * 1.5 \text{ kPa} = \underline{\underline{1.725 \text{ kPa}}} \end{aligned} \quad (4.4)$$

c) Load Application

To understand the manner of application of loads to a supporting truss it is necessary for the arrangement of the members of the floor system to be carefully studied.

The most common type of bridge floor is supported by a series of stringers parallel to traffic and running the length of each panel. The stringers frame into and are supported by the floor beams (transoms). The floor beams frame into panel points of the supporting trusses. The stringers and floor beams are for simplicity assumed to have simple end supports (see Figure 4.2).

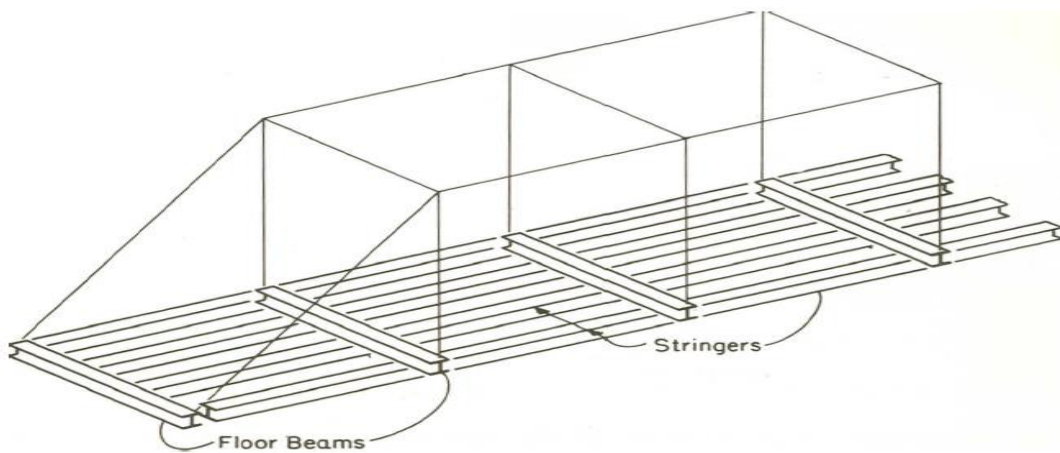


Figure 4.2: Typical arrangement of floor system

The Arrangement of floor system for this design is supported by a series of diamond shaped stringers attached to the floor beam which directly transfers the load to the side truss members as shown in figure 4.3.

d) Nodal load calculation

The above factored pressure load must be converted to concentrated nodal load for maximum deflection value during the design analysis of the steel truss using finite element method software. to do this a sample tributary area was considered.

The tributary area corresponding to one typical interior deck (floor) level joint is indicated in figure 4.3. First the pressure load on the tributary area was converted to line load by multiplying the pressure load by the width of the tributary area. And this line load was converted to a point load at the center node of the side line of the area which is done by multiplying the length of the tributary with the line load obtained in the above method.

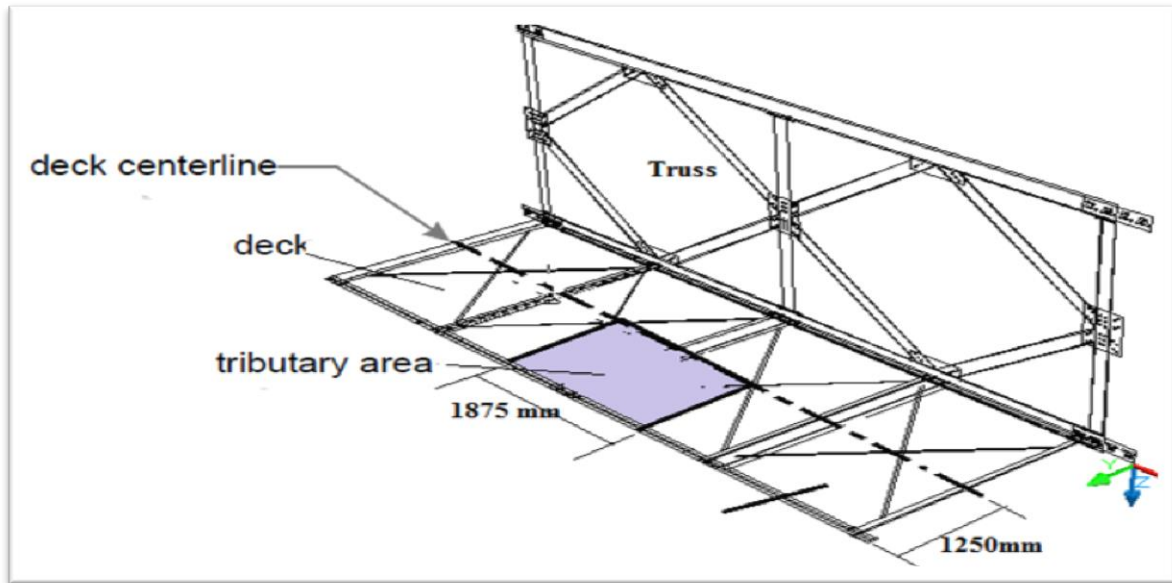


Figure 4.3: Floor (deck) with one side truss

From the above calculation the distributed factored pedestrian pressure load is:

$$Q = 7 \text{ kN/m}^2$$

- e) **Line load at the bottom chord:** To calculate the line load at the side of the tribute area (bottom chord), the pressure load was multiplied by the width.

$$\begin{aligned} F_l &= Q * w & (4.5) \\ &= 7 \text{ kN/m}^2 * 1.25\text{m} \\ &= 8.75 \text{ k N/m} \end{aligned}$$

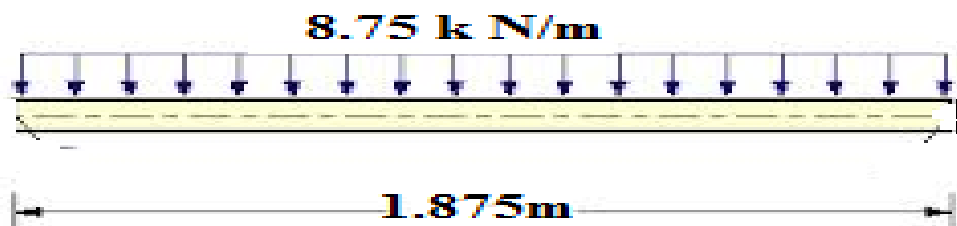


Figure 4.4: Distributed line load on bottom chord between two nodes

Note: the distributed load (line load) from the above result is located throughout the bottom chord but did not include end post of the chord.

f) Nodal load at bottom chord

To calculate the concentrated nodal load on each point of the bottom chord, the distributed load from equation 4.5 was multiplied by its length.

$$F_n = F_l * l \quad (4.6)$$

$$F_n = 8.75 \text{ kN/m} * 1.875\text{m}$$

$$= 16.4 \text{ kN}$$

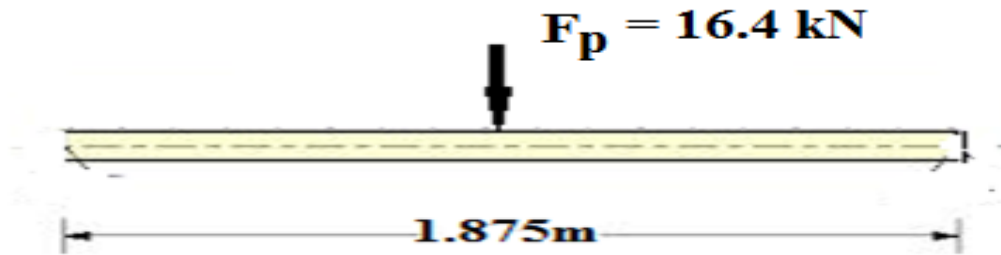


Figure 4.5: Point load at the center of two nodes in bottom chord

From the above calculation considering a simply supported beam, the load at each node of the bottom chord truss is **16.4 kN** except at both ends which is half of the load (**8.2 kN**). And the result is the same for other bottom chord, because the bridge is symetry.

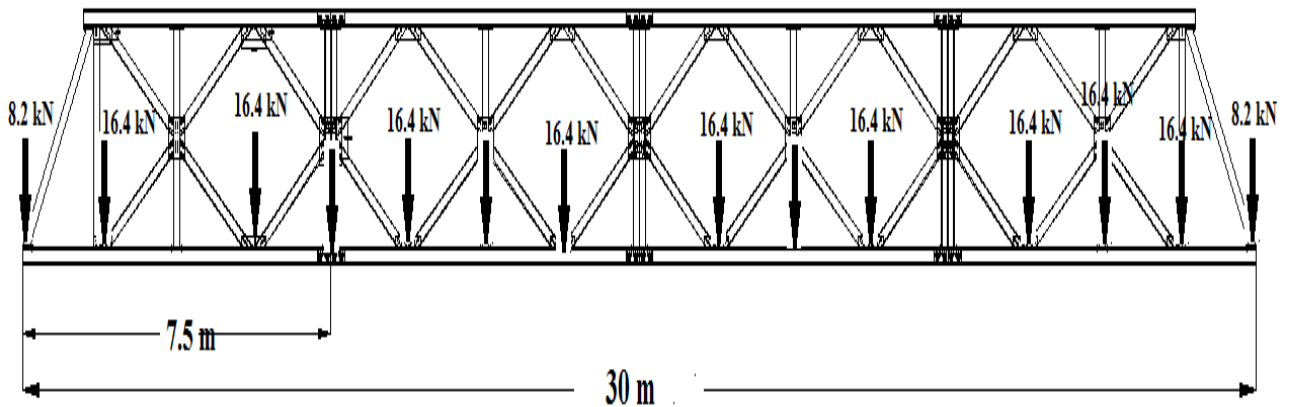


Figure 4.6: Point loads on bottom chord for one side of the steel truss

4.3 Analysis of Steel Truss Bridge Using FEM Software (ANSYS)

4.3.1 Approach & Formulation

To make this FEA problem much simpler, several basic assumptions have been made.

a) **Connections:** The girder-beam connections used in an actual truss bridge uses gusset plates, for simplification, the gusset plates were omitted from the finite element analysis and instead, simply line connections converging to a point were used instead. As illustrated below.



Figure 4.7: Simplification of gusset plate joint

b) **Loading application:** A single point load of 16.4 kN at each node and 8.2kN will be used at the end nodes of the span for maximum deflection calculation.

c) **Program Selection & Other ANSYS Assumptions**

The truss bridge was modelled using the SOLIDWORK 2014 and CATIA V5R16 and analysed using ANSYS 14 finite element analysis software. Metric units were used in Millimeter (mm) for distances and Newton's (N) for loads.

- **Constraints:** The truss bridge assembly is fixed in all degrees of freedom at the support ends.
- Total Dead Load (Self Weight) of the truss assembly is considered by the software applying the gravitation acceleration of 9.81m/s^2 .
- ANSYS Analysis Type: Static Truss Analysis.
- Model : truss analysis

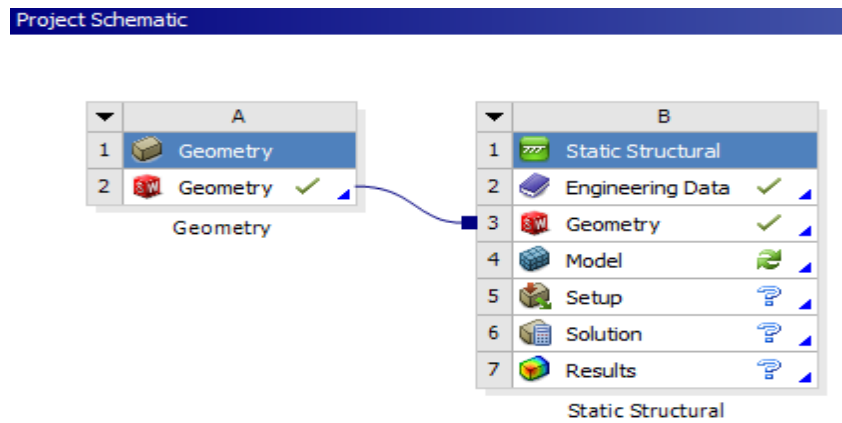
4.3.2 Analysis of steel truss using ANSYS WORKBENCH software

Analysis system: static structural analysis

Units:

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4): The 3D Geometry of the truss is modeled using solid work 2014 and imported to workbench 14



Geometry: all dimensions are imported from solid work 2014

Length X	30000 mm
Length Y	10500. mm
Length Z	2500. mm
Properties	
Volume	3.2372e+009 mm ³
Mass	25412 kg
Length	5.2555e+005 mm
Cross Section	Channel
Cross Section Area	11776 mm ²
Cross Section IYY	2.7787e+007 mm ² ·mm ²
Cross Section IZZ	8.9867e+006 mm ² ·mm ²
Statistics	
Nodes	2877
Elements	1535
Mesh Metric	None

Material Data: Structural Steel

Structural Steel > Constants

Density	7.85e-006 kg mm ⁻³
Coefficient of Thermal Expansion	1.2e-005 C ⁻¹
Specific Heat	4.34e+005 mJ kg ⁻¹ C ⁻¹
Thermal Conductivity	6.05e-002 W mm ⁻¹ C ⁻¹
Resistivity	1.7e-004 ohm mm

Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
250

Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
343

Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2.e+005	0.3	1.6667e+005	76923

Mesh:

Object Name	<i>Mesh</i>
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Fast

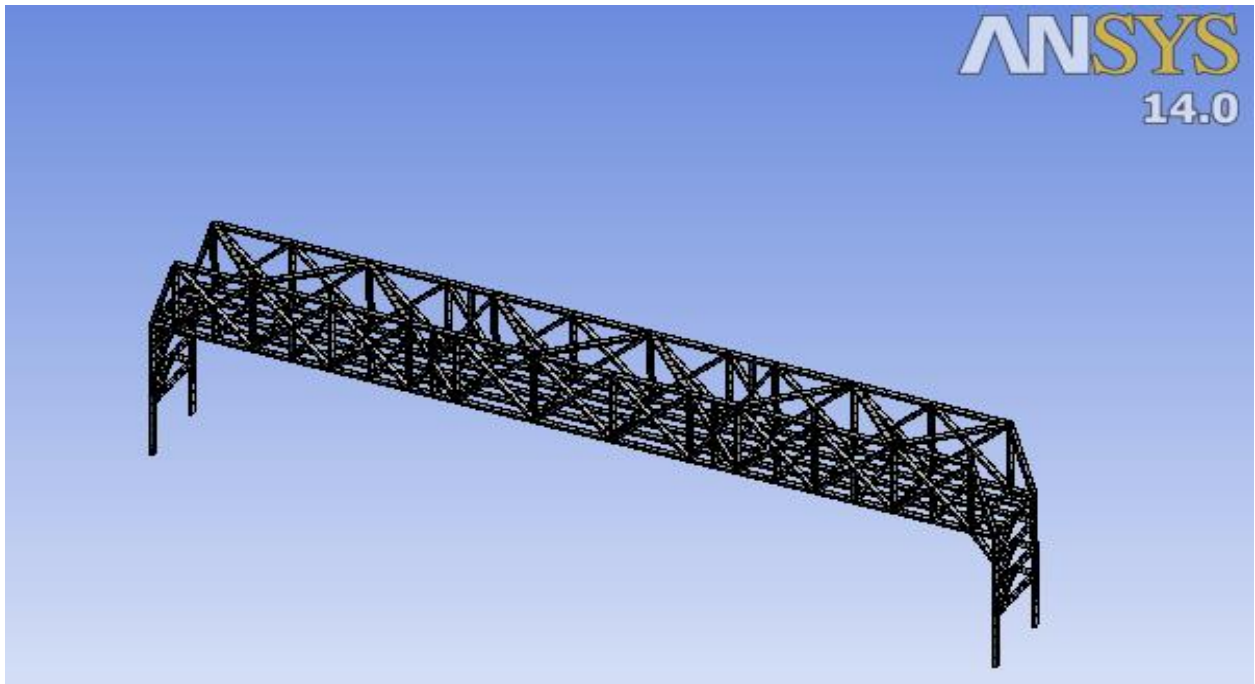


Figure 4.8: Meshing of the steel truss pedestrian bridge in workbench software

- a) **Load:** A 16.4 kN force is applied on each node except the end nodes. The end nodes are subjected to a point load of 8.2 kN which is half of the middle nodes since the area is half of the middle.

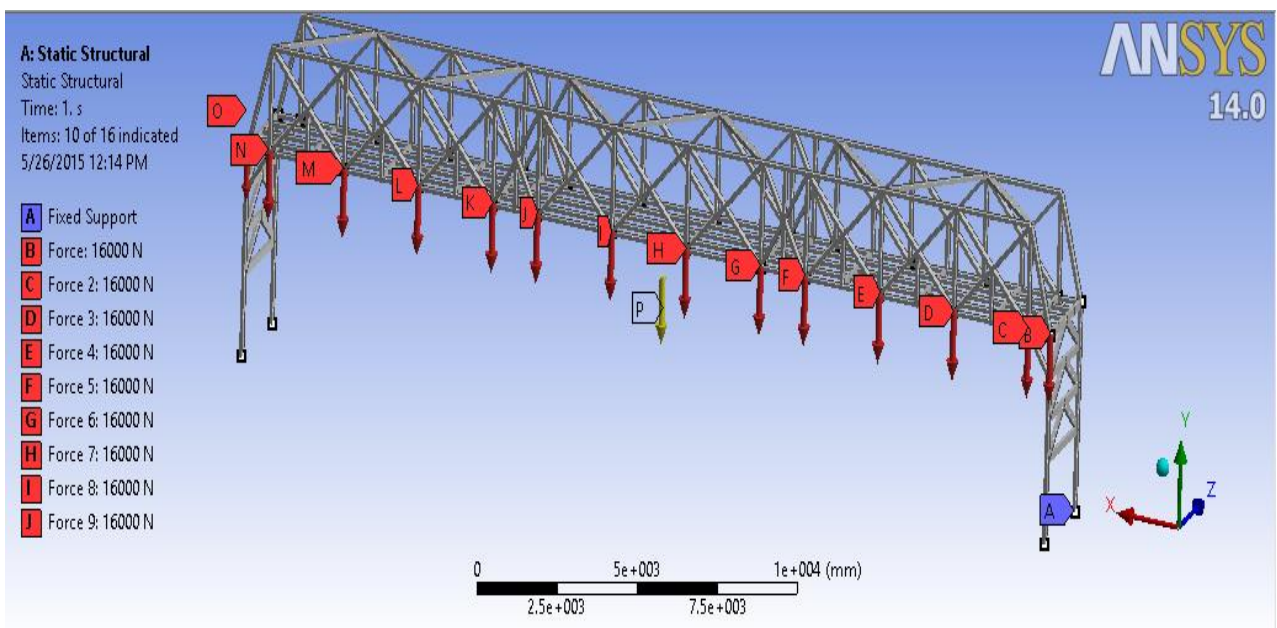


Figure 4.9: Loads applied at each node of bottom chord of the steel truss in workbench

b) **Total deformation:** the maximum deformation is 5.8 mm which are at the middle of the tress.

