Development Toward an Impact Resistance Test on Glass Fiber Reinforced Polymer (GFRP) Grating

By

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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(CIVIL ENGINEERING)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2012

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.

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NURUL NASYIHAH BINTI HAMBALI

ABSTRACT

The major problems deals with steel usage at offshore structures are corrosion and excessive bulk weight. The corroded structure has to replace with new ones while heavier platform needs a lot of equipment for loadout, transport and install. These causes huge increment in cost. Therefore, the researchers came with an alternative to replace steel with an advance composite material such as Glass Fiber Reinforced Polymer (GFRP). GFRP is a composite material consists of continuous glass fiber embedded in resin matrix. The resistance impact test must be conducted to check the ability of the GFRP grating toward high impact. Therefore, an impact testing rig becomes an essential tool for such research activities but there is no specific standard available to meet this objective.

This paper is focused on design of drop weight testing rig and development toward GFRP grating impact resistance test. The research is the emphasis on mechanical design of the drop weight testing rig. The rig has load impactor, guided by two 2.75m I-beam columns, which can impact the grating up to 1373.4 J. Using Eurocode 3 as reference; the details design of the testing rig is produced. The testing rig is designed to meet the impact test parameters which are adjustable drop heights, variable impact loads and using 1.25m x 1.25m GFRP grating.

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CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 BACKGROUND STUDY

Offshore oil and gas platforms are mainly exposed to corrosive and hostile marine environments. Corrosion happens to the offshore structures because present of sun, temperature, oxygen, moisture and salt contained in the water [1]. The combination of these factors caused corrosion to the steel elements of the offshore structure. The platforms cost up to hundreds of millions of dollars and are expected to be productive in next tenth years. Therefore, the platforms require continuous preventive maintenance to ensure save and long-lasting operation. According to the U.S. Minerals Management Service, there were more than 900 fires and explosions, 1,548 injuries and 60 fatalities related to offshore energy exploration and production in the Gulf of Mexico from 2001 to 2009 [2]. Those accidents were majorly cause by equipment failure, poor equipment maintenance and saltwater corrosion, operator error, harsh weather conditions, rig collapse, loss of well control and human error.

Older offshore structures are also a contribution factor for accidents to occur. Based on an article written by Ben Casselman, half of the Gulf's more than 3,000 production platforms are 20 years old or more and a third date back to the 1970s or earlier, long before the modern construction standards was made. The West Cameron 45-A platform is one of more than 100 structures built in the 1940s and 1950s still active operations in the Gulf of Mexico. Casselmen also highlighted about an accident occurred on the platform caused by corrosion. A severely corroded pipe connecting high-pressure gas was exploded and released gas into the air during routine maintenance. It worsens when the emergency valves that should have cut off the flow of gas automatically didn't close properly [3]. Retrofits certainly corroded elements such as steel on the platform are not efficiently work as it will increase the cost. Therefore, a lot of research has made to replace steel usage to other composite materials as it gives huge advantages to the oil and gas production.

Beside corrosion, the massive load carried by the topside of the platform also is a significant problem for the industry. Ellis (Regional Director for the Americas at Mustang Engineering) said, “As space is to weight, weight is to cost. Therefore, there’s always a focus on reducing topsides weight as much as possible to provide more options and opportunity to reduce costs.” [4]. The reduction of weight of topsides starts from design basis, selection and layout of equipment and continuous weight control. Replacement of steel to composite materials saved a huge ton of topsides weight as well as millions dollar cost.

In addition, the bulk weight of offshore platform topsides affects the overall economics of the offshore operation. Appropriately designing and fabricating the topside structure may minimize total usage of steel thus reduce its weight is proven cost effective and production of oil and gas may raise [5]. Also an accurate management and prediction of the topside weight during the early phases of design leads to the successful completion and delivery of light weight topsides for heavy weight project.

Introduction to composite materials such as GFRP grating for walkways at the offshore platform gives a lot of beneficial toward an offshore business. Huge amount of money can cut off and productivity of oil production may increase. Before the grating immediately install, few tests are necessary for check the strength, durability, and efficiency of the GFRP grating due to harsh offshore condition. One of the tests is an impact resistance test which is needs to be conducted to know the performance of the GFRP grating toward drop weight impact load.

In conclusion, the major problem of high strength steel due to corrosion and the cost of maintenance of any deteriorates is very expansive. Offshore installations will deteriorate and corrode with time, with hazardous walkways and poorly supported pipes or other infrastructures are not only putting workers at risk of serious injury, but in the event of a major incident can worsen the consequences. Furthermore, usage a lot of steels in offshore platform structure contribute to increase in weight as well as the cost of transportation of the platform. Introduction to composite materials as Glass Fibre Reinforced Polymer (GFRP) has become alternative to the engineers to reduce usage of conventional steel. The advantages of GFRP are light weight, corrosion resistance, lower cost of construction and maintenance [6].

1.2 PROBLEMS STATEMENT

Use a lot of steels on the topside of offshore platforms lead to two major problems. First is due to corrosion. Offshore installations such walkways will deteriorate and corrode with time and produce a highly dangerous working environment. The second problem is the bulk weight of the steel. The cost of transportation will increase as weight increase. Both problems lead to high involvement of cost. Therefore, introduction to advance composite materials, Glass Fibre Reinforced Polymer (GFRP) become an alternative for engineers to reduce the application of steel on the topside of offshore platforms. The advantages of GFRP are light weight, corrosion resistance, lower cost of construction and maintenance. An impact test is needed to be conducted to see the performance of GFRP grating in term of free fall impact. But there is no standard code is available. Therefore, it leads toward this project which is focused on design of drop weight impact testing rig.

1.3 OBJECTIVES

The main objectives that need to be achieved by the end of this project which are:

1. To design a testing drop impact rig for study of impact resistance test on Fiber Glass Reinforced Polymer (GFRP) grating.
2. To provide all parameters and requirements for impact resistance test of GFRP grating in term of testing procedures.

1.4 SCOPE OF STUDIES

To conduct an impact resistance test, the parameters and methodology of the test must be prepared. Parameters for the test such as drop heights, drop loads, grating size are obligatory. In this study, the focus is on designing a testing drop weight impact rig. As there is no standard available for impact test on GFRP grating, the reference is based on literature papers and industry’s impact test machine. Appropriate structure analysis is required for stability, flexibility and safety of the testing rig.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1 FIBER REINFORCED POLYMER (FRP)

Fiber Reinforced Polymer (FRP) composites consist of glass, carbon or aramid continues fiber bond together in a matrix of epoxy, polyester, or vinyl ester as resin [7]. The fiber will carry loads while the resin will transfer shear. FRP is an anisotropic which is properties is acknowledgeable in the direction of applied load [8]. It is different from conventional steel and aluminium which is isotropic, uniform properties from all directions. Therefore, the FRP composite materials achieve best mechanical behaviours in fiber direction placement. The individual constituent's properties are not that superior. But the composite materials are improved from the individual properties as it takes advantage of the different strengths and abilities of different materials. Therefore, the FRP composites become an alternative for engineer in the construction industry today.

There is no doubt high strength steel has been used since decades for construction purposes such as reinforcement in the concrete structure as well as retrofitting. But limitations with steel usage are difficulty in handling because of bulk weight and deterioration of the bond because of corrosion of steel. Offshore platforms also have these problems. Corroded walkways, pipes and other infrastructures may cause accidents to the workers. In addition, usage much steel in offshore platform structure contributes to increase in weight as well as the cost of transportation of the platform. These problems lead many researchers worked on new advance composite materials like FRP. The unique characteristics of FRP are light weight, corrosion resistance, and low cost for maintenance and transportation [9]. The types of FRP used are Glass Fiber Reinforced Polymer (GFRP), Carbon

Fiber Reinforced Polymer (CFRP) and Aramid Fiber Reinforced Polymer (AFRP) [10]. This paper only focuses on GFRP and its impact resistance behaviour.

Figure 2.1 shows typical stress-strain curve for FRPs and conventional steel [11]. Steel wire undergoes elastic state proportionally before it yields and experience plastic state in low stress until it fails permanently. When the steel yields, large deflections ensue and inelastic energy is absorbed results in a structure. On the other hand, FRP materials experience linearly elastic before it fails. It does not have yielding part cause sudden failure to the materials. Next, the stiffness of the steel wire is higher than the FRPs materials. This shows that steel is much high strength while FRPs is quite brittle. This brittleness of FRP must be considered in the design. As the FRPs are a lightweight material, therefore higher thickness is not a problem. Lastly is about ultimate tensile strength. The FRPs show higher ultimate tensile strength before it fails compared to steel material. Hence, the FRPs are able to experience fiber tensile higher than steel. Among all FRPs, CFRP is the strongest and most expensive follow by AFRP and GFRP is the lowest in term of strength and price.

