COMPARATIVE STUDY ON HONEYCOMB STRUCTURE FOR WEIGHT REDUCTION OF GANGWAY MONORAIL

By

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ABSTRACT

Lightweight materials nowadays usually applied in transportation industry. The transportation industry is continuously searching for methods to increase efficiency and decrease fuel consumption. Weight reduction in gangway monorail is a systematic approach that needs to be thoroughly planned, implemented, and maintained in order to coordinate efficient and cost effective. The monorail industry takes into account regarding weight ratio seriously plus added with the weight of passengers. This is where weight reduction plays an important role to increase the efficiency and ensure the integrity of monorail industry.

This project is aimed to study the comparison of weight reduction of gangway monorail by comparing existing and new result using NX Nastran but maintains the performance specifications as the weight of gangway is too heavy and must be reduced from 615kg to 510kg. Only part of gangway which is main frame will be analyzed since this is the most critical area where passengers standing. Furthermore, the criteria of Kuala Lumpur Monorail Fleet Expansion (KLMFEP) will be evaluated into this project and aluminium honeycomb sandwich panel is to replace as the new material. In addition, the first stage of the project is by designing the gangway main frame following the original shape and continued by analysis by NX Nastran to see the difference results.

The final outcome of this project is a demonstration of aluminium honeycomb sandwich panel in gangway monorail with safety factor and its behavior that is illustrated by a simple practicality of graphical visual engineering interface. In which, the manufacturer can utilized this study as improvement in monorail industry and monitor the performance of the material to make important economic and safety decision. It is hoped that this project will benefit engineers and manufacturers that is currently working on reducing weight of gangway monorail.

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CHAPTER 1: INTRODUCTION

This chapter consists of (1.1) project background, (1.2) problem statement, (1.3) objectives and (1.4) scope of study.

1.1 Project Background

A Gangway can be defined as a covered passageway that allows passengers move safely from one vehicle to another in rolling stock. The gangway is designed as a stand-alone unit, using sealed enclosure to protect passengers from the elements while moving from one vehicle o another. It consists of the External Bellows, Internal Bellows, Floors and Main Frame. Meanwhile the Main Frame acts as a connection between the Gangway and Car Body as well as the backbone for all other Gangway components. The Main Frame is made out of C-Channel Aluminium Alloy where several portions are welded to each other forming the assembly. The Gangway Main Frame also mounted with a fixed floor and side floor. The Main Frame is bolted from the Main Frame to the inside of the car body so that it is easily accessible for maintenance and installation.

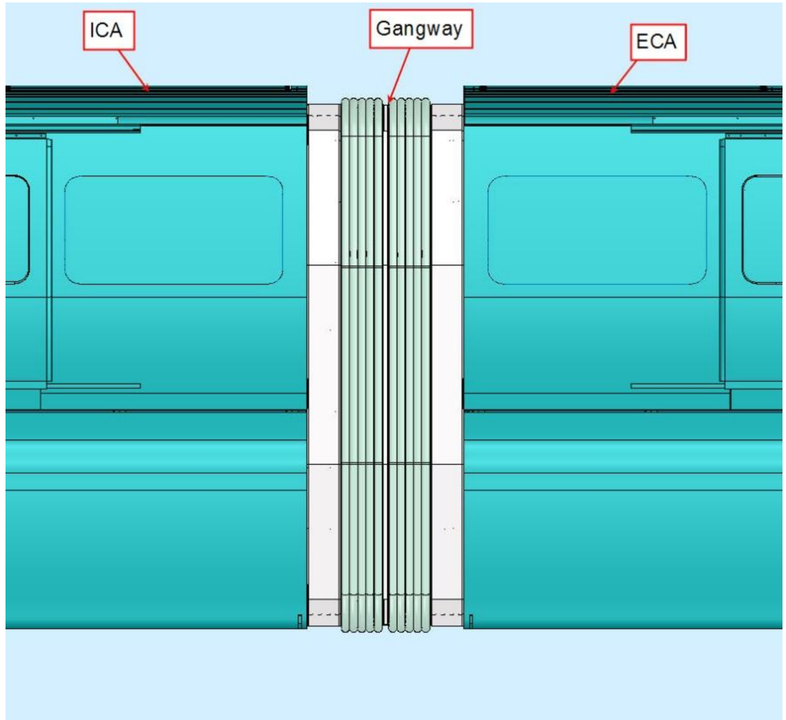

Figure 1: Location of gangway assembly (FDR, 2010)

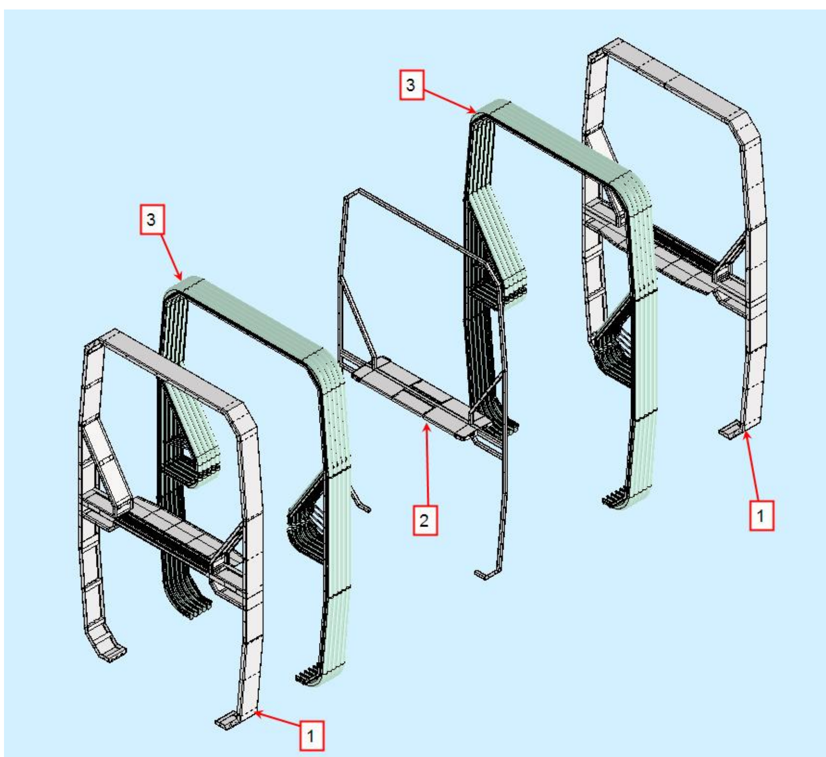

Figure 2: Main components of gangway (FDR, 2010)

Table 1: Components names and estimated weight as per Figure 2 (FDR, 2010)

Number	Components Name	Estimated Weight/Assembly
1	Main Frame	120kg
2	Floor Assembly	100kg
3	Bellows Assembly	260kg

1.2 Problem Statement

Lightweight materials nowadays usually applied in transportation industry. The transportation industry is continuously searching for methods to increase efficiency and decrease fuel consumption. Since the existing weight of gangway assembly is about 615kg. It's too heavy and must be reduced to 500kg – 510kg by choosing material Aluminium Honeycomb Sandwich Panel but maintain the performance specifications. However, safety design factor will be done by doing analysis using CAE software. In this case, the solution will be working out.

Figure 3: Overweight gangway (SCOMI, 2013)

1.3 **Objectives**

The objectives of the project as follow:

1) To study finite element analysis on gangway main frame by comparing existing and new results but maintain the performance specifications
2) To investigate design safety factor of Aluminium Honeycomb Sandwich Panel for gangway monorail

1.4 **Scope of Study**

The scope of study is prepared in order to ensure the project is wisely managed and complete within the time frame and limitations. The scope of study involved as follows:

1) To perform finite element analysis on Gangway Main Frame which based on Aluminum Honeycomb Sandwich Panel properties
2) Develop analysis based on criteria in Kuala Lumpur Monorail Fleet Expansion Project (KLMFEP)

1.5 **Relevancy of the Project**

The project will be relevant to the company as well as manufacturer as the result from the project will reduce weight of the gangway. A part from that, finite element analysis also will be carried out by using Siemens NX Nastran. Hence it's meet the engineering's requirement. Besides, by implementing this project, new faces of gangway will be introduced in assembly of the next train. Otherwise, if the project is not conducted, the weight of gangway will be overload and will cause inconvenience in terms of safety for the trains. Meanwhile, by conducting the project, as a learning curve to adapt in working industry and it's also related to the course undertaking.

1.6 **Feasibility of the Project**

The deadline of the project is on the December 2013. This means that there is an ample time to complete the project. This project is feasible within the time frame as the fundamental of designing and finite element analysis is one of the syllabuses in engineering study. The scope of this project only covers for weight reduction of gangway and finite element analysis to avoid time constraint. In this case, only vertical loading will be analyzed as this is the most critical loading condition to the gangway structure. It is also considered the material properties of aluminium honeycomb eg: modulus of elasticity, yield strength, poisson's ratio etc. Which means the project is very feasible for improvement in monorail industry.