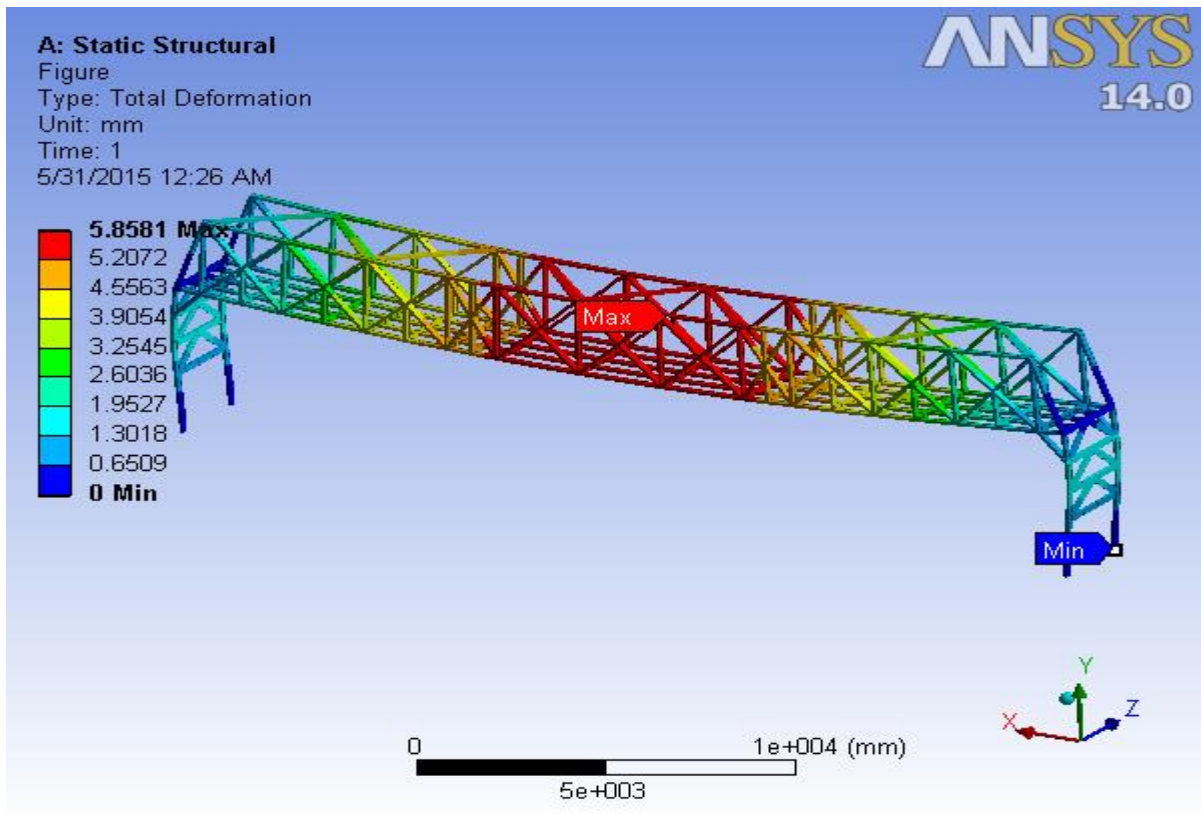


Figure 4.10: Total deformation of steel truss

c) **Directional Axial forces**

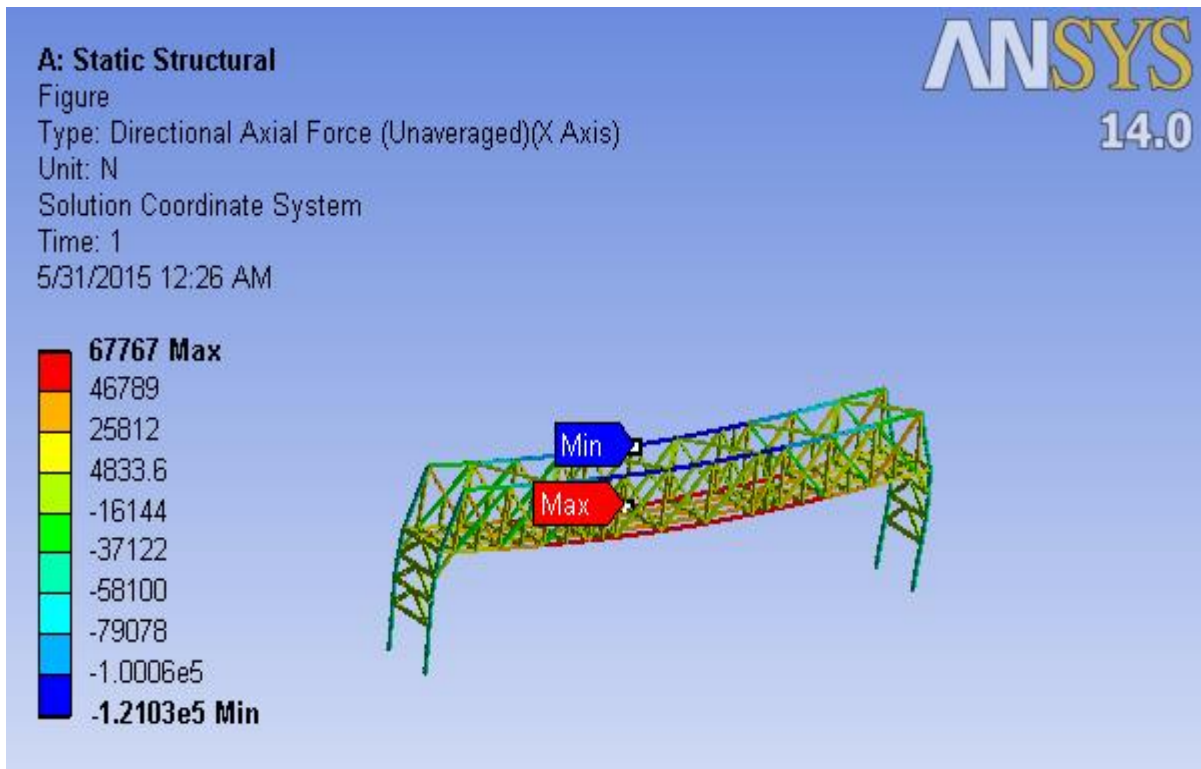


Figure 4.11: Directional axial forces on members of the steel truss

d) **Direct stress:** it is the effect due to the axial force.

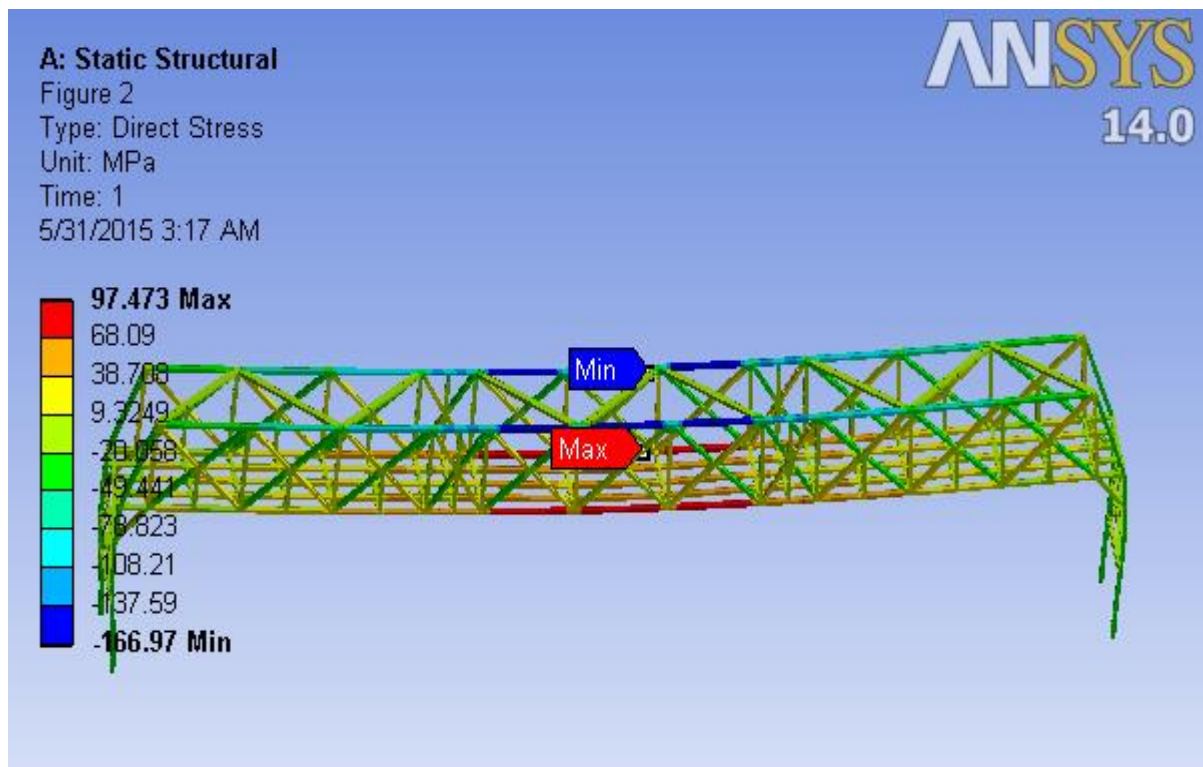


Figure 4.12: Direct stress on steel truss members

e) **Combined stress:** this is the effect due to both the axial and compression forces

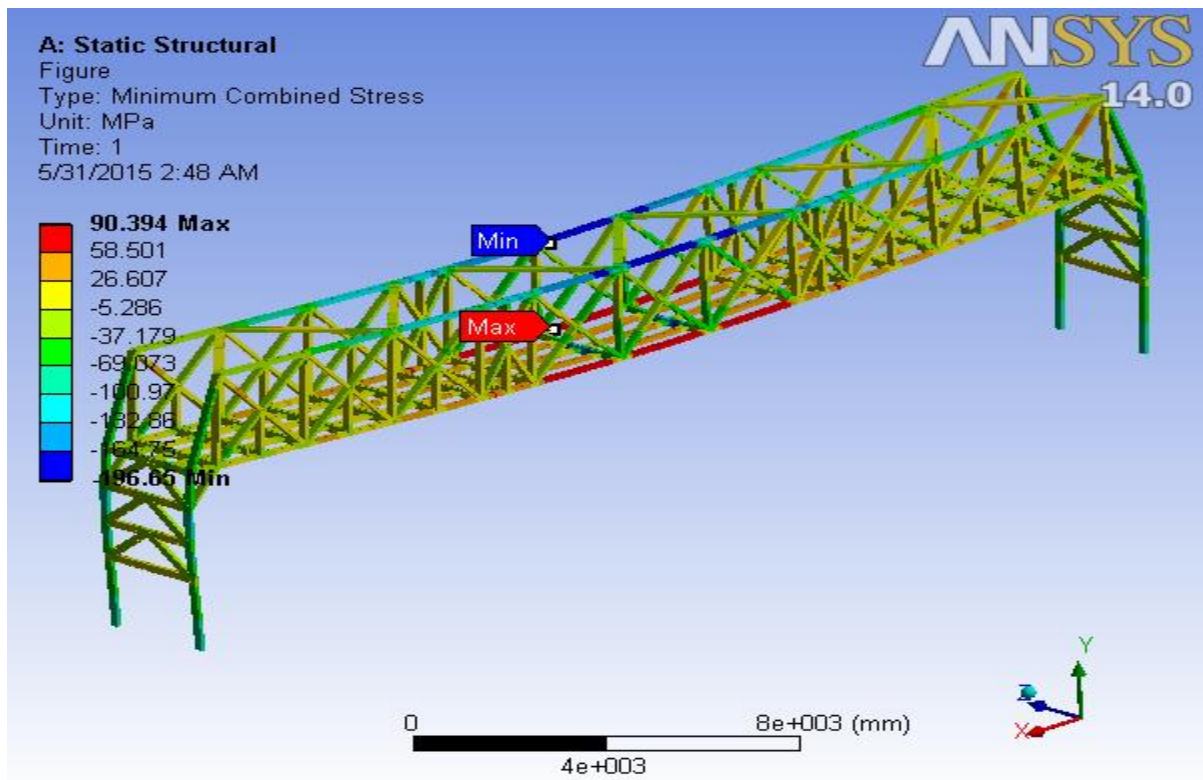


Figure 4.13: combined stress due to tensile and compression forces

f) Results

Table 4.3: Reaction results of steel truss in workbench analysis

Details of "Force Reaction"	
Location Method	Boundary Condition
Boundary Condition	Fixed Support
Orientation	Global Coordinate System
Suppressed	No
[-] Options	
Result Selection	All
Display Time	End Time
[-] Results	
<input type="checkbox"/> X Axis	-1.2573e-007 N
<input type="checkbox"/> Y Axis	1.2756e+005 N
<input type="checkbox"/> Z Axis	-4.505e-007 N
<input type="checkbox"/> Total	1.2756e+005 N

Deflection: The deflection of the truss assembly is interesting, since it is within the design range. The maximum limit for the deflection is given by ERA design manual which is span/500 mm. for this design the value is 6mm.

There for in this analysis the maximum deflection is 5.8mm which is less than the limited value by the ERA, this implies that the result is within the design limit and acceptable by the standards.

Stress: The middle section of the steel truss is subjected to maximum stress. From this Design the maximum stress due to the axial force which is due to tensile and compression is 97MPa and -166MPa respectively.

From the above result factor of safety can be calculated as follows.

$$\begin{aligned}
 \text{safety Factor} &= \text{yield stress of the material} / \text{maximum stress} \\
 &= 250\text{MPa} / 97\text{Mpa} \\
 &= \underline{\underline{2.5}}
 \end{aligned}$$

There for the truss can resist twice the normal load applied which makes it safe during emergency and unexpected load case.

4.3.3 Wind loading analysis

The truss was designed with a wind load of 1.725 kPa on the full vertical projected area of the bridge. Arbitrary area was added to the truss to include wind load on signs and advertisement boards supported by the pedestrian truss bridge.

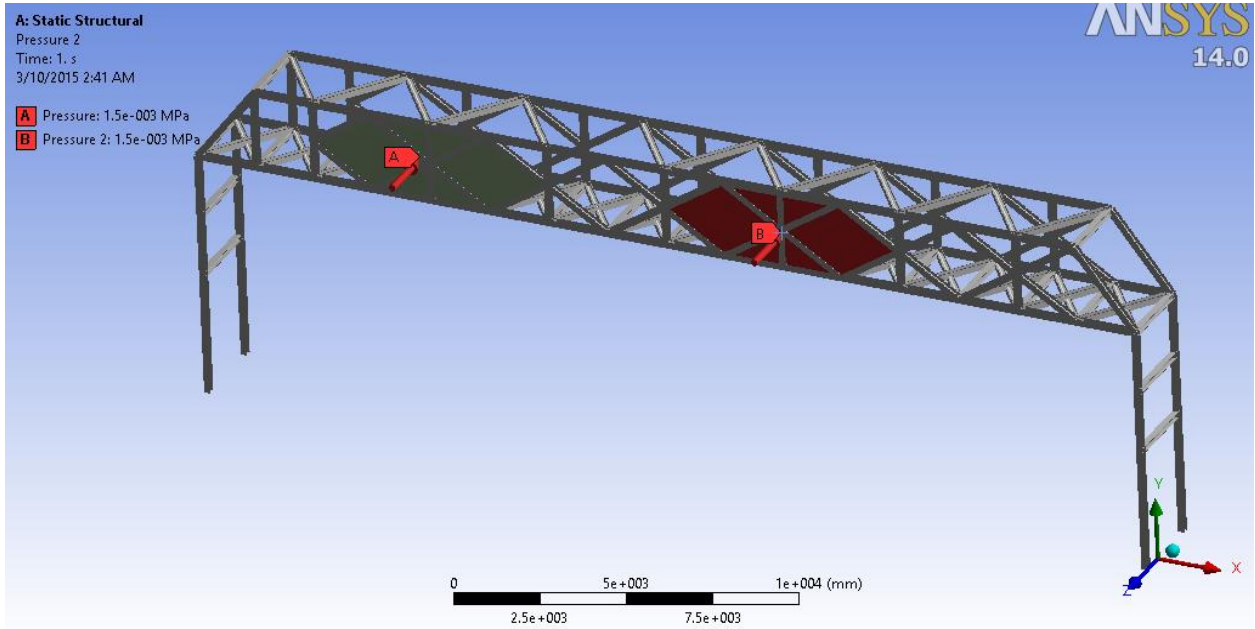


Figure 4.14: Wind load on vertical projection area of steel truss

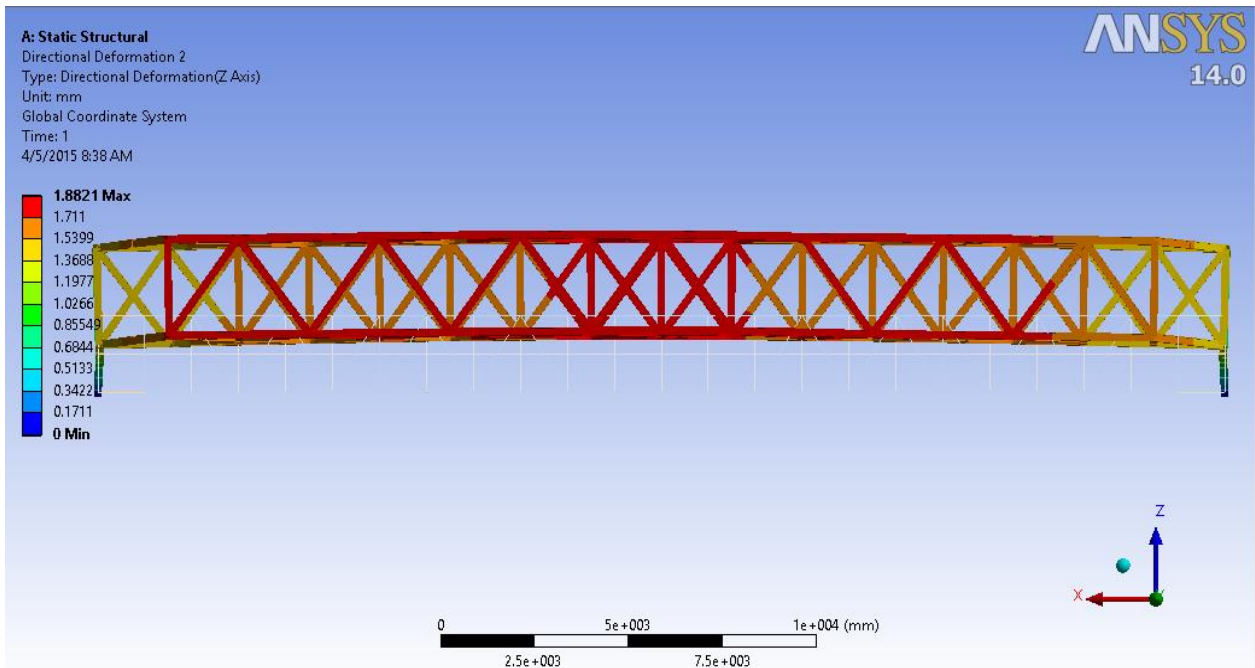


Figure 4.15: Scaled deformation of truss due to wind load

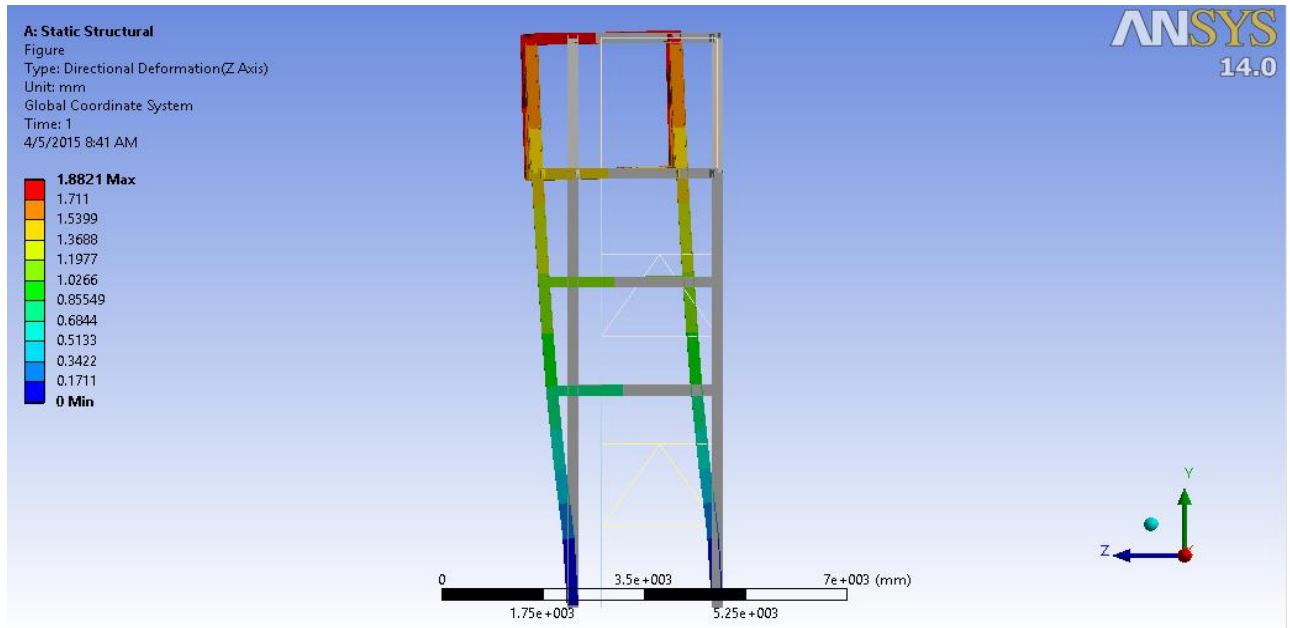


Figure 4.16: Side view of deformed (scaled) and un deformed shape of truss due to wind load

I. Linear Buckling analysis for the support I beam

Checking for buckling resistance of the support is necessary. Therefore it is analysed in the ANSYS WORKBENCH software by applying the reaction force obtained from truss analysis (see figure 4.14) on top of the support beam. This force produces axial deformation and buckling.

a) Material Data

Structural Steel

Structural Steel > Constants

Density	7.85e-006 kg mm ⁻³
Coefficient of Thermal Expansion	1.2e-005 C ⁻¹
Specific Heat	4.34e+005 mJ kg ⁻¹ C ⁻¹
Thermal Conductivity	6.05e-002 W mm ⁻¹ C ⁻¹
Resistivity	1.7e-004 ohm mm
Compressive Yield Strength MPa	343

Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa	343
----------------------------	-----

Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa	460
-------------------------------	-----

b) Model meshing

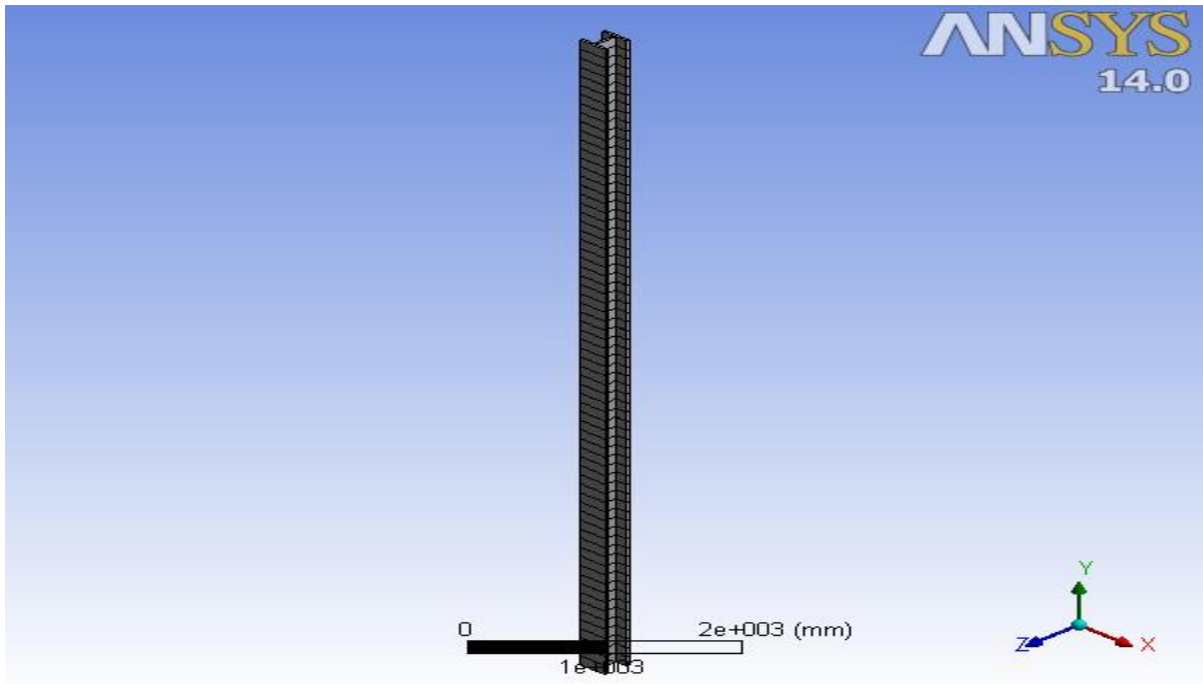


Figure 4.17: Model meshing of I beam support at workbench 14

c) **Results:** Static linear deflection of the support along its axis is 0.14mm. see figure 4.17

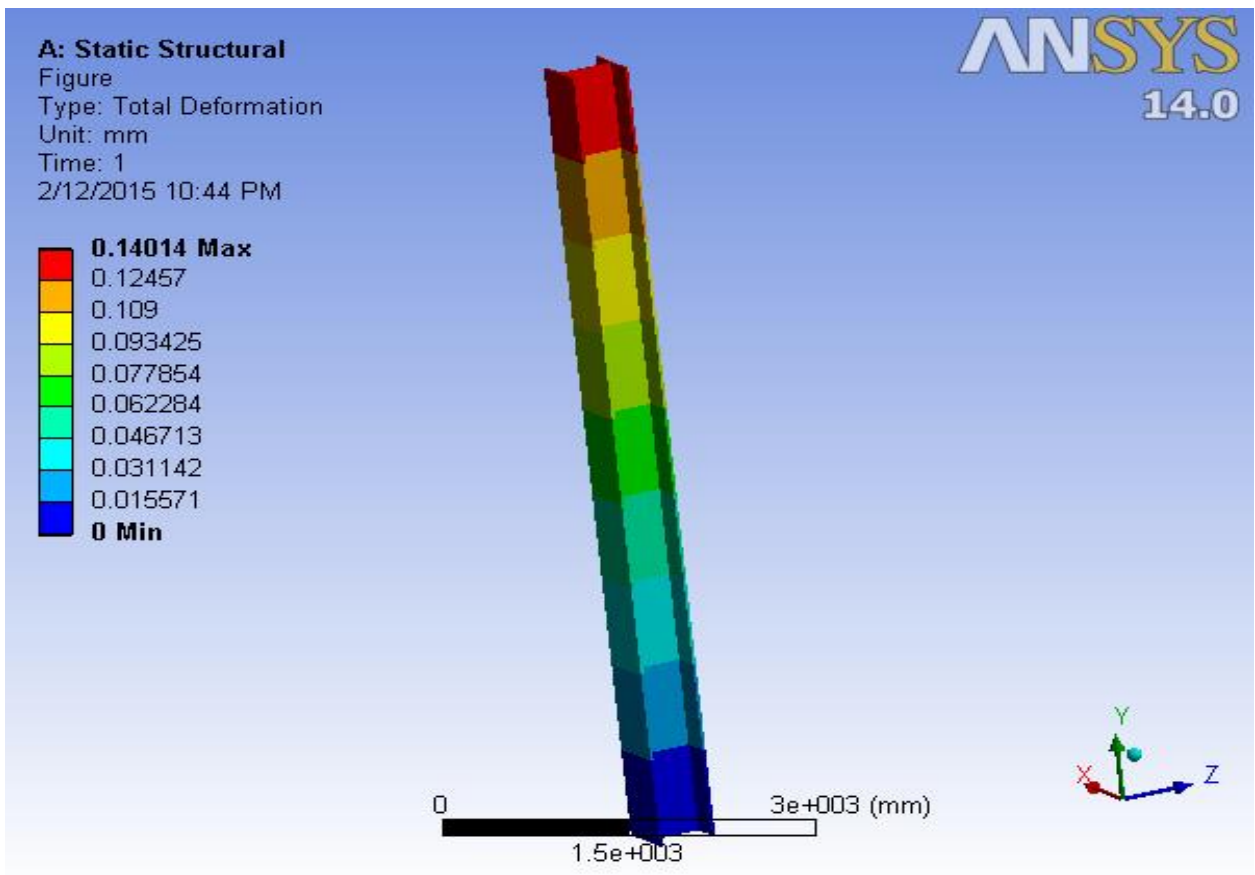


Figure 4.18: Deformation of support along its axis

- d) **Linear Buckling:** Maximum linear buckling deformation of the support is 0.889 mm as the maximum reaction force obtained from truss analysis is applied at the top of the support beam.

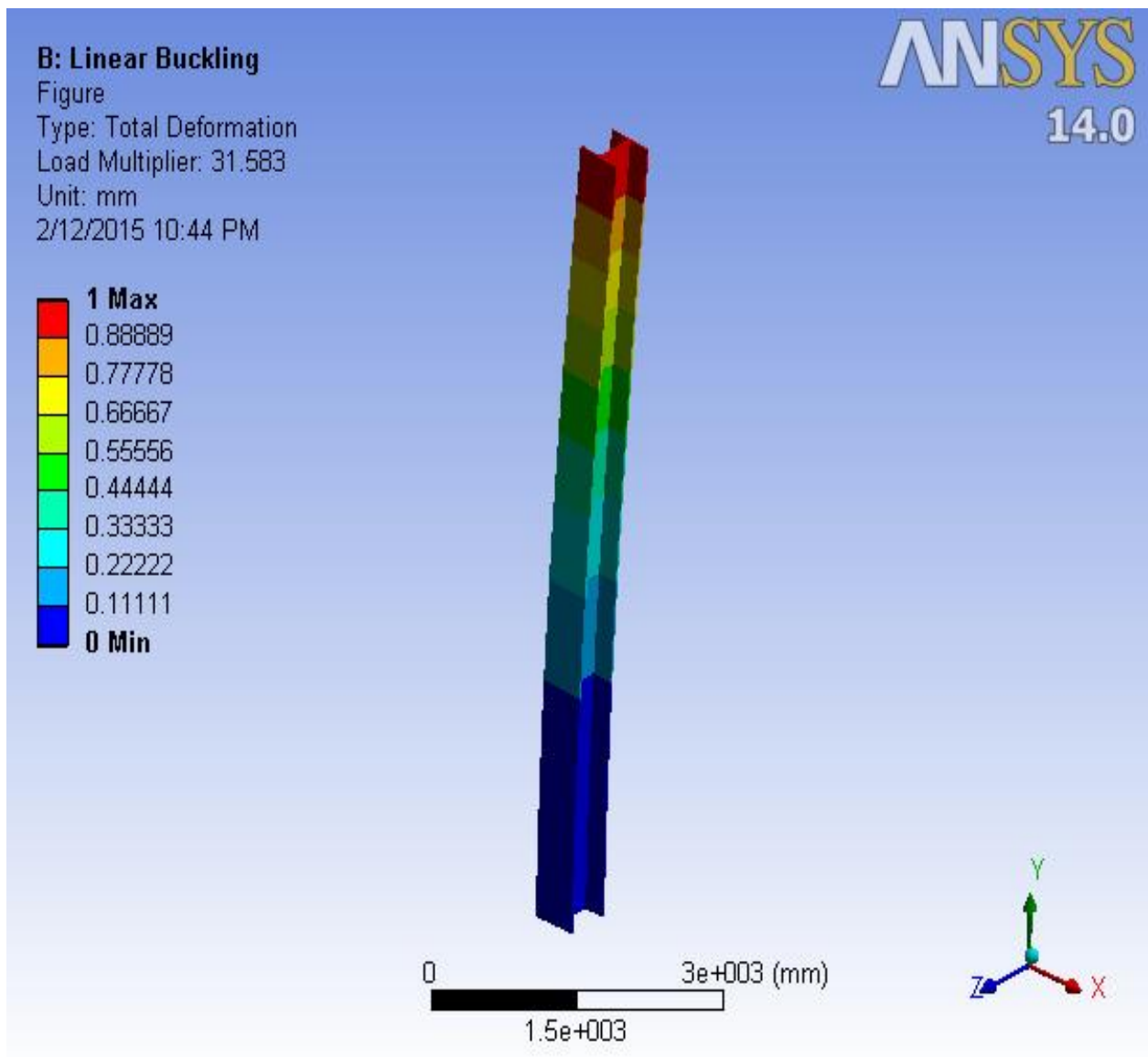


Figure 4.19: Linear buckling of support

CHAPTER FIVE: DETAIL DESIGN OF MODULAR STEEL TRUSS BRIDGE

Basic designs have been developed based on the specifications of table 4.1. Panels are bolted together in the workshop into modules that are transported to site and the modules are bolted at site to make the truss bridge. In this design the truss bridge is made up of four modules in which each module contains a two side panel. This will require the least assembly work on site.

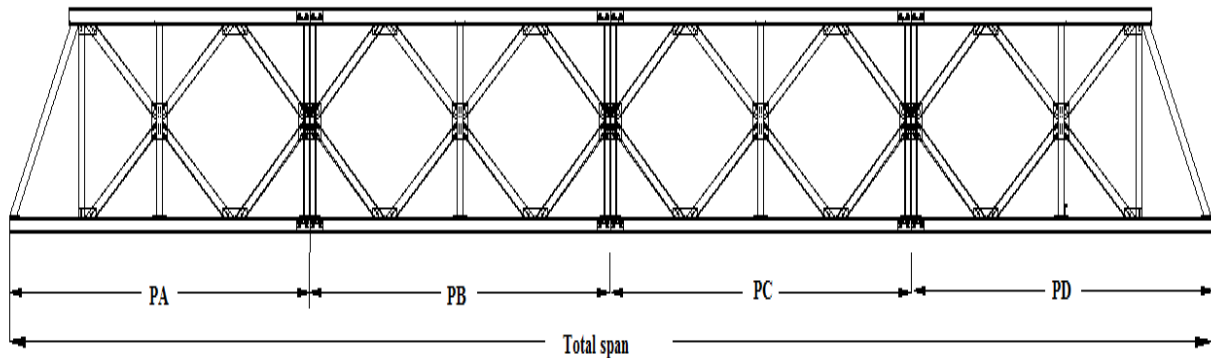


Figure 5.1: Four panels arranged in the side truss

5.1 Detail of side panels

Standard layouts of panels are used for each design but panel lengths vary depending on the required span of the footbridge.

The steel truss is made up of eight (8) panels which is half of them are located on the front side and half of them on the back side. As we can see in figure 5.1 side panel A is symmetry with side panel D and side panel B is symmetry to side panel C. This also works for the back side truss.

a) Types of members

There are three types of members in a typical panel; the chord (top and bottom), the vertical and the diagonal members. These are axially loaded compression or tension members. Panels are bolted together in the workshop into modules that are transported to site. Modules are likely to weigh up to 300 to 400kg and will be quite bulky to transport. This method is only likely to be possible if there is access for trucks directly to the footbridge site.

Figure 5.2 shows the layout of the Side panels. Half have diagonals sloping from mid-point of the verticals to mid-point of the bottom chord and Half have diagonals sloping from mid-point of the verticals to mid-point of the Top chord. The arrangement and numbering of side panels is shown in Figure 5.2 and 5.3 and dimensions are given in Table 5.1.

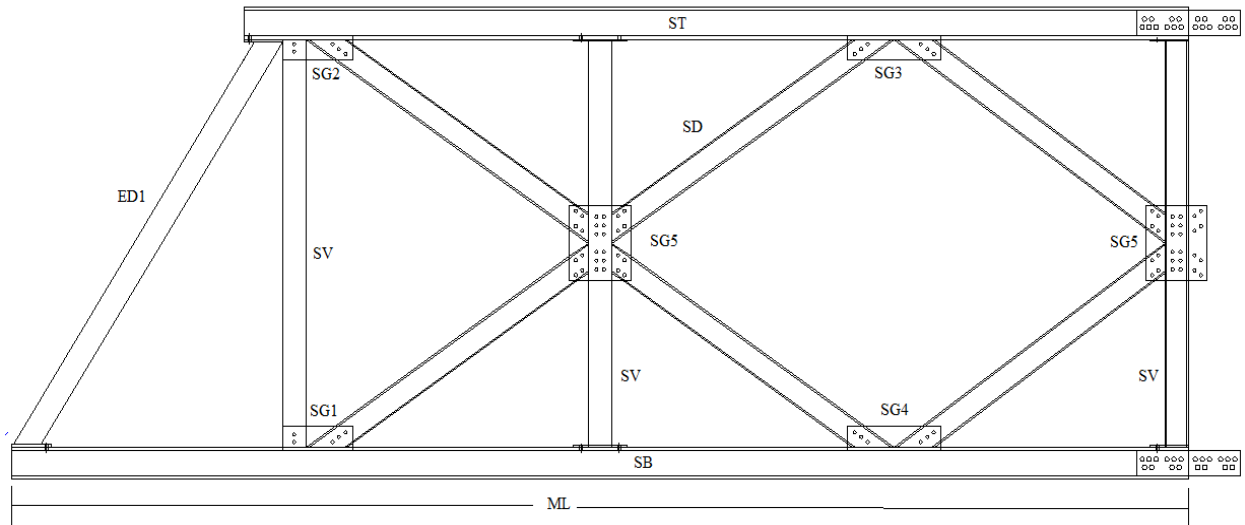


Figure 5.2: panel at both ends of the side truss

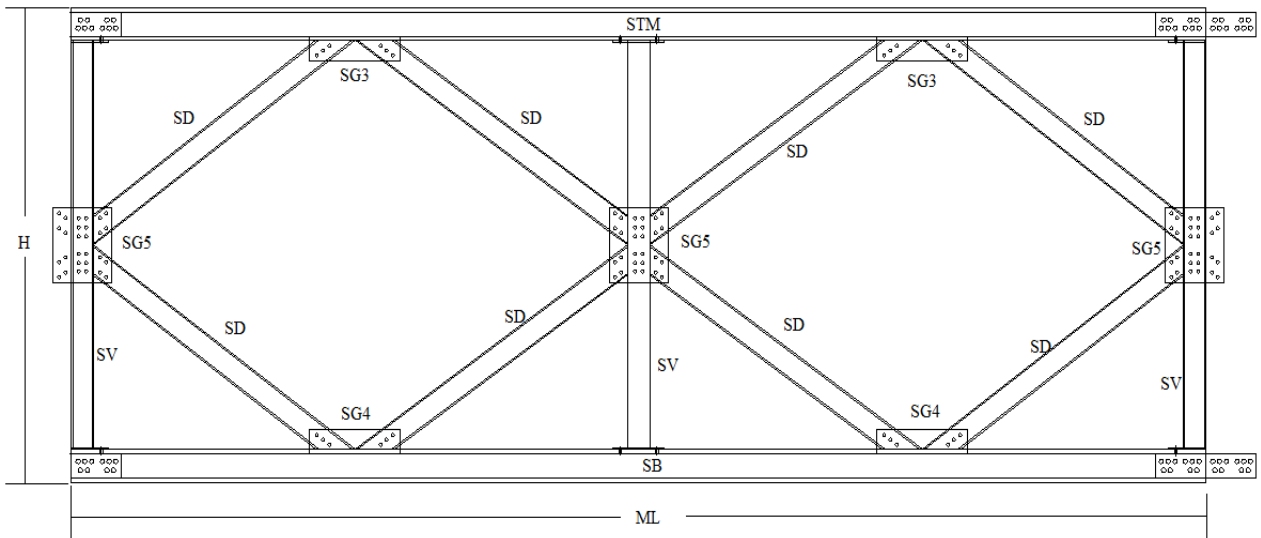


Figure 5.3: Panel at the middle of the side truss

Table 5.1: Material list and cross section for side panels per single panel

Member dimension list for side panels (per panel)					
Member	Cross Section in mm	Length in mm	Quantity	Section profile	Remark
Bottom chord (SB)	150 x 100 x 15	ML=7500	1	I-beam	
Top chord (ST)	100 x 100 x 15	6180	1	I-beam	panel (PA & PD)
Top chord (STM)	100 x 100 x 15	ML=7500	1	I-beam	For mid panels (PB & PC)
Verticals (SV)	100 x 45 x 8	2500	3	Channel	
Diagonals (SDM)	100 x 45 x 8	2100	6	Channel	Measure and fit
Diagonals (SD)	100 x 45 x 8	2100	4	Channel	Measure and fit
Plate SG1	150 x 6	450	2	Flat bar	Only in end panels
Plate SG2	150 x 6	450	2	Flat bar	Only in end panels
Plate SG3&SG4	150 x 6	600	4	Flat bar	
Plate SG3&SG4	150 x 6	600	2	Flat bar	panels PA & PD
Plate SG5	460 x 6	540	2	Flat bar	
Spacer SS	60 x 6	100	16	Flat bar	

b) Material property

The top and bottom chords are modeled in ANSYS workbench using Hot Rolled Structural Steel RT128 and the vertical and diagonal members using ST80.

Table 5.2: Mechanical property of steel

Steel Description	Yield strength Mpa	Ultimate strength Mpa	Modulus Mpa	Density kg/m ³	member
RT128	345	400	2000	7870	Chord
ST80	250	343	2000	7870	Vertical and diagonal

5.2 Details of Base Panel

The base panel is constructed using two main members namely the stringers and floor beam which is made from double channel sections of Kality metal products factory with yield strength of 250 MPa and ultimate strength of 343 Mpa is used. This floor beam supports the deck directly (See Figure 5.4). The floor beam used is a lattice beam made from 10 mm thick ST100.

Table 5.3: Detail dimension of base panel

Dimension list for base panels (per module)					
Member	Cross Section in mm	Length in mm	Quantity	Section profile	Remark
Floor beam	150 x 75 x 10	2500	8	Channel	
Stringer	50 x 50 x 6	6180	8	Angle Iron	

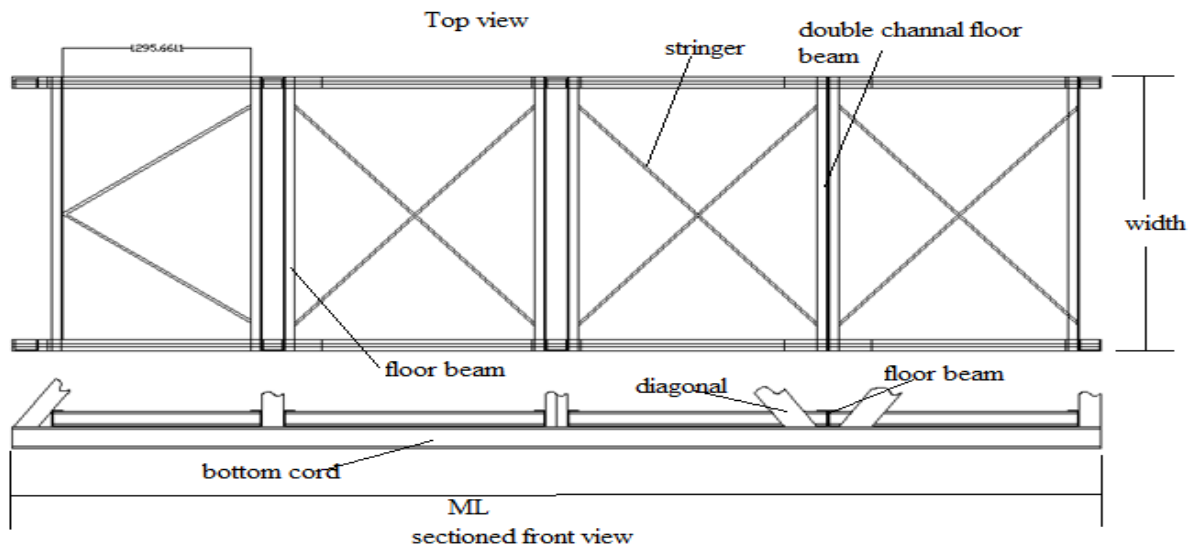


Figure 5.4: Components of base panel for steel truss bridge

a) Checking Floor Beam for Deflection

The simply supported floor beam is checked for maximum deflection by considering a simply supported beam at the contact point with bottom longitudinal (chord). The factored pressure load on the floor beam must be converted to concentrated center nodal load to analyze for maximum deflection of the beam.