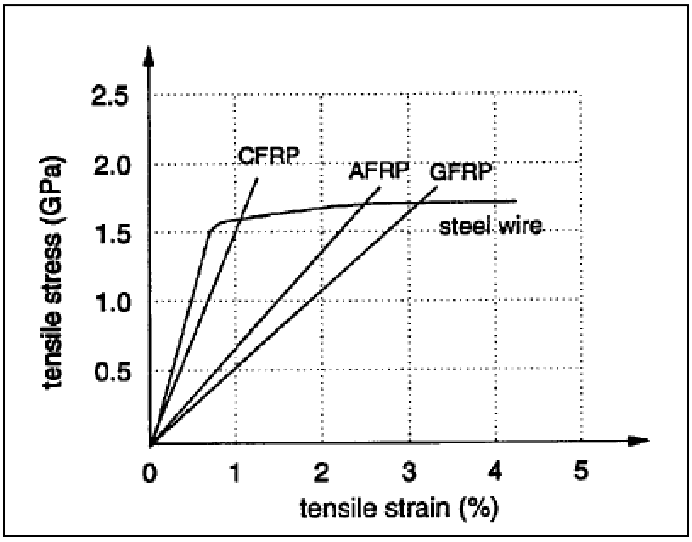


Figure 2.1 : Schematic stress-strain curves for different types of FRPs and steel wire.

There are two major FRPs grating manufacturing which are pultruded and molded process. Pultruded process is a mechanized process creates a continuous composite profile by pulling raw composites through a heated die [12]. The materials bond such as rowing, stitch mat and surface veil is passed through a resin bath and heated die which produce different sections. The shape and size of FRP can vary from this process. On the other hand, molded is casted by pouring liquid resin where fibers roving are laid in the mold. The size and shape is limited to the mold. In this study, molded GFRP grating being used to test the impact performance.

2.2 GLASS FIBER REINFORCED POLYMER (GFRP)

2.2.1 Glass Fiber

GFRP is one of composite materials from FRP commonly used. Function of glass fiber in the GFRP is as load carrier. The glass fiber is based on silica (SiO_2) with the addition of oxides of Ca, B, Na, Fe and Al. Glass fiber has been categorized into 3 classes which are E-glass (high electrical resistance), S-glass (very high tensile strength) and C-glass (high corrosion resistance) [13]. E-glass is the most frequently use as it produced from lime-alumina borosilicate which can be easily found the raw materials such as sand. The GFRP is less expensive compared to other FRPs but lower in strength and stiffness [8]. But the strength and mechanical properties are still adequate and acceptable for reinforcement, load carrying and retrofitting purposes. The weight and strength properties are also favourable when compared to metals.

Deiveegan, and Kumaran (14) conducted an experiment on behaviour of full scale size concrete columns reinforced internally with non-metallic reinforcements (GFRP) combined bending and axial loads. Different parameters like shape of columns, ratio of reinforcement, types of GFRP reinforcements, grades of concrete and slenderness of the columns. They found that failure modes; rupture and concrete crushing are acceptable in the design of concrete. The factor of safety for design

GFRP reinforced concrete will be higher than conventional steel reinforced concrete because of low durability of GFRP. Another study performed by Sam et al [10] in observing performance of concrete beam reinforced with different sections of GFRP like I-section, plate and control specimen with steel. The experiment result shows that GFRP reinforced concrete is low load carrying capacity and low stiffness due to lower modulus of elasticity of GFRP. The specimens also show larger deflection and less number of cracks compared to conventional steel reinforced concrete.

Current retrofitting techniques for concrete also have been transformed from conventional steel plate to advance composite materials. It strengthened by research evidence on FRP composites as retrofitting materials instead of steel. An experimental study was conducted by Saafan [15] on the effectiveness of the GFRP wrap on the inadequate shear strength design of simply supported beam. 20 beams were categorized into 3 groups which are controlled beam without and with steel strengthening and GFRP wrap strengthened. The shear strength with GFRP wrap is significantly increased then insufficient the shear capacity design of concrete beam.

The properties of GFRP have been investigated and studies in past decades as the advantages are significantly recognized such as light weight, corrosion resistance and low maintenance cost. Performance of GFRP bars under elevated temperatures has been studied by Alsayed et al [16]. The residual tensile strength of the bars has been tested after being subjected to elevated temperature for different periods. 60 bars were covered with concrete while 60 bars were bare bars. The total 120 samples were exposed to three different temperatures (100°C, 200°C and 300°C) in three different times (1, 2 and 3 hours). The plastic behaviour of polymer on elevated temperatures has been observed. The GFRP will not burn directly, but the bond between resin and glass will weaken and indirectly decrease the strength of the GFRP in increase time and temperature.

2.2.2 Resins

A resin is clear liquid plastic products which hardened when cool to stick polymer together. It acts as shear transfer and fiber bonder in GFRP. It divided into two categories which are thermosets and thermoplastics [8]. Thermoset resins (e.g. polyester, epoxy, phenolic) transforms into matrix binders after curing the resin through an irreversible chemical reaction. Thermoplastics resin (e.g. polyethlene, PVC) return to a solid state (matrix) once processing is done. By heating, thermoplastic resins are softened from solid state before processing (making a composite) without chemical reactions.

The most common resins used are epoxy, vinyl esters and phenolic. The right curing agent should be carefully selected as it will affect the type of chemical reaction, pot life and final material properties. Epoxies are generally found in marine, automotive, electrical and appliance purposes. Epoxies can be high in cost, but it may worth the cost when high performance is required. Vinyl ester is a product developed by combination property of fast curing polyester and workability of epoxy resin. It has higher physical properties of polyesters but less cost than epoxies. The vinyl ester can withstand high toughness demand and offer excellent corrosion resistance. The phenolic resins are made from phenols and formaldehyde. It is rated for good resistance to high temperature, good thermal stability, and low smoke production.

2.3 ADVANTAGES AND DISADVANTAGES OF GFRP VS. CONVENTIONAL STEEL

Major problems handling the steel are low corrosion resistance, low durability and difficulty in handling at construction size because of its excessive size and weight [7]. These problems were supported by research by Saafan [15] pointed out the disadvantages of steel plates which are difficult to manipulating at side due to bulk size and deterioration of bond caused by corrosion of the steel. Therefore, introduction of new advance material composites, Glass Fiber Reinforced Polymer (GFRP) brings new hope to engineers to design material for more effective and efficient production.

Based on study conducted by many researchers on GFRP, there are a lot of proven advantages of this advance composite material. Metiche & Masmoudi [6], mentioned that the GFRP is a perfect material as an alternative to traditional engineering steel material as their advanced paint and resin systems have made the GFRP virtually maintenance free for next few years to come. The unique characteristics are lightweight, corrosion resistance, low maintenance and also low initial cost. A study conducted by Sen, Reddy and Shubhalakshmi [8] stated that the GFRP characteristics has won over steel in many aspects. The GFRP has higher ultimate strength and lower density than conventional steel. The installation of this material is a lot easier due to low weight. The GFRP can be formed in complicated form and shape also cut to length on site. The research also supports other papers on the advantages of GFRP which include resistance to corrosion, good fatigue and damping resistance, high strength to weight ratio and electromagnetic transparency.

On the other hand, there are also disadvantages dealing with this new material. The experienced design material engineers and also the contractors are limited in number. Therefore, it is difficult to deal with GFRP either design or installation. Lack of data on long-term performance made design engineers had hard time to predict the performance of the materials in generations times. No standard codes on GFRP make the thing worse. Next, even though the maintenance cost is low, but the initial cost of GFRP is quite high compared to conventional steel [7]. The cost of supply and installation of GFRP will be a lot high but the cost had been balanced with low maintenance in its service life.

2.4 IMPACT RESISTANCE TEST

O'Riordan [17] on behalf of Relinia Company was performed an impact resistance test on GFRP grating of their product. Two samples were used to compare performance conventional steel and composite materials which are Flowforge Open Grating (steel grating) and GRID3838 (GFRP grating). The 76kg steel bullet was released from varies height which minimum height 0.62m and maximum 2.75m. Based on the test, the steel grating showed elastically deformed on force of 5kN. The steel grating absorbed all the force of the billet, but not able to dissipate a sufficient amount of the energy to prevent elastic deformation. While in GFRP grating, were able to absorb all the energy of billet in all the tests criteria up to 2.75m equal to 20kN of force. The samples will not deformed, but eventually split in two after fourth and fifth impact on the same sample. This experiment can concluded that Flowforge Open Grating (steel grating) exhibits very poor impact resistance properties while GFRP grating exhibits excellent initial impact resistance properties but only failing after multiple times of impact blow.

