Design of A Structural Beam for Future UTP Composite Canopy

by

Mohd Irsyaduddin bin Ab. Latif

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2009

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CERTIFICATION OF APPROVAL

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January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Irsyaduddin bin Ab. Latif

ABSTRACT

Composite are used in many structural applications due to their high specific mechanical properties. Universiti Teknologi Petronas (UTP) has a structural canopy which can be replaced with composites. The objectives of this project are to design and analyze the current structure of UTP canopy and compare with the design made from composite material. The material to be used in this project is Glass Fibre Reinforced Epoxy (GRE) which is combination of woven E- Glass Fibre and Epoxy matrix. In this project, the current structure of the beam has been designed in CATIA V5 to estimate the volume and the mass of the structure. All the dimensions and shapes have been referred to the current design data from Kuala Lumpur City Centre Berhad. Finite Element analysis has been conducted to see the deflection of the beam in consideration of its weight and distributed load from the roof and rain load. From the results obtained it is possible to substitute the current material with GRE with modification of the thickness of the beam. The thickness of current structure made from Steel is 12mm thickness while for GRE is 26mm. 56% weight reduction can be obtained if GRE substitute the current material. The cost of the material to build a beam made from GRE is 62% higher than steel but if considering the maintenance cost of GRE could be reduced.

ACKNOWLEDGEMENTS

First and foremost, all praise to Allah s.w.t for granting me the opportunity to complete this final year project, which has proven to be a very enriching experience.

It is with pleasure that I express my heartfelt thanks to all who have assisted me either directly or indirectly during the course of this project. My gratitude goes to my supervisor, Mr. Muhamad Ridzuan bin Abd. Latif, who helped me to achieve the project's objectives. His contribution on this project was an invaluable. I would like to acknowledge that without his guidance, all my efforts would not have been fruitful.

I would also like to thanks to the Property and Management Maintenance staffs especially En Ir. Aminuddin b. Mat Isa and En. Mohd Zuhairi b. Mohd Salleh provided me the structural data and not forget all my colleagues who have been very cooperative in helping and sharing the ideas throughout the analysis work. Without their contribution, the completion of this project seems to be impossible.

I would like to thanks to my parents for their support encouragement and understanding from beginning until the completion of this project.

Thanks to all

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LIST OF ABBREVIATIONS

UTP	Universiti Teknologi PETRONAS
CAD	Computer Aided Design
CATIA	Computer Aided Tridimensional Interactive Application
GRE	Glass Fibre Reinforced Epoxy
GRP	Glass Fibre Reinforced Polymer
FE	Finite Element
AISC	American Institute of Steel Construction
LAP	Laminate Analysis Program

CHAPTER 1

INTRODUCTION

1.1 Background of study

Universiti Teknologi Petronas (UTP) is covered by very large size canopy, as in Figure 1. A canopy is an overhead roof or structure that is able to provide shade or shelter [1]. It is an architectural projection that provides weather protection, identity or decoration, and is supported by the building to which it is attached and a ground mounting, by not less than two stanchions (upright support posts) [1]. A canopy comprises a structure over which a fabric or metal covering is attached. Modern frame materials offer high strength-to-weight ratios and corrosion resistance. The proper combination of these properties can result in safe, strong, economical and attractive products [2]. At present, applications for fibre- reinforced plastic structures are increasing rapidly due to their high specific stiffness and strength. In building construction, the main reason for using FRP to replace steel and concrete is its good corrosion resistance [3]. Building structures are usually required to be designed for long term service and safety.

Figure 1: Structures of UTP Canopy

1.2 Problem statement

Almost all of the canopy components such as girder, beams, trusses and roof panels made from Steel as in Figure 2. The weight for the canopy component such as beam was very heavy. There are 600 cantilever truss beams required to make UTP canopy. The weight for each beam is 1643 kg. Steel has disadvantages such as reduced durability caused by its vulnerability to chemical agents and corrosion [3]. Since the remaining UTP academic blocks will be built in the future, the current structure of UTP canopy to need to be redesigned an analyzed to substitute with lighter and more corrosion resistant composite materials.

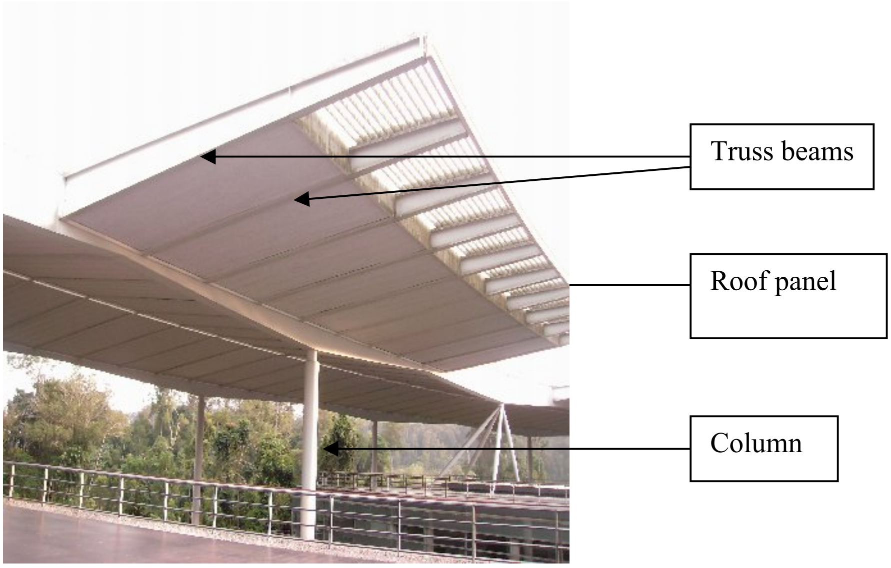

Figure 2: Components of UTP canopy

1.3 Objectives of the study

- To design an existing UTP Canopy Structural component with a suitable composites as its material, and.
- To analyze the stresses at some of the Canopy components under loading condition using basic software, CAD tools such as Laminate Analysis Program (LAP), CATIA and ANSYS

