PSZ 19:16 (Pind. 1/07)

UNIVERSITI TEKNOLOGI MALAYSIA

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name	:	SIAW YANG HOW
Date of birth	:	04/05/1987
Title	:	CONCEPTUAL DESIGN OF A MULTI-PURPOSE FLOATING STRUCTURE
Academic Session	:	2009/2010

I declare that this thesis is classified as :

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
√	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
☐	**OPEN ACCESS**	I agree that my thesis to be published as online open access (full text)

I acknowledged that Universiti Teknologi Malaysia reserves the right as follows:

1. The thesis is the property of Universiti Teknologi Malaysia.
2. The Library of Universiti Teknologi Malaysia has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by :

SIGNATURE	**SIGNATURE OF SUPERVISOR**
	ASSOC.PROF.DR.ABDUL KADIR MARSONO
(NEW IC NO. /PASSPORT NO.)	**NAME OF SUPERVISOR**
Date : 14 APRIL 2010	Date : 14 APRIL 2010

NOTES: *If the thesis is CONFIDENTAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

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

Tandatangan	: ………………………………
Nama Penyelia	: ASSOC.PROF.DR.ABDUL KADIR MARSONO
Tarikh	: 14 APRIL 2009

CONCEPTUAL DESIGN OF A MULTI-PURPOSE FLOATING STRUCTURE

SIAW YANG HOW

A report submitted in partial fulfillment of the
requirements for the award of the degree of
Bachelor of Civil Engineering

Faculty of Civil Engineering
Universiti Teknologi Malaysia

APRIL 2010

"I declare that this final year project is the result of my own work and research except as cited in the references."

Signature : …………………………………….
Name : SIAW YANG HOW
Date : 14 APRIL 2010

To beloved family and friends,
Thanks a lot for all your endless supports and encouragement.

ACKNOWLEDGEMENT

Special thanks to my supervisor, Associate Prof. Dr. Abdul Kadir Marsono for his guidance, advice and encouragement throughout this long journey. I really appreciate every effort you have done for me as a supervisor and as a friend.

Apart from that, I would like to express my gratitude to those who have given me pointers and advice on the usage of Multiframe and SketchUp.

Last but not least, my sincere appreciation also extends to all my parents, friends and those who have provided assistance at various situations and occurrences during of this study.

ABSTRACT

Flood is the most frequent and costly hazard in the world. It cost a lot of long term effects onto environment, economy and human. Therefore, actions need to be taken in reducing the effects. But, the exact time of the flood still cannot be estimated for people to do early preparation to face the flood. The floating structure has been long designed but the technology is too expensive. It may be stay unused for a long time and never been called on to float. Somehow, public also would not spend on a product due to unexpected and unpredicted event. Study on the conceptual design of multi-purpose floating structure using Basic Ship Theory had been carried out. Parametric studies had been done on suitable materials and geometry for the floating structure. The structures are designed in size 3.2m x 3.2m x 1.1m using ferrocement, steel truss and timber T- section. The size of the box has been chosen to fit in a room of IBS-home. Checks were made against the structures immersion into water to check their behavior and stability. The analyses took the load of self weight and four persons dressed only with their one day food and drink ration. The water is characterized at 0.2m length and 1.2 m height wave condition. The analyses results show that ferrocement and timber are suitable as the materials for the floating structure. The truss system is suitable to replace the ferrocement thin wall in the middle of the floating structure for weight saving. The structures are stable and semi-submersible under assumed condition. From the theoretical approach, the findings suggest that the floating structure can be used as multi-purpose structure such as rainfall collect or fish tank and agricultural at no flood condition.

ABSTRAK

Banjir ialah bencana alam yang paling kerap berlaku dan menyebabkan kerugian yang besar. Ia menyebabkan banyak kesan jangka panjang terhadap alam sekitar, ekonomi dan penduduk. Oleh itu, tindakan perlu diambil untuk mengurangkan kesan daripada banjir. Tetapi, banjir berlaku dengan tidak dijangka supaya penduduk boleh siap sedia sebelum banjir. Rumah apung telah direkabentuk sejak dulu dengan harga yang mahal dan ia mungkin tidak pernah diguna dalam jangka masa yang panjang. Tambahan lagi, penduduk tidak akan berbelanja dalam produk yang hanya digunakan untuk sesuatu perkara yang tidak tentu akan berlaku. Oleh itu, kajian dalam rekabentuk struktur apung telah dilakukan dengan menggunakan konsep asas pembinaan kapal. Kajian parametrik terhadap bahan dan geometri yang sesuai telah dijalankan. Struktur telah direkabentuk menggunakan simenfero, kerangka besi dan kayu dengan dimensi 3.2m x 3.2m x 1.1m. Kestabilan struktur dalam air juga dikaji. Analisis- analisis dijalankan dengan mangambil kira berat diri struktur, berat empat orang siap berpakaian, berat makanan dan minuman untuk sehari. Keadaan air yang digunakan dalam analisis adalah berombak kecil dengan 0.2 m panjang dan 1.2m tinggi. Keputusan kajian menunjukkan simenfero dan kayu adalah sesuai dalam rekabentuk struktur ampungan. Selain itu, kerangka besi juga sesuai untuk mengantikan dinding tengah struktur ampungan yang biasa direkabentuk dengan dinding konkrit. Struktur yang direkabentuk dalam kajian adalah stabil dan terapung pada tahap yang selamat. Kesimpulannya, struktur ampungan tersebut boleh digunakan sebagai tangki takungan air hujan, kolam ikan dan tujuan penanaman semasa tiada banjir.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 General

Flood is natural hazards that we always occur around us. *NashGayeLord* said: *"Floods are the most frequent and costly natural hazards, causing almost 90 percent of all the damage related to natural disasters."*

From ARDictionary, flood is the rising of a body of water and it is overflowing onto normally dry land. Flood is causing a lot of effects onto the economy, environment, human being and it is also leading to various diseases.

It causes economy lost and many resources needed for repair due to damages. For example, the flooding in Jiangxi of China in 1998 caused huge damage and economic loss of HK$156 billion. 400 buildings surrounding the lake were submerged, lead to more than 1 million people homeless. Only after flood, the related government was allocated extra funds for aiding and reconstruction and has directly slow down the country's economy.

Flood also causing effects on the environment where it damages the buildings such as bridges, residential housing, roads and the agriculture sector. The environment will be very dirty and messy with rubbish and sediment after the flood including trees and plants damage.

Besides, flooding also brings infection of diseases such as military fever, pneumonic plague, dematopathia, dysentery, common cold (type A),breakbone fever and food poisoning. During flood, the victims were forced to eat and drink the contaminated food and water which lead to the food poisoning. The dirty environment with rubbish and animal corpse here will fasten the infection of disease.

In addition, flooding is also causing people and livestock death due to drowning and injuries. For example, 0.23 billion of people affected in the flooding of JiangXi, including 3 thousand people dead, 1 million people lost their homes in year 1998.

National Geography Channel stated that by Year 2020, Netherland, Bangladesh, Bangkok and Singapore will be under water due to global warming. That means there will be a massive flood during that time.

1.2 Background Problem

Today, very large floating structures (VLFS) technology are used in constructing floating airports, bridges, piers, docks, entertainment facilities(like casino), recreation park and floating cities. VLFS technology normally divided into types, namely pontoons-type and semi-submersible type. The pontoon-type floats on the sea surface and it is more flexible compare to the semi-submersible type. In contrast, the semi-submersible type is suitable to be used at the open sea where the wave heights are relatively large. The former type is used for oil and gas exploration in sea.

Recently, developers, architects, environmentalists, engineers, and citizens of some countries like United State, Netherland and Holland have focused on how housing can be made safer and more resilient so that devastating flood can mitigate. They are looking into building houses that float when the flood is occurring. They had designed two types of houses name amphibious house and floating house.