Figure 2.2 : Flowforge Open Grating after Impact from 76kg billet at 0.62m height

Fibergrate Composite Structures Company [18] also did perform a FRP Molded Grating Drop Test for their product. The purposes of the test were to develop primary knowledge about impact performance, to determine the relative capability between Fibergrate® product and various other grating products and lastly to extract a certain amount of data that may be used in engineering design materials. The 3' x 3' grating sample exposed to impact from 340 pound weight and height varies from 2' to 6' onto the sample. The full instrumentation of impact test as shown in Figure 2.x below. Test results indicated that Fibergrate® square mesh grating demonstrates a high degree of impact resistance. Failure of material was limited such that a sufficient residual strength capacity was retained to permit passage over these sections. In every case, the corrosive resistance capability could be recovered by performing minor localized patching and sealing operations. Besides that, structural damage would vary from brand to brand. It is based on function of glass content; higher the glass content the greater the damage. But no glass at all would damage catastrophically.

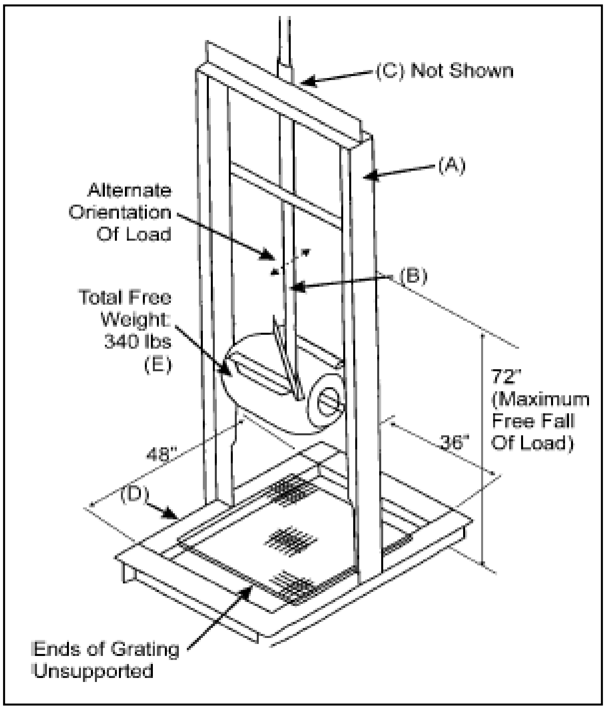


Figure 2.3 : Apparatus schematic: (A) vertical guide tower, (B) guide pipe, (C) release mechanism, (D) impact platform, (E) impact head

Impact test on GFRP grating is rarely been found. Therefore, the literature reviews are also had been made based on impact test on other materials such as concrete structure.

Gupta et al [19] conducted a study on the behaviour of fiber reinforced shotcrete beams and plates under impact loading using the drop-weight instrument machine. Then, the result compared with their static response. Eleven samples with four different fibers being used which are steel, polypropylene, carbon and PVA. For each of them was tested on different fiber shape, geometry, cross section, length, diameter, tensile strength and fiber weight. The simply supported beams were tested using 60.3kg hammer drop from 0.45 m height while the simply supported plates were tested using a huge 578kg hammer from the same height. The schematic diagrams for each test as shown in Figure 2.2 below. Data was recorded using cell load (to measure load impact) and using the accelerometer (to measure acceleration during impact) at 10μs interval. With acceleration data, velocity and displacement at load-point can obtain using integration.

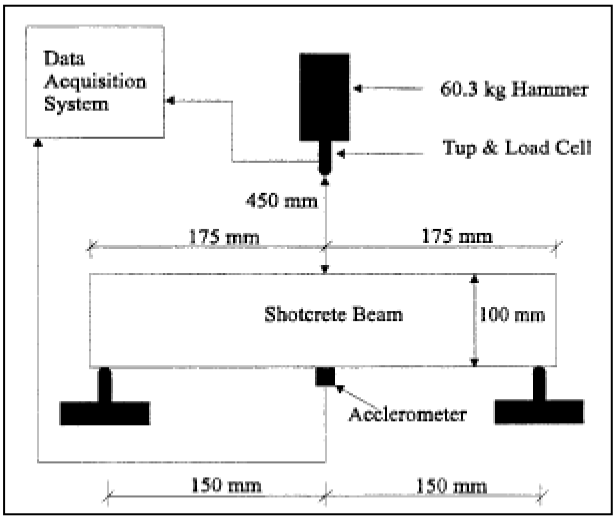


Figure 2.4 : Schematic diagram of impact load application on beam

Another experimental study conducted by Tang and Saadatmanesh [20] on impact effects beam strengthened with fiber-reinforced polymer laminate. Carbon fiber and Kevler fiber were glued on top and bottom of concrete beam using epoxy. The impact test was done using drop weight as shown in Figure 2.3 below. Steel cylinder impactor with 222 N and 127 mm diameter being used. The accelerometer was placed at the bottom of impact load point to measure acceleration of impactor while drop on the sample. The load of impactor was measured using load cell which installed at the beam support. Other instruments which differ from experiment conducted above is two pieces of a Linear Variable Differential Transducer (LVDT) were attached at each side of the beam used to measure deflection of the specimen. Dial calliper which used to measure permanent (residual) deflection induced by impact loading. Twelve strain gauges being placed on the laminates, half on the top another half on the bottom. The purpose was to monitor the distribution of longitudinal strains of the surfaces. The reaction of impact only at the first half cycle while the reaction after that was inertia force. The reaction force increase as drop height increase, the deflection also increase but the frequency of vibration will decrease. As number of impact increase, the stiffness of the laminate will decrease.

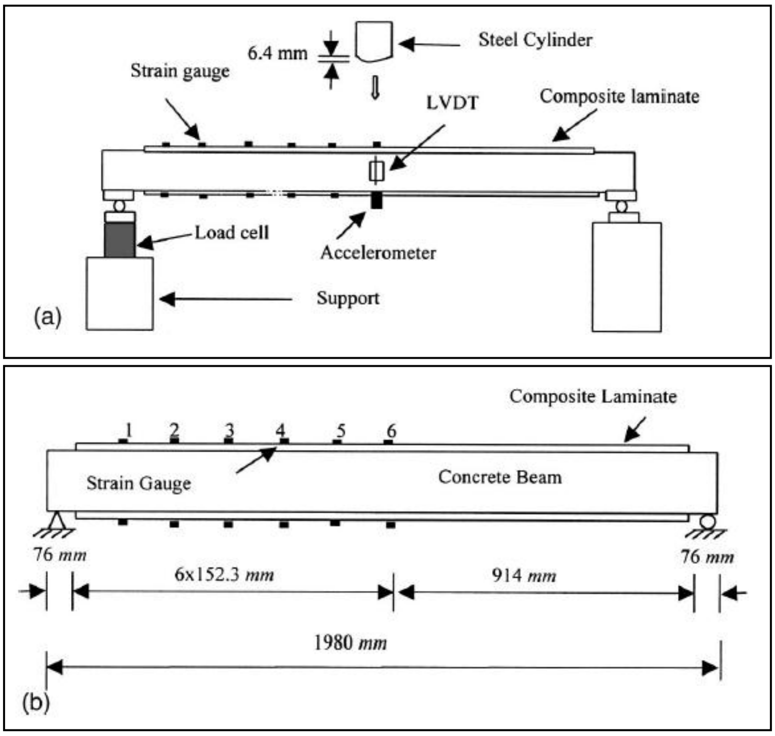


Figure 2.5 : Schematic diagram for impact test instrumentation (a) Test Setup, (b) Placement of strain gauge

2.5 DROP WEIGHT TESTING RIG DESIGN

To design a machine, a basic requirement and general guideline need to take account so that the machine meets their functions, attain structure stability, safety and cost efficient. There is study on useful criteria and elements also worked example for drop test for crashworthiness studies conducted by Shuaeib *et.al.* [21]. A drop impact test machine must conforms with following requirements:-

- Allow for accurate pre-positioning of impact
- Allow accurate and convenient control of drop height
- Allow an unobstructed free fall
- Provide a specimen to absorb energy and expected shock.

In the basic mechanical components, the first element is propulsion and guidance. The load must conveniently bring up for impact and the location of impact on the specimen must occur at right location and correct orientation. The second point is frame layout. Although there are many frame skeleton testing rig available, but the choice will depend on the size of the machine and degree of flexibility required. The next element is foundation. The size and type of foundation depends upon the application requirement such as speed and load. The forth components for design is structural design checks. Design load, free body diagram, column buckling, shear and moment diagram and analysis must be conducted to achieve stability of the structure. The last element is energy consideration. Kinetic energy of falling weight depends on its weight and height of the drop. Then, the energy is absorbed by specimen and the frame and some lost at the guidance due to opposing frictional forces.