CHAPTER 2: LITERATURE REVIEW

The literature review for this project will be in fragmented flow which consists of (2.1) Code of practice and design constructions of passenger carrying trains, (2.2) Behavior of sandwich structure, (2.3) Analysis using SIEMENS NX Nastran, (2.4) Proof Loading.

2.1 **Code of Practice and Design Constructions of Passenger Carrying Trains**

It is important for designing and constructions of passenger carrying trains to take into account international standard and code practices referring to British Standard (BS 6853:1999) and International Electrotechnical Commission (IEC 61133). Most of the manufacturers and suppliers rely on these standards to ensure the quality control and the deliverance of services. These standards enhance the safety of industry operations as well as passengers, assure quality, and minimize confusion.

According to BS 476-7, selection of a particular material must be made wisely in order to prevent fire. The surface structure which is very critical in determining risk of flame spread and fire development. The material must be made from fire retardant to reduce the time for fire from spreading and ability to absorb heat transfer. Apart from that, IEC 61133 stressed on vehicles intended to carry passengers or commercial loads must abide to these definitions:

i) Minimum load: Loading to be applied to enable the vehicle to move under its own power or to be towed.

ii) Normal load: Maximum load for the performance tests such as accelerating or braking.

iii) Crush load: Maximum load that it can operates safely under certain condition.

2.2 Behavior of Sandwich Structure

Gangway is a passageway for walking from one car to another. The gangway area shall be well insulated for noise and all materials that been used in construction of gangways must be fire resistant. All the components of the gangway play significant role in ensuring the safety of the passengers. The honeycomb sandwich construction is one of the most valued structural engineering innovations developed by the composites industry. However, the aluminium honeycomb sandwich structures have been received much attention in recent years because of their high strength/weight and stiffness/weight ratios, excellent heat resistance and favorable energy-absorbing capacity and many other industries (Rao, Rao, Sarwade & Chandra, 2012); the honeycomb sandwich provides the following key benefits over conventional materials:

1) Very low weight
2) High stiffness
3) Durability
4) Production cost savings
5) Maximum heat resistance

In selection of a minimum-weight ratio for face materials, by knowing the factor of merit is very useful (Vinson, J.R., 1999). The higher factor of merit the best material to select but it does not identify how much load it can withstand before failure. The best choosing core materials is with the highest ratio of Modulus of Rigidity, Gc per density, ρ.

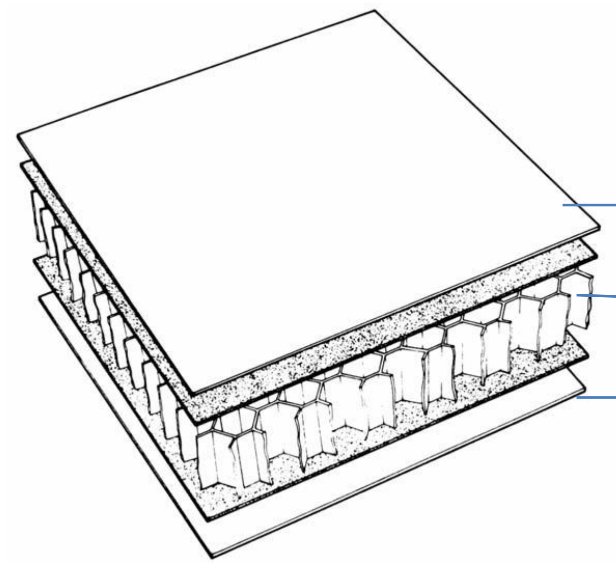

Figure 4: Sandwich construction with honeycomb core (Paika, Thayamballib, & Kima, 1999)

2.3 Analysis using SIEMENS NX Nastran

According to Rust and Schweizerhof (2003), NX Nastran is finite element (FE) software purposely for static, dynamic as well as muliphysics analysis and LS-DYNA in generally for transient dynamic analysis of highly nonlinear problems. NX Nastran includes of Nastran Parametric Design Language (NPDL) for higher programming language. Most of the LS-DYNA applications in real industrial problems are dominated by thin shell elements including some beam and solid elements. Jen and Chang (2006) emphasized on FE method using Nastran to elucidate the local stress/strain behavior of a material by using the local fine-mesh model. For the complex shape and dimension by application of tetrahedral four-node solid elements and the accuracy acquired by comparing the resulted mesh with the experimental result. The von-Misses stress must be less than yield stress meaning that the material behaves elastically everywhere and no yielding occurs. Jen and Chang also stated by using sub-modeling technique can overcome the difficulties associated with complex configuration of specimens and the high computational cost in the numerical simulations.

In the sub-modeling technique a global coarse-mesh model is developed and numerically analyzed first before the global model act as the boundary conditions of the local mesh (Jen, Ko, & Lin, 2009). Burton and Noor (1997) claimed that construction of the geometry by reflecting and/or translating one cell element may minimize the usage of time. Only half of the structure will be meshed to represent the whole body by reflection.

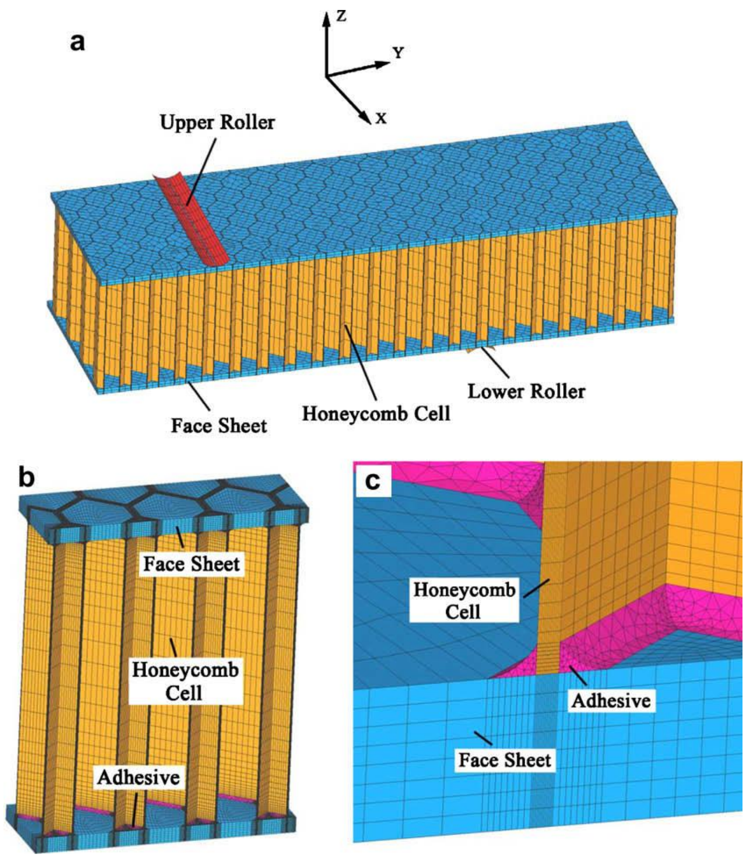

Figure 5: (a) Global coarse-mesh FE model, (b) local fine-mesh model, and (c) enlarged view of the local meshes near the portion of the adhesive joint (Jen & Chang, 2009)

2.4 Proof Loading

The proof load is the largest load that wishes to apply in a structural test. It is usually larger than the largest load expected the structure to encounter in normal operation. To prove beyond reasonable doubt that the structure can safely take the design load is so; a proof load which is greater than the design load is applied. This proof load is calculated to be below the yield load where the yield load is the load that would cause permanent deformation on the structure or equipment.

Fatigue loading conditions, ISO7206/3, have been applied to a hip stem to predict its elastic stress via large deflection finite element analysis. It has been demonstrated via experiments that the high cycle fatigue-life of hip stems can be adequately predicted by using alternative fatigue theories, such as Morrow, Smith–Wat- son–Topper (SWT), and Goodman. (Ploeg et al.,2009).

Experimental studies have shown that a cellular material under repetitive loading develop cracks at the microscale in regions with high stress concentration, from which fracture propagates throughout the strut cross sections (Sevilla et al., 2007; Zardiackas et al., 2001; Zhou and Soboyejo, 2004). It is essential in the design of a cellular component to capture and account for the microscopic stress and strain distribution. Accordingly, knowledge of the mechanical properties of sandwich structures is urgently needed for their design and application. However, understanding the fatigue behaviors of sandwich structures is important for assessing their long-term durability and reliability because sandwich structures frequently experience cyclic loadings in many applications.

Belingardi et al. (2007) investigated the bending fatigue behavior of honeycomb sandwich beams using undamaged specimens and specimens with interfacial debond. The S-N curves for these two kinds of specimens were presented. Jen et al. (2008) employed finite-element-based interfacial parameters to evaluate the fatigue lives of the sandwich structures with a face-core interfacial debonding failure mode.