Amphibious house, it is a structure that builds on land that rise and fall with the water level. An amphibious house is supported by the underground concrete piles and it has a hollow concrete basement with foam built in it. When the water rises or falls, the houses will float by sliding along two mooring poles at the front and the rear of the buildings. These have been successfully implemented in Holland and cost nearly USD300 thousand to build.

While the floating house are similar to houseboat in managing rising and falling water levels but it is built to float year round no matter what the weather. The floating house is build at a fixed point mooring and using the system similar to amphibious house. The difference is the floating house float on the water depend to the water tide of the river, lake or sea all over the year.

1.3 Problem Statement

By now, scientists had already warned that if the global warming trend continues, parts of the United States, United Kingdom, Netherlands, Bangladesh and Vietnam will be under water by the end of the century.

In Malaysia, floods are the regular disasters which occurring nearly every year during the monsoon season. The consistent devastating floods had happened for years in some regions around Malaysia such as Johor, Kelantan, Kuala Lumpur, Malacca, Pahang, Sarawak and Sabah. These floods had claimed hundreds of lives and also disrupt our economy.

It is beyond the control of structural engineer in controlling the floods from happening but we can reduce the lost by doing early preparation to face the unexpected. One of the ways reducing the life lost cause by the flood is by building amphibious houses and floating houses that can save properties and lives.

The real problem are the technology in building of amphibious houses and the floating houses still not yet implemented in Malaysia construction sector due to its pricey construction. The structures may also sit around for fifty years and never been called on to float unless it can be ultilised for other purposes at no flood conditions.

The public would not spend on a product due to some unexpected and predicted event unless a multi-purpose floating structure is embedded in their life style.

1.4 Objectives

The main objective of the research is to conceptually design a multi-purpose floating structure. By referring to the main objective, the relating objectives are as follow:

(i) To conceptually design a multi-purpose floating structure using basic ship theory.
(ii) To carry out parametric study on suitable materials and geometry for the floating structure.
(iii) To carry out check against stability using Large Angle Stability analysis.

1.5 Scope and case study of research

The load case study of this research is four persons with their one day food and drink ration staying on the floating structure during flood. The scope of this research is listed as below:

(i) Design a square floating structure with size 3.2m x 3.2m x 1.1m using ferrocement, steel and timber to fit standard rooms inside IBS-housings.

(ii) Conceptualise the shape of the floating structure.

(iii) Analyse parametrically the geometry and materials for optimum design

(iv) Study the stability of the floating structure against the load and environment case study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The boat is a comparatively small open craft that can be carried aboard a ship. Today, we always cannot differentiate a boat and a ship except by size. Actually, the distinction between a boat with a ship is varies on regional definitions where a boat can be placed on a ship but a ship cannot be placed on a boat.

Boats have being used in short distance transportation since ancient times. Circumstantial evidence, such as the early settlement of Australia over 4000 years ago, suggests that boats have been used since very ancient times. The earliest boats have been predicted to be log boats. The oldest boats to be found by the archaeological excavation are log boats from around 7000-9000years ago, though a 7000 year-old seagoing boat made from reeds and tar has been found in Kuwait as described by *Wikipedia, the free encyclopedia*.

Normally, the boats we see are built of wood, bamboo and steel. But, steel shortages lead the US military to order the construction of concrete ships which normally built of steel and ferrocement during both World War I and World War II. The oldest known ferrocement watercraft was a dinghy built by Joseph-Louis in Southern France in 1848 as described in *Wikipedia, the free encyclopedia*.

2.2 Boat Design Concept

No occupation can be properly developed without any tools or concepts, whether it is farming or boat construction. Many tools or concepts needed for the study of boat construction are already in hand, provided by mathematics, applied mechanics and physics.

2.2.1 Stability

Generally, stability means a structure is stable enough to withstand and respond to all the out coming forces that disturb it. K J Rawson and E C Tupper (2001a) define stability as the tendency of a body or system to return to its original state after it has suffered a small disturbance (*K J Rawson and E C Tupper*, 2001a).

How can we know is a structure stable or not? K J Rawson and E C Tupper (2001a) tell that if a floating body is very stable it will return quickly to the upright and may engender motion sickness.

Basically, boat stability is divided into initial stability and ultimate stability (complete stability). A vessel's stability can be divided into two categories; initial stability and ultimate stability (*Michael Carr,* 2000).

2.2.1.1 Initial Stability

Initial stability is the stability of a structure when small values of heel's angle are involved. Initial stability defines the angles of heel that are normal to a vessel's operation. This is usually between zero and 15 degrees of heel (*Michael Carr,* 2000).

For small values of β, it follows that

$$\overline{GZ} = \overline{GM} \sin \beta$$
$$= \overline{GM}\, \beta$$

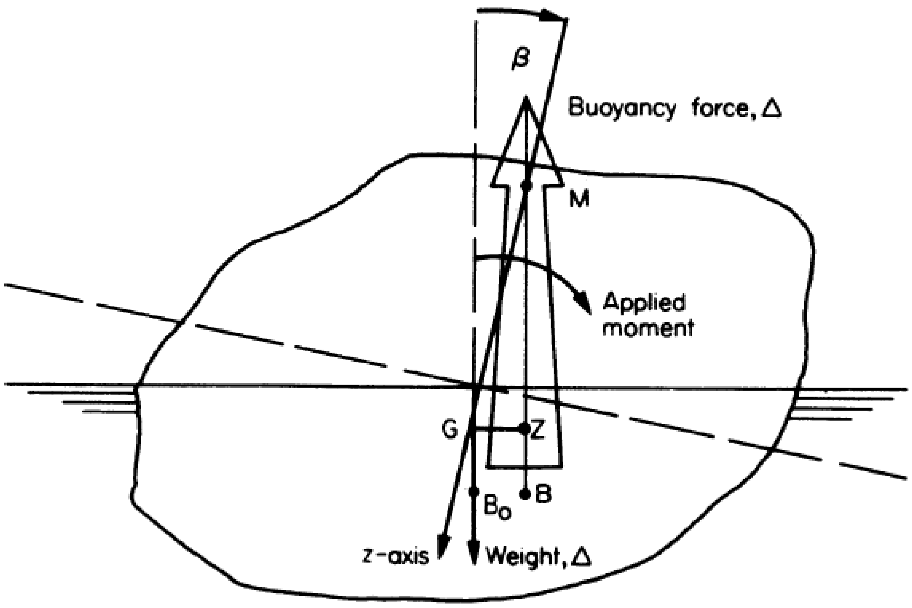


Figure 2.1 Action of buoyancy force and weight for small rotational disturbance

B_o	=	Centre of buoyancy
G	=	Centre of gravity
B	=	New centre of buoyancy
M	=	Point of intersection
β	=	Turning angle caused by rotational disturbance

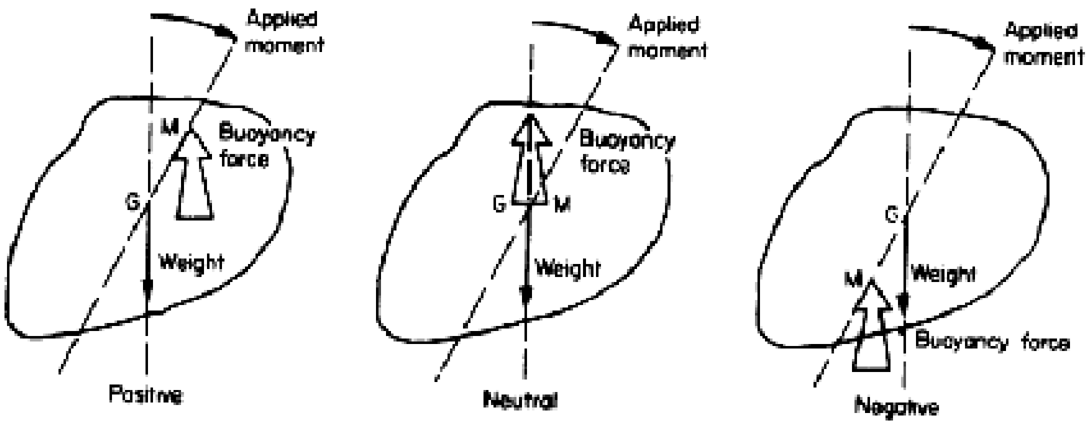


Figure 2.2 The three stability conditions

The distance $\overline{GM}$ is termed the metacentric height and is said to be positive when M lies above G. This is the condition of stable equilibrium, for should M lies below G the moment acting on the body tend to increase β and the body is unstable.