Analysis system: static structural analysis

Model (A4): The 3D Geometry of the base channel is modeled using ANSYS WORKBENCH 14

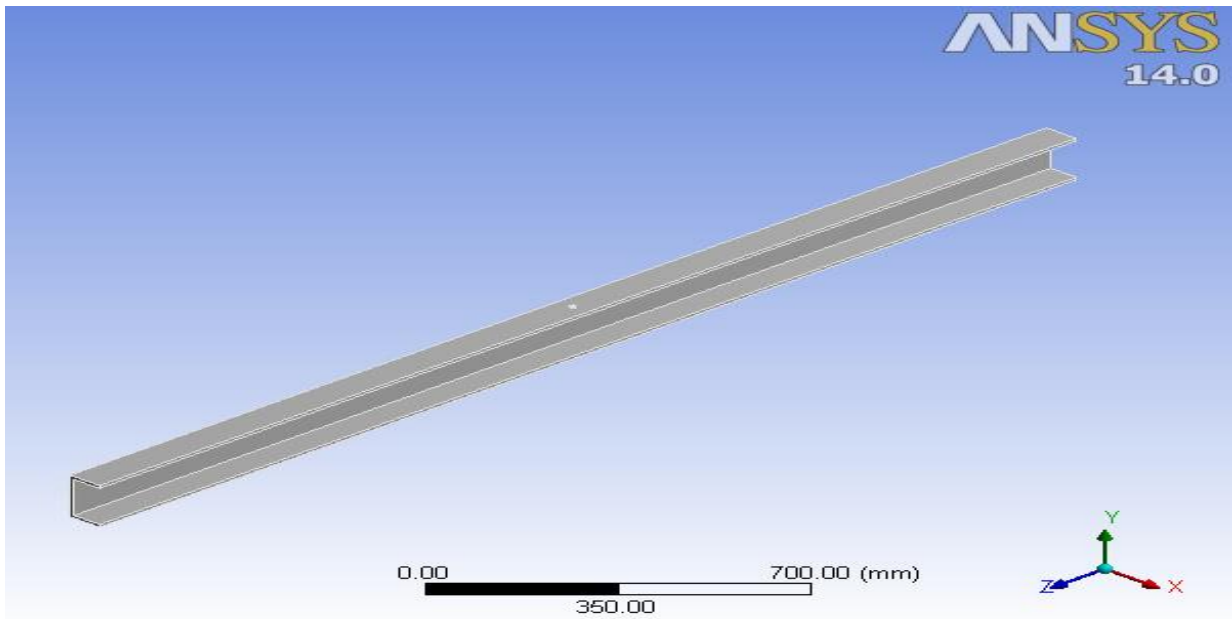


Figure 5.5: Model of base channel in workbench

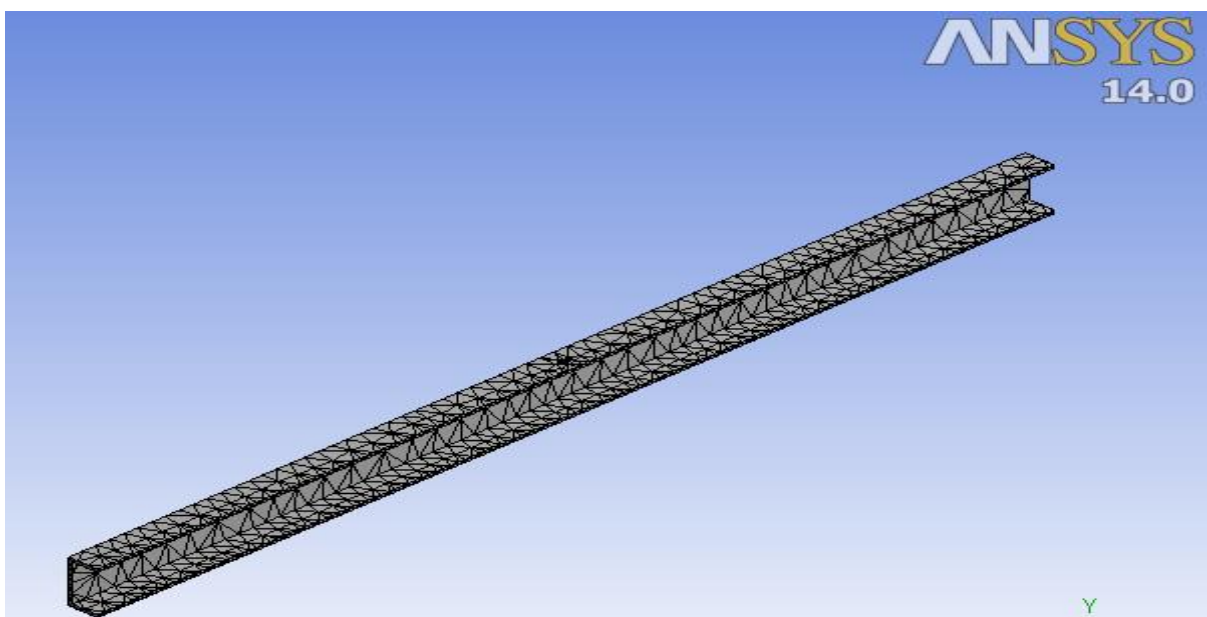


Figure 5.6: Meshing of base channel

Load: A16.4 kN force is applied on each node except the end nodes. The end nodes are subjected to a point load of 8.2 kN but to design for maximum effect 32.8 kN load was applied at the center of the beam.

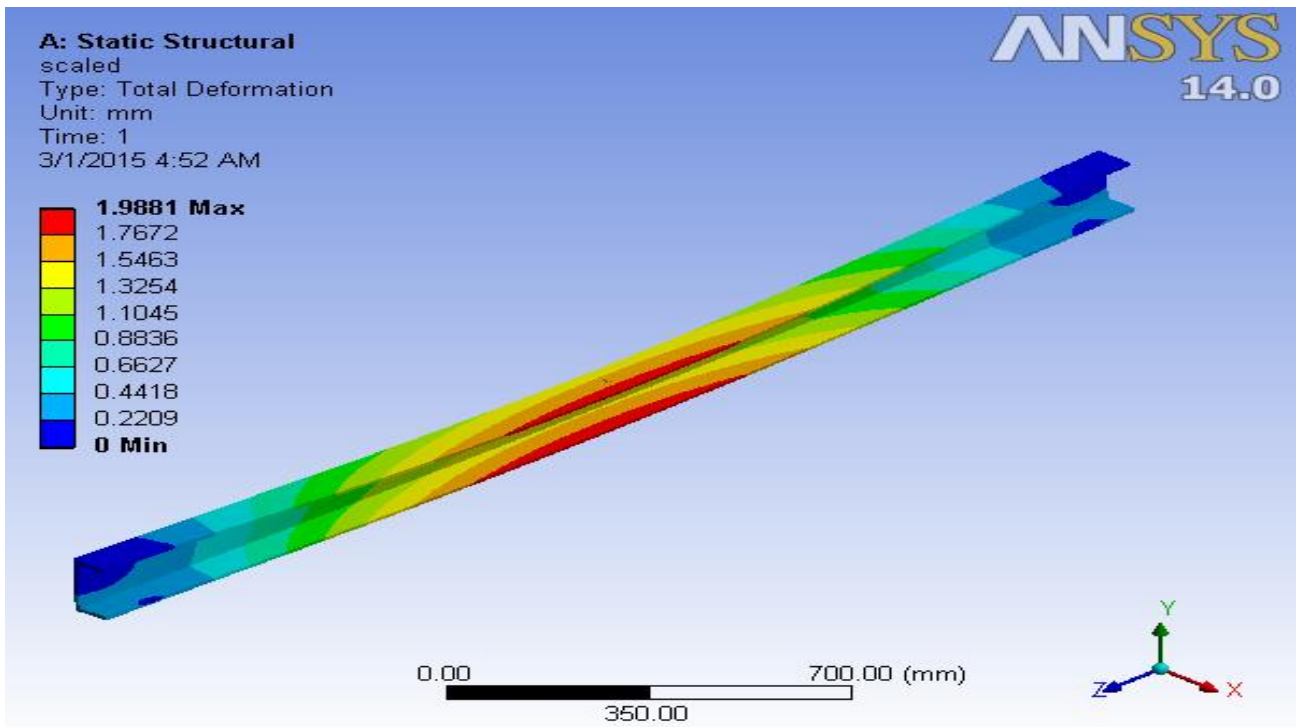


Figure 5.7: Total deformation of base channel

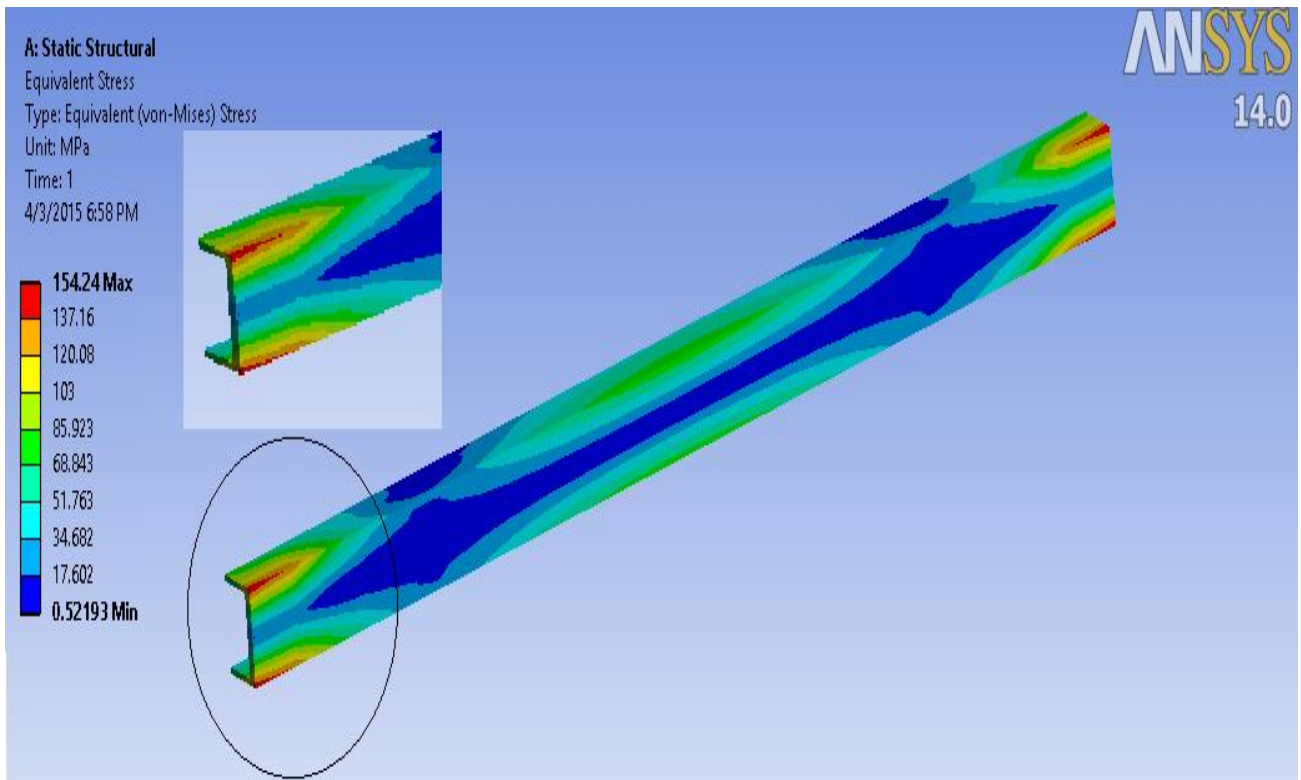


Figure 5.8: Equivalent stress on the base channel

b) Result discussion

Deformation

The ANSYS analysis result for the channel floor beam is very interesting; the deformation of the beam is less than the maximum allowable deformation of the beam that is 1/500 times the length of the beam.

Stress

The maximum stress induced in the channel by the applied load is less than the allowable stress of the material.

5.3 Details of Joining Bracket

Joining brackets are connecting bars that uses to clamp two modules during the assembling of steel truss. In this design, since the steel truss contains 4 modules a total number of 12 joining brackets are needed to connect these three modules.

See Appendix for details of the Joining Bracket and of drilling the holes for the bolts that bolt the panels and modules together.

Table 5.4: materials list for joining bracket

Member	Cross section in mm	Length	Number	Profile	Remark
Joining bracket	160 x 30	600 mm	12	Flat bar	Angle profile can be used
Stiffeners for bracket	30 x 3	500 mm	12	Flat bar	Optional
Joining bolts/joint	M30	65 mm	20		

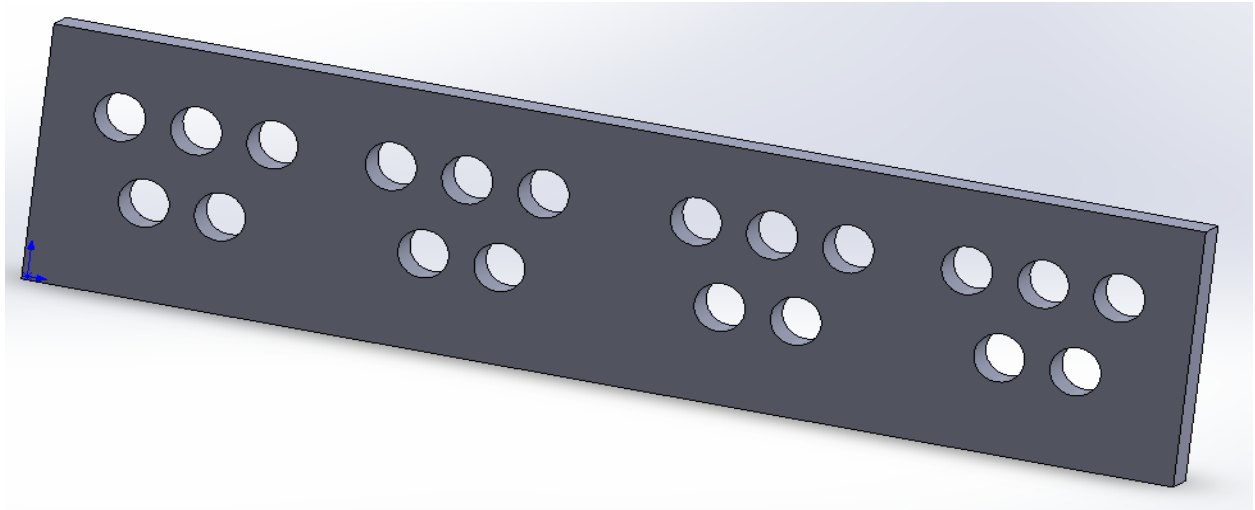


Figure 5.9: Solid work model of joining plate

5.4 Design of Connections

5.4.1 Design of Welded Connections

The required strength of a connection is determined from analysis of the entire structure with factored loads acting on it. A detailed analysis of the connection produces required strengths for its components. The components of connections are the connectors (i.e., welds and bolts) and the connecting elements (plates or gussets). According to AASHTO article 10.19.1.1, connection shall be designed for not less than the average of the required strength at the point of connection and the strength of member at the point but in any event not less than 75% of the strength of the member.

Of the different types of welds, fillet welds are chosen for connecting members with the chords. The welding was done at the end of the verticals and diagonals to attach a plate which helps for bolting of the vertical and diagonal members with the chord. And alternatively welding can be an option to connect the mid panel vertical five members (one vertical and four diagonals) instead of using bolt.

The design strength of welds is the lower value of

$$\phi F_{bm} A_{bm} \text{ and } \phi F_w A_w$$

Where: F_{bm} = nominal strength of the base material

F_w = nominal strength of the weld electrode

A_{bm} = cross sectional area of the base material

A_w = cross sectional area of the weld

ϕ = resistance factor

Values for ϕ , F_{bm} , and F_w are given in table 5.5 below [12].

Table 5.5: Values for ϕ , F_{bm} , and F_w

Fillet welds				
Type of weld or stress	Material	Resistance factor, ϕ	Nominal strength, F_{bm} or F_w	Required weld strength level
Stress on effective area	Base weld electrode	0.75	$0.6 F_{EXX}$	Weld metal with a strength level equal to or less than "matching" weld metal may be used.
Compression or tension parallel to axis of weld	Base	0.90	f_y	

where, F_{EXX} = nominal tensile strength of the weld metal, ksi

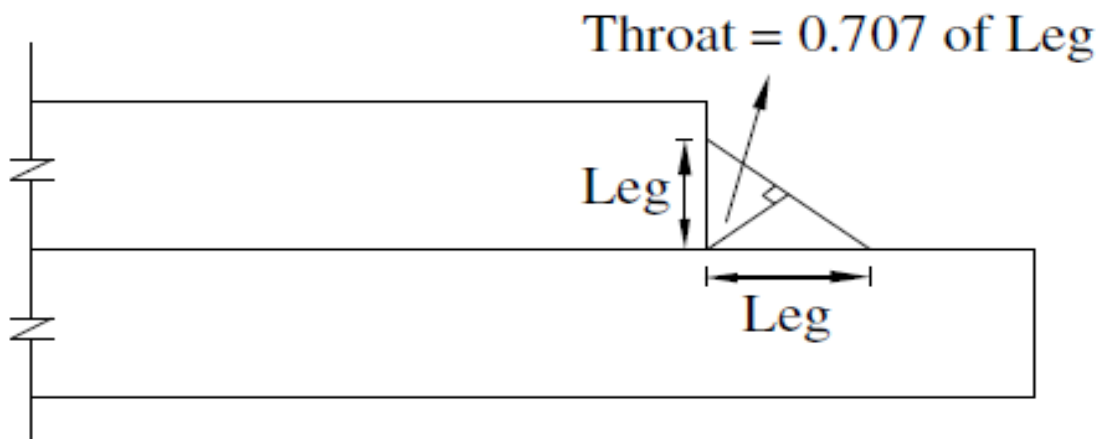


Figure 5.10: Weld throat

$$A_w = (\text{length of weld}) (\text{throat})$$

$$A_w = L * \text{throat}$$

The throat length is shown in Fig. 4.93

For fillet weld the minimum weld size is determined by the thicker of the two parts joined.

The minimum size of fillet weld is given in table 5.6 [12].

Table 5.6: Minimum size of fillet weld

Material thickness of the thicker parts joined, t , in	Minimum size of fillet weld,* in
$t \leq 1/4$	1/8
$1/4 < t \leq 1/2$	3/16
$1/2 < t \leq 3/4$	1/4
$t > 3/4$	5/16

* Leg dimension of fillet welds

a) Design of fillet weld

Member capacities as tension members

When the truss members are subjected to tensile forces applied through the centroid axis of a member, the result is a uniform tensile stress at each cross section. The design tensile strength of a structural steel depends on the appropriate cross sectional area. The design tension resistance capacity of the cross section is calculated as followed.

$$N_{t,Rd} = A \sigma_y / \gamma_m \quad (5.1)$$

For the vertical and diagonal members

$$\sigma_y = 343 \text{MPa},$$

$$A = 17.35 \times 10^2 \text{ mm}^2$$

$$\gamma_m = 1.5$$

$$N_{t,Rd} = A \sigma_y / \gamma_m = 17.35 \times 10^2 \text{ mm}^2 * 343 \text{MPa} / 1.5$$

$$N_{t,Rd} = \frac{1735 \text{mm}^2 * 343 \text{MPa}}{1.5} = 399 \text{kN}$$

The full and 75% capacities of members are listed below. E70 electrodes are to be used.