In the data retrieval section, three instrumentations is used; namely electronic instrumentations (transducers), image acquisition system (photography equipment) and electronic data acquisition. The transducer is used to measure load, acceleration and velocity. Three sensors are also used in the transducers which are accelerometers, load cells and photo sensors. The image acquisition system (photography) is able to measure deflection in great details because used high speed digital camera system. Lastly, for data acquisition system two methods is applied which are using oscilloscope and using computer-based data acquisition systems (Virtual Instruments). Both methods include signal-conditioning components either built in or separately connected.

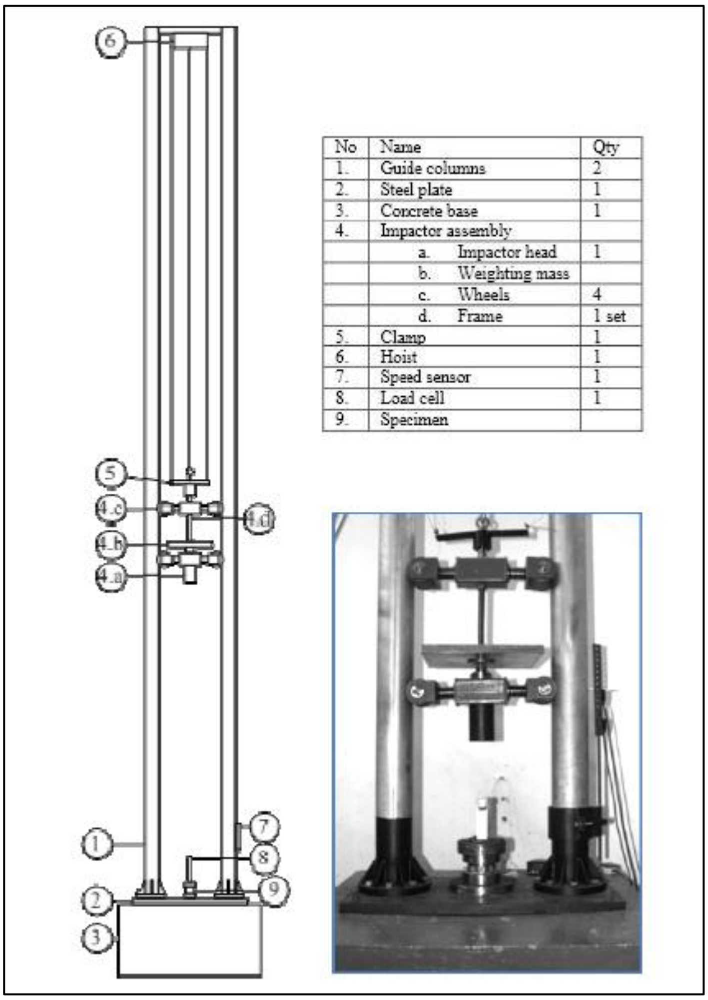
Sharma and Raghupathy [22] conducted a study on design and fabrication of equipment for low velocity impact testing of composite sandwich panels specified in salient features. The experiment involved three types of impact machines which are drop-weight impact rig for low velocity of small load impact, pendulum impactor that involves of a steel ball hanging from a string and lastly gas-gun impactor. The important design parameters for the drop weight rig are such as energy to produce incipient damage, peak impact force, energy perforation threshold, restitution coefficient, material properties, staking sequence, boundary conditions, nose impactor dimensions and weight and drop height and others. The drop load impact and drop height are variables to achieve maximum machine flexibility and reproducibility. The drop weight impact machine developed is able to reach 1.5m height, load varies from 2.5 to 12.5kg, and maximum energy up to 180J. The overall view of the drop impact test machine as shown in Figure 2.6 below.

Figure 2.6: Falling weight impact test equipment

The testing rig has two vertical stainless steel rods as column attached on a heavy steel base. The specimen is clipped by using adjustable bolt, placed on a laminate steel plate 20mm thickness and has rectangular grooved at the centre which is mounted on steel base. To minimize the friction, cylindrical guide is used for dropping purpose of steel rods. The impactor probe consists of three parts namely dropping head, base for mounting penetration probes and penetration impactor as shown in Figure 2.7 below. Two penetration impactors are used which are hemispherical stainless steel with diameter 12.5mm and 50mm length; and flat type size 25 x 25mm. PCB ICP force sensors are used to measure transient impact force history. Further analysis is done using Visual Basic and C++ to obtain various impact response parameters. The outputs are computerized produced of absorbed load versus time and absorbed energy versus time.

Figure 2.7 :Assembly of impactor

Another impact testing rig design studied conducted by Gunawan *et al.* [23] on development of a dropped weight impact testing machine for vehicle crashworthiness. The machine is able to perform impact with maximum speed of 10m/s, maximum load of 150kg, and maximum height of 170mm. An impactor was elevated and then released at a certain height above the specimen. The specimen was hit by the impactor with an impact speed depends on the drop height. The kinetic energy from the impactor was absorbed by the specimen wall's progressive folding until it decrease and stop. A load cell was used to measure crushing force and recorded by data acquisition system which placed between specimen and steel base. A speed sensor was used to measure velocity of the impact before hit the specimen. The testing machine design was divided by four subsystems, namely: frame, impactor assembly, clamp mechanism and hoist and instrumentation. The schematic diagram and a picture of dropped weight impact machine as in Figure 2.8 below.



No	Name	Qty
1.	Guide columns	2
2.	Steel plate	1
3.	Concrete base	1
4.	Impactor assembly	
	a. Impactor head	1
	b. Weighting mass	
	c. Wheels	4
	d. Frame	1 set
5.	Clamp	1
6.	Hoist	1
7.	Speed sensor	1
8.	Load cell	1
9.	Specimen	

Figure 2.8 : Schematic diagram and picture of dropped weight impact machine

Two stainless steel columns are 6m height, 11.4m outer diameter and 6mm inner diameter. They were mounted on 3cm thick base plate then placed on 1m x 1m x 2m concrete block. The concrete block was half-buried in a square hole with width of 1.2m and depth of 1.7m on the floor. 0.2m layer of sand was buried in the hole to isolate the shock and vibrations during impact. The impactor assembly consists of an impactor frame, impact head, weighing masses and rollers. The roller was equipped with a pretension spring that keep roller always in contact with the guide column. The mass of the frame, roller and impact head without weighing masses was 20kg. The possible added mass can up to 150kg of total weight of system. Load cell was used to measure crushing force while speed sensor was used to measure speed of impactor before it hit the specimen. If there is no significant friction on roller, the velocity of impactor before hit the specimen is:

$$v = \sqrt{2gH}$$

Where v is velocity of impactor, g is gravitional acceleration and H is height of impactor drop. The functional tests were conducted by calculate the impact velocity, measure the crushing force and mean of crushing force. The impact speed and time history can be measured for further analysis.

A new drop weight impact machine for studying fracture process in structural concrete was showed in the research by Zhang *et al.* [24]. The machine consists of two main parts which are mechanical structure and data acquisition system. The mechanical system includes hammer guided by two robust columns which can impact the specimen with energy up to 7860J. The data acquisition system involves piezometer force sensors, accelerometers and optical fiber photoelectric sensor plus oscilloscopes and signal conditioners.

The machine was located on the strong floor in the laboratory. 3.7m high of prestressed columns against upper and lower 1m thick of strong floor slabs as shown in Figure 2.9 below. A 95mm thick steel plate was placed to support the attached specimen. The frame consists of 90mm diameter column guided an adjustable height of hoist, chain system and hammer for the impact. This machine has ability to drop from 2595mm height. Two hammers were used in this experiment to meet the purpose to test different types of specimens. The first one was aluminium hammer with load 18.6kg while another one was steel hammer with increment 15kg from 60.55kg to 315.55kg. Instrumentation used involved force sensors, accelerometers, magnetics strips and magnetic sensor, optical fiber photoelectric sensor and data acquisition system.

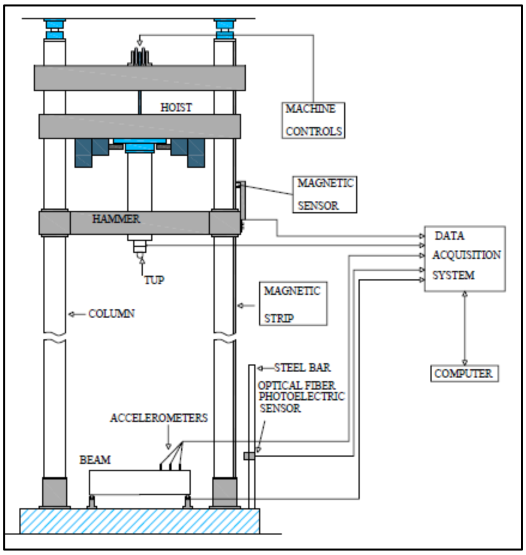


Figure 2.9 : Schematic diagram of drop weight impact machine

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY

3.1 PROCESS WORK OF FYP

The scope of FYP research is to develop an impact resistance testing machine. The requirements and problems which lead to the test is essential to identify. Table 3.1 below shows summary of parameters of impact resistance test as guidance in testing rig design. Figure 3.1 shows process flow of designing a testing rig.