1.4 Scope of study

The Canopy consists of four main components such as beams, connections, columns and trusses. The scope of work for this project focuses on the beam analysis of a UTP canopy only. This canopy will be designed using CAD software, CATIA and for the analysis, will use LAP and ANSYS software.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Composite Materials

Composite materials are formed by the combination of two or more materials to achieve the desired physical and chemical properties that are better to those of its constituent [5].The main components are fibres and matrix. The fibres provide most of the stiffness and strength while the matrix binds the fibres together thus providing load transfer between fibres and between the composite and external loads or support. The design of structural component using composites involves both material and structural design [5].

2.2 Glass Fibre Reinforced Plastic Epoxy

Glass Fibre Reinforced Plastic Epoxy also called (GRE) is a composite material which groups under Glass Fibre Reinforced Polymer, (GRP). This composite material uses glass fibre reinforcement and epoxy resins as the matrices and is widely used in high performance structural applications.

2.2.1 Glass Fibre

There is S- Glass or E- glass fibre could be used for the analysis in this project which is higher in modulus of elasticity compared to other material especially Steel[10]. The tensile strength, σ_u for the S-glass fibre is in the range of 3.5 to 4.6 GPa or E-Glass fibre is about 1.5 to 3.0 GPa as compared to steel has only about 0.25 to 2.1 GPa.

2.2.2 Epoxy Matrix

The matrix will be used for this project is epoxy resins. It because of better mechanical properties and performance at higher temperature lower degree of shrinkage compared to other resins such as polyester or Vinylester [10]. It has known to have better corrosion resistance as well. This epoxy resin should be applied along with a hardener such as amine or anhydride. The density of the resin is 1.2g/cm^3.It can be cured at room or at elevated temperature. The cost for the Epoxies based on Bisphenol A is about $2.40 per kg while those based on Novalac resins cost about $4.40 per kg[10]

2.3 Serial or Parallel mixing Theory

The main hypothesis to do numerical model of the Serial Parallel mixing Theory are;

i. Composite is made by two component materials which are fibre and matrix

ii. For each component materials, it has the same strain in parallel(fibre) direction and same stress in serial direction

iii. The volume fractions of compounding materials should be in direct relation with the composite materials

iv. The distribution of phases in the composite is considered as Homogeneous Distribution.

v. Perfect bounding between component should be taken as consideration

Figure 3 shows the improvement of classical mixing theory which replacing the iso-strain hypothesis for an iso-strain condition in the fibre direction and iso-stress condition in the transversal direction, this allows to simulate all components distribution in the composite.

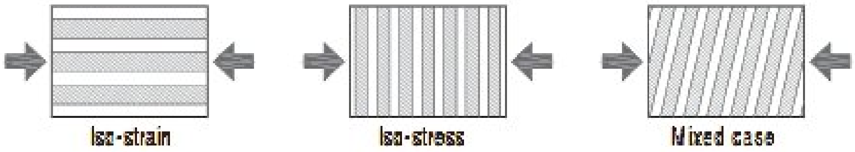

Figure 3: Different distribution of components in a composite material [18]

Based on this hypothesis the equations below can be presented.

Parallel Behaviour: ${}^{c}\varepsilon_p={}^{m}\varepsilon_p={}^{f}\varepsilon_p$

$${}^{c}\sigma_p={}^{m}k\,.\,{}^{m}\sigma_p+{}^{f}k\,.\,{}^{f}\sigma_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 1$$

Serial Behaviour: ${}^{c}\varepsilon_s={}^{m}k\,.\,{}^{m}\varepsilon_s+{}^{f}k\,.\,{}^{f}\varepsilon_s$

$${}^{c}\sigma_s={}^{m}\sigma_s={}^{f}\sigma_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where

ε_p =Parallel component of the strain

ε_s = Serial component of the strain

σ_p =Parallel component of the stress tensor

σ_s = serial component of the stress tensor

^{m} = Matrix materials ie: resins such as Epoxy, Polyesters

^{f} =Fibre Materials ie: Glass Fibre, Carbon Fibre

${}^{m}k$ = Volumetric Participation of matrix in the composite material

${}^{f}k$ = Volumetric Participation of fibre in the composite material

2.4 Previous researches done using Glass Fibre Reinforced Polymers

Up to now many different researchers have carried out analysis using glass fibre reinforced polymers in their structures and equipments. Among them, Sapuan, S.M[6] analyzed Glass Fibre Reinforced Epoxy composite hovercraft hull base. He has done the research to produce corrosion resistant and lower density composite for a hovercraft. In this research, he was used Computer Aided Design software, CATIA to develop the design while for structural analysis part, he was used Finite Element method, NASTRAN/PATRAN software. C. Ozes[7] researched the stress analysis of pin loaded woven-glass fibre The results have been compared using experimental and numerical method. It can be seen that the numerical results agree well with the experimental results

2.5 Structural applications using composites

Over a period of more than 20 years in the Glass-Fibre Reinforced Polyester (GRP) roofing and architectural features industry, there have been many advances in the manufacturing process and use of GRP within the construction sector [3]. The roofing structures required very strong and lightweight materials [2]. It is important to designing and manufacturing the roof that has these characteristics. The greatest advantage of GRP over other conventional materials however is the ability to design and build large structures conceived as a whole and not as an assembly of parts which have to be jointed together [3]. R.P wool conducted a research on using bio-based composite roof structure [8]. This soy bean based materials were tested for suitability in roof structure. The large scale bio-based composite structures were successfully manufactured yielding good mechanical performance for roof structures.