Tensile capacities of the main members are:

$$\text{Diagonal member: } N_{t,Rd} = 399 \text{ kN} \quad 75\% N_{t,Rd} = 299.25 \text{ kN}$$

$$\text{Vertical member: } N_{t,Rd} = 399 \text{ kN} \quad 75\% N_{t,Rd} = 299.25 \text{ kN}$$

For E70 electrodes the design strength is:

$$\phi F_w = (0.75) (0.6) (F_{EXX}) = (0.75) (0.6) (70) = 31.5 \text{ ksi}$$

$$\phi F_w = (31.5) (6895) = 217.19 \text{ MPa}$$

$$\text{Capacity of weld} = \phi F_w A_w = (217.19) (3.54) (L) = 767.77 \text{ N} * L$$

$$\text{Capacity of weld} / L = \phi F_w A_w / L = \mathbf{0.77 \text{ kN/ mm}}$$

The plate connection is done using a set consisting of two plates, 5mm thick, one on top and the other at the bottom of the diagonal members and is located at mid height and on the chords of panel. It connects the vertical and diagonal members. The weld on one plate is to be designed to carry half the 75% capacity of the member, the other half being carried by the other plate weld. The vertical members are connected to the chord members without the use of plates. One side of the connection carries half the 75% capacity of the member. The weld to be used is a fillet weld of size 5 mm on the sides and the end.

Check the length requirement to carry this force by the plate and weld.

$$\text{Capacity of base plate} = \phi F_{bm} A_{bm}$$

from table 5.5 $\phi = 0.9$, $F_{bm} = F_y = 345\text{MPa}$, $t = 10\text{mm}$

$$\text{Capacity of base plate} = (0.9) (343\text{Mpa}) (L) (10 \text{ mm}) = 3.1 \text{ kNmm}$$

$$\text{Capacity of base plate}/L = 3.10 \text{ kN/mm} > 0.77\text{kN/mm}.$$

Therefore, use weld capacity to determine weld length.

From table 5.6 minimum leg dimension for $t = 10 \text{ mm}$ is 3.18mm

Use a leg dimension of 5mm.

$$\text{Throat thickness} = (0.707) (\text{leg dimension})$$

$$= (0.707) (5) = 3.54 \text{ mm}$$

The maximum required of the capacities is $299.25 \text{ kN}/2 = 149.6 \text{ kN}$

$$\text{Length of weld required} = 149.6 \text{ kN} / (\phi F_w A_w / L) = 149.6 \text{ kN} / 0.77 = 264.77\text{mm}$$

Use 280 mm long weld.

Use end return length = 2 weld size = $(2) (5) = 10\text{mm}$ for plate corners.

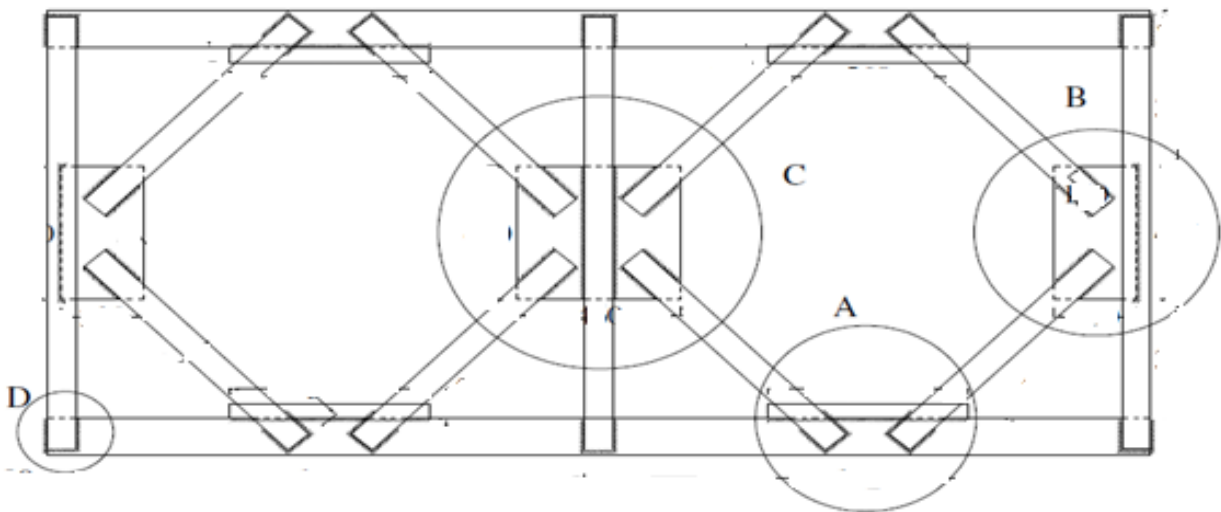


Figure 5.11: weld connections on panel

5.4.2 Design of Bolt Connections

The capacity of bolt connection shall be determined from the shear capacity of the bolt at the shear plane and the bearing capacity on each connected plane.

For this design the M16 bolt are used to connected truss members using plates and M20 bolts are used to bolt the vertical members with the longitudinal chord and M30 bolts are used to clamp the modules using the joining bracket. And also the M30 bolts are used to fix the steel truss with the support (I-beam).

a) Check for shear capacity

Assumed material for M20 bolt is ST80 with $\sigma_y = 250$ MPa, $\sigma_u = 335$ MPa

The shear capacity F_{VRD} of a bolt shall be taken as:

$$F_{v,RD} = 0.6 A_b \sigma_u / \gamma_m \quad (5.2)$$

Where:

$F_{v,RD}$ is the specified minimum ultimate strength of bolt

A_b is the cross sectional area of bolt

$$\begin{aligned} A &= \pi r^2 \\ &= \pi * (8\text{mm})^2 = \mathbf{201\text{mm}^2} \end{aligned}$$

$$\begin{aligned} F_{v,RD} &= 0.6 * 201 \text{ mm}^2 * 343\text{MPa} / 1.25 \\ &= \mathbf{33.1\text{kN}} \end{aligned}$$

The full member capacity of ST80 is:

$$RT80: N_{t,Rd} = 399\text{kN} > 33.1 \text{ kN}$$

Shear stress

$$\begin{aligned} \sigma_v &= \frac{F_{t\max}}{A} \quad (5.3) \\ &= 46.4\text{kN}/201\text{mm}^2 = \mathbf{230 \text{ Mpa}} < \sigma_y = 250\text{Mpa} \end{aligned}$$

b) Check for bearing capacity

The bearing capacity $F_{b,RD}$ of a bolt shall be taken as:

$$F_{b,RD} = 1.50 d \cdot t \cdot F_y / \gamma_m \quad (5.4)$$

Where:

d is the diameter of bolt

γ_m is factor of safety

t is the thickness of the connected part

F_y is the lower of the nominal yield strength of bolt and the connected part.

$$d = 16 \text{ mm}$$

$$t = 20\text{mm} + 10\text{mm} = 30 \text{ mm}$$

$$f_y = 250 \text{ MPa}$$

$$F_{b,RD} = (1.5) (16\text{mm}) (30\text{mm}) (250) / 1.25 = 144\text{kN} < 399\text{kN}$$

5.4.3 Design of Plate Types Used

Three different sized plates were used to connect the members of the truss using bolts and their detail drawing is listed in the appendix.

Plate A

Plate A is a 600mm x 150 mm, 10 mm thick plate with $\sigma_y = 250 \text{ MPa}$ that connects the two diagonals with the top and bottom chord of panel using welds as shown in figure 5.11.

Plate B

Plate B is a 540mm x 460 mm, 10 mm thick plate with $\sigma_y = 250 \text{ MPa}$ that connects the four diagonals with the vertical at end panel using bolts or welds as shown in figure 5.11.

Plate C

Plate C is a 460mm x 390mm, 10 mm thick plate with $\sigma_y = 250 \text{ MPa}$ that connects the four diagonals with the vertical member at the mid panel using bolts or welds as shown in figure 5.11.

Plate D

Plate D is a 450mm x 150mm, 10 mm thick plate with $\sigma_y = 250 \text{ MPa}$ that connects the vertical member with the top and bottom chord of the panel using bolts or welds as shown in figure 5.11. this plate also used to connect the inclined end posts with the top and bottom chords.

5.5 Design of Decking

Galvanized steel floor plates supported on steel cross doubled channel beam was used for the flooring system of the pedestrian steel truss bridge. A layout of this arrangement is shown in figure 5.12.

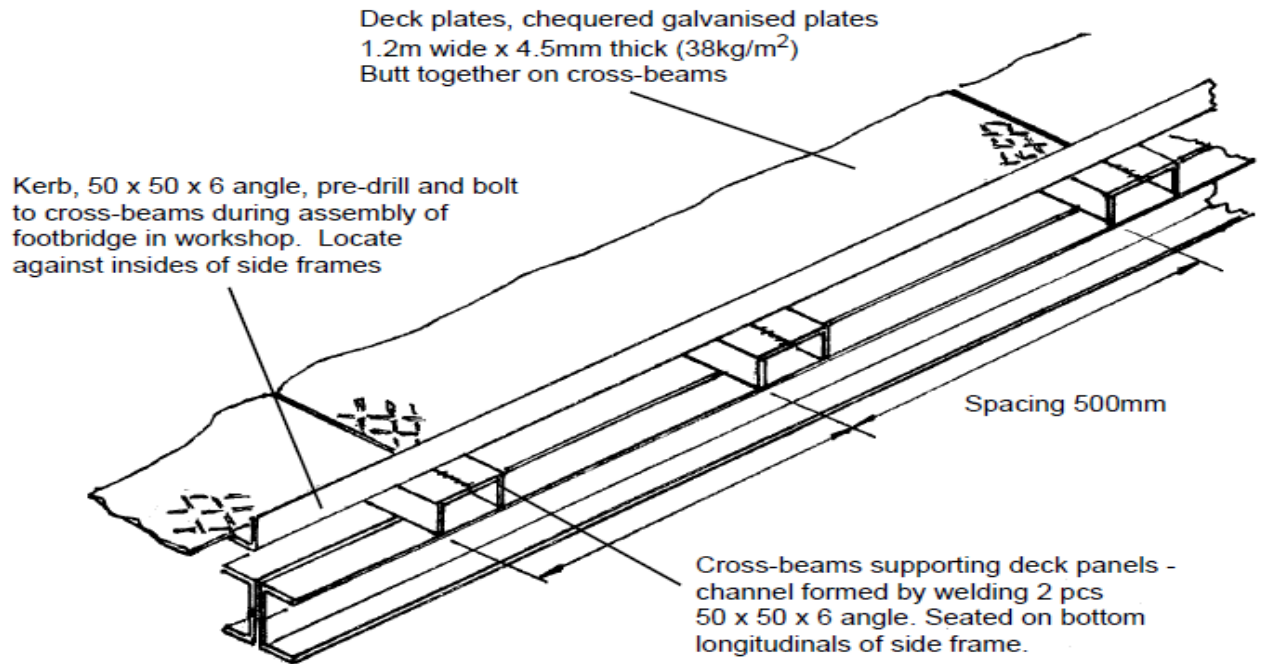


Figure 5.12: Galvanized steel floor plate

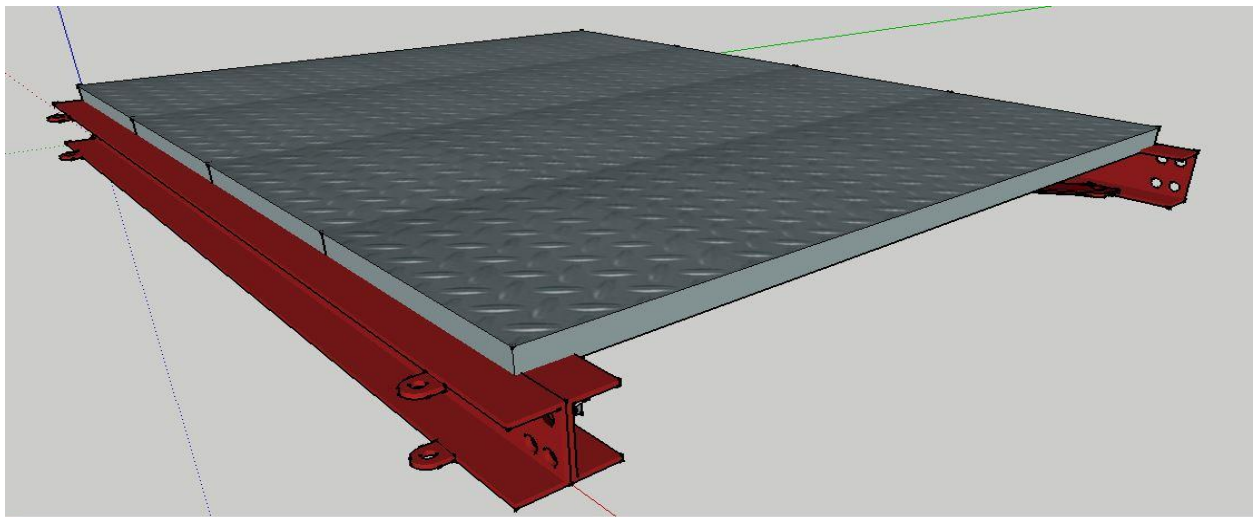


Figure 5.13: Model of single base panel with steel floor

5.6 Specifications for Prefabricated Steel Truss Bridge

These specifications are for a fully engineered clear span bridge of welded steel construction and shall be regarded as minimum standards for design and construction as manufactured

5.6.1: Bridge Dimensions

Table 5.7: Specification of pedestrian steel truss bridge

Measurement	Dimension		
Length of the span	30 m	Type of truss	Bailey truss bridge
Railway width	12 m	Use	Pedestrian crossing
Width of the span	2.5 m	Material	Structural steel
Height	8 m	Number of span	single
Road width	18 m		

5.6.2 Steel Truss Bridge Design

a) Transient Load

Pedestrian bridges shall be designed for an evenly distributed live load of 4kN/m² of deck.

When the deck area exceeds 80 m² the load may be reduced in accordance with the following formula:

$$W = 85(0.25 + (15/A^5))$$

W = Pedestrian Load (kN)

A = Deck influence area (mm²)

b) Vehicle Load

Pedestrian bridges with the occasional slow moving maintenance or emergency vehicles, impact is not required.

c) Wind Load

Pedestrian bridges shall be designed for wind loads as specified in the *AASHTO*. Unless otherwise directed by the Owner, the Wind Importance Factor, I_r , shall be taken as 1.15.

The loading shall be applied over the exposed area in front elevation including enclosures. Wind load on signs supported by the pedestrian truss bridge shall be included.

d) Deflection:

The vertical deflection of the truss due to pedestrian load shall not exceed span (L)/500mm.

e) Load factor

The steel truss bridge shall be designed for the load combinations and load factors specified in AASHTO LRFD.

f) Welding

Filler metal shall match characteristics of the base material. Welders will be well certified.

*All welds are to be 100% visually inspected.

g) Materials:

All structural members shall be made of structural steel and have a minimum thickness of material of at least 5mm.

h) Safety Rails

Continuous rails shall be located on the inside of steel truss for pedestrian safety.

i) Railings & Accessories

All railings shall have a smooth inside surface with no protrusions or depressions. All ends of angles and tubes shall be closed and ground smooth. In accordance with ERA, railings for pedestrian should be a minimum height of 1.5 m above the floor deck.

j) Delivery and Erection

Delivery is made to a location nearest the site, which is easily accessible to normal, over the road tractor/ trailer equipment.

The manufacturer will provide detailed, written instruction in the proper lifting procedures and splicing procedure (if required). The method and sequence of erection shall be the responsibility of the manufacturer of the supplied bridge or a Certified Erector.

The bridge manufacturer shall provide written inspection and maintenance procedures to be followed by the bridge owner.

k) Assembly and Testing of truss bridge

Before transporting the footbridge to site it should be fully assembled in the workshop to make sure all panels bolt together without problems.

When assembled the footbridge should be tested to its design load to check that it behaves satisfactorily and that its deflection is within the design limit (6mm per span).The preferred method of testing is by “crowd loading”, equivalent to 4 persons/m².

l) Protective Treatment

The steel needs to be protected as effectively as possible against corrosion. The most effective method is galvanizing all components but this treatment is unlikely to be available.

The following treatment is therefore recommended before bolting together the panels:

- Thoroughly wire brush all surfaces to remove scale and any rust
- Paint all surfaces with a good quality, oil-based, anti-corrosion paint by spraying or brushing. Careful attention should be given to getting into all corners, inside drilled holes and sealing joints such as along the top longitudinal

m) Maintenance

The steelwork should be carefully inspected at intervals of about 1 year, paying particular Attention to:

- Tightening of any bolts that have worked loose
- Repairing any areas of paintwork that have deteriorated
- Checking for any cracks around welded joints
- Cleaning out any soil or rubbish that has accumulated in corners, joints etc.

The footbridge should be completely repainted every 2 to 3 years.

CHAPTER SIX: ASSEMBLY OF TRUSS BRIDGE

Convenient sized parts for transport to site. Assembly on site involves bolting the parts together and fitting the steel deck, tasks that can be carried out under supervision of a competent technician by local carpenters and others skilled in using their hands. There are three alternative at which the bridge may be broken down into parts for transportation:

- a) Individual members that are predrilled in the workshop transported and bolted Together on site. This method requires considerable accurate drilling of holes in the workshop and careful assembly on site.
- b) The steel members are cut and welded up into panels in the workshop and the Panels drilled for bolting together. Panels are transported to site and bolted together on site. This significantly reduces pre-drilling and assembly work. Panels may weigh up to about 100kg.
- c) Panels are bolted together in the workshop into modules that are transported to site. The modules are bolted together on site. This will require the least assembly work on site. Modules are likely to weigh up to 300 to 400kg and will be quite bulky to transport. This method is only likely to be possible if there is access for trucks directly to the footbridge site.

The third alternative was selected as the best compromise to minimize site assembly time and least pre-drilling operations. Standard designs have therefore been developed for modular steel Truss footbridge which is made of panels that are bolted in a workshop to make the modules. Details of the construction assembly drawing of the side panel members are given in Appendix.

6.1 Assembly and Construction of Side Panels (Left Side)

The left side truss contains four (4) panels that are symmetrically located and single panel is constructed from different members like the top and bottom longitudinal, vertical and diagonal members, plate and connecting bolts. Plates are used to hold the diagonal members running from the center of the vertical members to the center of both the top and bottom longitudinal. The module lengths (ML) and section details are shown in table 5.1.