If M and G coincide the equilibrium is neutral as shown in Figure 2.2 (*K J Rawson and E C Tupper* 2001a).

By mathematically, a rectangular block (Figure 2.3) is stable if

$$\overline{GM} > 0$$

$$\overline{GM} = \frac{T}{2} + \frac{B^2}{12T} - \frac{H}{2}$$

$$= \frac{CH}{2} + \frac{B^2}{12CH} - \frac{H}{2}$$

$$= \frac{H}{2}(C - 1) + \frac{B^2}{12CH}$$

where C = specific gravity

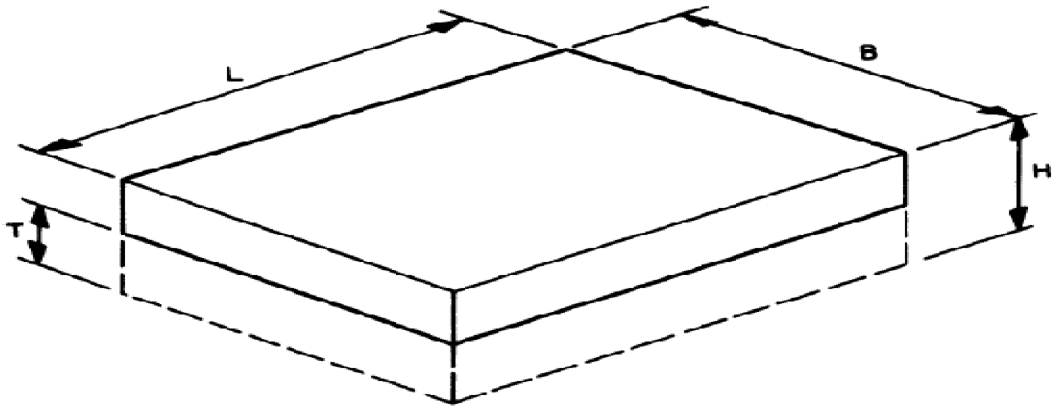


Figure 2.3 Homogeneous block floating freely

Similar expressions can be derived for homogeneous blocks of other cross sectional shapes.

2.2.1.2 Ultimate stability

In ultimate stability, transverse stability at large angles is considered but it is inconsiderable in a small boat design.

2.2.2 Floatation

2.2.2.1 Properties of Fluids

The mass density of a fluid, ρ is the mass of the fluid per unit volume.

$$\text{Density, } \rho = \frac{\text{Mass of the fluid,m}}{\text{Volume of the fluid,V}}$$

The weight density, w of a fluid is the weight of the fluid per unit volume

$$\text{Weight Density, w} = \text{Mass Density, } \rho \text{ x Gravity, g}$$

The ratio of the density of a solid or liquid to the density of pure water is the specific gravity, γ.

$$\text{Specific Gravity, } \gamma = \frac{\text{Density of a solid or liquid,}\rho}{\text{Density of pure water,}\rho_w}$$

Table 2.1 Properties of some common materials

Material	Mass density, ρ ***(kg/m^3)***	Reciprocal mass density, u **(m^3/Mg)**	Specific gravity, γ
Fresh water	*1000*	1.00	1.00
Salt water	1025	0.975	1.03
Steel	7689	0.13	7.7
Air	1.293	774.775	-
Portland Cement	1506	0.66	

Source: *K J Rawson and E C Tupper* 2001a

2.2.2.2 Archimedes' Principle

Archimedes' principle is named after Archimedes of Syrucuse, who first discovered the floatation law. Basically, Archimedes' principle is stressed that when an object is immersed in a fluid, the fluid exerts on the object a force whose magnitude is equal to the weight of the displaced fluid and whose direction is opposite the force of gravity.

In *Wikipedia, the free encyclopedia*, Archimedes' principle may be stated as any object wholly or partly immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object. Archimedes' principle states that when a solid is immersed in a liquid, it experiences an upthrust equal to the weight of the fluid displaced (*K J Rawson and E C Tupper* 2001a).

In order to float, an object needs to displace a greater weight of fluid than its own weight because the buoyant force equals the weight of the fluid displaced. That means a floating object must have a density (mass divided by volume) less than the density of the fluid. If the object's density is greater than the fluid, it will sink.But ships will float even they are made of metal because they have enough empty space inside where their total average density is less than the density of water.

Let consider any object of arbitrary shape and volume *V* surrounded by a liquid. The force the liquid exerts on an object within the liquid is equal to the weight of the liquid with a volume equal to that of the object. This force is applied in a direction opposite to gravitational force that is, of magnitude:

$$F = \rho V_{disp} g$$

where ρ is the density of the liquid, V_{disp} is the volume of the displaced body of liquid , and g is the gravitational acceleration at the location.

The net force on the object is thus the sum of the buoyant force and the object's weight.

$$F_{net} = mg - \rho Vg$$

If the buoyancy of an (unrestrained and unpowered) object exceeds its weight, it tends to rise. An object whose weight exceeds its buoyancy tends to sink.

Commonly, the object in question is floating in equilibrium and the sum of the forces on the object is zero, therefore;

$$mg = \rho Vg$$

and therefore;

$$m = \rho V$$

showing that the depth to which a floating object will sink (its "**buoyancy**") is independent of the variation of the gravitational acceleration at various locations on the surface of the Earth.

2.2.2.3 Hydrostatic data

A ship keeps on changing its weight, disposition of cargo, draught, trim, freeboard and density of water in which it floats throughout its life time. Therefore, the effects of the changes should be known in the design state by going through some calculation. Collectively, the information obtained through calculation is known as hydrostatic data.

Hydrostatic data consists of center of buoyancy above keel (KB), transverse metacenter above keel (KM), CB aft of amidships, CF aft of amidships, displacement, tonnef per centimeter immersion (TPC) and moment to change trim one centimeter (MTc). This data can be used to plot against draught to form hydrostatic curves.

Tonnef per centimeter immersion (TPC) is a device used in ship design to find the approximate parallel sinkage of a ship due to addition of weight. TPC are calculated for all waterplanes for a ship, forming an important part of the hydrostatic data.

Moment to change trim one centimeter (MTc) is the amount of moment that act above the center of floatation and cause the difference between the draught forward and aft as many as one centimeter(*K J Rawson and E C Tupper* 2001a).

2.2.3 Hydrostatic Pressure

Hydrostatic pressure is the pressure causing by the water that acting on the surface of an object.

The hydrostatic pressure of liquid on the submerged portion of a structure follows the simple relationship:

$$P = \rho h$$

where P = unit pressure

ρ = density of the fluid

h = the depth of water (*P.Kumar Mehta*, 1991)

2.3 Materials

2.3.1 Ferrocement

Ferrocement is a composite material and it is used in construction around the world. Basically, ferrocement is a cement-rich mortar reinforced with layers of wire mesh. National Academy of Science (1973) states that ferrocement is a highly versatile form of reinforced concrete made of wire mesh, sand, water, and cement, which possesses unique qualities of strength and serviceability.

2.3.2 Historical background

Ferrocement has been established for quite a long time and it is related to the establishment of reinforced concrete and ferrocement boat. National Academy of Science (1973) reported that the first known example of reinforced concrete was a ferrocement boat. Joseph-Louis Lambot's original French patents on wire-reinforced boat were issued in 1847 not long after the development of Portland cement as shown in Figure 2.4.