CHAPTER 3: METHODOLOGY

Methodology is a step of the procedures that have to follow in order to complete the project. The research methodology for this project is mostly done by experience learned from internship project, self-reading, and self-exploration on various matters related to technical knowledge and tools required to study the comparison of aluminium honeycomb. This chapter consists of (3.1) Project methodology, (3.2) Gantt chart and key milestone, and (3.3) Tools and equipment.

3.1 Project Methodology

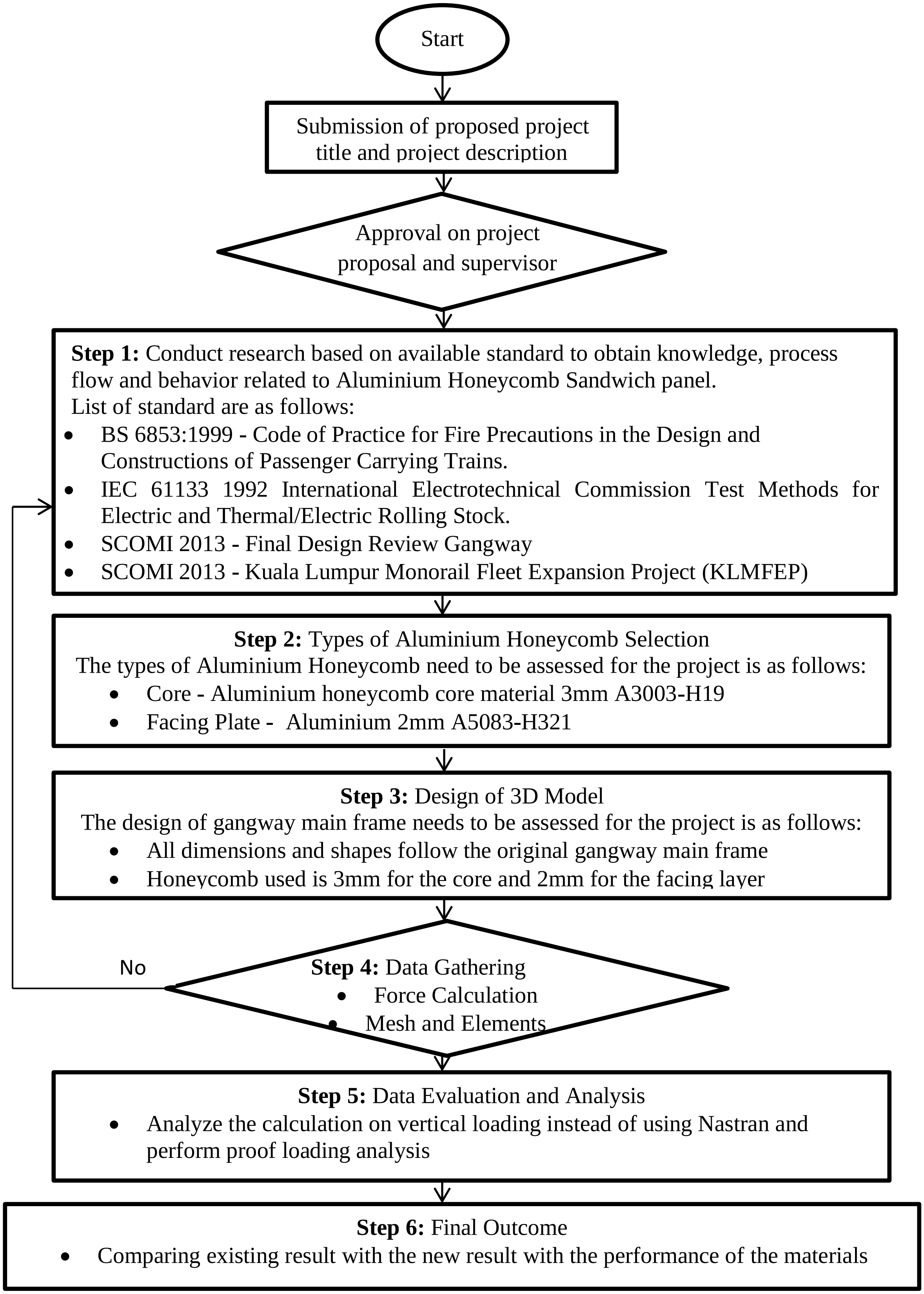

Figure 6: Project Methodology

Figure 6 illustrates the project methodology that need to be carry out in order to implement the project smoothly. The flowchart shown is a guide for the overall project work throughout this final year project and it is ensured to accomplish within the time given. The details of each step are as follows:

Step 1: Preliminary Research

Initial research is conducted which consist of background study related to aluminium honeycomb sandwich panel and any other materials used widely in transportation industry. The research of the project will be carried out through three approaches which are reading, interviewing and observation. Reading will be done on related materials such as International Electro technical Commission (IEC 61133), Final Design Review, Preliminary Design Review and others. Second is interviewing, it is two way sessions with the respective engineers and the technicians on the concept and theory of gangway and its application. Lastly is observation by doing site visit to the respective company and study how the analysis of gangway main frame is done. The objectives, scope of study and significant of study are identified to create the boundary of this project. Literature review is also conducted to further identify the behavior of aluminum honeycomb and finite element using NX Nastran, design standard and code practices and analysis of inspection data. Related performance specification and results of existing gangway are reviewed to decide the performance of new result. In addition, the author needs to have an adequate skills and knowledge to use SIEMENS NX Nastran as a main tool to complete this project.

Step 2: Aluminium Honeycomb Selection

The selected aluminium honeycomb A3003 and A5083 are aluminium that most widely used in transportation industry. These aluminium honeycomb are selected because lightweight material and strength to resist from loadings. Aluminium honeycomb A3003 and A5083 are one of the most well-known materials that need to be periodically inspected compared to other aluminium materials such as Aluminium Alloy

6061, Aluminium Alloy 1100, and Aluminium Alloy 1050. Thus, aluminium A3003 and A5083 are the best recommended to start with for materials replacement.

Step 3: Design of 3D Model

Design process is primarily responsible to produce 3D models and 2D drafting of parts and assemblies from various sources but not limited to existing design as well as modification. In this project, Aluminium Honeycomb Main Frame design comes from the original design of main frame. The difference is using another material which is aluminium honeycomb sandwich panel and the thickness of the honeycomb used is 3mm for the core and 2mm for the outer layer. This is to ensure no interference occur when it comes to real life application. Since this design stresses on weight reduction, density of the material is the main concern.

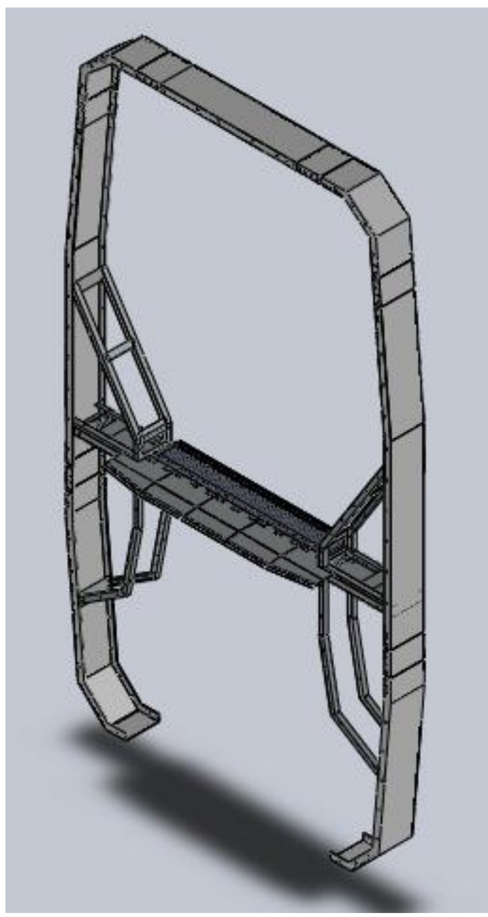

Figure 7: Designed Gangway Main Frame

Step 4: Data Gathering

The collected and gathered data are force calculation and mesh element that will be used during pre-processing of analysis. The force calculation is calculated based on Kuala Lumpur Monorail Fleet Expansion Project (KLMFEP) criteria such as mass per passenger, passenger per area and g level. The elements used in this analysis will be **2D Thin-shell** and **3D Solid elements** with the material thickness 5mm. The mesh used in this analysis will be **2D CQUAD4** and **3D CTETRA4** with the elements size 5mm.