2.5.1 Composite Roof Structural Applications

A large, long span roof structure developed for a Conference Hall and Library Building at Bahrain [4]. The roof consisted of five vaults as primary structural composite elements. The actual weight of one vault assembly is about 30 tones, which is less 50% lighter compared to steel structure. It was installed at 28m above ground level, and considered the temperature variation 15^0 to 50^0C and wind loads due to gust of 120 kmph. This project involved of conceptual design, detailed engineering, tooling, manufacturing, assembly and installation at site took 16 months to be completed. It used Composite materials because of the ease of moldability, complete resistant to environmental corrosion and high load bearing capacity at a relatively low weight. During the analysis and design, the vault dimensions were determined by the architectural requirements. Structural analyses were carried out using finite element technique. Initially, the stress patterns and deflections were identified. During the detailed engineering stage, macro mechanical analyses were carried out to arrive at the laminate design such as number of layers, lamination sequences and angles. Figure 4 illustrates the final FE model was built using 3-D laminated composite general shell elements. The anticipated deflections in the support structure under different load cases such as superimposed load, wind loads and thermal load were considered in the analysis in order to optimize the steel support structure. The limiting states of design, for deflections and stresses, were set up us per guidelines provided by the structural design of polymer composites- EUROCOMP Design Code and Handbook [12].

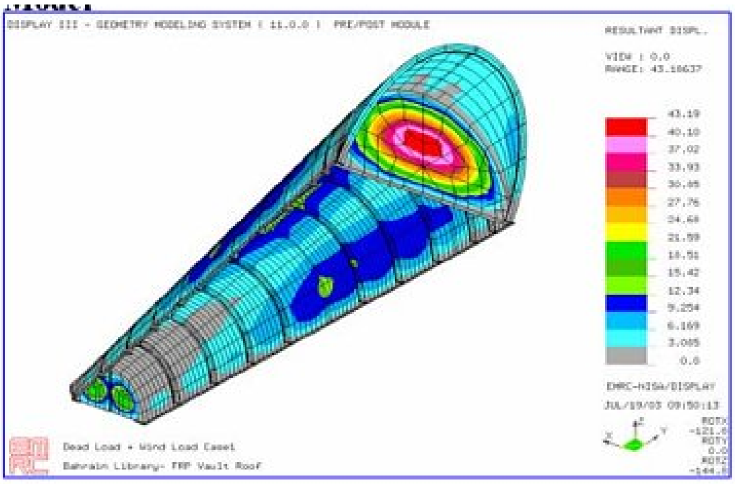

Figure 4: Roof of the library analyzed in Finite Element Software

2.6 Durability of the Building built by GRP

GRP has been used in construction for a long time ago. The example of building being built by GRP was Mondial House whereas built on the bank of the river Thames in London on 1974[11]. This futuristic design and decorated with white GRP panels. This was a very large building, reaching a height of 46m. It was also designed for good weathering resistance and durability. The design lifetime for this building was expected 50 years durability. This designed was easily maintained because it can be cleaned and polished by hand without any special tools and equipment.

2.7 Loads

2.7.1 Dead Loads (Self Weight)

Building dead load shall be estimated based on the actual state of the building concerned. The weight of each part of the building shall be calculated using the density of the materials, the unit weights or the combined weights.

2.7.2 Rain Load

It caused by the environment in which a particular structure is located. If rain water accumulates on the roof faster than it runs off, it can cause ponding. Ponding should be prevented by having a suitable slope of the roof which is ¼ in/ft or more together with good drainage system. During heavy storm, strong wind will occur and there is the water accumulated on the roof, it will push that water toward one end can cause failure. To avoid ponding in the roof system, AISC specification states that equation below[19]

$C_p + 0.9\,C_s \leq 0.25$..1

$I_d \geq 25(S^4)10^{-6}$...2

$C_p = \frac{32\,L_p L_p^4}{10^7\,I_p}$..3

$C_s = \frac{32 S L_s^4}{10^7\,I_s}$...4

Where;

Lp = Column spacing in direction of girder (Primary member length),ft

Ls = Column spacing perpendicular to girder direction(secondary member length), ft

S = Spacing of secondary members, ft

Ip = Moment of Inertia of primary members, in4

Is = Moment of Inertia of secondary members, in4

Id= Moment of Inertia of the steel deck

2.8 Deflection on the beam

It is important to take careful considerations of deflection of a roof design system. It because rain can accumulate on areas of the roof, which then causes ponding, then could cause failure of the roof. The deflections of steel structures are usually limited to certain maximum values. The limitation for deflection should be considered because excessive deflection may damage other materials attached to it. The appearance of structure is often damaged by excessive deflection. High deflection could make the person not confidence to use the structure. Standard American Practice for building has been set the limit service live load deflection to less than L/360 of the span length. AISC does not specify exact maximum permissible deflection because of it depends on materials, types of structure and loading. So the limitation must be set by the individual designer on the basis of their experience and judgement. The deflection of the beam depends on its length, its cross sectional shape, the material, here the deflecting force is applied, and how the truss is supported [15]. Figure 5 illustrates the structure is supported by cantilever type which is fixed on one side only.