Figure 2.4 Lambot's original boat built in 1848 now rests in the Brignoles Museum in France. *(National Academy of Science,* 1973*)*

The concept of ferrocement is widely used in ship and barges building during both World War I and World War II. It was the time of the US military facing the shortage of steel for ship and barges building. Therefore, US military ordered the construction of small fleets of ocean-going concrete ships, the largest of which was SS Selma.

In the early 1940's, Pier Luigi Nervi considered ferrocement as a boatbuilding material and it is started using it in Italy. He modified the original ferrocement concept when he found that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristic of an approximately homogenous material and capable of resisting high impact. *(National Academy of Science,* 1973*)*

After World War II, Nervi demonstrated the ability of the ferrocement boat. He built the ship called "Irene", had 165 ton of displacement with a ferrocement hull 1.38inch (35mm) of thickness. According to Nervi, the ship was 5 percent lighter and costing 40 percent less than a similar hull made of wood.

Despite this evidence that ferrocement was an adequate and economical boatbuilding material, it gained wide acceptance only in the early 1960's in the United Kingdom, New Zealand, and Australia. *(National Academy of Science,* 1973*)*

2.3.3 Advantages of ferrocement

Actually, ferrocement can contributed a lot of advantages in the construction. The materials needed in mixing ferrocement like ordinary Portland cement, sand and wire mesh are available in most of the countries. National Academy of Science (1973) notes that its (ferrocement) basic raw materials are available in most countries.

Ferrocement also can be shaped into any shape easily based on the users' needs. It is more durable than other construction materials like woods and steel if it is properly fabricated.

"*It can be fabricated into almost any shape to meet the needs of the user; traditional designs can be reproduced and often improved. Properly fabricated, it is more durable than most woods and much cheaper than imported steel, and it can be used as a substitute for these materials in many applications."* (National Academy of Science, *1973*)

Ferrocement also does not need any complicated skill or technology to produce it.

"Ferrocement construction does not need heavy plant or machinery." (National Academy of Science, *1973*)

Use of ferrocement also can help in saving the construction cost and maintenance cost.

"Use of ferrocement will result in saving in cement and steel to the steel to the extent of 50 per cent in building and other allied industries. At the same time, the structures constructed with ferrocement will be more efficient, durable, strong and maintenance free. This will be an added saving in the economy in addition to saving in huge cost of corrosion management and prevention. Ferrocement structures last much longer than similar steel structures. The use of ferrocement will reduce the requirement of raw materials such as iron ore for steel and limestone etc., for cement."(J.A.Desai, 2008*)*

Besides that, ferrocement also perform well in earthquake where it is extremely flexible, as the load of the structure is widely distributed. It is also fire resistant.

2.3.4 Ferrocement materials

Generally, ferrocement is a thin shell of highly reinforced Portland cement mortar which consists of wire mesh, cement, sand and water.

Various kind of reinforcing mesh can be used in constructing ferrocement structures. The basic requirement in selecting reinforcing mesh is flexibility. People commonly will use chicken wire because it is the cheapest and easier to use. National Academy of Science (1973) reported that chicken wire mesh is adequate for structural requirement of most boats in developing countries and for all uses on land but it also states that chicken mesh is not the most recommended mesh for high performance structures.

National Academy of Science (1973) also informed that the quality of cement used is not too critical. Ordinary Type 1 or 2 Portland cement is adequate; grades for more specific purpose are unnecessary even for boatbuilding.

The grade of the sand used is seldom important unless to improve the mortar workability. The adequate sand is volcanic sands and beach sand as state by National Academy of Science (1973). Organic debris and silt should be washed out because they do not bond to the mortar and this will reduce the strength of the ferrocement.

Lastly, the water especially the water containing impurities should be filtered and purified before using in mixing process.

2.3.5 Applications of ferrocement

Ferrocement is a very useful composite material which is widely used in various applications. Ferrocement mainly used to build homes, boats, food-storage facilities, food technology, low cost roofing, disaster relief, bridges, and a variety of other structures.

National Academy of Science (1973) concludes the following potential applications of ferrocement (See Figure 2.5).

- Fishing and Cargo Boats
- Tugs and Barges
- Bridges
- Docks and Marinas
- Permanent food-storage dumps
- Seed (vegetables, etc.) storage
- Starch, flour, sugar storage
- Silage storage
- Edible oil storage (olive, peanut, cottonseed, palm, etc.)
- Grain storage (rice, wheat, corn, sorghum, millet, etc.)
- Manioc-soaking vats
- Fermentation tanks for cocoa, coffee, etc.
- Retting tanks for sisal, jute, hemp, etc.
- Gas tanks (for liquid and natural gas)
- Cooling towers
- Sewage troughs, lagoons, septic tanks, and other treatment facilities
- Guttering
- Leather-processing facilities
- Dyeing vats
- Grain dryers
- Copra dryers
- Greenhouse, packinghouse, and drying tables
- Pads for drying tea, coffee, cocoa, coconuts, other oilseeds, peppers, spices, etc.
- Cattle feeders and water troughs
- Cattle dips
- Water storage (drinking or irrigation)
- Pipes and irrigation conduits
- Ovens and fireplaces
- Slabs or shingles for roofs
- Decorative panels and tiles
- Wall paneling
- Floors
- Telephone and power poles
- Lining for tunnels and mines
- Stakes for supporting vine crops, tomatoes, beans, etc. (for termite resistance)
- Pothole repairs (squares of ferro-cement sized and laid in the hole)
- Timber-treatment enclosures
- Shutters and formwork for use in standard concrete construction

Figure 2.5 Potential applications of ferrocement

J.A.Desai (2008) also states that ferrocement has been in use for about 50 years for construction of boats, ships, roofs, irrigation like gates and other allied structures as well as houses, swimming pools, bridges, walkways, jetties and water storage tanks. Lots of square feet of ferrocement plates have been constructed and used in water storage structures, roofing etc.

2.3.6 Process in using ferrocement as building materials

To construct something from ferrocement, someone starts by creating a frame of wire mesh. The mesh is often layered to create a matrix. Then, a mixture of cement, sand, and water is produced. Next, spread the mixture over the frame to produce a very thin concrete layer (See Figure 2.7 and Figure 2.8). After that, the ferrocement structure is allowed to cure. The curing time is varies depend on the climate and situation. Finally, the strong and thin structures are produced. The whole process is shown in Figure 2.6.

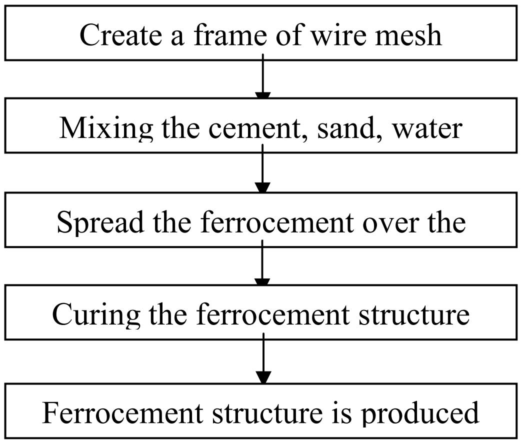


Figure 2.6 Ferrocement structure construction process

Figure 2.7 A paste of mortar is forced into the layers of mesh by hand

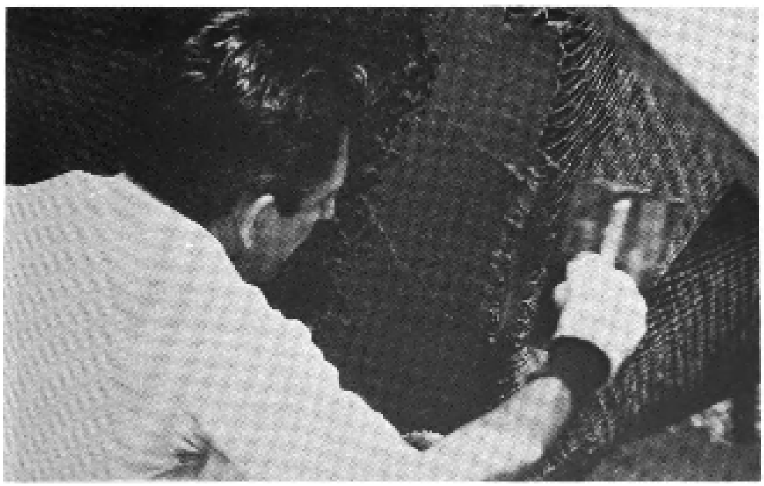


Figure 2.8 The mortar is dried enough to remain in place when applied. A formwork is not needed.