<table>
<tr><td>Identifying Problems</td><td colspan="2">Corrosion problem and bulk weight of conventional steel. Corrosion of steel caused high cost maintenance and retrofit of offshore facilities. Bulk weight of topside of platform caused high cost in transportation to offshore spot.</td></tr>
<tr><td>Alternative Solution</td><td colspan="2">Replace conventional steel to advance composite materials; Glass Fiber Reinforced Polymer (GFRP)</td></tr>
<tr><td>Test conduct</td><td colspan="2">Impact resistance test on GFRP grating</td></tr>
<tr><td>Specimen</td><td colspan="2">1.25m square GFRP grating specimens are same in type of glass fiber but differ in type of resins</td></tr>
<tr><td>Testing rig</td><td colspan="2">Impact test machine need to be properly design and fabricated</td></tr>
<tr><td>Analysis</td><td colspan="2">1. Deflection while impact and after impact of the GFRP grating
2. After effect of the GFRP grating</td></tr>
<tr><td rowspan="2">Variables</td><td>Constant</td><td>Size of GFRP grating (1.25m)</td></tr>
<tr><td>Manipulated</td><td>1. Load of impact test (18kg, 42kg, 70kg)
2. Height of impact test (2m, 1.5m, 1m)</td></tr>
</table>

Table 3.1: Summary data of the GFRP grating impact resistance test

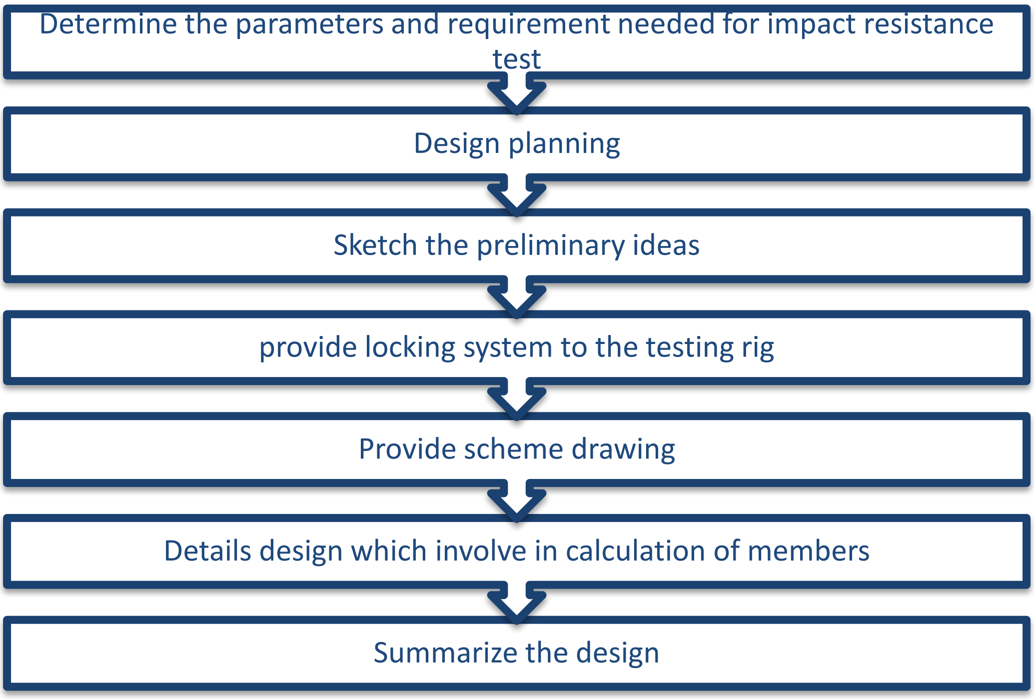


Figure 3.1: Process Flow of the Impact Testing Rig

3.2 KEY MILDSTONE

Table 3.2 and Table 3.3 below are the key milestone that need to be achieve throughout both of the semester of final year project 1 (FYP I) final year project 2 (FYP II).

Semester 1

Milestone	**Week**
Project Proposal	Week 3
Extended proposal (10%)	Week 6
Proposal Defense (40%)	Week 9
Interim Report (50%)	Week 11

Table 3.2 : Key milestone for FYP I

Semester 2

Milestone	Week
Progress Report (10%)	Week 7
Pre-SEDEX (10%)	Week 11
Dissertation (40%)	Week 13
Technical Report (10%)	Week 13
VIVA (30%)	Week 14

Table 3.3 : Key milestone for FYP II

3.3 GANTT CHART

Project scheduling is important because it is an integral part of the project planning process. A detail schedule needs to be prepared so that the student can manage time and resources allocate effectively. Microsoft Project is used to create this Gantt chart and the planning as Figure 3.2 below.

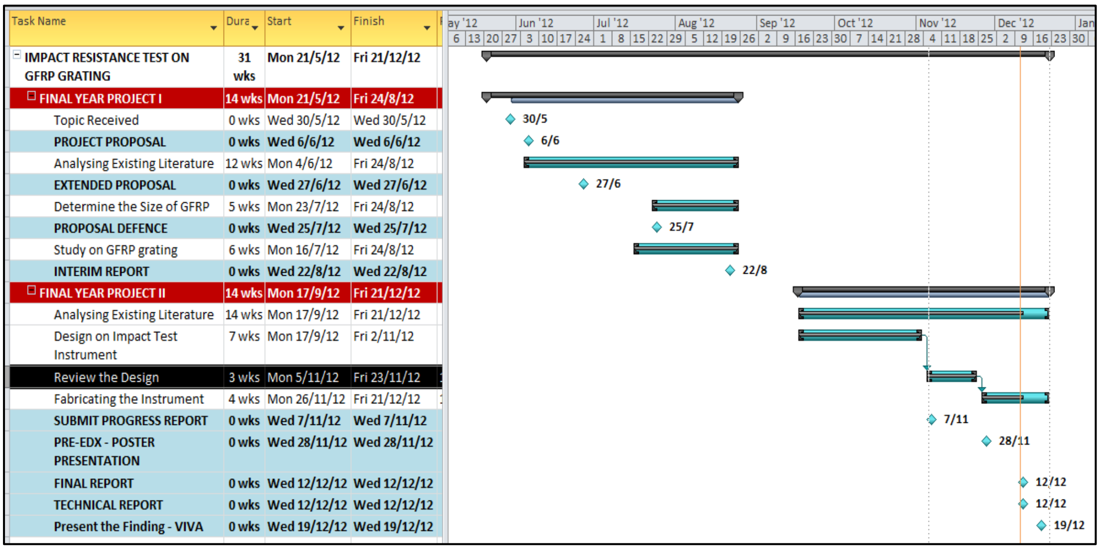


Figure 3.2: Gantt chart of FYP

3.4 TOOLS

The tools that needed of this project as in Table 3.4 below:

Tools	Purpose
AutoCAD 2007	For better illustration of impact resistance test machine.
Microsoft Project 2010	To plan Final Year Project's schedule
Eurocode 3 standard	To design steel members
GFRP sample	To test the specimen
Impact Testing Rig	As a final product of the study

Table 3.4 : Tools required for Impact Resistance Testing Rig

CHAPTER 4

RESULTS AND DISCUSSION

4.0 RESULT AND DISCUSSION

4.1 IMPACT RESISTANCE TEST PARAMETERS

Parameters as Table 4.1 below are needed for impact resistance test to design the testing rig. After the requirements for testing finalize, the process of testing rig design can start.

	Parameters	Remarks
1.	GFRP grating	1.25m x1.25m
2.	Impactor loads	70kg, 42kg, 18kg
3.	Drop height	2m, 1.5m, 1.0m
4.	Maximum energy	1373.4 J
5.	Maximum kinetic energy before impact	6.26 m/s
6.	Observe results	Deflection Condition of GFRP grating

Table 4.1 : Parameters of Impact Resistance Test

4.2 ENERGY OF THE IMPACT

Different height and impactor load create different energy toward the impact. The result also may vary. Use the Potential Energy Equation, the energy of impactor can be obtained

$$Potential\ Energy, PE = mgh$$

Where m = mass of impactor (kg),

g = gravitational acceleration (9.81m/s^2) and

h = height of drop (m)

Velocity of impactor before hit the GFRP grating can be calculated using Kinetic Energy Equation.

$$Kinetic\ Energy, KE = \frac{1}{2}mv^2$$

Where m = mass of impactor (kg),

υ = velocity of the impactor before it hit the grating

Assume energy loss is negligible, total energy, E_T before the impact is potential energy equal, PE to kinetic energy, KE.

$$E_T = mgh = \frac{1}{2}mv^2$$

. Table 4.2 is the summary of energy and velocity from impactor varies with load and drop height. The energy of the impactor is directly proportional to height of drop and weight of impactor. Highest energy is 1372.4J from highest drop and largest load. On the other hand, velocity is dependent on drop height of impactor regardless its weight.