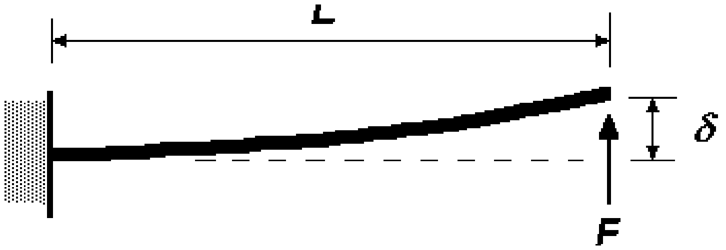

Figure 5: Deflection on the cantilever structure

$$\delta = \frac{FL^3}{3EI} \qquad (5)$$

Where;

δ : Deflection

F: Force

L: Length of the beam

I: Moment of Inertia

E: Modulus of Elasticity

2.9 Moment of inertia

The moment of inertia of a structure will be determined by the beam's cross-sectional shape and thickness [15]. The moment of inertia is not related to the length or the beam material.(refer figure 6)

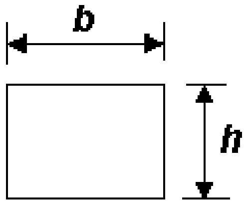

Figure 6: Moment of Inertia for rectangular section

$$I = \frac{bh^3}{12} \tag{6}$$

Where;

I: Moment of Inertia

b:width of the rectangular section

h: Height of rectangular section

CHAPTER 3

METHODOLOGY

3.1 Design of beam

For this project, the truss of UTP Canopy will be redesigned back similarly with original design by using Computer Aided Three Dimensional Application, CATIA Software. All the dimensions and shapes of the new structure should be maintained to look similar with the current design for an aesthetic purpose. It should be designed almost similar with the current structure. Some of the Finite Element Software which is ANSYS may be used together with CATIA for the structural analysis. The weight and the volume of the beam can be estimated from this software.

3.1.1 Beam Specification

The beam that will be designed back in CATIA should conform to the current designs and standards. Below are the design specifications of the truss;

1. The standard cantilever type truss beam
2. The length of a beam is 12950mm tappered , height 1250mm at fixed point, 500mm at cantilever end and width 300mm.
3. The pitch angle for this truss is 1.5^{o} height
4. The loads acting towards the structure are live load which is subjected to the weight of Kalzip Aluminium sheet and Rain load.

Figure 7 below shows the beam that was designed in CATIA. All the dimensions and shapes were designed as same as current design. Only sagging parts were not drawn in this design

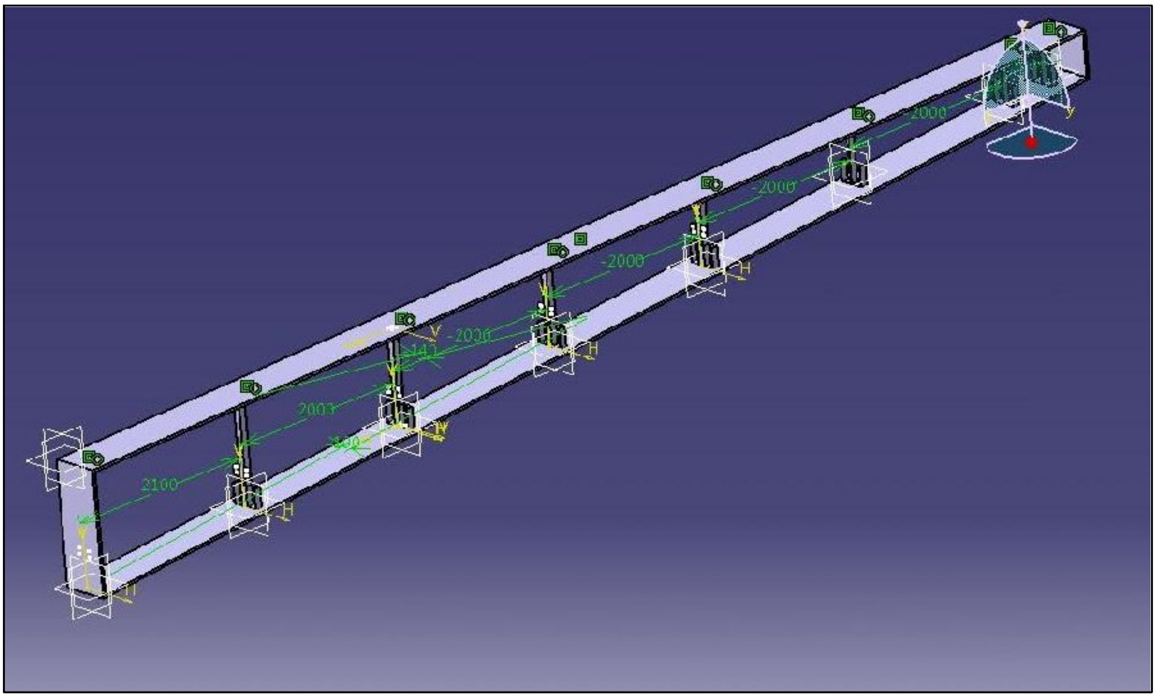

Figure 7: Conceptual design of composite beam

3.2 Analysis of the beam using Finite Element Software.

The study was carried out on two-dimensional truss section model with finite element modelling and analysis using computer software ANSYS. There are three stages in the finite element analysis are pre-processing, numerical analysis and post processing [18]. The pre-processing included the construction of geometry modelling and finite element mesh. The parameters defined at this stage are the geometry, type and size of element, material properties and boundary conditions, which represent the actual structures to be solved. The numerical analysis stage involved the complex solution by the finite element software, ANSYS to obtain the results required. The post processing is the stage after the analysis. It concerns about the statistical or graphical presentation of the results obtained from the result. The result of the analysis will be used to compare the performance of the beam made from GRE and Steel.