2.3.6.1 Building A Ferrocement Boat

Based on National Academy of Science (1973), there are five fundamental steps in ferrocement boat construction:

1. The shape is outlined by a framing system.
2. Layers of wire mesh and reinforcing rod are laid over the framing system and tightly bound together.
3. The mortar is plastered into the layers of mesh and rod.
4. The structure is kept damp to cure.
5. The framing system is removed (though sometimes it is designed to remain as an internal support).

2.3.6.2 Ferrocement Food-Storage Silos in Thailand *(National Academy of Science,* 1973*)*

In Thailand, a family cheap, airtight bins made of ferrocement are sized to hold 4-10 tons of grain, other foodstuffs (e.g., peanuts, soybeans), salt, fertilizer, pesticide, cement, or 2000-5000 gallons of drinking water. These kinds of ferrocement bins are watertight and airtight.

The ferrocement bins can be easily constructed without using any heavy machinery and technically skills. The base of the Thailo is soucer shaped and it consists of two layers of 5 cm thick concrete (1 cement : 0.5 sand : 2 aggregate) with mesh reinforcement and an asphalt seal between as added protection at building sites subject to flooding (See Figure 2.9).

Its wall is reinforced with 2m long poles (water pipe or bamboo), reinforcing rods, and one layer of wire mesh on internal and external faces (See Figure 2.10). The mortar is mixed by hand and it is applied as a thick paste using trowels and fingers. The wall mortar consists of 1 part of standard cement, 1.75 parts sand with the optional addition of a plasticizer to improve workability. The water/cement ratio applied is approximately 0.3 with only enough water for the hydration and no excess moisture are left in the ferrocement which produce an impermeable ferrocement.

Finally, the structure is curing for several days under moistened sacking to avoid direct exposure to the drying effects of sunlight and wind are paramount construction considerations. Then, the bin can be tested by filling it with water for 1 week which is an excellent quality control test because the water is heavier than any other products is likely to be store. Any cracks or weak section caused by poor workmanship can be seen as leaks.

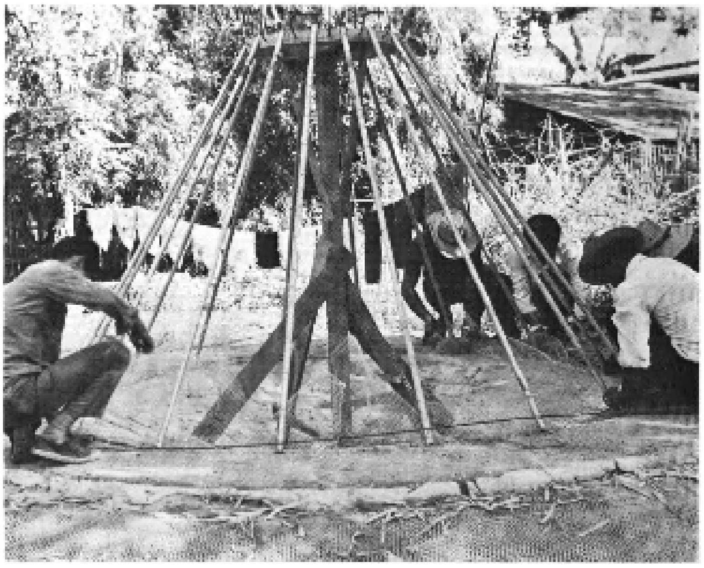


Figure 2.9 Construction of the walls after the base is complete. Mesh is integrated into the walls from base which is strengthened with waterpipes or bamboo struts. Then horizontal hoops of reinforcing rod are wired to the struts. *(Applied Scientific Research Corporation of Thailand)*

Figure 2.10 The frame is completed with one layer of wire mesh on the outside surface and one on the inside. Mesh, reinforcing rods, and struts are fastened together with short lengths of wire threaded through the wall and back and twist-tied with pliers. *(Applied Scientific Research Corporation of Thailand)*

2.4 Guideline for Design

2.4.1 BS8110-1:200

BS8110-1:2000 is the code of practice for structural use of concrete structures designs in British Standard. It provides recommendations for the structural use of concrete in buildings and structures, excluding bridges and structural concrete made with high alumina cement.

2.4.2 BS5268-2:2002

BS5268-2:2002is the code of practice for design of timber structures for structural use in British Standard. It provides guidance on the structural use of timber, glued laminated timber, plywood and other panel products in load-bearing members.

It includes recommendations on quality, grade stresses and modification factors applicable to these materials when used as simple members, or parts of built-up components, or as parts of structure incorporating other materials.

It also gives recommendations for the design of nailed, screwed, bolted, dowelled, connectored and glued joints. In addition, it provides recommendations for a method of test to assess the adequacy of structural assemblies, and it includes general advice on workmanship, various treatments which can be applied, inspection and maintenance.

2.5 Simulation Software

2.5.1 Multiframe

Multiframe is a structural engineering design and analysis software produced by FormSys company. FormSys stated that Multiframe is a suite of structural analysis and design software that works the way structural engineers do.

Multiframe gives intuitive, true windows interface, dynamic 3D visualization, comprehensive analysis and interactive summaries of results. Multiframe provides linear and non-linear analysis, static and dynamic options and buckling calculations. After the analysis, it comes out with the full report including the design and results.

2.5.2 Maxsurf

Maxsurf is software used by naval architects to model hull forms, access stability and strength, predict performance and carry out initial structural definition. It is created by Formsys. It works together with another seven programs such as Maxsurf Pro, Hydromax, Workshop, Hullspeed, Prefit, Hydrolink, Span and Seakeeper.

According Formsys, Maxsurf has the ability to generate any type of hull form, and to nearly any degree of complexity, including dynamically trimmed surfaces, myriad modeling aids and fairing tools, upright hydrostatic analysis, surface areas, centers and moments, offset data, and export to DXF / DWG for further detailing in the CAD program.

2.6 Recent Technologies

2.6.1 Very Large Floating Structures (VLFS)

Actually there is not an acceptable definition for very large floating structures (VLFS). One roughly definition VLFS can be defined as a floating structure that is very big in size placed on the water surface for its whole service life. H.R.Riggs defined it as a floating structure whose characteristics, especially its size and flexibility, require for its design, construction, and operation special consideration not required by conventional-sized floating structures. Basically, VLFS can be divided into two types which are semi-submersible-type and the pontoon type.

Semi-submersible-type floating structures are raised above the sea level using column tubes or ballast structural elements in order to minimize the effects of waves while maintaining a constant buoyancy force. Thus, they can reduce the wave-induced motion and are, therefore, suitably developed in high seas with large waves. (*C.M.Wang et al*, 2006)

In the other hand, pontoon-type floating structures lie on the sea level like a giant plate floating on water. These pontoon-type floating structures are suitable for application in calm waters, often inside a cove or a lagoon and near the shoreline. (*C.M.Wang et al*, 2006)

2.6.2 The Design of the Winston Land-Locked Floating House *(Winston International Corporation, 2005-2009)*

Winston Land-Locked Floating House (WLFH) (See Figure 2.11) has been designed by Winston International Corporation to protect people, their housing, automobiles, and all their precious belongings against devastating floods. The detailed design of the floating house can be seen in Figure 2.12, Figure 2.13 and Figure 2.14.