Weight (kg)	Drop height (m)	Energy (J)	Velocity (m/s)
70	2.0	1373.40	6.26
	1.5	1030.05	5.42
	1.0	686.70	4.43
42	2.0	824.04	6.26
	1.5	618.03	5.42
	1.0	412.02	4.43
18	2.0	353.16	6.26
	1.5	264.87	5.42
	1.0	176.58	4.43

Table 4.2 : Summary of energy from impactor varies with load and drop height

4.3 DESIGN CALCULATION

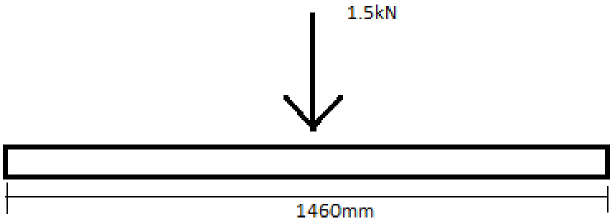
a) Column

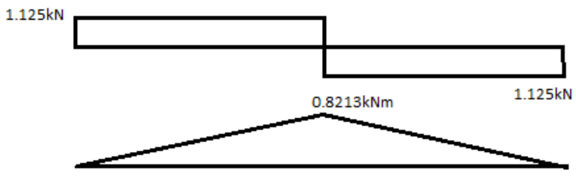
Reference	Calculation	Remark
	Try 152 x 152 x 30 UC L = 2750mm N_{Ed} = 1.5kN D = 157.5mm B = 152.9mm t = 6.6mm T = 9.4mm r = 7.6mm A = 3840mm^2 i_z = 38.2mm F_Y = 275N/mm^2	
Table 5.2	STEP 1 – Classification of section $$\varepsilon = \sqrt{\frac{235}{275}} = \sqrt{\frac{235}{275}} = 0.924$$ (a) Flange $$\frac{c}{t} = \frac{[152.9 - 6.6 - 2(7.6)]/2}{9.4} = 6.97$$ $$9\varepsilon = 8.316$$ $$\frac{c}{t} \leq 9\varepsilon$$ (b) Web $$\frac{c}{t} = \frac{157.5 - 2(6.6) - 2(7.6)}{6.6} = 19.56$$ $$33\varepsilon = 30.5$$ $$\frac{c}{t} \leq 72\varepsilon$$	CLASS 1 FLANGE CLASS 1 WEB COLUMN SECTION IN CLASS 1

EC3 6.2.4	STEP 2 – plastic compression resistance of section, $N_{c.Rd}$ for Class 1 section is given by	
Eq 6.10	$$N_{c,Rd} = \frac{Af_y}{\gamma_{mo}} = \frac{(3860mm^2)(275N/mm^2)}{1.00} = 1056kN$$	
Eq 6.9	$$N_{c,Rd} > N_{Ed}$$ $$1056kN > 1.5kN$$	OK!
EC3 6.3.1	STEP 3 – Buckling resistance of member	
	$$L_{eff} = L_{eff.y} = L_{eff,z} = 1.0L = 1.0(2750)$$ $$= 2750mm$$	
	Column will buckle about weak (z-z) axis. Slenderness ratio about z-z axis (λ_z):-	
Eq 6.46	$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0$$	
Eq 6.47	Design buckling resistance of a compression member $$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{m1}}$$	
Table 6.2	$$\frac{h}{b} = \frac{157.5}{152.9} = 1.03 \leq 1.2$$ $$t_f = 9.4mm \leq 100mm$$ $$\therefore use\ bucling\ curve\ c$$	
Table 6.1	$$\propto = 0.49$$ $$\lambda_z = \frac{L_{eff,z}}{i_z} = \frac{2750}{38.2} = 71.99$$ $$\beta_A = 1\ (section\ 1)$$	

Eq 6.49	$\lambda_1 = 93.9\varepsilon = 86.76$ $\overline{\lambda_z} = \left(\frac{\lambda_z}{\lambda_1}\right)(\beta_A)^{\frac{1}{2}} = \left(\frac{71.99}{86.76}\right)(1)^{\frac{1}{2}} = 0.83$ $\Phi = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \overline{\lambda^2}]$ $= 0.5[1 + 0.49(0.83 - 0.2) + 0.83]$ $= 0.9988$ $\chi = \frac{1}{\Phi + \sqrt{\Phi^2 + \overline{\lambda^2}}} = \frac{1}{0.9988 + \sqrt{0.9988^2 + 0.83^2}}$ $= 0.6433$ Plug into Eq 6.47, $N_{b,Rd} = \frac{\chi A f_y}{\gamma_{m1}}$ $= \frac{0.6433(3840mm^2)(275N/mm^2)}{1.00}$ $= 679.32kN$ $N_{b,Rd} \leq N_{Ed}$ $679.32kN \leq 1.5kN$	Buckling resistance OK!

b) Beam



Reference	Calculation	Remark
	<u>STEP 1 – Maximum shear and moment</u> PL = 1.5kN x 1.5 = 2.25kN  Maximum shear force, V = 1.125kN Maximum moment, M = 0.8213kNm <u>STEP 2 – Selection of UB</u> Try 305 x 165 x 40 UB D =303.8mm B =165.1mm t = 6.1mm T = 10.2mm r = 8.9mm A = 5160mm^2 $W_{el,y}$ =93.8cm^3 $W_{pl,y}$ = 142cm^3 I_y = 766cm^4 I_x = 8551cm^4 f_y =275N/mm^2	

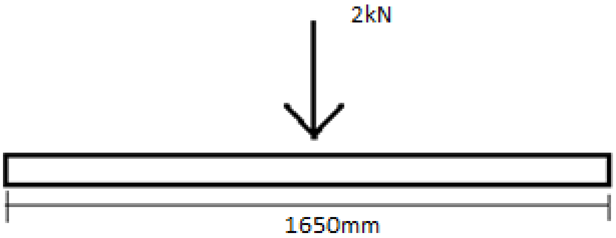
	STEP 3 – Classification of section	
	$$\varepsilon = \sqrt{\frac{235}{275}} = \sqrt{\frac{235}{275}} = 0.924$$	
	(a) Flange	
Table 5.2	$$\frac{c}{t} = \frac{[165.1 - 6.1 - 2(8.9)]/2}{10.2} = 6.92$$	
	$$9\varepsilon = 8.316$$	
	$$\frac{c}{t} \leq 9\varepsilon$$	CLASS 1 FLANGE
	(b) Web	
Table 5.2	$$\frac{c}{t} = \frac{303.8 - 2(10.2) - 2(8.9)}{6.1} = 43.54$$	
	$$72\varepsilon = 66.53$$	
	$$\frac{c}{t} \leq 72\varepsilon$$	CLASS 1 WEB
		BEAM SECTION IN CLASS 1
EC3 6.2.6	STEP 4 – Check shear strength	
Eq 6.17	$$\frac{V_{Ed}}{V_{c,Rd}} \leq 1.0$$	
	Design plastic shear resistance, $V_{pl,Rd.}$	
Eq 6.18	$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{m0}}$$	
	Shear Area, A_v,	
	$A_V = A - 2bt_f + (t_w + 2r)t_f$	
	$= 5160 - 2(165.1)(10.2) + (6.1 + (2 \times 8.9))(10.2)$	
	$= 5160 - 3368.04 + 243.78$	
	$= 2038.78\ mm^2$	

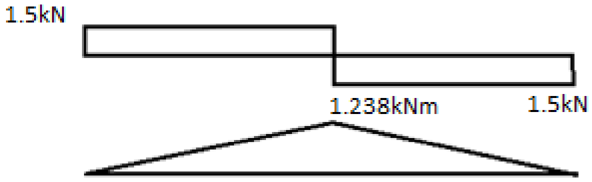
	Plug into the Equation 6.18 $V_{pl,Rd} = \frac{(2038.74mm^2)(275N/mm^2/\sqrt{3})}{1.00}$ $= 323.7kN$ $V_{Ed} \leq V_{pl,Rd}$ $1.125kN \leq 323.7kN$	SHEAR STRENGTH OK!
EC3 6.2.5 Eq 6.12 Eq 6.13	STEP 5 – CHECK BENDING CAPACITY $\frac{M_{Ed}}{M_{cRd,}} \leq 1.0$ Design plastic resistance for bending moment. $M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}f_y}{\gamma_{m0}}$ $M_{pl,Rd} = \frac{142000mm^3(275N/mm^2)}{1.00} = 39.05kNm$ $M_{Ed} \leq M_{pl,Rd}$ $0.8213kNm \leq 39.05kNm$	BENDING CAPACITY OK!
	STEP 6 – Check Deflection Unfactored load PL = 1.5kN $\delta = \frac{5WL^3}{384EI} = \frac{5(1.5 \times 1000)(1460)^3}{384(205000 \times 8551 \times 10000)}$ $= 0.00345mm$ $\frac{L}{350} = \frac{1460}{350} = 4.17$ $\delta < \frac{L}{350}$	OK!