In finite element analysis software, Figure 8 illustrates the steps required to analyze the model in ANSYS.

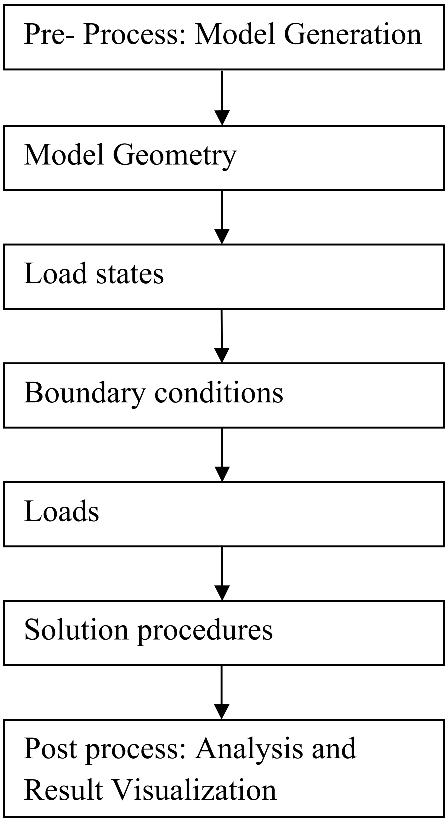

Figure 8: Steps to do analysis in ANSYS [18]

3.2.1 Pre- Process: Model Generation

In pre- process stage user needs to define element types, material properties of the model. In this stage, type of material to be used should be defined whether linear (linear elastic analysis) or non-linear (damage mechanics analysis), isotropic or orthotropic, constant or temperature dependant. Besides that, other properties such as ultimate strength, density and Young's Modulus should be defined as well.

3.2.2 Model Geometry

The purpose of doing model geometry is to allow the program to assemble the element stiffness matrix and the element equivalent force vector. The equilibrium equations can be obtained. Basically there are two methods to generate the model. The first is called Direct Mesh Generation which is create a mesh directly or the second option by using Solid modelling. For this analysis, Solid modelling will be used because boundary conditions, loads, material properties can be assigned to the solid model before meshing. Besides that, re-meshing can be altered without removing or loosing the current loads or boundary conditions.

3.2.3 Load states

In the load states, it consists of two steps, specifying boundary conditions and applying forcing functions to the model.

3.2.4 Boundary conditions

The boundary conditions are the known values of the degree of freedom (DOF) on the boundary. For the structural analysis problem, the DOF are displacements and rotations. For the fixed structure, there are three DOF; the displacement of x, y z direction will be zero 0

3.2.5 Loads

Loads can be defined as concentrated loads or distributed loads subjected toward the structure. A surface loads could be distributed load applied over a surface such as a pressure. A concentrated load applied on a node is directly added to the force vector

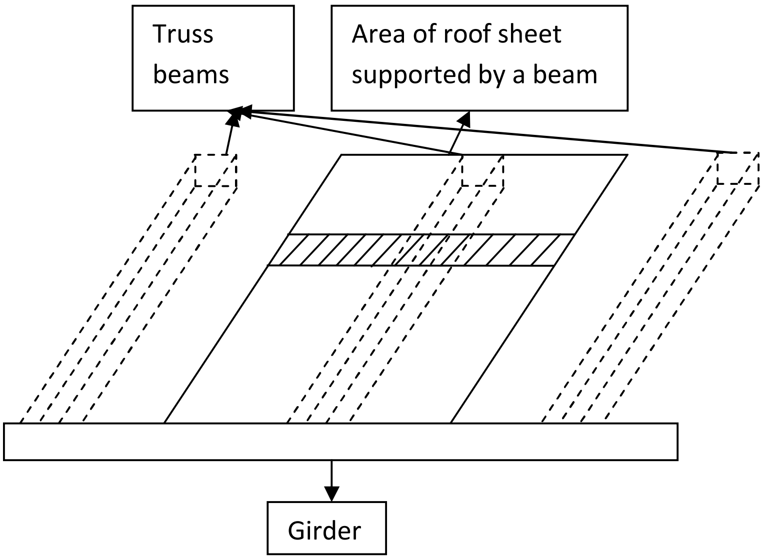

Figure 9: The load acting toward a truss

Figure 9 shows that a roof system with beams spaced 4 m on center is to be used to support dead load of 16 kN; a live load, rain load of 1kN and roof load 3.2kN.

D = 1.23kN/m

L= 0.247kN.m

R= 0.077kN/m

3.2.6 Solution procedures

In this phase the solver subroutine included in the ANSYS program solves the simultaneous equations that the finite element method generates. In Structural analysis firstly, ANSYS will solve the nodal degree of freedom values such as displacement and rotations. Then, stress and strains will be computed.