Winston International Corporation stated that the system is composed of telescoping piers set in concrete anchors supporting a catamaran floatation base attached to one, two, or three story buildings. These structure will rise above any recorded flood and float back to their original positions as the flood recedes.

Winston International Corporation also stated that this technology has been fully tested by accredited testing laboratories using computer testing methods. Test results state that “any Winston house can be analysed for any geographical area to withstand floods up to five feet above the recorded 500 year level.”

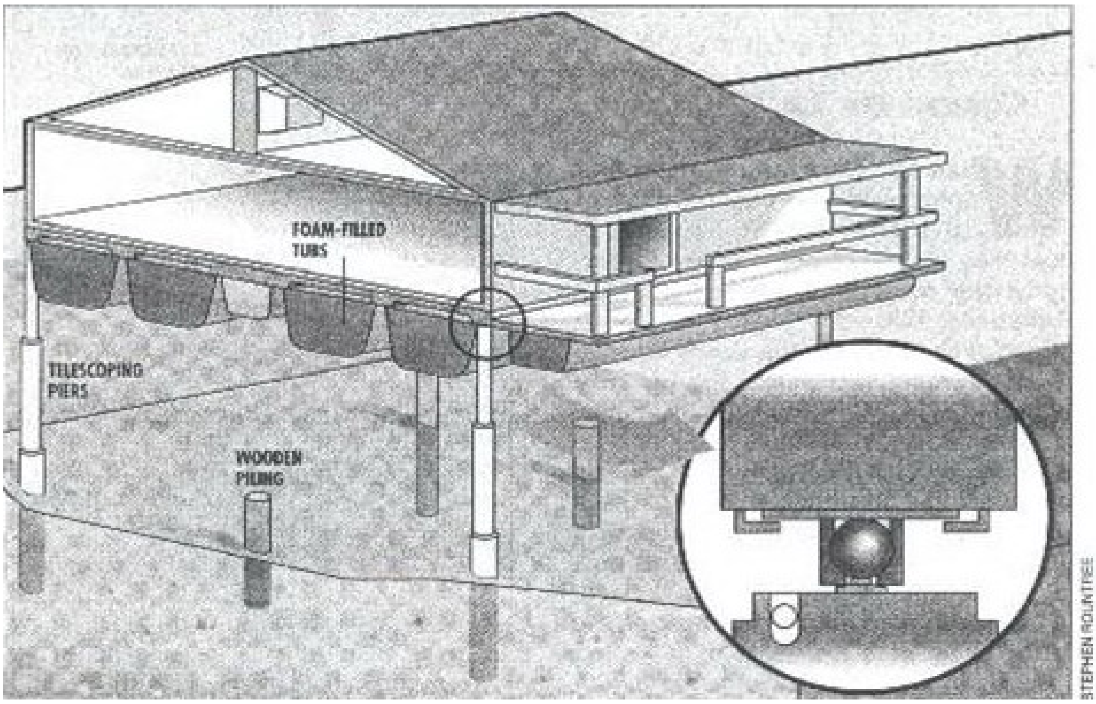


Figure 2.11 View of the Winston Land- Locked Floating House *(Judith Anne Gunther, 1995)*

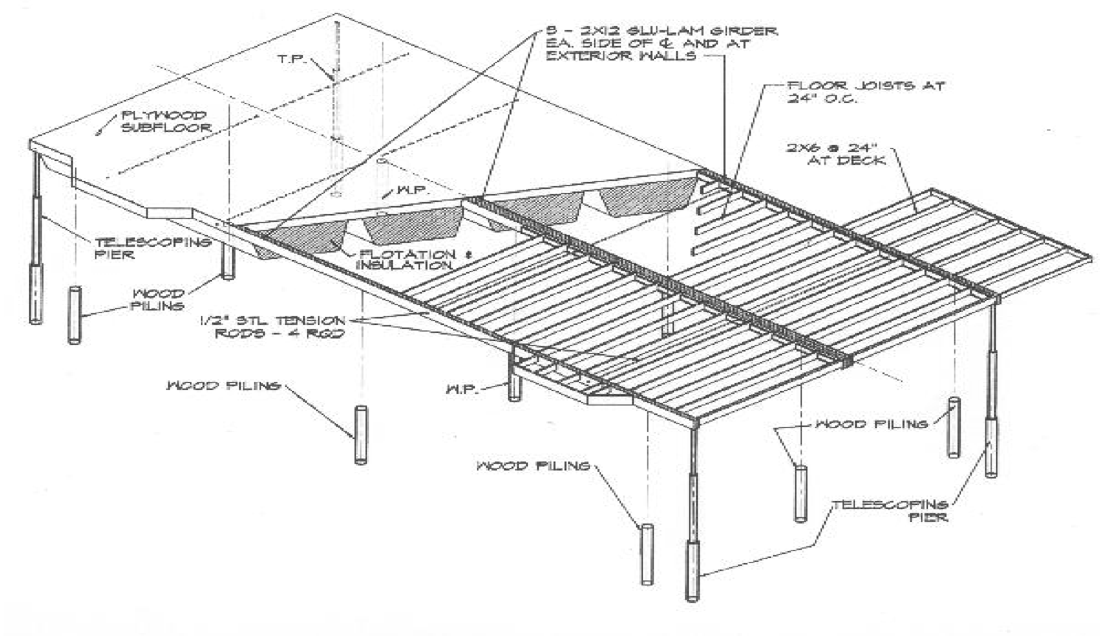


Figure 2.12 Detail design of the system *(Winston International Corporation, 2005-2009)*

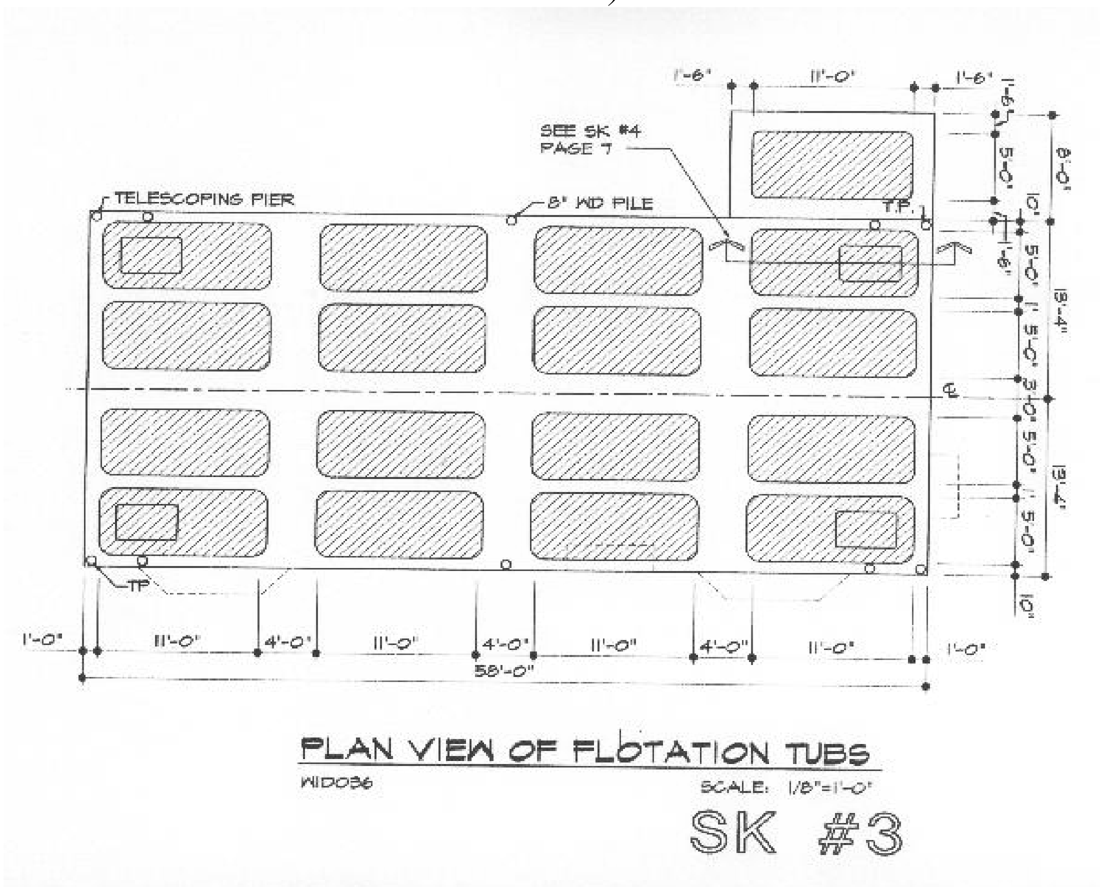


Figure 2.13 Plan view of the floatation tubs *(Winston International Corporation, 2005-2009)*