	Factored load PL = 2.25kN $\delta = \frac{5WL^3}{384EI} = \frac{5(2.25 \times 1000)(1460)^3}{384(205000 \times 8551 \times 10000)}$ $= 0.0052mm$ $\frac{L}{250} = \frac{1460}{250} = 5.84$ $\delta < \frac{L}{250}$	OK!
EC3 6.3.2 Eq 6.54 Eq 6.55	<u>STEP 7 – Lateral Torsional Buckling</u> $\frac{M_{Ed}}{M_{cRd,}} \leq 1.0$ Design buckling resistance moment $M_{b,Rd} = \chi_{LT} \frac{W_{pl} f_y}{\gamma_{m1}}$ $\overline{\lambda_{LT}} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{142000mm^3 \times 275N/mm^2}{0.8213kNm \times 1000}}$ $= 47.55$	
Table 6.4 Table 6.3	$\frac{h}{b} = \frac{303.8}{165.1} = 1.84 \leq 2$ $\therefore buckling\ curve\ a$ $\propto_{LT} = 0.21$ $\Phi_{LT} = 0.5[1 + \propto_{LT} \left(\bar{\lambda}_{LT} - 0.2\right) + \overline{\lambda^2}_{LT}]$ $= 0.5[1 + 0.21(47.55 - 0.2) + 47.55^2]$ $= 1136$	
Eq 6.56	$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 + \overline{\lambda^2}}} = \frac{1}{1136 + \sqrt{1136^2 + 47.55^2}}$ $= 0.00044$	

	Plug into the Equation 6.55 $$M_{b,Rd} = \chi_{LT} \frac{W_{pl} f_y}{\gamma_{m1}}$$ $$M_{b,Rd} = 0.00044 \frac{(142000 mm^3)(275 N/mm^2)}{1.00}$$ $$= 17.182 kNm$$ $$M_{Ed} \leq M_{b,Rd}$$ $$0.8213 kNm \leq 17.182 kNm$$	LATERAL TORSIONAL BUCKLING OK!

c) **Rectangular Hollow Section (RHS)**



Reference	Calculation	Remark
	<u>STEP 1 – Maximum shear and moment</u> PL = 2kN x 1.5 = 3kN  Maximum shear force, V = 1.5kN Maximum moment, M = 1.238kNm <u>STEP 2 – Selection of RHS</u> Try 100x50x8 RHS D =100mm B =50mm t = 8mm r = 7.6mm A = $2110mm^2$ $W_{el,y}$ $29.4cm^3$ $W_{pl,y} = 37.1cm^3$ $I_y = 73.5cm^4$ $I_x = 238cm^4$ $f_y = 275N/mm^2$	

	<u>STEP 3 – Classification of section</u>	
	$\varepsilon = \sqrt{\frac{235}{275}} = \sqrt{\frac{235}{275}} = 0.924$	
	(a) Web	
Table 5.2	$\frac{c}{t} = \frac{[100 - 2(8) - 2(7.6)]}{8} = 8.6$	
	$\frac{c}{t} = \frac{50 - 2(8) - 2(7.6)}{8} = 2.35$	
	$72\varepsilon = 66.53$	
	$\frac{c}{t} \leq 72\varepsilon$	RHS SECTION IN CLASS 1
EC3 6.2.6	<u>STEP 4 – Check shear strength</u>	
Eq 6.17	$\frac{V_{Ed}}{V_{c,Rd}} \leq 1.0$	
	Design plastic shear resistance, $V_{pl,Rd}$.	
Eq 6.18	$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{m0}}$	
	Shear Area, A_v,	
	$A_V = A - 2bt_f + (t_w + 2r)t_f$	
	$= 2110 - 2(50)(8) + (8 + (2 \times 7.6))(8)$	
	$= 2110 - 800 + 185.6$	
	$= 1495.6\, mm^2$	
	Plug into the Equation 6.18	
	$V_{pl,Rd} = \frac{(1495.6mm^2)(275N/mm^2/\sqrt{3})}{1.00}$	
	$= 237.5kN$	
	$V_{Ed} \leq V_{pl,Rd}$	SHEAR STRENGTH OK!
	$1.5kN \leq 237.5kN$	

EC3 6.2.5	<u>STEP 5 – CHECK BENDING CAPACITY</u>	
Eq 6.12	$$\frac{M_{Ed}}{M_{cRd,}} \leq 1.0$$	
	Design plastic resistance for bending moment.	
Eq 6.13	$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma_{m0}}$$ $$M_{pl,Rd} = \frac{37100mm^3(275N/mm^2)}{1.00} = 10.2kNm$$	
	$$M_{Ed} \leq M_{pl,Rd}$$ $$1.238kNm \leq 10.2kNm$$	BENDING CAPACITY OK!
	<u>STEP 6 – Check Deflection</u> Unfactored load PL = 2kN $$\delta = \frac{5WL^3}{384EI} = \frac{5(2 \times 1000)(1650)^3}{384(205000 \times 238 \times 10000)}$$ $$= 0.239mm$$ $$\frac{L}{350} = \frac{1650}{350} = 4.71$$ $$\delta < \frac{L}{350}$$	OK!
	Factored load PL = 3kN $$\delta = \frac{5WL^3}{384EI} = \frac{5(3 \times 1000)(1650)^3}{384(205000 \times 238 \times 10000)}$$ $$= 0.359mm$$	

	$\frac{L}{250} = \frac{1650}{250} = 6.6$	
	$\delta < \frac{L}{250}$	OK!
	<u>STEP 7 – Lateral Torsional Buckling</u>	
EC3 6.3.2		
Eq 6.54	$$\frac{M_{Ed}}{M_{cRd,}} \leq 1.0$$	
	Design buckling resistance moment	
Eq 6.55	$$M_{b,Rd} = \chi_{LT} \frac{W_{pl} f_y}{\gamma_{m1}}$$	
	$$\overline{\lambda_{LT}} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{37100mm^3 \times 275N/mm^2}{1.238kNm \times 1000}}$$	
	$$= 2.87$$	
	$$\therefore buckling\ curve\ d$$	
Table 6.4		
Table 6.3	$$\propto_{LT} = 0.76$$	
	$$\Phi_{LT} = 0.5[1 + \propto_{LT} (\bar{\lambda}_{LT} - 0.2) + \overline{\lambda^2}_{LT}]$$	
	$$= 0.5[1 + 0.76(2.87 - 0.2) + 2.87^2]$$	
	$$= 5.633$$	
Eq 6.56	$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 + \overline{\lambda^2}}} = \frac{1}{5.633 + \sqrt{5.633^2 + 2.87^2}}$$	
	$$= 0.0836$$	

	Plug into the Equation 6.55 $$M_{b,Rd} = \chi_{LT} \frac{W_{pl} f_y}{\gamma_{m1}}$$ $$M_{b,Rd} = 0.0836 \frac{(37100mm^3)(275N/mm^2)}{1.00}$$ $$= 1.345kNm$$ $$M_{Ed} \leq M_{b,Rd}$$ $$0.8213kNm \leq 1.345kNm$$	LATERAL TORSIONAL BUCKLING OK!

4.4 STRUCTURE ANALYSIS

Structural analysis had been done using StaadPro software. Result of the analysis as shown in figures below. Details results as attached in Appendix I.