To ensure the holes are aligned to the bolts and assemble the panels and modules together, the following instructions must be applied:

- Parts must be clearly marked and kept in the same order as they were drilled
- When the members have been manufactured, they need to be drilled and assembled in
Sequence

STEP 1: Assembly of End Panel A (PA)

- a) Lay down horizontally the bottom longitudinal (SB) section chord to which the plate's welded.
- b) Bolt the left end vertical and the right end verticals with the bottom longitudinal, respectively.
- c) The left end inclined member is bolted with the bottom longitudinal at the left end.
- d) The middle and end type gussets are attached accordingly to the vertical members.
- e) Measure the diagonals starting from the midpoint of the vertical's to the center point of the verticals at the bottom and top longitudinal members.
- f) Drill the diagonals for bolting them with the gusset plates using the measurements from step e.
- g) Attaché the top longitudinal I beam at the top side of the left and right end verticals

Note: *since the vertical and inclined members are a channeled profile, direction of the grooved side must be towards the inside of the bridge.*

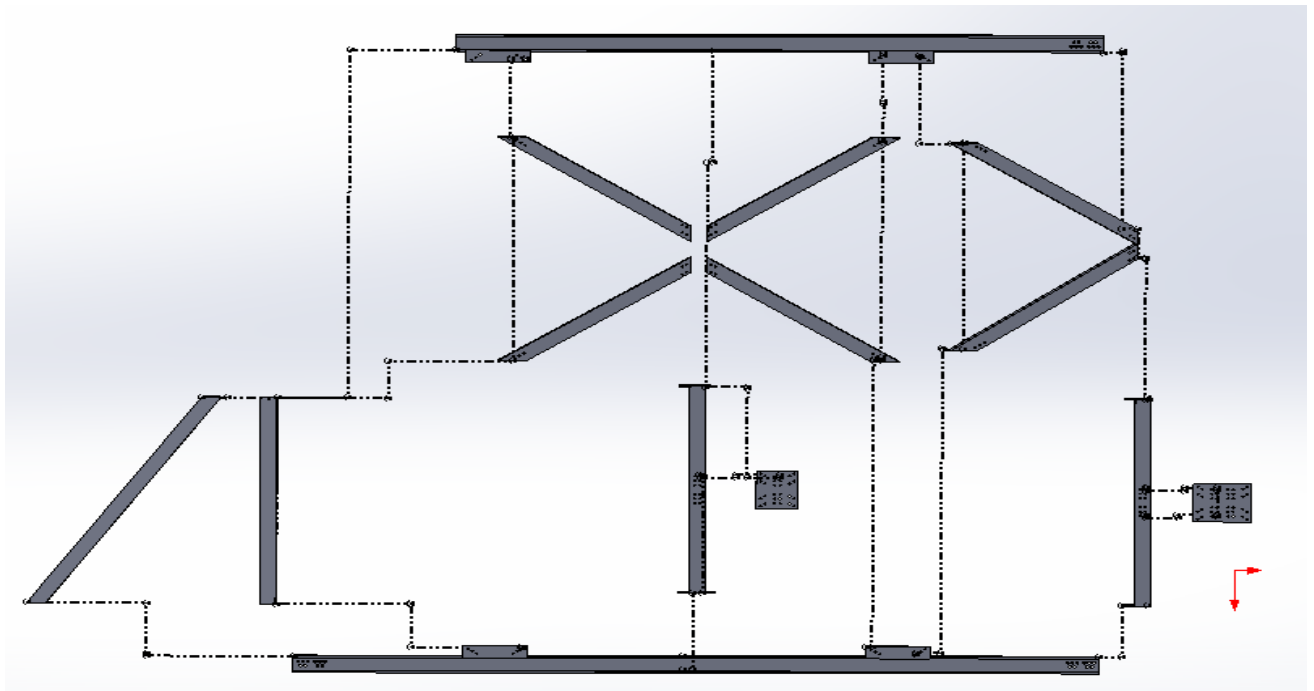


Figure 6.1: Steps to assembly panel A in solid work using line link

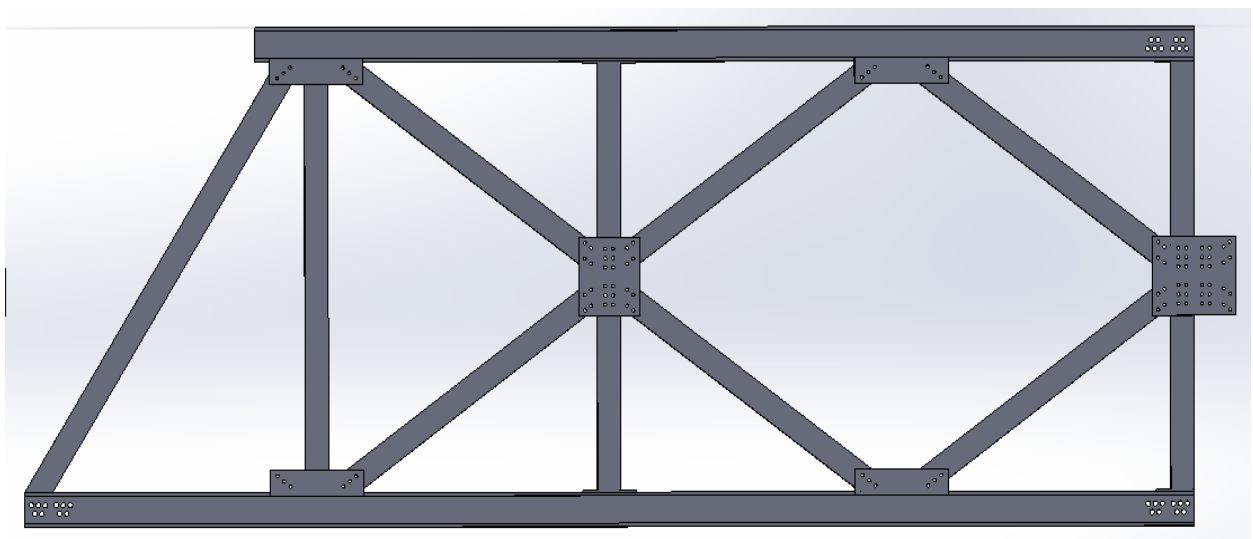


Figure 6.2: Assembly of End Panel PA

STEP 2: Assembly of Side Panel B (PB)

The assembly and construction of side panel s1 is similar with that of end panel, the only difference is that in this panel there is no inclined member at the end of the panel. The detail dimension and module length are listed in table2

- a) Lay down horizontally the bottom longitudinal (SB) I beam chord in which the plate welded to this longitudinal are directed upward.
- b) Bolt the left end, middle and right end vertical members with the bottom longitudinal starting from the left end respectively.
- c) Attaché the top longitudinal I beam at the top side of the left and right end verticals.
- d) The middle and end type gussets are attached accordingly to the vertical members.
- e) Take measurements from the center of the middle vertical to the center of the point of the distance from the middle vertical member to the end vertical member at the top longitudinal.
- f) Using the same starting point as step 2.5 measure the distance up to the center point of, the distance between the mid and end vertical at the bottom longitudinal.
- g) Drill the diagonals for bolting them with the gusset plates using the measurements from step e and f.
- h) The same procedure as step d and e is repeated to make the other side diagonal members.

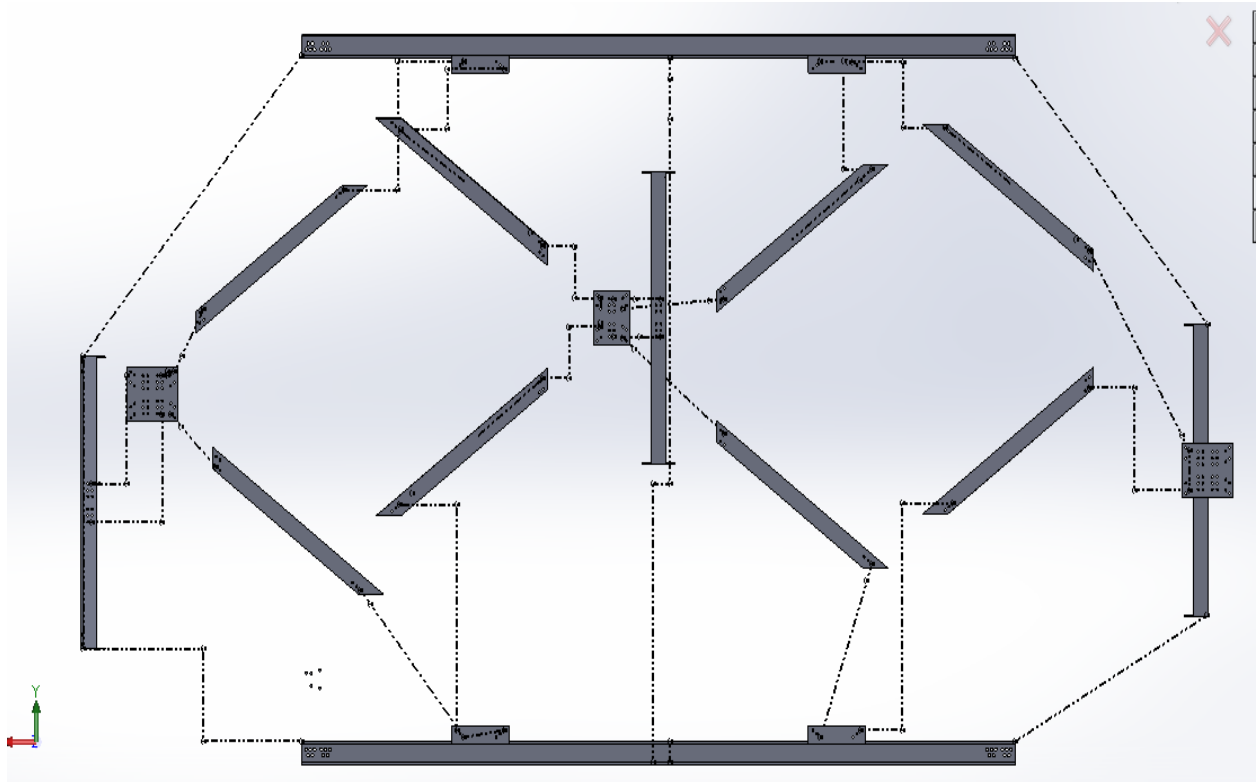


Figure 6.3: Steps to assembly panel B in solid work using line link

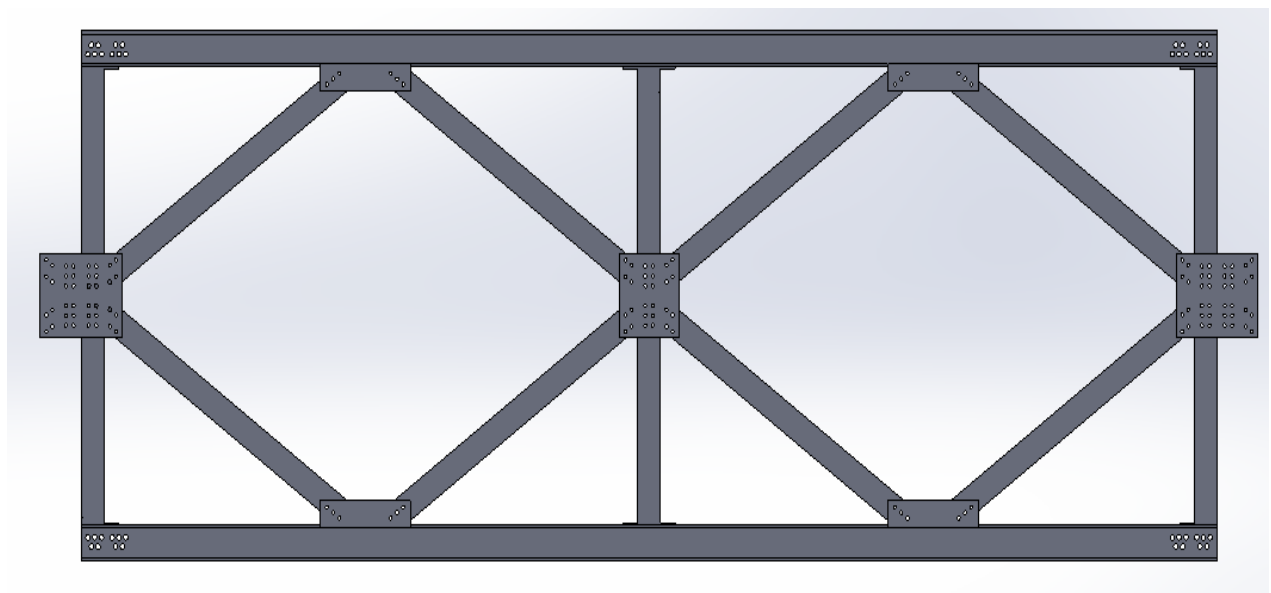


Figure 6.4: Assembly End Panel PB

STEP 3: Assembled of Side Panel C (PC)

Since side panel C is the same with the left end panel PA, the same procedures and steps are used during the assembly and construction process of this panel.

STEP 4: Assembly of End Panel P4 (Right End)

The right end panel E2 is the same but symmetric with the left end side panel E1. Therefore the same producers and steps were followed during the assembly and construction process.

6.2 Assembly and Construction of Right Side Panels

The left side truss and right side truss are symmetry and the same, therefore the same methods of assembly can be used for the right side panels as that of the left side panels.

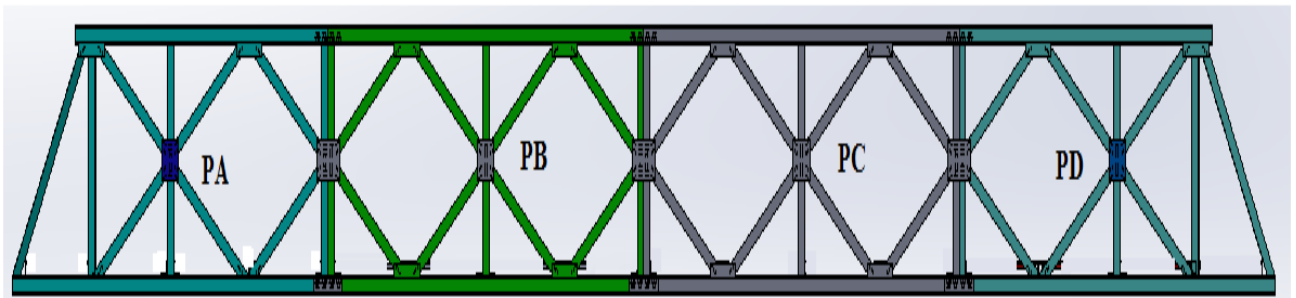


Figure 6.5: Panels arranged in side truss

6.3 Assembly and Construction of Base Panel

The assembly of base panel is done simply by bolting the stringer angle iron with the channel base member as shown in the figure 6.7.

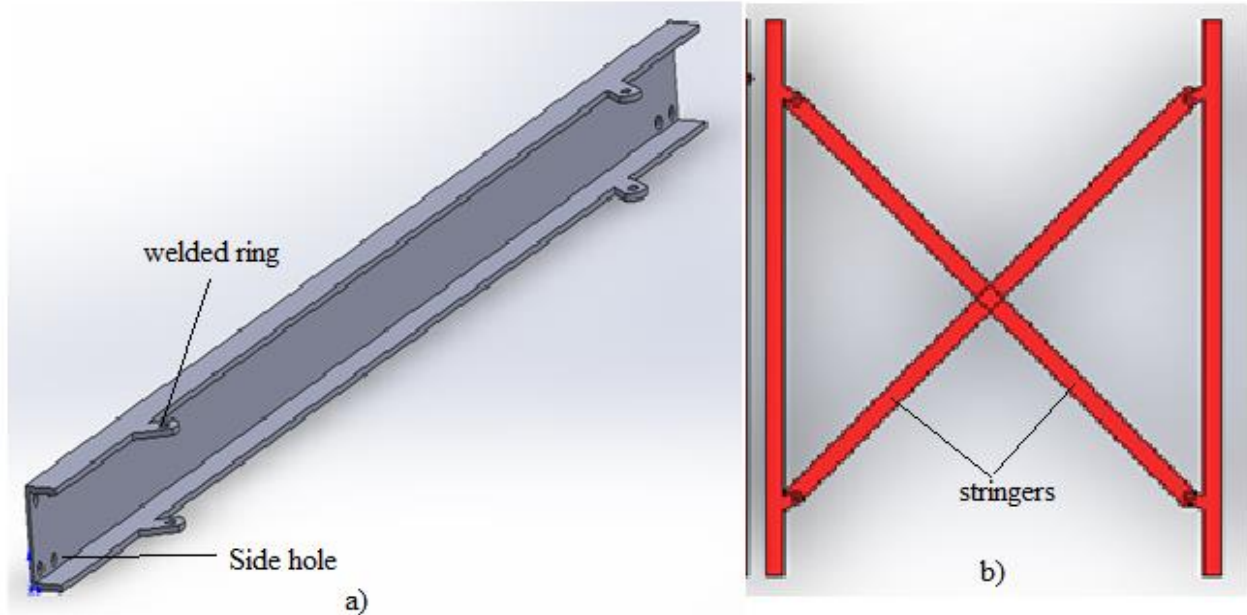


Figure 6.6: Model of a) Base channel and b) Angle iron stringers

STEP 1: Assembly of Base Panels

- a) Lay down horizontally two base channels symmetrically in which the channel side is in front of the second base.
- b) Clamp the angle iron stringer with the base channel at the attached ring using bolt M16 in a diagonal form starting from one side of the base channel to the opposite side of the second base channel.
- c) Clamp the second angle iron stringer with the base channel at the attached ring using bolt M16 in a diagonal form starting from one side of the base channel to the opposite side of the second base channel.
- d) Repeat the above (step a- step c) to assemble the bottom stringer cross member see figure 6.7.

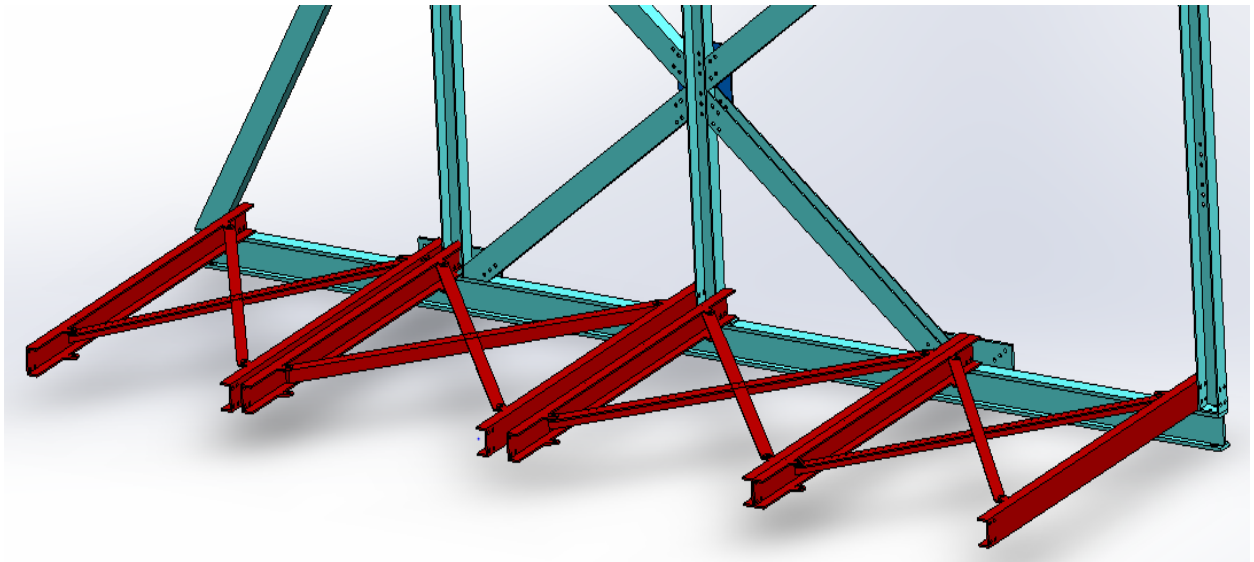


Figure 6.7: Model of assembled base panel (red colure)

Fixing of the deck plate with the base panel

The deck is to be made up of 16mm thick galvanized steel deck plate supported on stringers spaced 550mm apart which are in turn supported on base beams with 1850mm spacing. M10 bolts are used to clamp the galvanized steel plate with the base channel.

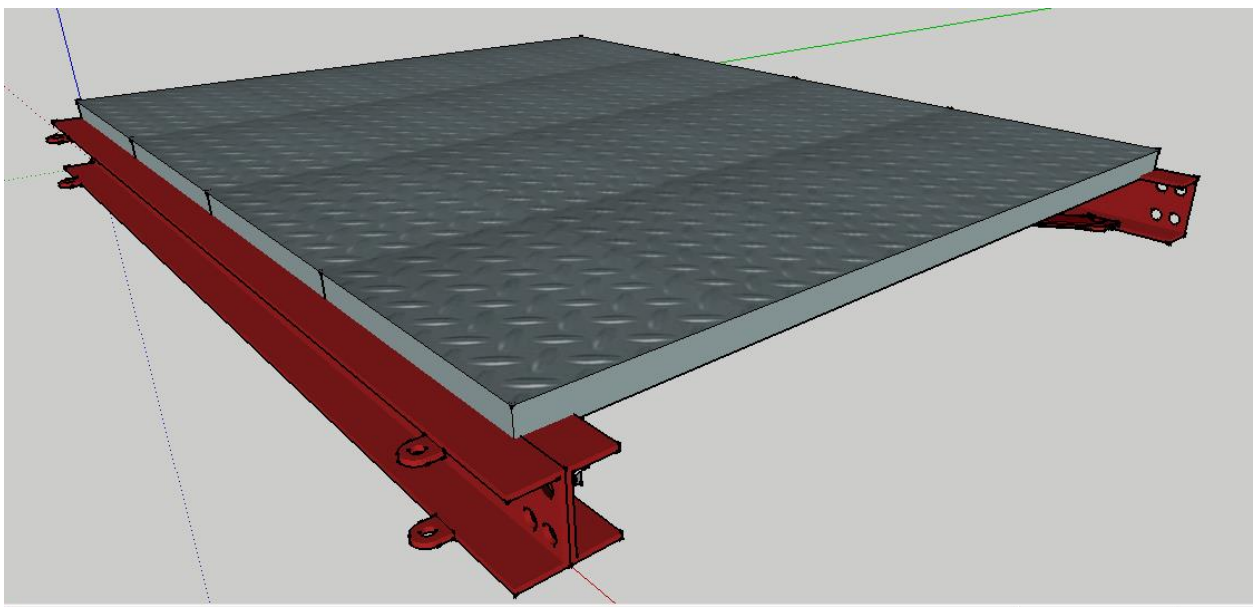


Figure 6.8: Deck plate on the base channel

6.4 Assembly and Construction of Truss Module

Panels are bolted together in the workshop into modules that are transported to site and the modules are bolted together on site. This will require the least assembly work on site. Modules are likely to weigh 300kg-400kg and will be quite bulky to transport. This option is suited to mainly flat to moderate rolling terrain.

In this truss design eight (8) panels are used to make all three modules which make the truss. Before transporting the module to site it should be fully assembled in the workshop to make sure all panels are bolted together without problem.