Step 5: Data Evaluation and Analysis

The force calculation calculated from KLMFEP criteria is applied in NX Nastran to assess the load distribution rates and boundary conditions include when the gangway bolted to car body and weight of bellows. The performance specifications are to maintain including the design of main frame, thickness, boundary conditions and many more. As a part of data assessment, a force which is known as **proof loading** is applied vertically (perpendicular to the floor). The force is applied only to the standable area of the floor since this is the most critical load. The design will be iterated until acceptable safety factors are achieved.

Step 6: Final Outcome of the Project

At this stage of project methodology, the author needs to compare the existing result and the new result with the performance of the materials. The existing result and new result will be compared to see the difference between two materials in terms of strength towards proof loading. The features designed would be able to reduce weight and perform adequate durability of any resistance.

The finite element analysis of this project should be run smoothly by using SIEMENS NX Nastran which is aim to evaluate the behavior of the materials and analyze if any defects will happen. The finite element analysis will be evaluated by the project supervisor and CAE engineers. Several recommendations are suggested for future improvement of this project.

3.2 **Gantt Chart and Key Milestone**

All activities involves in project methodology have been put in an appropriate Gantt chart to accomplish the finite element analysis of this project. The Gantt chart includes the timeframe for first and second semester together with the key milestone to be achieved. Gantt chart for FYP I and FYP II are shown in Table 5.

Table 2 : Gantt chart for FYP 1 and FYP II

	FYP Schedule Timeline	FYP I (20 May – 23 Aug 2013)														FYP 2 (23 Sept – 27 Dec 2013)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Introduction** *What is Gangway? *Understanding Project Description																												
2	**Literature Review** *Research on behavior of Aluminium Honeycomb Sandwich Panel *Research on Modeling and Analysis by Solidworks and NX Nastran.																												
3	**Modeling** * Design assembly of Gangway Main Frame in Solidworks																												
4	**Analysis of Gangway Main Frame in NX Nastran** * Data analysis * Data collection																												
5	**Dissertation write up**																												

Completed On Progress To Be Done Milestone

3.3 Tools and Equipment

Computer Aided Design (CAD) and Computer Aided Engineering (CAE) software perform the function of the program it implement which act as a mean to perform the analysis of aluminium honeycomb (new material) and aluminium alloy 6061 (existing material). The selection details of tool and equipment that can be used to achieve the objective of this project are as follows:

Table 3: Program software selection

No	Program software	Description
1	Solidworks	It is an average powerful Computer Aided Design (CAD) software tool that can be used to provide a suite of surfacing, reverse engineering, and visualization solutions to create, modify, and validate complex innovative shapes.
2	SIEMENS NX Nastran	It is an engineering simulation software (computer-aided engineering, or CAE) and offers engineering simulation solution sets in engineering simulation that a design process requires. The tools put a virtual product through a rigorous testing procedure (such as crashing a car into a brick wall, or running for several years on a tarmac road) before it becomes a physical object.

Based on the program software selection, the most suitable CAD tool for this project is Solidworks. Most design teams who work in monorail industry used this CAD software in performing their routine or project tasks but most of the employees perform those tasks by other means such AutoCAD, CATIA and many more. Thereby, the author proposed an alternative way to automate the tasks by using Solidworks to have a clear instruction for SIEMENS NX Nastran to follow.

This tool works by running on Microsoft Windows and same like other CAD software but it more user-friendly compared to other software. It has capabilities to provide a suite of product development tools mechanical design, design verification, data management, and communication tools.. In other hand, SIEMENS NX Nastran designed to perform a specific task such as processing model geometry, assembling matrices, applying constraints, solving matrix problems, calculating output quantities, conversing with the database, printing the solution and many more.. This tool can be integrated with other CAD software such as Solidworks and CATIA. Compared to other FEA software, this tool has its own in conjunction with third-party preprocessors and require little experience generating a full suite of commands for geometry.

In significance of this project, Solidworks and NX Nastran are the best practice to perform this project. The command and interface are less complex than other CAD and CAE software and this tool is able to solve difficult problems in basic approach. The author will then be able to utilize the both software as a mean to analyze the overall performance of aluminium honeycomb and aluminium alloy 6061.

CHAPTER 4: RESULT AND DISCUSSION

After almost seven month's duration to complete Final Year Project, a complete model of gangway main frame has been meshed by using FEA software, NX Nastran. A model of honeycomb gangway main frame has been successfully constructed during Final Year Project I. This chapter consists of two sections which are (1) Material properties, (2) Modeling, (3) Finite element analysis.

4.1 Material Properties

The existing material that been used is aluminium 6061 alloy and will be replaced by new material which is aluminium honeycomb 3mm A3003-H19 for core and for facing plate is aluminium 2mm A5083-H321. Material properties for existing material are shown in Table 4 while for new materials are shown in Table 5 and 6.

Table 4: Existing material – Aluminium 6061 Alloy, thickness 5mm (Solidworks, 2010)

Item	
Elastic Modulus (Mpa)	6900
Poissons Ratio	0.33
Shear Modulus (Mpa)	2600
Tensile Strength (Mpa)	224
Yield Strength (Mpa)	115
Density (kg/m3)	2700

Table 5: New material - Aluminium honeycomb core material 3mm A3003-H19 (Rao, Sarwade, & Chandra, 2012)

Item	
0.2% yield stress (Mpa)	190
Elongation %	4.0
Compressive Strength (Mpa)	4.6
Compressive Modulus (Mpa)	1000
Shear Strength, L (Mpa)	2.4
Shear Strength, W (Mpa)	1.50
Shear Modulus, L (Mpa)	440
Shear Modulus, W (Mpa)	220
Core Density (kg/m3)	83.2

Table 6: New material - Facing plate material 2mm A5083-H321 (Rao, Sarwade, & Chandra, 2012)

Item	
Young's Modulus (Mpa)	71,070
Yield Strength (Mpa)	268
Tensile Strength (Mpa)	367
Elongation at rupture %	13
Facing Plate Density (kg/m3)	2660

4.2 Modeling

The model of honeycomb gangway main frame is able to demonstrate the original design of gangway main frame of the project which is the milestone for Final Year Project 1. The figures below show the model of original gangway main frame and honeycomb gangway main frame using Solidworks.

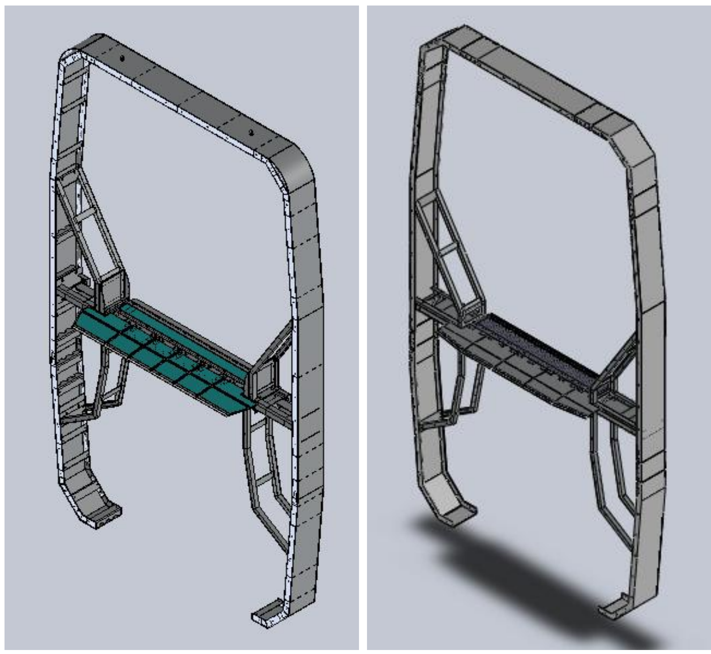

Figure 8: (Left) Original Gangway Main Frame (Right) Honeycomb Gangway Main Frame (Isometric View)

Based on the figures, the original gangway main frame has slippery protection (green color) to avoid passengers from falling down but that is not the main concern for the project. Only frame is made from aluminum honeycomb while the side floor remains the same from the original material which is aluminium 6061. In addition, there is no stiffeners which act as supporter for honeycomb main frame as to reduce weight.

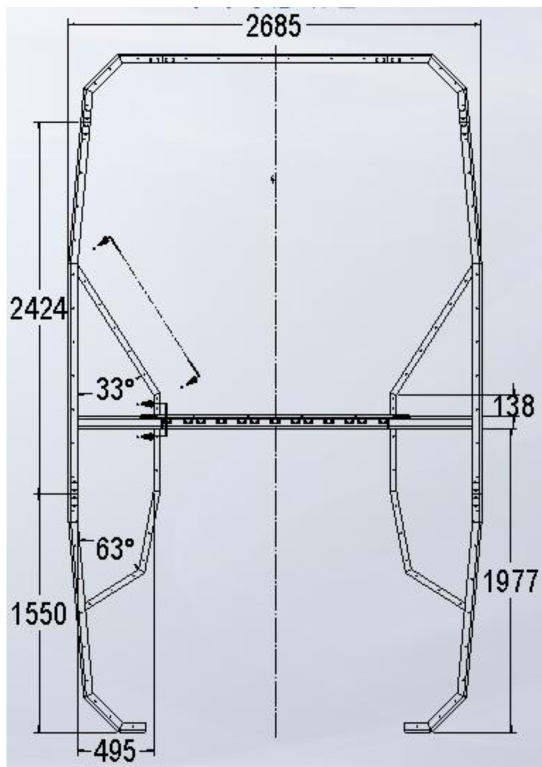

Figure 9: Dimension of Honeycomb Main Frame (mm)

All dimension and shapes following the original gangway main frame with the exception of proposed material. The table shows the weight reduction of the honeycomb gangway main frame.