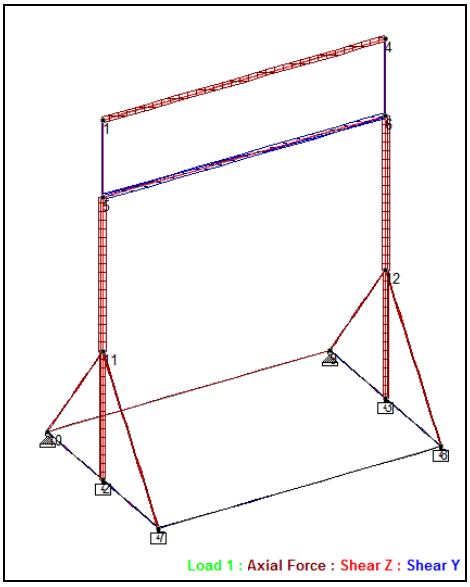


Figure 3.3 : Axial Forces Diagram

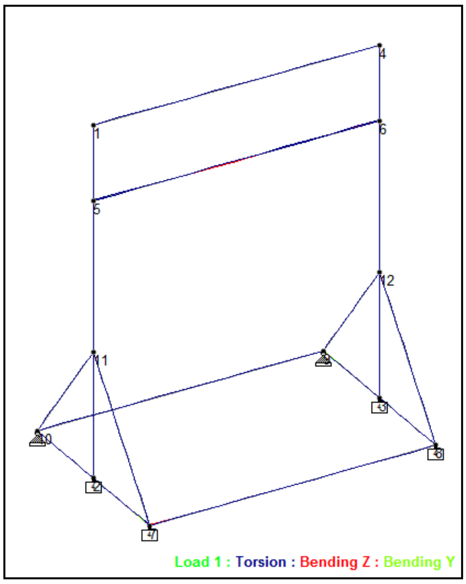


Figure 3.4: Bending Diagram

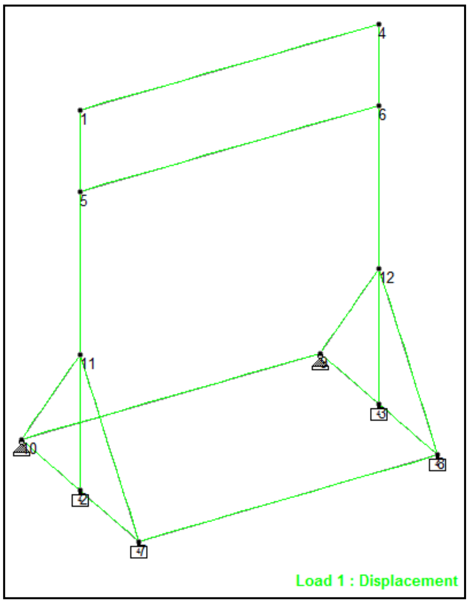


Figure 3.4: Displacement Diagram

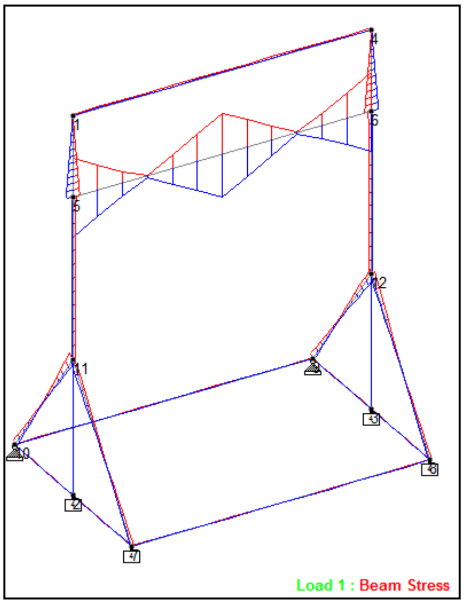


Figure 3.4:Beam Stress Diagram

4.4 DROP WEIGHT IMPACT TESTING RIG

The drop weight testing rig is able to perform impact with maximum speed of 6.26m/s, maximum energy is 1373.4 J when at maximum load of 70kg, and maximum height of 2000mm. The testing machine design was divided by two subsystems, namely: frame and locking system. The frame is supported by two 152 x 152 x 30 UC columns. Four 305 x165 x40 UB beams are used as a base of the rig. An impactor is located at 100 x 50 x 8 RHS beam. The beam is elevated and then released at a certain height above the grating. The grating is hit by the impactor with an impact speed depends on the drop height. Assume energy loss of the system is negligible, total energy is equal to potential energy plus kinetic energy. The testing rig is able to perform testing with varies drop height and impactor load. The GFRP grating used for testing is 1.25m x1.25m. Figure 4.1 shows the schematic diagram of detailed design of impact resistance testing rig from front view and side view.

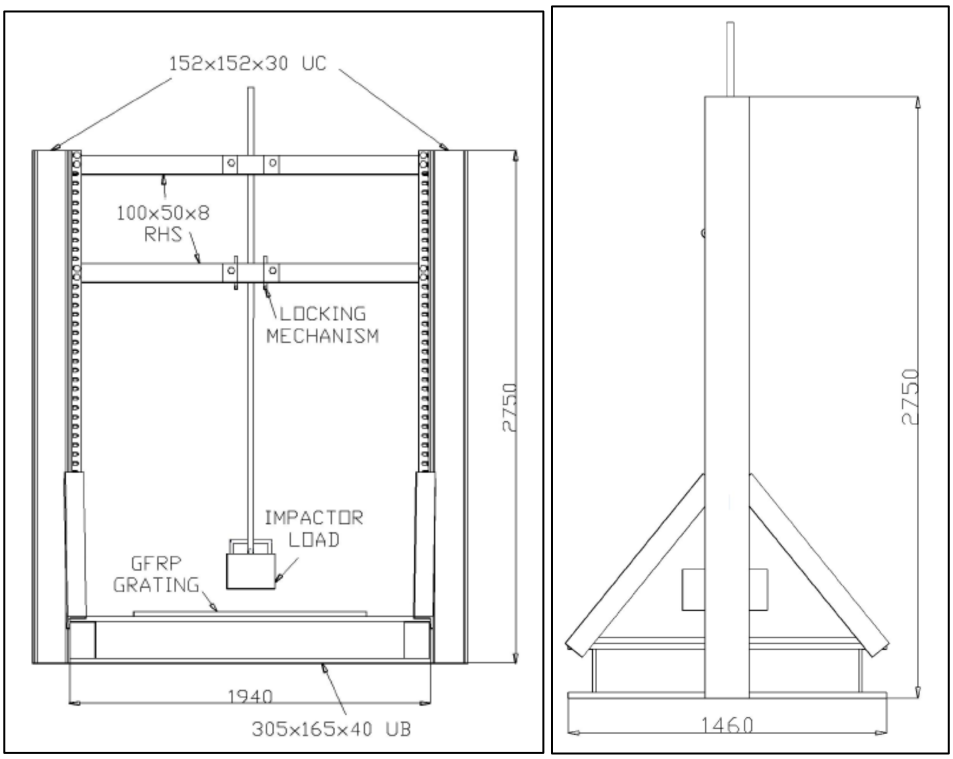


Figure 4.1 : Schematic Diagram of Detailed Design of Impact Resistance Testing Rig (a) front view (b) side view

When the load pulls up, the locking system has played the role. The rod frame will hold the impactor statically. When the impact testing is conducted, the person must pull the rope attached to the rod frame. The rod frame will rotate upward and unlock the impactor. Therefore, the impactor will drop free fall to the GFRP grating. The locking system of impact testing rig as shown in Figure 4.2 below.

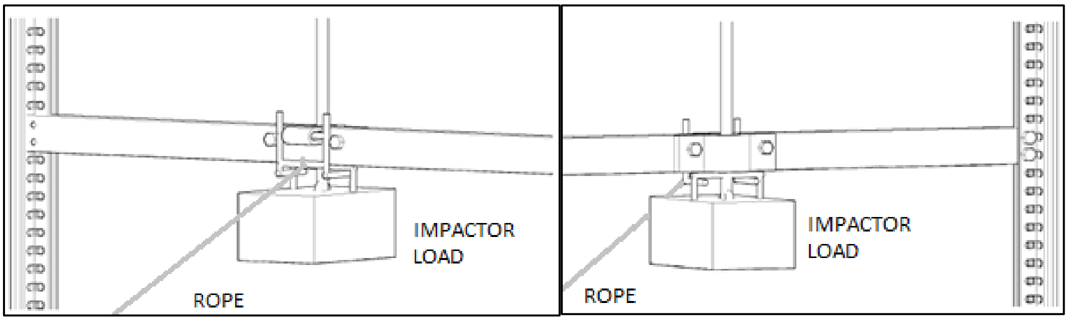


Figure 4.2 : Locking system of impact testing rig (a) back view (b) front view

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The major problems deals with steel usage at offshore structures are corrosion and excessive bulk weight. Both cause huge increment in cost. Glass Fiber Reinforced Polymer (GFRP) is used as an alternative to replace steel usage. GFRP is a composite material consists of continuous glass fiber embedded in resin matrix. The advantages of GFRP are corrosion resistance, lightweight and low maintenance cost.

The drop weight impact testing rig has been successfully designed. The testing rig is able to produce an impact load to the specimen up to 1373.4 J with maximum velocity before impact is 6.26 m/s. The impact rig can be further improved by equipped it with computer-based data acquisition system so that more accurate of data interpretation can be obtained.

5.2 RECOMMENDATION

This research has not complete yet. It must be continued until the result for impact resistance test can be obtained. Further research need to be done to obtained details and precise the design of impact testing rig. So that, the standard code for impact testing machine for GFRP grating can be produced in the future.

- Continue with instrumentation of data acquisition of impact test.
- Designing a connection of machine such as bolts and welds.
- Stimulate the design using Finite Element Method (FEM).

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APPENDIX I

RESULTS OF STRUCTURAL ANALYSIS USING STAADPRO SOFTWARE