3.2.7 Post process: Analysis and Result Visualization

After the solution has been computed, the result will be analyzed in the post- processes stage. The results will be displayed graphically or by listing the values numerically. Post processes of commercial codes will produce contour plots of stress and strain distribution or deformed shapes of the object.

3.3 Determine the material properties for GRE

For composite material it should be designed concurrently with the composite structure unlike using steel. It should be determined by using Laminate Analysis Program (LAP). This software used for analyzing composite materials and structures based on laminate theory.

Table 1: Analysis specification for numerical predictions

Description	Specifications
Material	Composite (50% S-Glass Fibre and 50% Epoxy resin)
Beam	Orientation, Quasi-isotropic
	E-Glass Fibre: E_f=72.4 Gpa v =0.34 $\sigma_{f\,=}$ 3400MPa $\rho_{f\,=}$ 2570 kg/m^3 Properties[10]
	Epoxy Resin: : E_r=3.1 Gpa $\sigma_{r\,=}$ 62.053 MPa $\rho_{r=}$ 1200 kg/m^3 Properties[10]
Element	
i. Mesh	Solid
ii. Element Shape	Tetra
iii. Masher	Tetra Mesh
iv. Topology	Tetra 10
v. Global Edge Length	Automatic calculation
Boundary Condition	Fixed in *x,y,z* direction at bolt holes

Table 2: Details of Parameter

Volume	$0.209m^3$
50% of E-Glass fibre & 50% Epoxy resin	
Mass of E-glass, $\rho_f V$	$=(2570kg/m^3)(0.209m^3)(0.5)$ = 269kg
Mass of Epoxy resin, $\rho_r V$	$=(1200kg/m^3)(0.209m^3)(0.5)$ =125 kg
Total mass	=394 kg
W_t E-Glass	68.27%
W_t Epoxy Resin	31.73%
$\rho_{composites}, m/v$	$1885.17Kg/m^3$
Modulus Elasticity of composites	
$E_{composites}, E_f V_f + E_r V_r$	$(7.24 \times 10^7)(0.209)(0.5) + (3.10 \times 10^6)(0.209)(0.5)$ =7.89Gpa $=7.89 \times 10^3 N/mm^2$
Tensile strength of the composite:	
$\sigma_{composite}, \sigma_f V_f + \sigma_r V_r$	$=(3.40 \times 10^6)(0.209)(0.5) + (62.05 \times 10^3)(0.209)(0.5)$ =361 Mpa =0.361 Gpa
Poisson ratio	0.34
Truss weight	394 kg

CHAPTER 4

RESULT AND DISCUSSION

This analysis should prove that the current design should safe to operate under applied forces. The maximum strength of the structure should be less than Yield Strength to avoid plastic deformation from occurred. Then, Fibre-Reinforced Epoxy composite was chosen to develop the canopy truss. The modifications should be made if the performance of a new material is exceeding the maximum value of Structural Steel. The preliminary analysis had been done by using Finite Element Analysis software ANSYS. This analysis is to look the total deformation and maximum principal stress for both materials.

4.1 Plane Stress Assumption

The model created in a single plane and the loading is in the same plane. This condition is called plane stress condition, it is a 2D approximation the deflections and the stresses. The maximum deflection occurs at the free end of the beam.

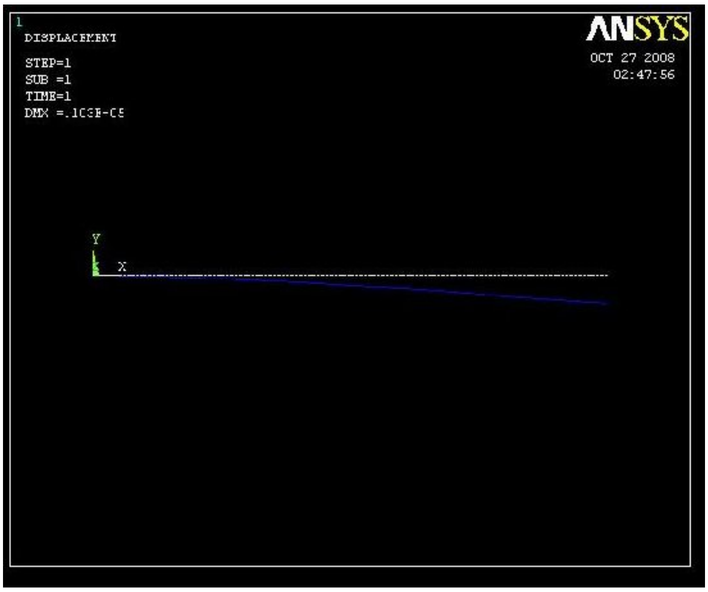

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Figure 10: Deflection of steel beam

Figure 10 shows the maximum deflection of the steel beam when the only self weight considered.

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Figure 11: Deflection of GRE beam

Figure 11 shows the maximum deflection of the Glass Fibre Reinforced Epoxy (GRE) beam when the only self weight considered. Based on the both figures the deflections are maximum at the free end of cantilever beam and the deflection of the GRE beam is higher than original design.