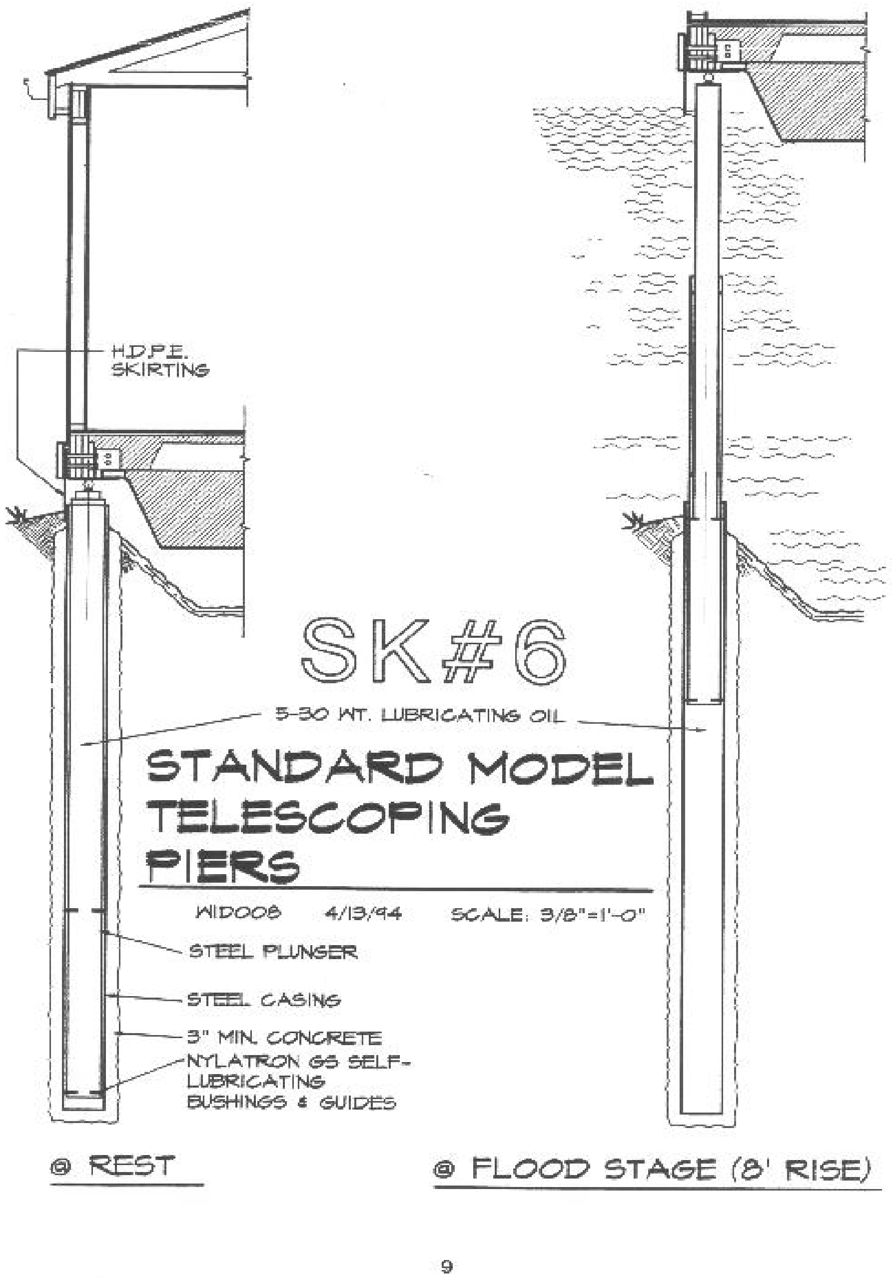


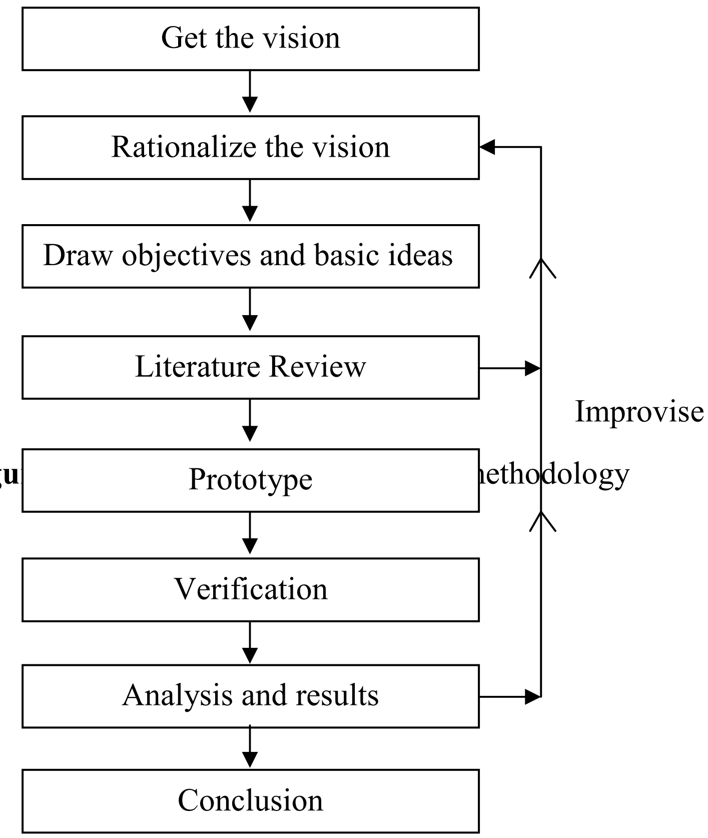
Figure 2.14 Design of the telescoping piers *(Winston International Corporation, 2005-2009)*

CHAPTER 3

METHODOLOGY

3.1 Introduction

In order to achieve the listed objectives in Chapter 1 along with guidelines and references in Chapter 2, various methods are used to conduct this research. Based on Figure 3.1, at the very beginning stage of this research, a clear objective and basic ideas are drawn to create a systematic and smooth process throughout the research.



Figu ethodology

3.2 Model Prototyping

The steps of prototyping underwent a systematic process of structural engineering as shown Figure 3.2.