Table 7: Weight comparison of Aluminium 6061 and Honeycomb

Material and thickness	**Main Frame Assembly**	**Gangway Assembly**
Aluminium 6061, 5mm	120kg	600kg
Aluminium Honeycomb, 5mm	80kg	510kg

4.3 Finite Element Analysis

4.3.1 Mesh and elements

Meshing elements for main frame have been done based on 2D thin shell and 3D solid elements. The quarter analysis approach has been used by reflect it to get the full result. By applying meshing by layer for model of honeycomb main frame which is for two facing plates take about 1mm and 3mm for honeycomb core. The meshing used is CQUAD 4 for 2D meshing and CTETRA 4 for 3D meshing. However, for two facing plates 2D meshing has been applied whereas for core 3D meshing applied,

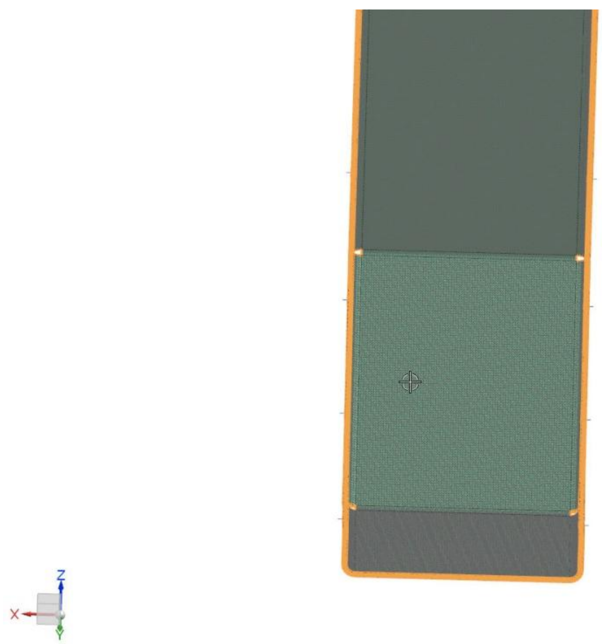

Figure 10: 3D meshing on honeycomb core

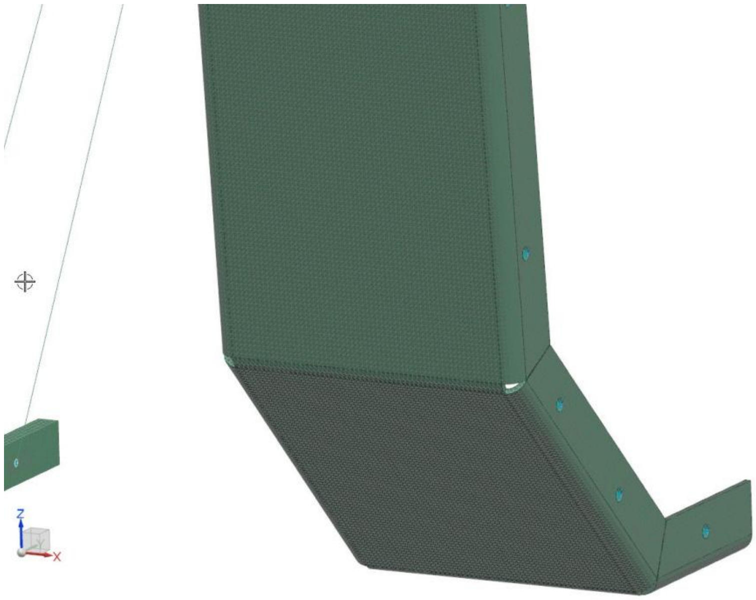

Figure 11: 2D meshing on facing plate

Nevertheless for the floor and external main frame it uses 2D meshing CQUAD 4 because it is considered as a plate meanwhile for 3D meshing CTETRA 4 it is considered as casting components with elements size 5mm.

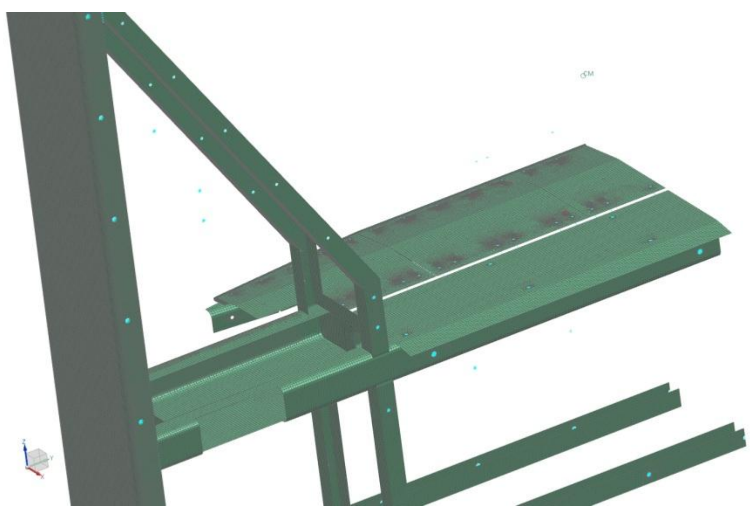

Figure 12: 2D meshing on floor and external frame

4.3.2 Connections

Besides meshing, another important step in FEA is connection. It will distribute applied forces according to a certain situation. Hence for main frame, there will be a bellow and center frame attached together to complete the assembly. In this case, 1D connection using Rigid Body Element (RBE) 2 are used to simplify the bolt connection from the gangway frame to the car body structure and to connect bellow to main frame and center frame because it will distribute force equally to any direction, unlike RBE 3 will distribute highest force to the nearest direction. Similarly center mass will loaded on top of the flooring.

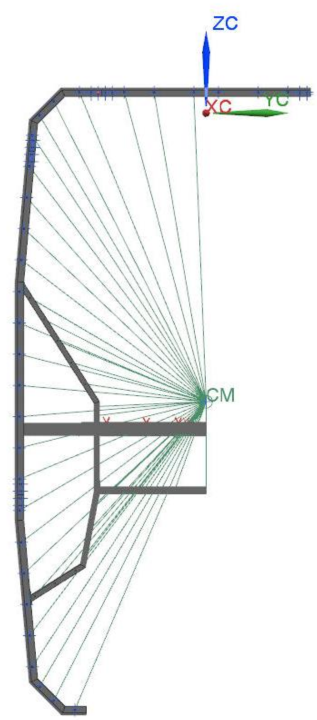

Figure 13: 1D connection (bellow)

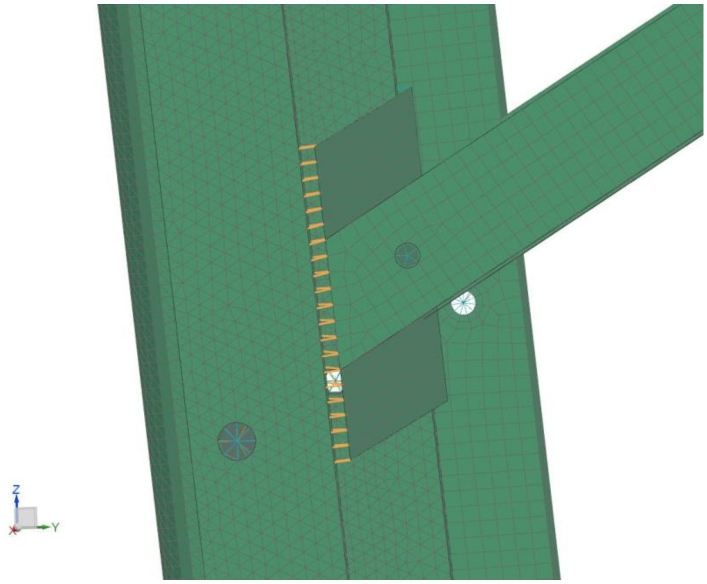

Figure 14: 1D connection (node to node)

Figure above shows 1D connection using RBE 2 by node to node because to attach the plate to the main frame, otherwise there will be some flying part that makes unreadable date for the software to solve. The main frame will be attached to carbody, therefore holes for bolt by using RBE 2 but using different type of 1D connection (point to face) as to connect bellow to main frame and center frame as shown below.