4.2 Three-Dimensional analysis of Structural Steel

Under loading condition and fixed support at the one side of beam, Maximum Principal Stress and Material deformation of Structural Steel have been obtained. Based on the analysis the maximum Principal Stress for Structural Steel is 72MPa (refer Figure 12). If we considered the safety factor is one, the structure still below than Yield Strength of Structural Steel which is 250 MPa. The stress is maximum at the fixed support of cantilever structure since the moment here is maximum at x=0. While for the total deformation, the value is maximum near the end of cantilever structure which is 84mm, (refer Figure 13). This value is still safe to avoid ponding on the roof. The maximum deformation should be less than 86mm.

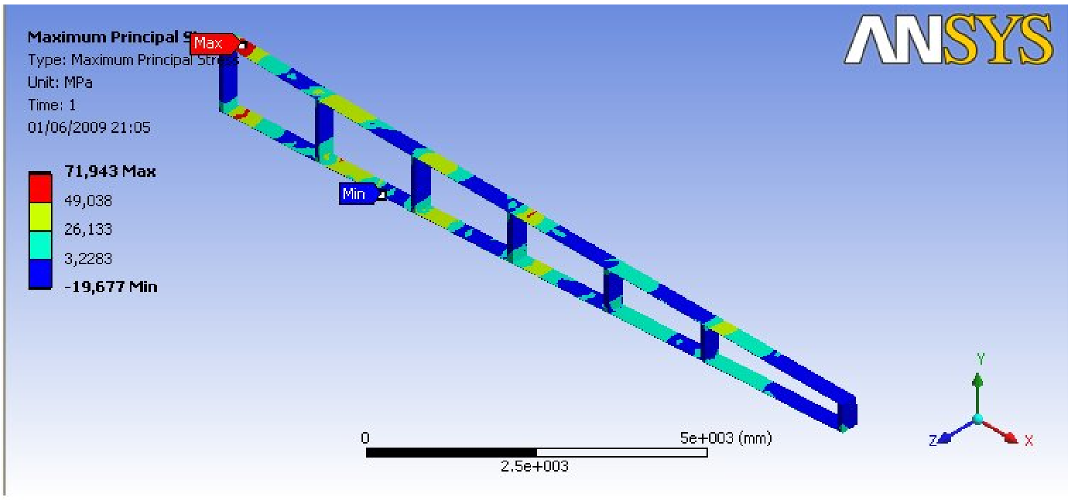

Figure 12: Maximum Principal stress for Structural Steel

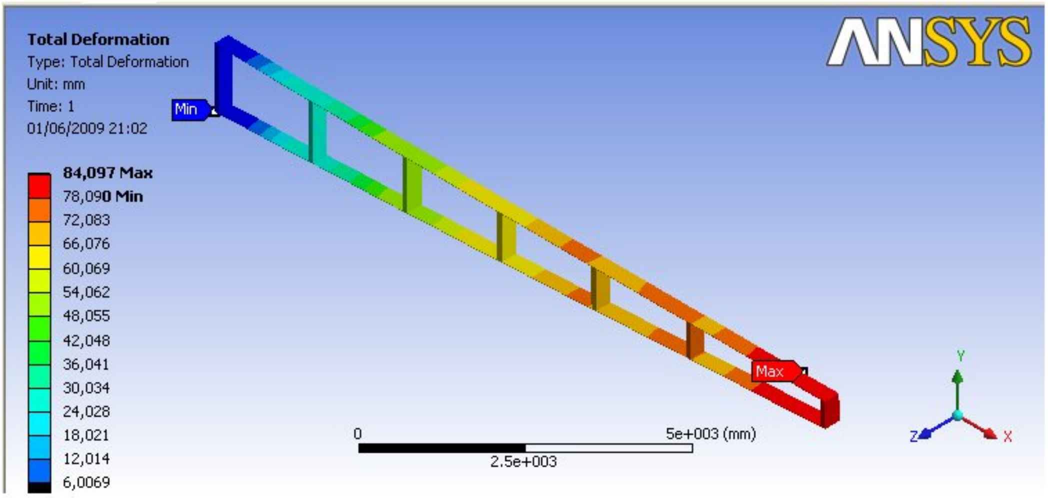

Figure 13: Total deformation for Structural Steel

4.3 Three-Dimensional analysis of GRE

Before proceedings analyze the structure made by composites in ANSYS, the material properties of the composites need to be determined first using the software called LAP or by experimental result. In this case the composites should be analyzed as solid. Based on LAP result, the effective stiffness of the structure has been determined. The targeted value for this structure is the design should be less than Yield Strength and Ultimate Tensile Strength of the materials, the deformation should be less than 86mm and the weight should be less than original structure which is 1643 kg. The analysis is failed using material made by GRE. So the modifications had been made to the thickness of the new structure. The thickness is doubled from original value for each analysis. The design is only safe when the thickness of upper and bottom part adjusted to 26mm. Based on figure 14, the maximum Principal Stress for GRE is 23MPa, near the pivoted area. It still safe to be used since this value is below than tensile strength, 360 MPa. The maximum deformation for this thicker design is 84mm, (refer figure 15) which is not exceeding the deformation limit which is 86mm. Although the thickness of the bottom and upper part is increased one times from the original design the weight of the new structure made by GRE still lower than original design. About 56% mass reduction obtained if using GRE.