6.4.1 Assembly and Construction of Left End Module (ML-1)

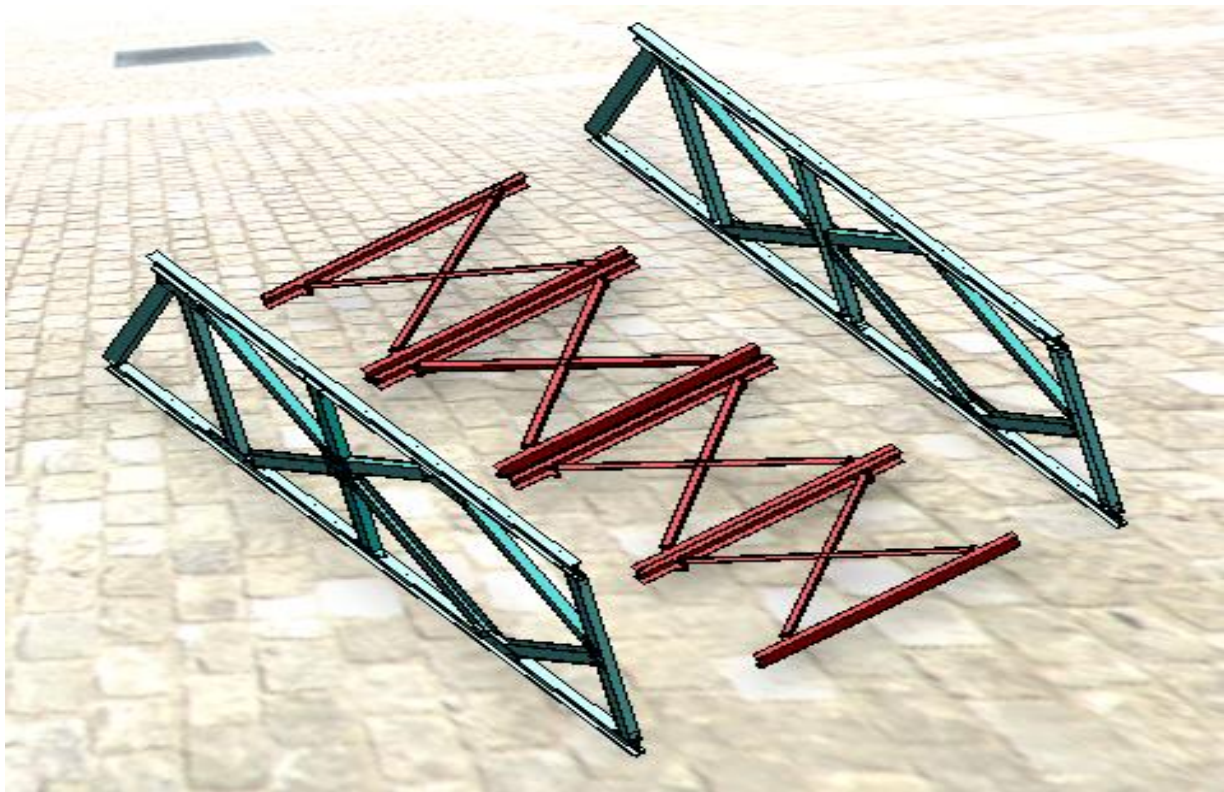


Figure 6.9: Base panel and two side panels used to construct end module (ML-A)

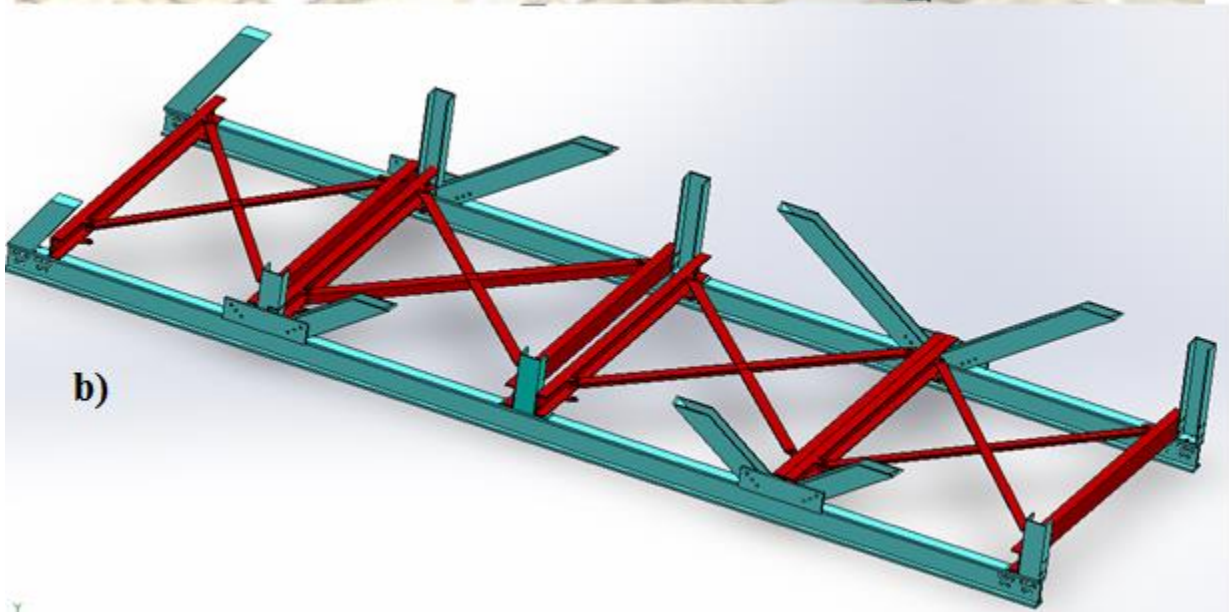
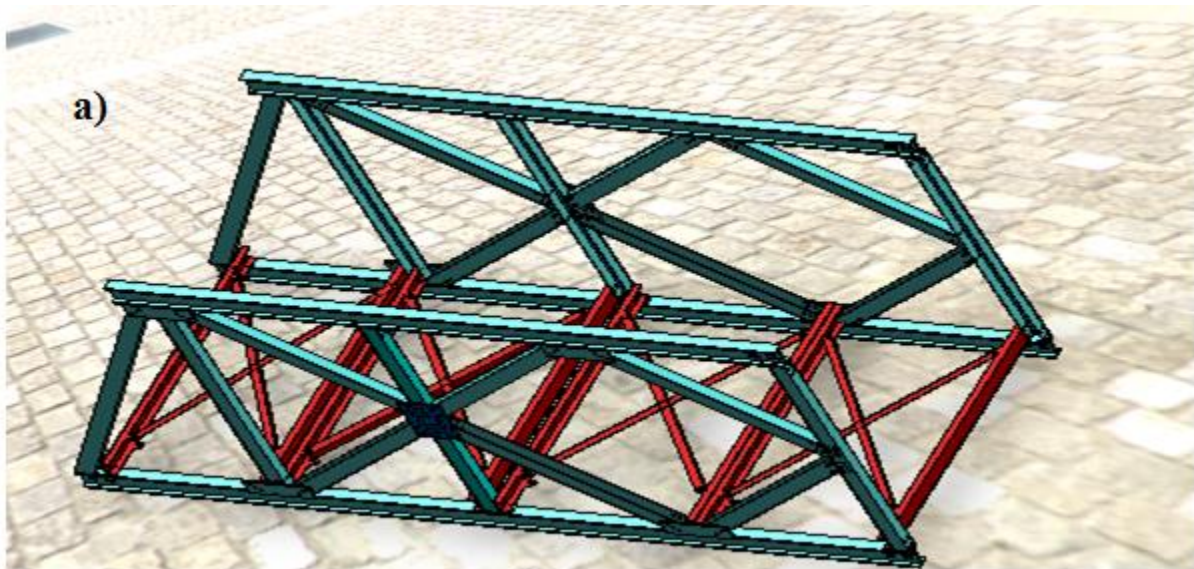


Figure 6.10: Assembled (a) and Inclined section view (b) of end module

5.4.2 Assembly of the middle Modules (ML-B and ML-C)

The second and the third modules are similar

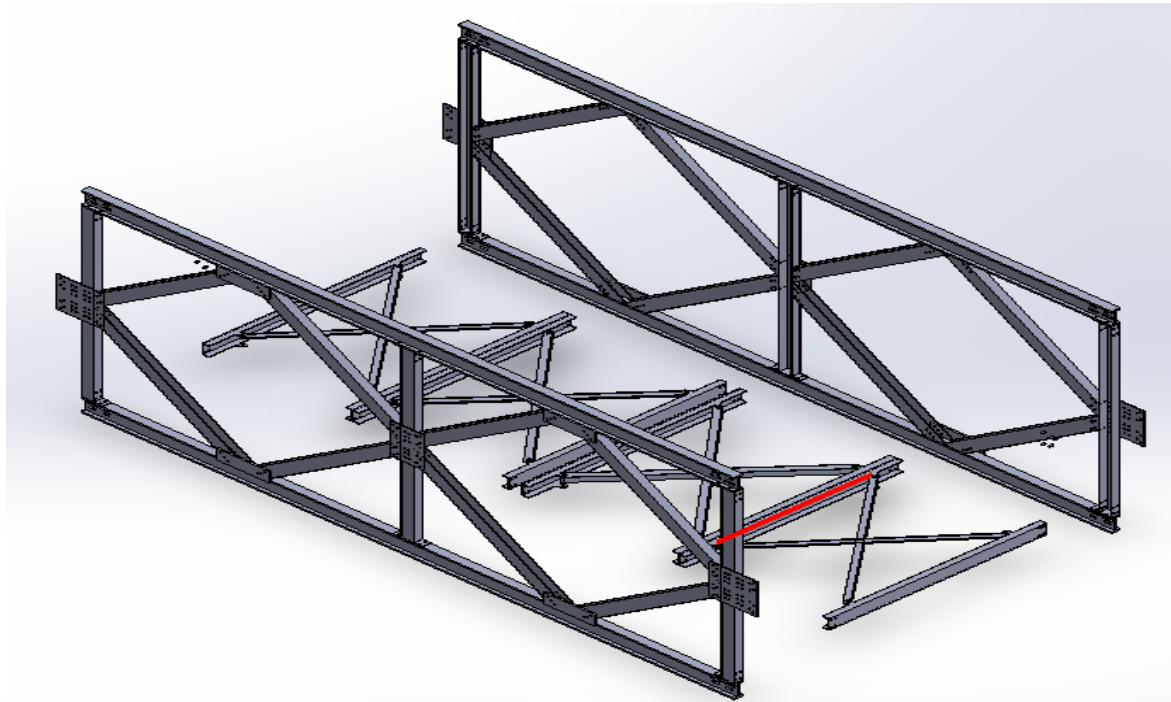


Figure 6.11: Base and side panels of module B and module C

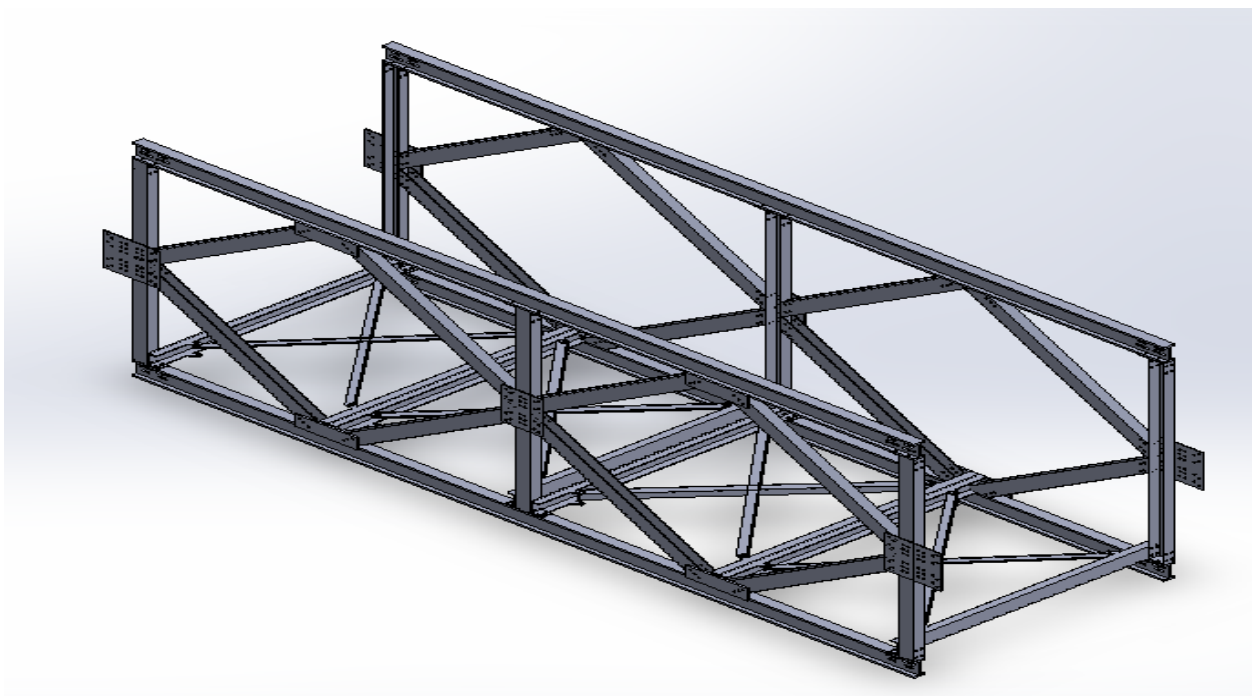


Figure 6.12: Assembly of middle module using solid work

5.4.3 Assembly of Right end Module (ML-D)

The left end module and the right end modules are symmetric to each other as you seen in the figure below

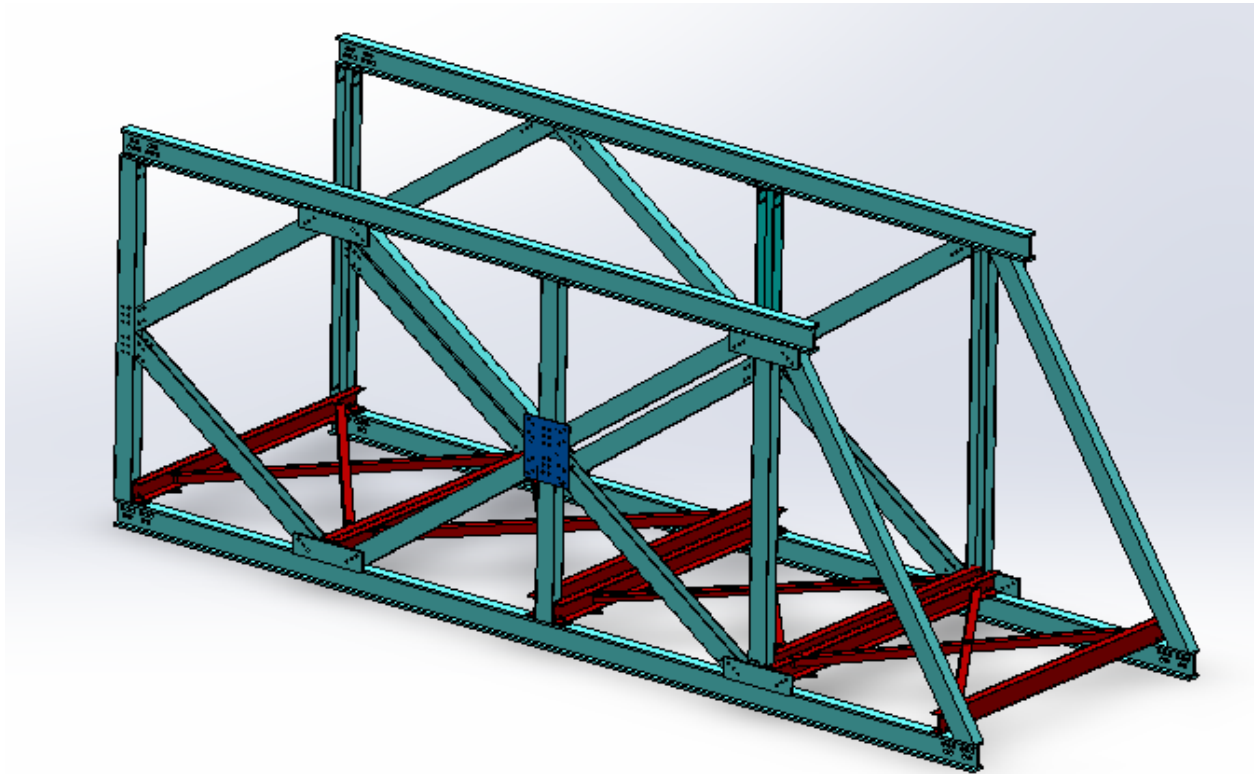


Figure 6.13: Isometric view of module D

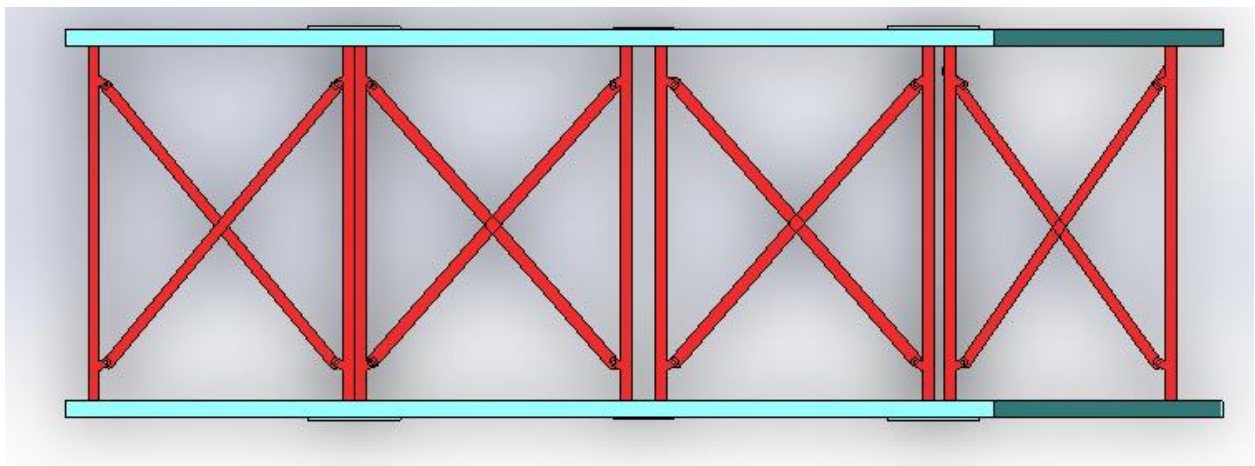


Figure 6.14: Top view of end module ML-D

6.5 Assembly and Construction of Truss Bridge

Construction of the truss bridge is going to be done in the site by assembling the four modular trusses which already assembled on the workshop. To connect one module with the other module Joining Bracket and plates are used.

The joining brackets have advantages other than connecting module truss which is supporting the lateral load due to pedestrians on the truss bridge.

Steps of assembling the truss

- check the entire assembled module for any failure during the transportation of the modules from workshop to site.
- Place each module in a leveled surface according to their arrangement respectively
- Attaché the two joining bracket at each vertical end of module one (MLA) using M30 bolts.
- Connect the second truss module (ML-B) with the first joining bracket which is already bolted with module one.
- Use plate to connect the vertical end member of module one with the vertical end member of module two.
- Attach two joining bracket to the two free end of module two(ML-B)
- Connect one end of the third truss module (ML-B) with the joining brackets at the free end of module to which is already bolted with module one.

Use the above steps to assemble the third and fourth module.