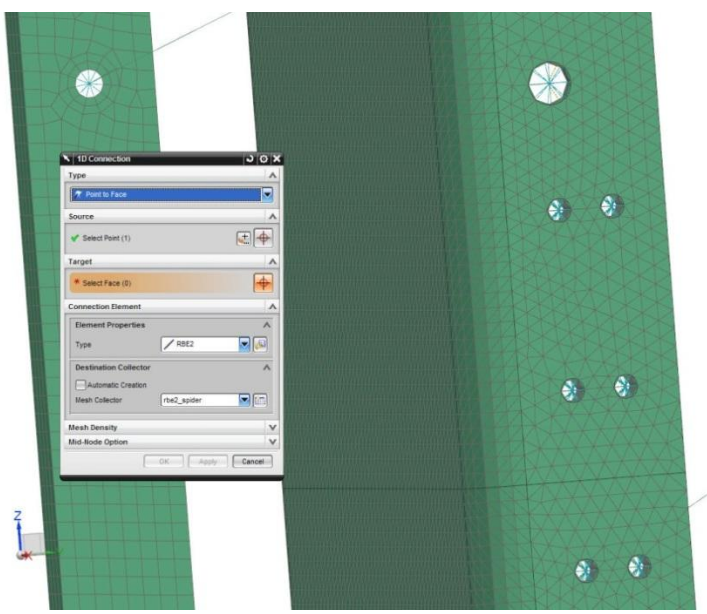

Figure 15: 1D connection (point to face)

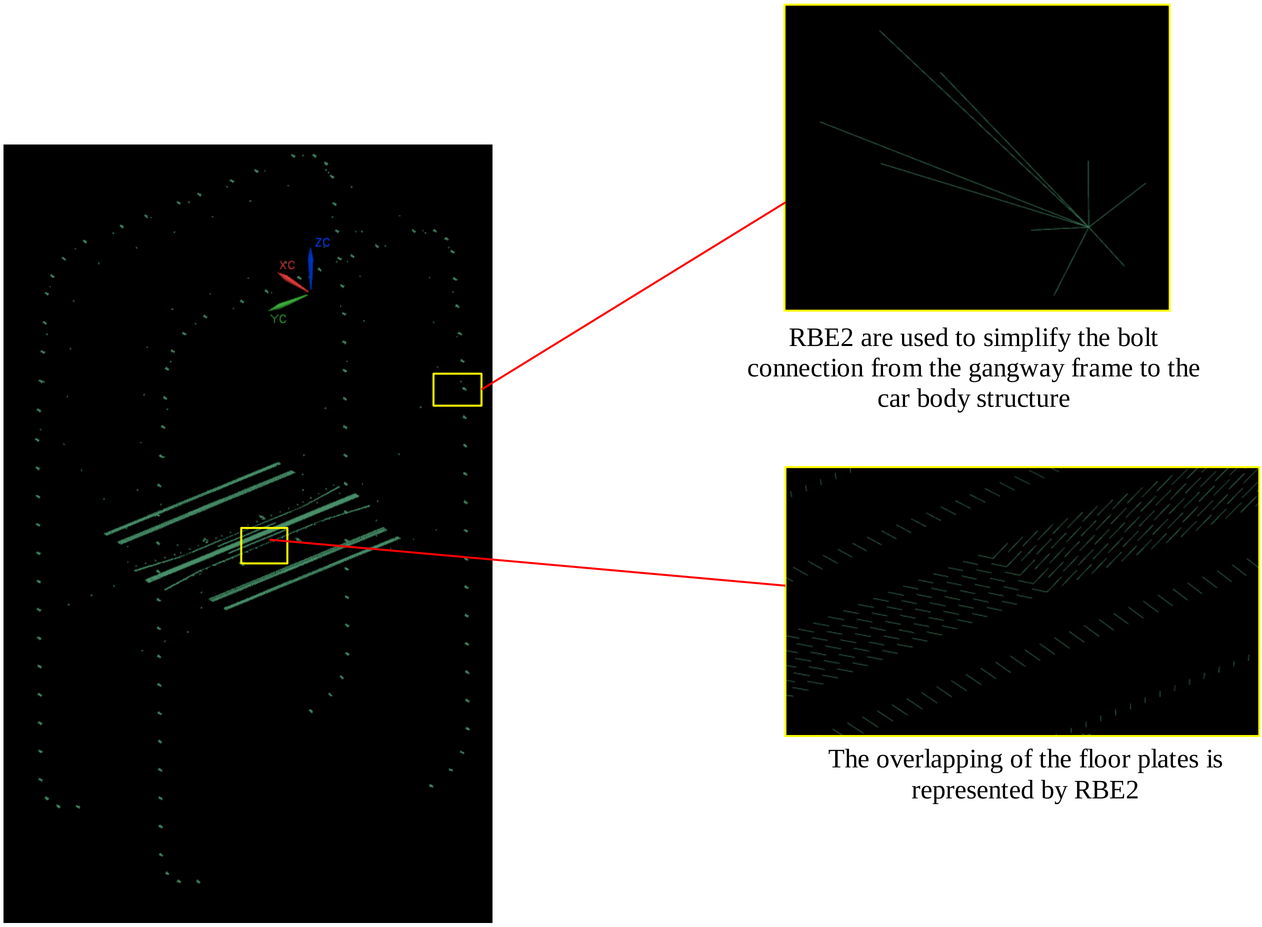

Figure 16: Main frame bolted to carbody

Figure above shows RBE2 are used to define the contact of the overlapping center floor and to simplify the bolt connection of the gangway frame to carbody. As the main frame is attached together with bellow and external frame to carbody, this is important to define the contacts.

4.3.3 Boundary Conditions

4.3.3.1 Constraints

The bottom of the floor is constrained in such a way that it is not allowed to move in z direction, but free to move in x and y direction. Assuming that the drawbar and the nylon wear plate bracket are rigid, this will represent the effect of having a support structure mounted on the drawbar supporting the bottom of the floor. The bellows are replaced with center mass and located on the center of the floor.

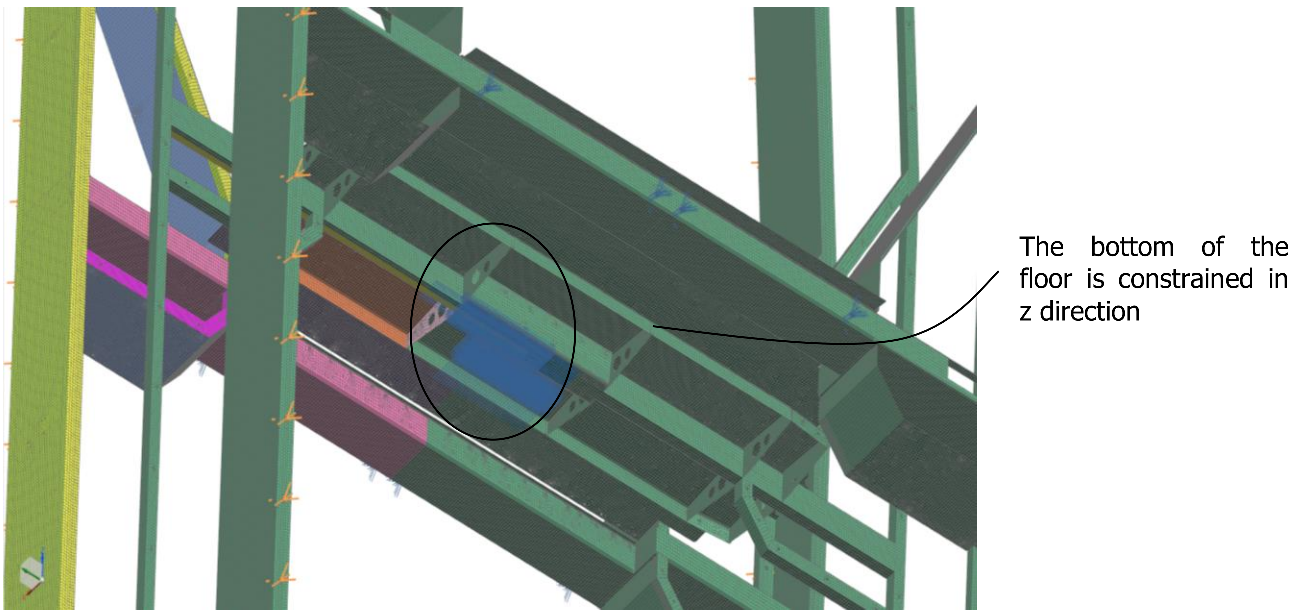

Figure 17: Constraint main frame to carbody

Fixed constraints are applied to the mounting point of the gangway frame to the carbody. This is assuming that the carbody is very stiff (rigid). The constraints are defined in Table 8.