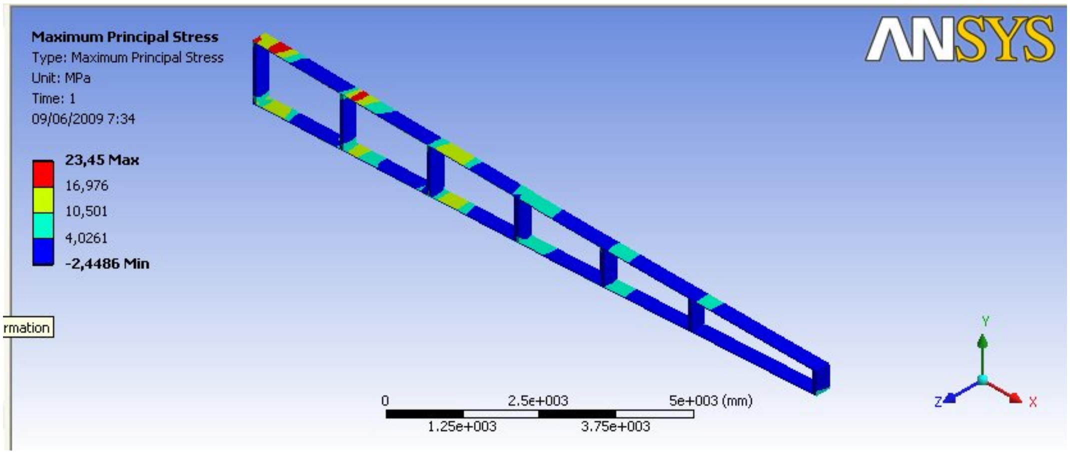

Figure 14: Maximum Principal Stress for GRE

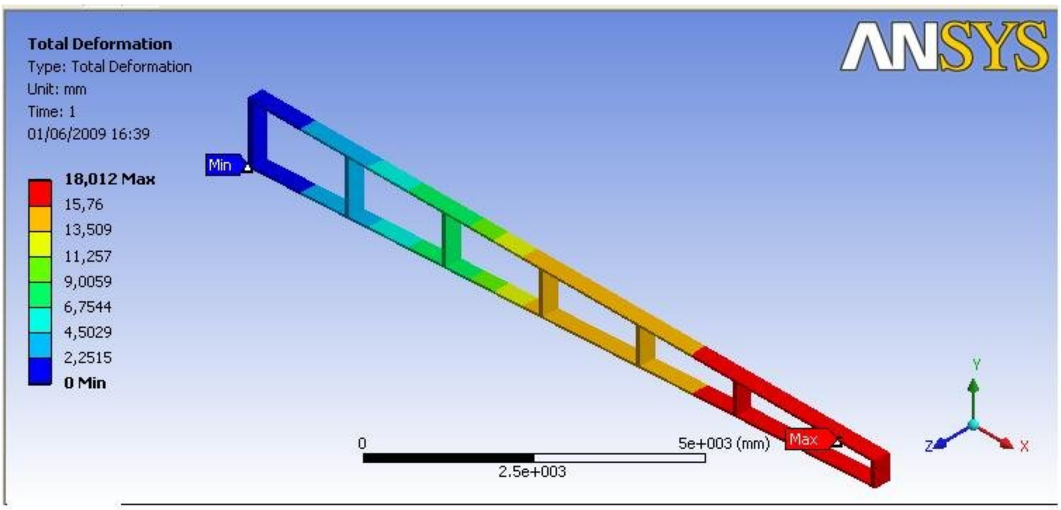

Figure 15: Total Deformation for GRE

4.4 Cost Estimation

The cost for the beam made from current and new materials has been calculated. To build a beam made from steel, it would cost \$1180[20], while to build the same beam made by GRE it would cost \$1908. The price of these materials has been taken from composite newspaper [17]. The cost of Epoxy based on Bisphenol per kg is \$2.40 while for E- Glass Fibre it would cost \$2.80 per kg[17]

The total of material to be made up by Glass Fibre Reinforced Epoxy is calculated

Price of Epoxies based on Bisphenol A resins / kg = \$2.40/kg

Price of E- Glass Fibre =\$2.80

From this design it required 227kg of resin and 487kg of Glass Fibre.

Total Cost= Weight of Epoxy Resin(Price/kg) + Weight of E- Glass Fibre (Price/kg)

$$(\$2.40/\text{kg})(227\text{kg}) + (\$2.80/\text{kg})(487\text{kg})$$

$$= \$1908$$

It results higher cost of materials to build a beam from GRE compared to Steel but, the design made from GRE can reduce the maintenance cost such as coatings and cleanings.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Design and analysis of the beam for future UTP canopy were completed successfully in CATIA, ANSYS and LAP. All the major components have been designed completely in CATIA to estimate the volume of the beam. Analysis of the current structure made by structural steel done successfully to determine it's performance such as maximum principal stress and total deformation. The maximum displacement of the cantilever truss made from Steel and GRE had been compared in this study using 2-Dimensional, 3-Dimensional Finite Element Software, ANSYS. 56% of mass reduction can be obtained by using GRE but with modifications of the current design. 14mm thickness should be added at the bottom and upper part of the current design. The cost of material to build a new beam made by GRE is 62% higher compared to steel.

5.2 Recommendations

Based on these results, it can be recommended that;

1. Design for processing- Fabrication design should be made for the future construction such as Vacuum Infusion Process, Pultrusion or Resin Transfer Moulding.
2. Other Structural members such as girders, roof plates, and joints can also be replaced with composite materials.

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APPENDICES

1.1 ANSYS report

1.1.1 Analysis of a Truss made by Structural Steel

1.1.2 Analysis of a Truss made by GRE

1.1.3 Analysis of a Truss made by GRE (26mm Thickness)

1.2 LAP result

1.3 Material Properties for proposed design.