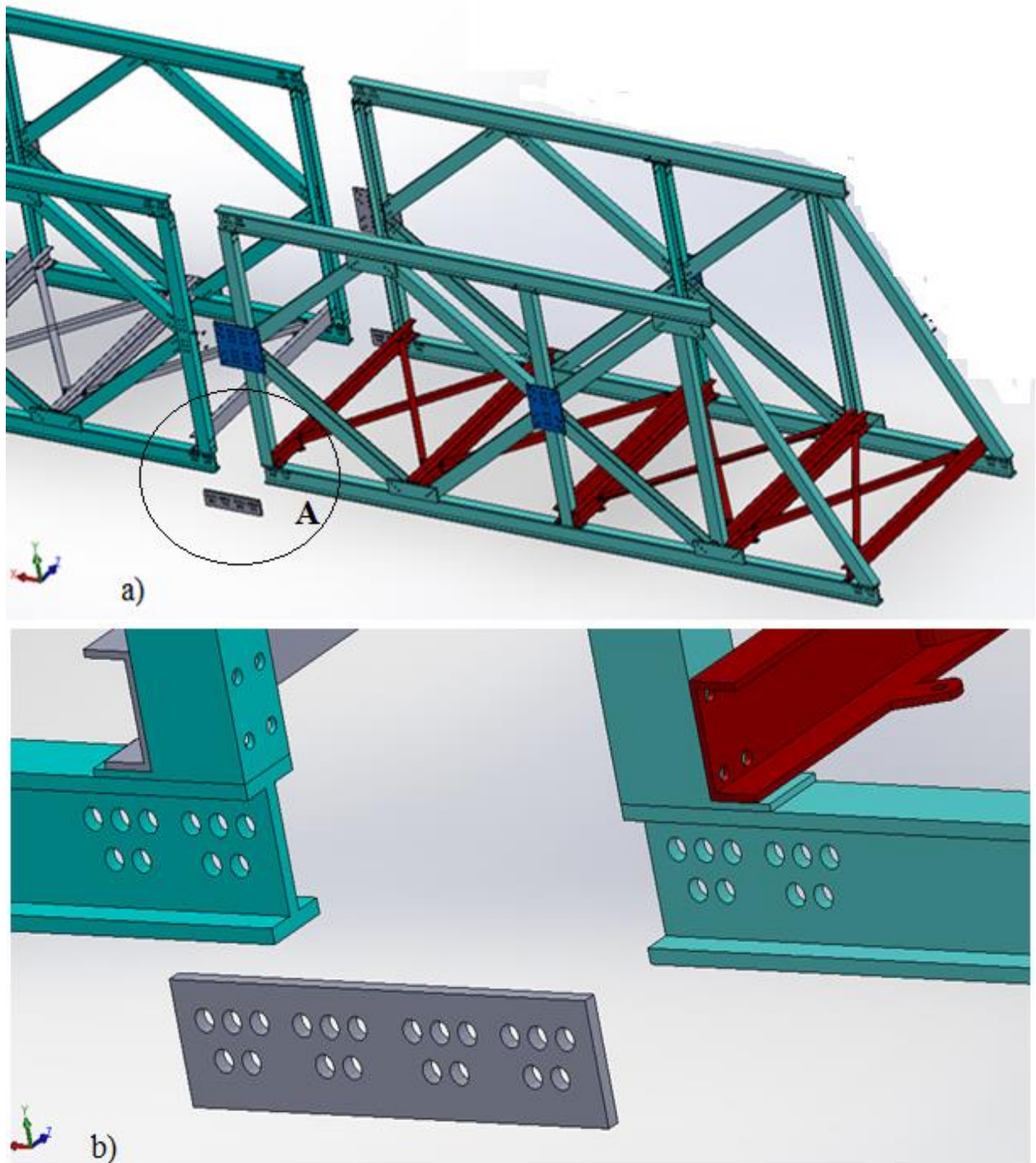


Figure 6.15: a) Assembly of truss modules using Joining Bracket) detail view of section (A)

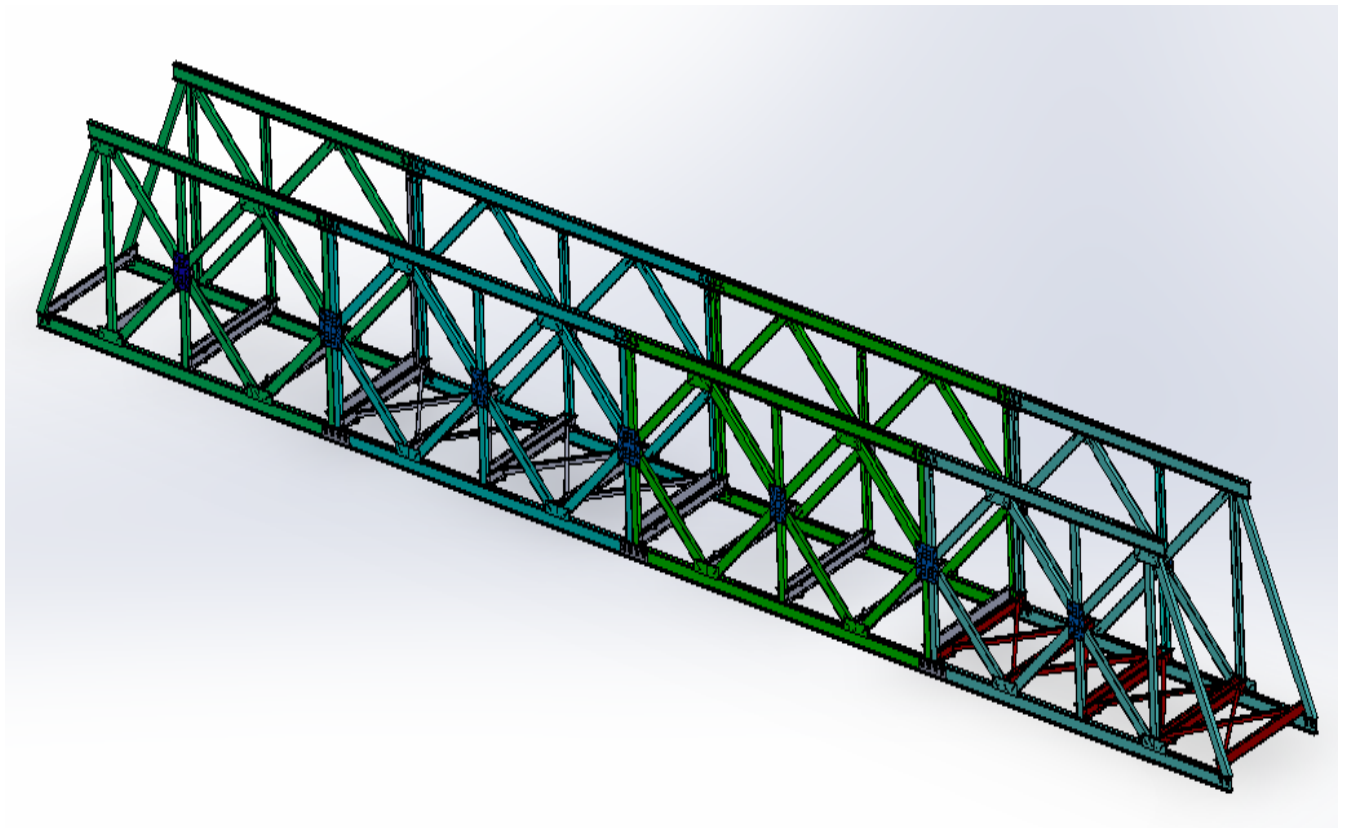


Figure 6.16: Assembly of the four modules

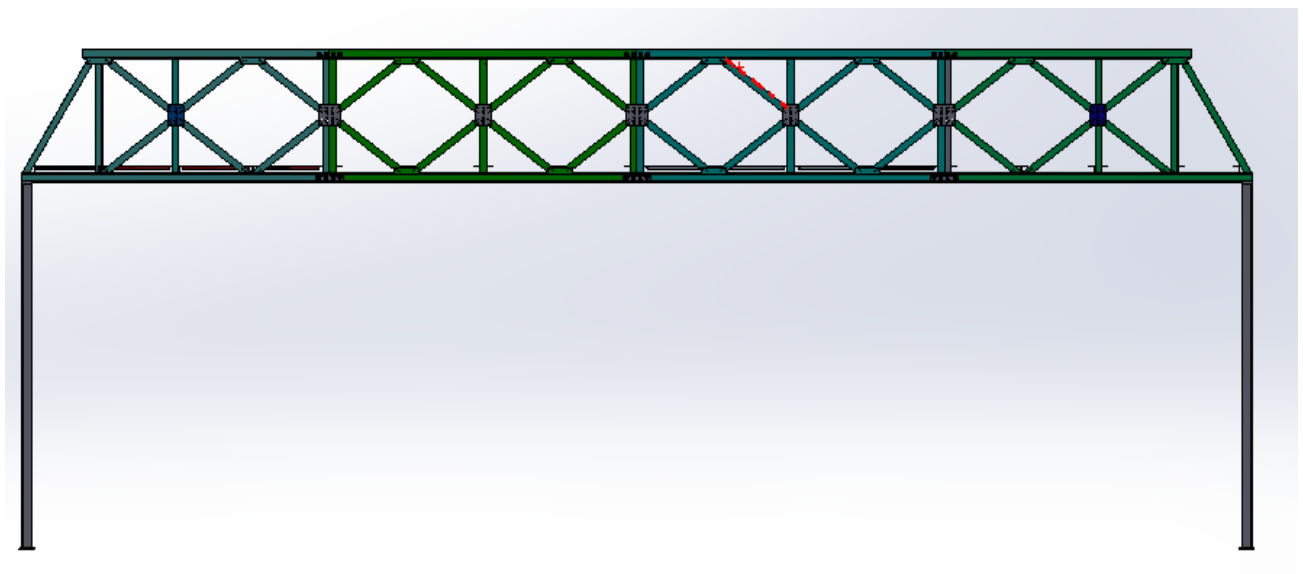


Figure 6.17: Front view of assembled steel truss pedestrian bridge

6.6 Fixing of Steel Truss on Support Beam

It is important that the steel truss is securely fixed on the support beam but at the same time steel expands and contracts with changes in temperature. This must be allowed for in the method of fixing or it may buckle. A suggested arrangement is shown figure 6.18. In this case, one end of the footbridge is bolted down to the support while the other is prevented from moving sideways but allowed to slide longitudinally.

As shown in the figure 6.18 the slot part allows the truss to move freely along the longitudinal when it expands. The extrusion at two sides prevents the lateral movement of the steel truss.

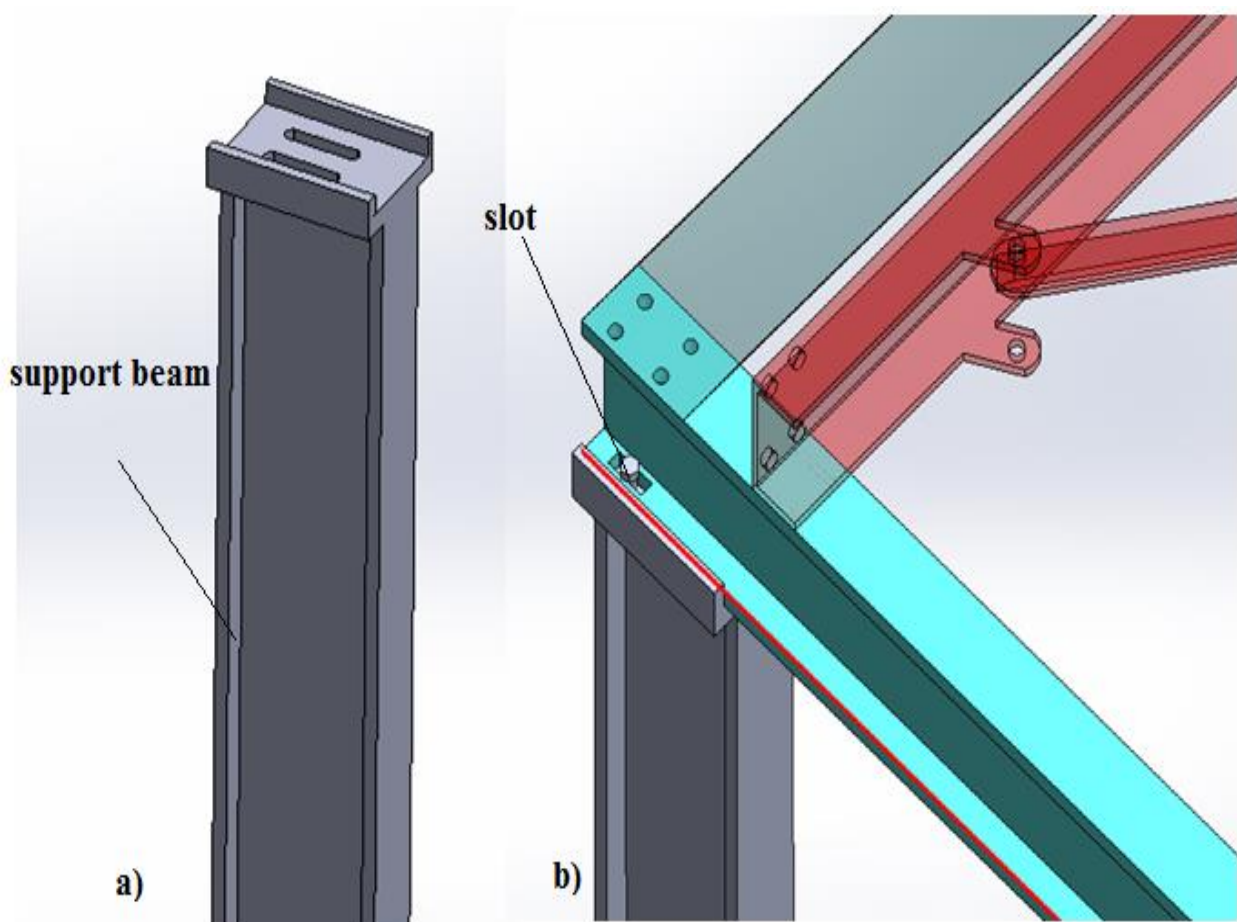


Figure 6.18: a) support beam; b) Fixing of the steel truss on the support

6.7 Lifting of the steel truss

During the assembly of steel truss bridge modules can be transported using heavy vehicle (truck) from the workshop to site. At site a ATF 70G-4 terrain cranes is used to lift the 49 ton (section 4.3.2) steel truss bridge and clamp with the support beam.

The terrain cranes uses extended boom with telescopic sections to lift the weight (truss bridge) and some of them are equipped with a jib. A typical terrain crane is able to hold very heavy loads due to its cable lines. During lifting of the steel truss bridge swinging of bridge is prevented manually by applying balanced manpower using cables attached at each end of the truss bridge. The terrain crane has a capacity of lifting 30-80 ton weight and maximum height of 59.5 m see figure 6.19 [20].

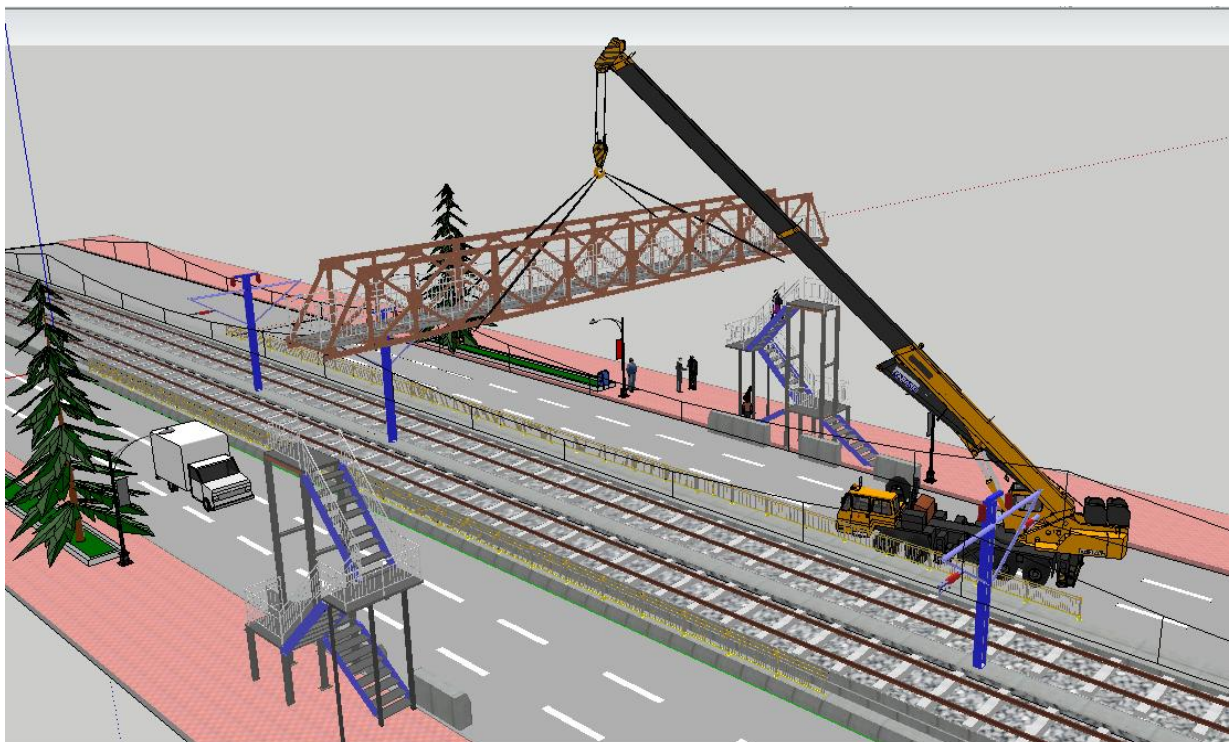


Figure 6.19: 3D Model of lifting the truss bridge using Terrain crane

6.8 Testing of Footbridge and Maintenance

Before transporting the footbridge to site it should be fully assembled in the workshop to make sure all panels bolt together without problems.

When assembled the footbridge should be tested to its design load to check that it behaves satisfactorily and that its deflection is within the design limit (4mm/m span). The preferred method of testing is by “crowd loading”, equivalent to 4 persons/m².

Protective Treatment

The steel needs to be protected as effectively as possible against corrosion. The most effective method is galvanizing all components but this treatment is unlikely to be available. The following treatment is therefore recommended before bolting together the panels:

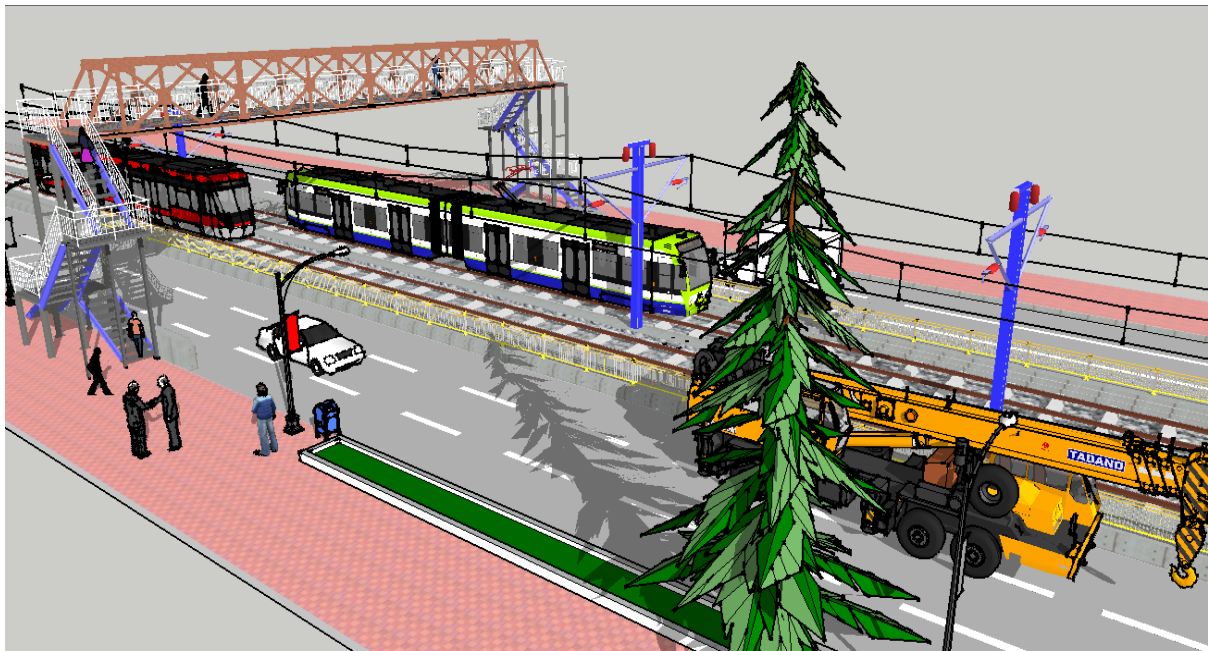
- On completion of welding the panels clean up all welds and weld splatter by grinding and wire brushing
- Thoroughly wire brush all surfaces to remove scale and any rust
- Paint all surfaces with a good quality, oil-based, anti-corrosion paint by spraying or brushing. This should comprise 3 coats – a primer/undercoat followed by 2 top-coats. Careful attention should be given to getting into all corners, inside drilled holes and sealing joints such as along the top longitudinal.
- After installation all surfaces should be carefully inspected and any places where the paint has been damaged should be recoated.

Maintenance

The steelwork should be carefully inspected at intervals of about 1 year, paying particular Attention to:

- Tightening of any bolts that have worked loose
- Repairing any areas of paintwork that have deteriorated
- Checking for any cracks around welded joints
- Cleaning out any soil or rubbish that has accumulated in corners, joints etc.

The footbridge should be completely repainted every 2 to 3 years.



a)



b)

Figure 6.20: a) 3D simulation of pedestrian steel truss bridge for Addis Ababa LRT **b)** from elevation view

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The ANSYS analysis for this steel truss is done based on the standard loading system, and the results are within the limited preconditions sated by the standard value.

From this we can conclude the ANSYS analysis for this truss is very insightful. The study has addressed the possibility of analysis and design of steel bridges with locally available steel profiles. Based on the analysis and design made so far, the study has proved that, construction of steel bridge with locally available steel profiles is an option worth .Even though the cost of local production is closer to importing it is still a good option since it helps in the capacity building of local design, fabrication and construction firms, creates job opportunities for many people and is a saving in foreign currency. For many short span temporary bridges in road construction projects, these local assembled steel truss bridges can be used as temporary bridges. In addition to the fact that these assembled steel bridges are preferable in inaccessible areas they also take very short time to erect.

6.2 Recommendations

Being an alternative solution to the method of bridge design, the following recommendations can be made based on the study:

- a) Fabrication of standard steel sections with higher strength and large thickness should be encouraged.
- b) A counter check on quality needs to be conducted on imported steel bridges to confirm quality standards.
- c) The government should take measures that encourage local design and production such as making such productions tax free.
- d) Private companies should be encouraged to engage in the design and fabrication steel bridges with locally available steel profiles in designing and building bridges and given supports for the development of the system.

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