Table 8: Constraints definition

Degrees of freedom	Condition
Translation x	Free
Translation y	Free
Translation z	Fixed
Rotation x	Fixed
Rotation y	Fixed
Rotation z	Free

4.3.3.2 Forces

Proof loading is a case load that been analyzed when the train in static condition neglecting other elements such as movement of the wind, coefficient of friction and many more. The forces are applied vertically (perpendicular to the floor) and only to the standing area of the floor (red arrows).

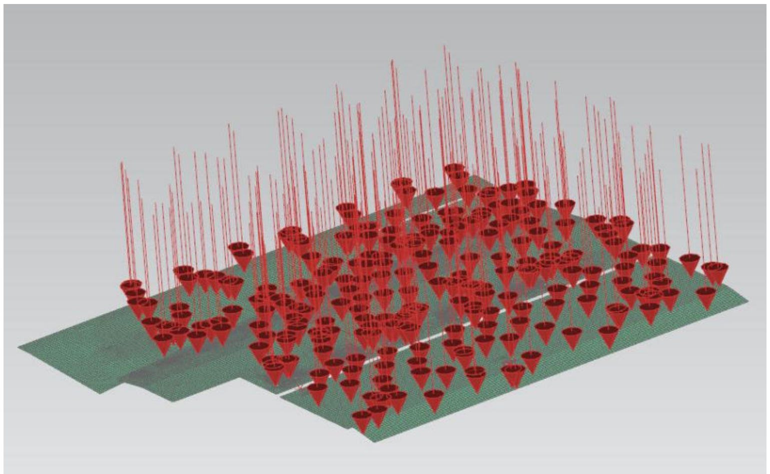

Figure 18: Boundary condition - Forces

In order to get the force, mass on the gangway can be calculated by using this formula:

$$Passenger\ mass\ on\ gangway\ (kg) = Floor\ area \times (Pass/M^2) \times (Mass/Pass)$$

Where,

Floor area is where vertical force is applied in m^2,

Passenger per m^2 is one passenger in one unit area,

Mass per passenger is average 68kg.

The sample of calculation below shows the passengers mass on the gangway using the formula above:

$$Passenger\ mass\ on\ gangway\ (kg) = 2.1\ m^2 \times 7 \times 65kg = 955.5\ kg$$

Applied forces are a combination of vertical, lateral and longitudinal forces originating from the 'g' forces experience by the train during operation. The types of each force can be calculated using the formula below:

$$Force\ (N) = Passenger\ mass\ on\ gangway \times (g\ level) \times (g)$$

Where,

Passenger mass on the gangway in kg,

G level in terms of vertical, lateral or longitudinal,

Gravity in 9.81m/s^2,

The sample of calculation below shows the applied force using the formula above for **vertical** force:

$$Force\ (N) = 955.5 \times 1.25 \times 9.81 = 11717\ N$$

Table 9: Force calculation

Load case	Floor area (m^2)	Load	Pass/ m^2	Mass/ pass (kg)	Pass. mass on the gangway (kg)	Vert 'g' level	Vert force (N)	Lat 'g' level	Lat force (N)	Longi 'g' level	Longi force (N)
Proof Loading	2.1	AW 4	7	65	955.5	1.25	11717	0.2	1876	0.17	1594

4.3.4 New results

After completion of force calculation, the data will be used in solving the analysis and the model will be run at component level. There are several important points to been analyzed besides Maximum Von-Misses stress such as safety factor. The safety factor is how much the designed part actually will be able to withstand load that applied. The safety factor is a ratio of maximum strength to intended load for the actual item that was designed. The safety factor can be calculated using the formula below:

$$\text{Factor of Safety} = \frac{\text{Material Strength}}{\text{Design Load}}$$

Where,

Material strength is stress limit based on yield strength value (MPa).

Design load is Maximum Von Misses stress in megapascal (MPa).

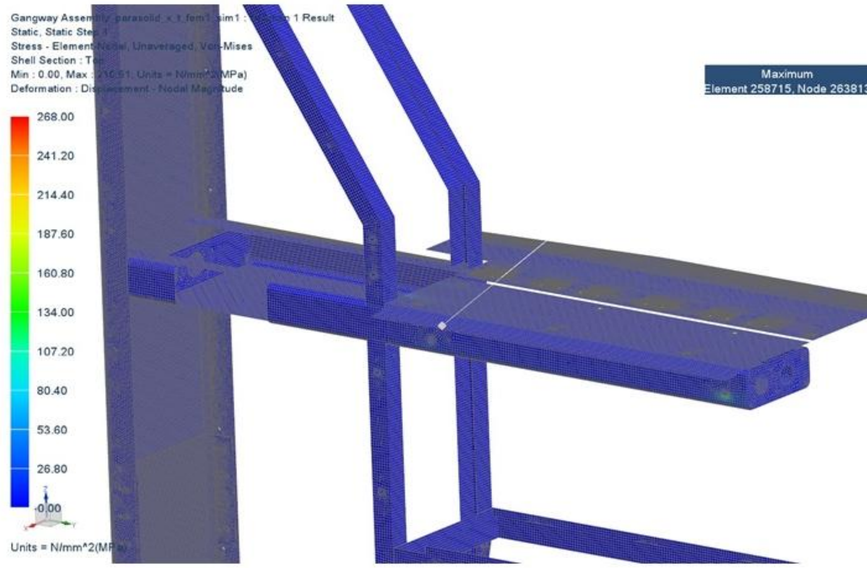

Figure 19: Von Misses stress

Figure above shows where the Von Misses stress is located and since the value is not exceeded the stress limit; it shows this material can withstand the load applied. The maximum deflection is to show maximum of the material can withstand or bend before it going to crack as shown below:

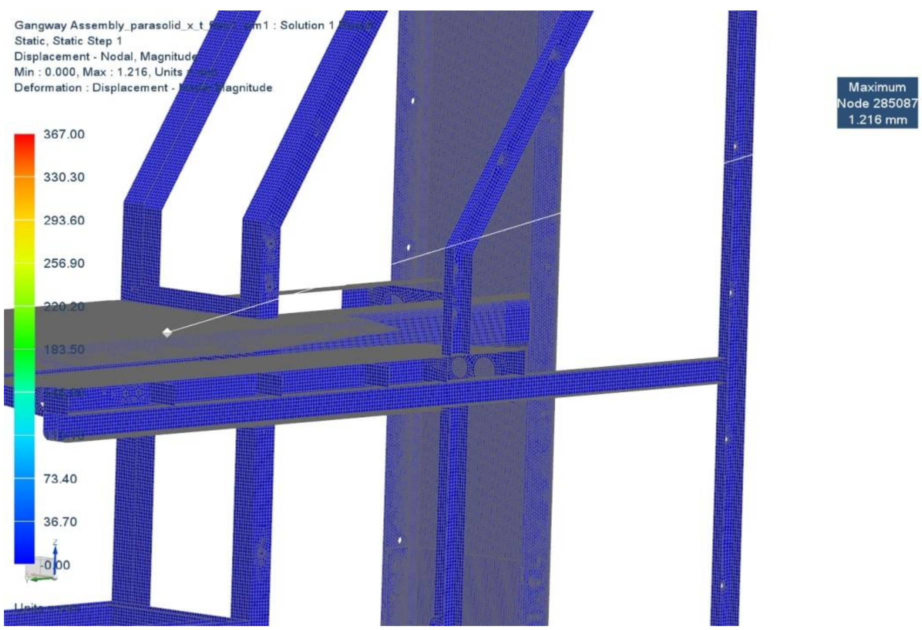

Figure 20: Maximum deflection

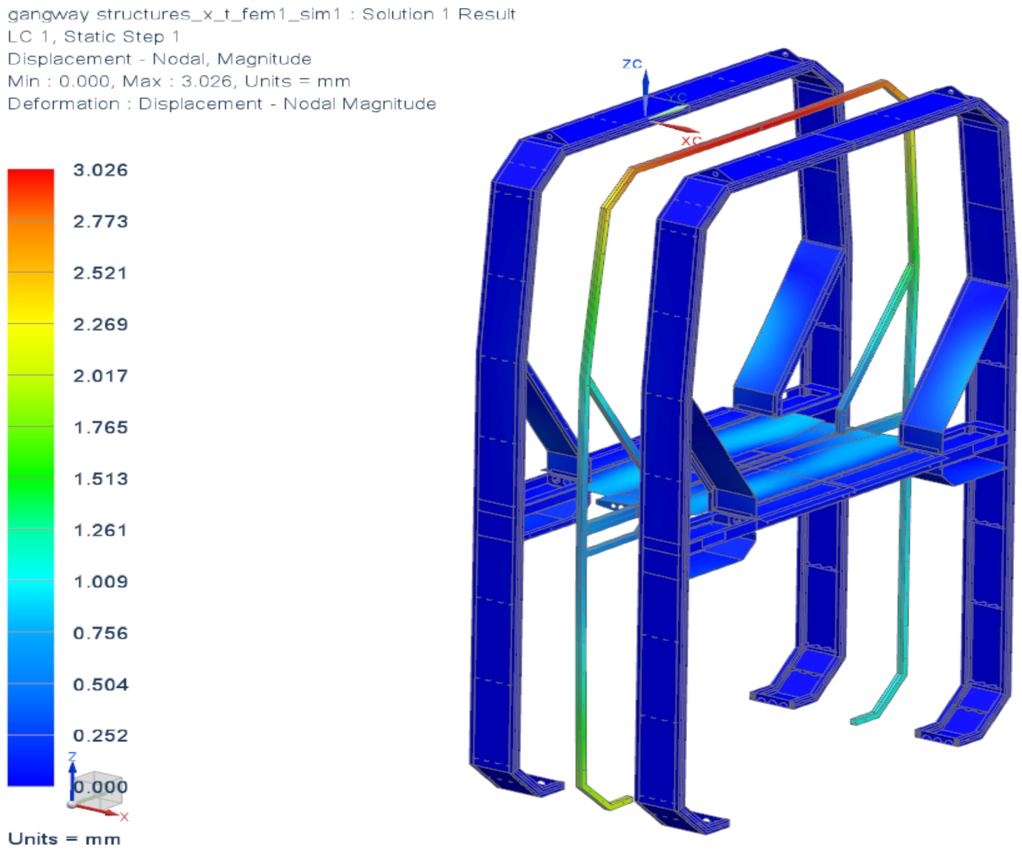

Figure 21: Gangway Structure Full Assembly

Based on the safety factor formula, the value of safety factor obtained is 2.55 which is the minimum value in monorail industry. Meanwhile it shows that the material can withstand the static load without any other loads interfering. The result summary of the analysis for aluminium honeycomb as shown below:

Table 10: Result summary

Load case	Maximum deflection (mm)	Max. Von Misses stress (MPa)	Stress limit (MPa)	Safety Factor	Judgement
Proof Loading	1.22	105	268	2.55	PASS

4.3.5 Existing design results

Similarly for the existing design results, all the processes involved in finite element analysis are remain the same with the new results. The only differences are material properties and result summary. The figure below shows the Von Misses stress for getting safety factor.

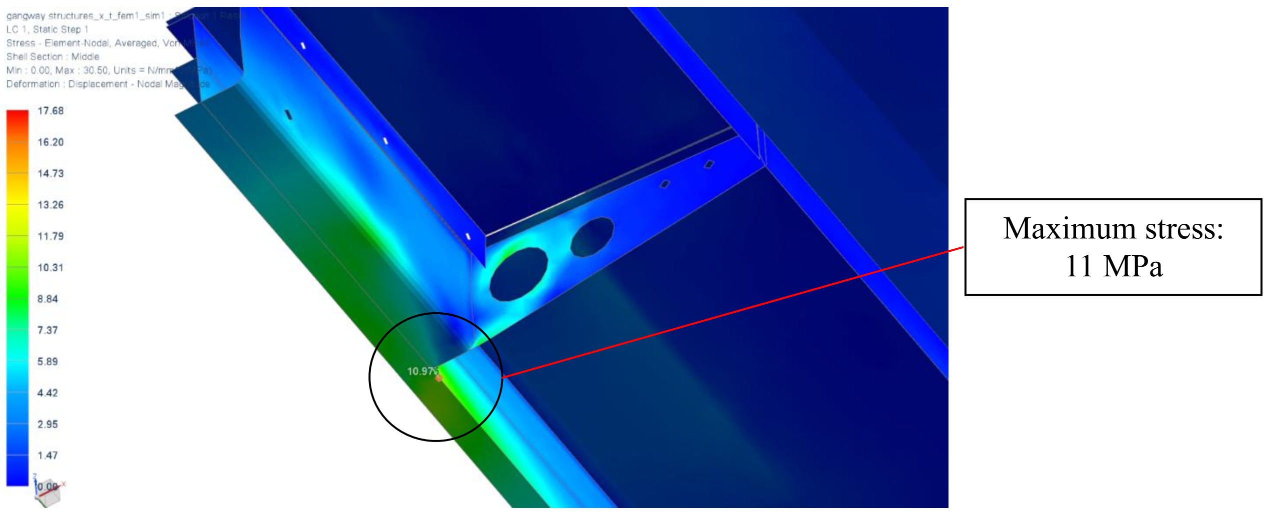

Figure 22: Maximum Von Misses stress

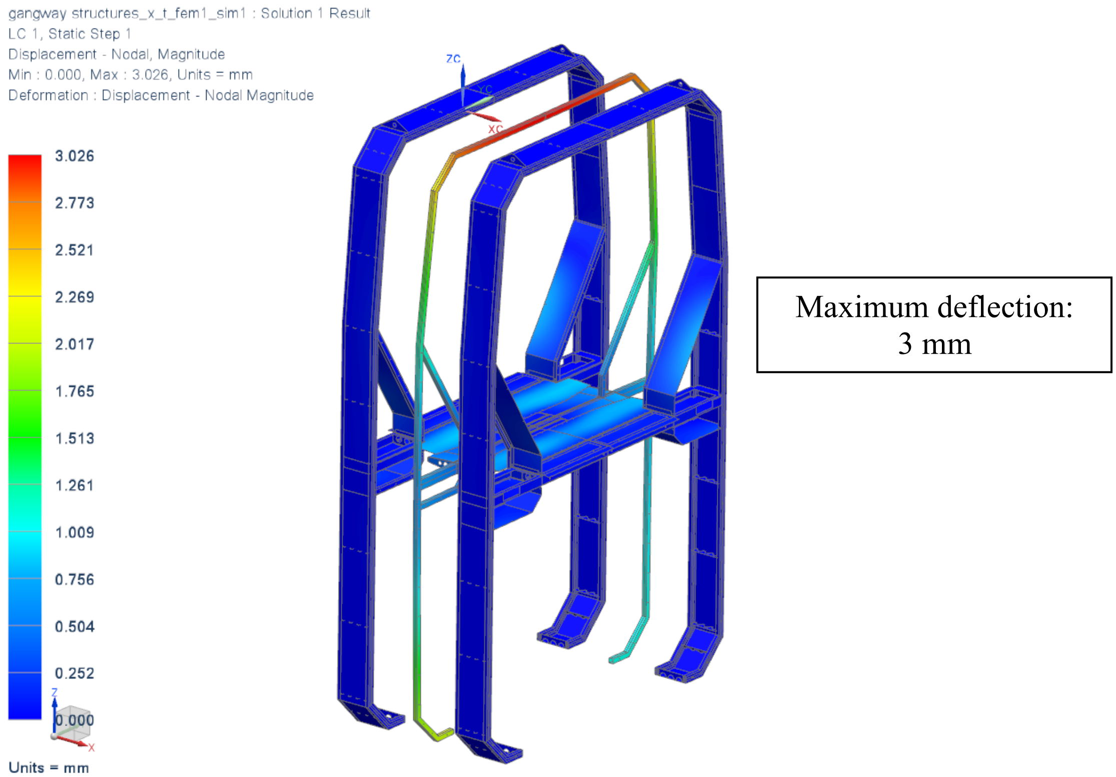

Figure 23: Maximum deflection

Based on the safety factor formula, the value of safety factor obtained is 10.5 which is higher than new result value. It shows that the solid aluminium 6061 alloy has higher strength rather than aluminium honeycomb sandwich panel. However it shows that the material can withstand the static load firmly. Table below shows the result summary for aluminium alloy 6061:

Table 11: Existing design result summary

Load case	Maximum deflection (mm)	Max. Von Misses stress (MPa)	Stress limit (MPa)	Safety Factor	Judgement
Proof Loading	3.0	11	115	10.5	PASS

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Throughout this preliminary research of the project, the author has looked several approaches and alternatives in order to implement the right procedure and analysis for the project. During the development stage, aluminium honeycomb main frame has been designed in Solidworks to further continue in NX Nastran for analysis.

5.1 Conclusion

In conclusion of this project is a demonstration of aluminium honeycomb sandwich panel in gangway monorail with its modeling and its behavior that is illustrated by a simple practicality of graphical visual engineering interface. Even though the new result has lower in terms of safety factor than the existing result, it still acceptable in designing and can be improve in future. In which, the engineers and manufacturers can utilized this study as improvement in monorail industry and monitor the performance of the material to make important economic and safety decision. It is hoped that this project will benefit engineers and manufacturers that is currently working on reducing weight of gangway monorail.

5.2 Recommendations

This project has a huge potential to be improved further if the right amount of time and resources is allocated. There are several recommendations that can be considered in order to enhance and improve the project to obtain much better outcome in the user point of view.

- In the future, due to time constraint, the design of gangway can be transport to aluminium honeycomb for better accuracy of result.
- Finite element analysis done in details in order to produce excellent verdict.

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