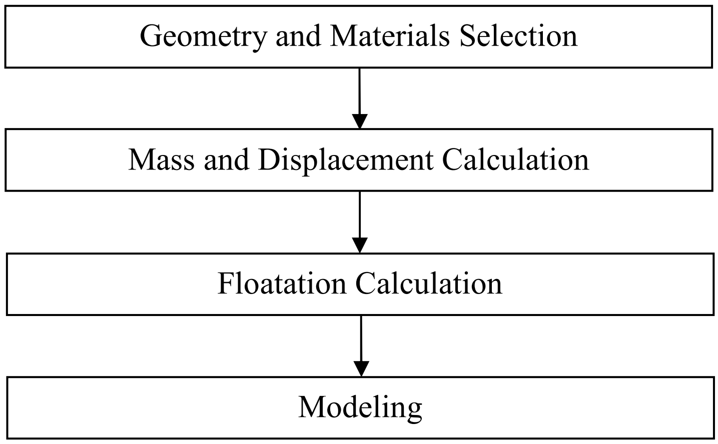


Figure 3.2 A flowchart of steps for prototype process

3.2.1 Geometry and Materials Selection

The floating structure is designed with size of 3.2m x 3.2m x 1.1m that able to accommodate 4 persons with their food and drink for one day to stay and particularly move around. It also serves as compartment to be placed inside rooms of IBS buildings. Ferrocement is selected as the main material for the structure because it is durable and it is essential in thin shell structure construction. The wire mesh and chicken mesh are used as ferrocement and with sizes of 150mm x 150mm x 4.2mm and 50mm x 50mm x1.5mm.

Before there would be ferrocement walls in the middle of the pontoon to prevent deflection failure, but the walls would cause the structure heavy weight. The truss system is used to replace the wall to increase the floatation of the structure. To make the structure useable for other purposes when there is no flood, the top cover is designed using timber that able to be removed easily. The thin timber sections have check against deflection failure and the timber section is redesigned as T-section.

3.2.2 Mass and Displacement Calculation

Ferrocement Cover

Mass of ferrocement cover, M_{cf} = V_{cf} x ρ

where V_{cf} = Volume for ferrocement cover, m^3
ρ = Density for ferrocement (2400kg/m^3)

Volume for ferrocement cover, V_{cf} = L x W x t

where L = length, m
W = width, m
t = thickness, m

Timber Cover

Volume for timber section, V_{ct} = (L x W x H) – 2(l x w x h)
Mass of timber cover, M_{ct} = V_{cf} x ρ x n

where n_1 = number of timber section

Truss

Volume of truss beam void space, V_{bv} = L x W x H
Volume of truss beam, Vtb = L x W x H

Mass of hollow truss beam, V_{hb} $= n_2 (V_{tb} - V_{bv}) \times \rho_{steel}$

where n_2 = number of truss beam

Volume of truss column void space, V_{cv} = L x W x H

Volume of truss column, Vtc = L x W x H

Mass of hollow truss column, V_{hc} $= n_3 (V_{tc} - V_{cv}) \times \rho_{steel}$

where n_3 = number of truss column

Volume of truss center column void space, V_{ccv} = L x W x H

Volume of truss center column, V_{tcc} = L x W x H

Mass of hollow truss center column, V_{hcc} $= (V_{tcc} - V_{ccv}) \times \rho_{steel}$

Volume of truss brace void space, V_{bbv} = L x W x H

Volume of truss brace, V_{tbb} = L x W x H

Mass of hollow truss brace, V_{hbb} $= n_4 (V_{tbb} - V_{bbv}) \times \rho_{steel}$

where n_4 = number of truss brace

Mass of the whole truss, M_T $= M_{hb} + M_{hc} + M_{hcc} + M_{hbb}$

Body Mass

Volume of void body mass, V_{vb} = L x W x H

Volume of body mass, V_b = L x W x H

Body Mass, M_B $= (V_b - V_{vb}) \times \rho$

Load

Load = 4 x weight per person + weight of food and drink per person per day

Weight per person = 70kg

Weight for food and drink per person per day = 8kg

Displacement without load

For Sample 1 and Sample 2

Total mass without load, D = $M_T + M_B + M_{cf}$

For Sample 3 and Sample 4

Total mass without load, D = $M_T + M_B + M_{ct}$

Displacement with load

For Sample 1 and Sample 2

Total mass with load, D = $M_T + M_B + M_{cf}$ + Load

For Sample 3 and Sample 4

Total mass with load, D = $M_T + M_B + M_{ct}$ + Load

3.2.3 Floatation

If the Design Water Level is lower than the height of the structure, then the structure is floating and addition of load is permitted.

Design water level, DWL $= \frac{D}{LxWx\rho}$

where D = Total mass with load or without load, kg

L = Length of the structure, m

W = Width of the structure, m

ρ = Water density ($1000kg/m^3$)

3.2.4 Modeling

Four prototype models (Figure 3.3) are modeled in Maxsurf for Upright Hydrostatic, Large Angle Stability and Longitudinal Strength analyses. The properties for each prototype models are listed in Table 3.1.

Table 3.1 Properties of the prototype models

Prototype Model	**1**	**2**	**3**	**4**
Materials	F & S	F & S	F, S & T	F, S & T
Thickness of ferrocement structure (mm)	40	50	40	50
Top Cover Material	F	F	T	T
Truss Material	S			
Body Material	F			
*F = Ferrocement *S = Steel *T = Timber				

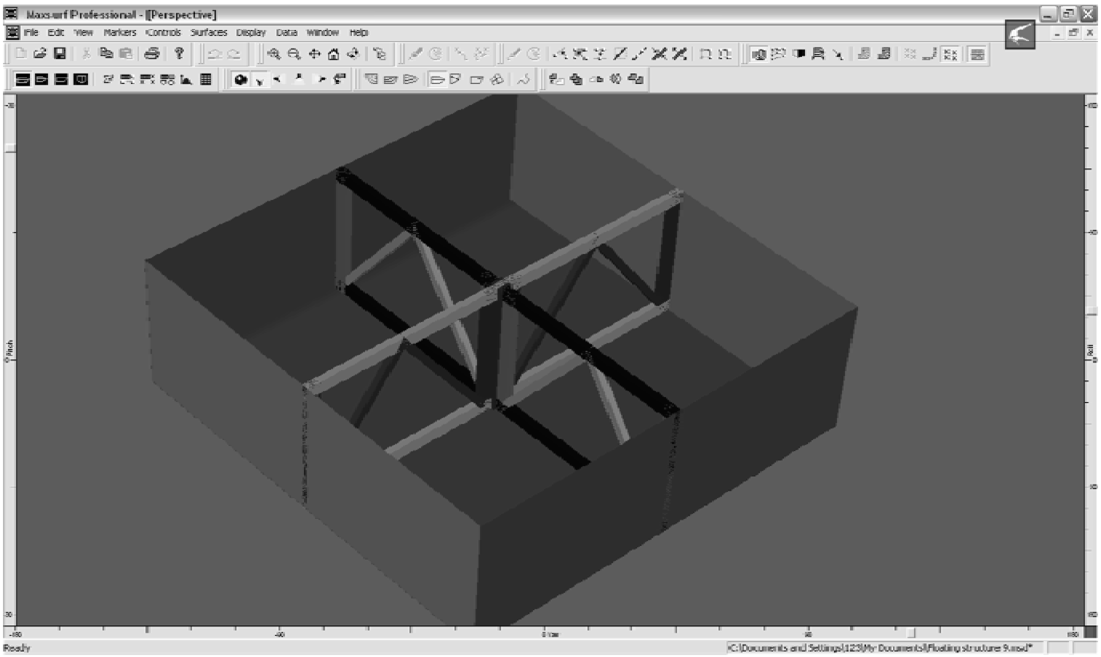


Figure 3.3 Prototype modeling in Maxsurf

Besides that, the truss system (Figure 3.4) and timber section (Figure 3.6) are modeled in Multiframe for their capacity analysis. For truss system, the steel sections used are 100 x 50 x 5RHS (top chord, bottom chord and vertical member), 50 x 50 x 5SHS (bracings) and 100 x 100 x 5SHS (center column) respectively. The truss system is a combination of four truss dimension as 1.5m x 1m is used in this research as shown in Figure 3.4.

Timber sections (Figure 3.5) are used in Prototype Model 3 and 4 to replace the ferrocement cover. The timber used is D35 strength class of hardwood specified in BS5268-2:2002. The timber sections properties are shown in Table 3.2.

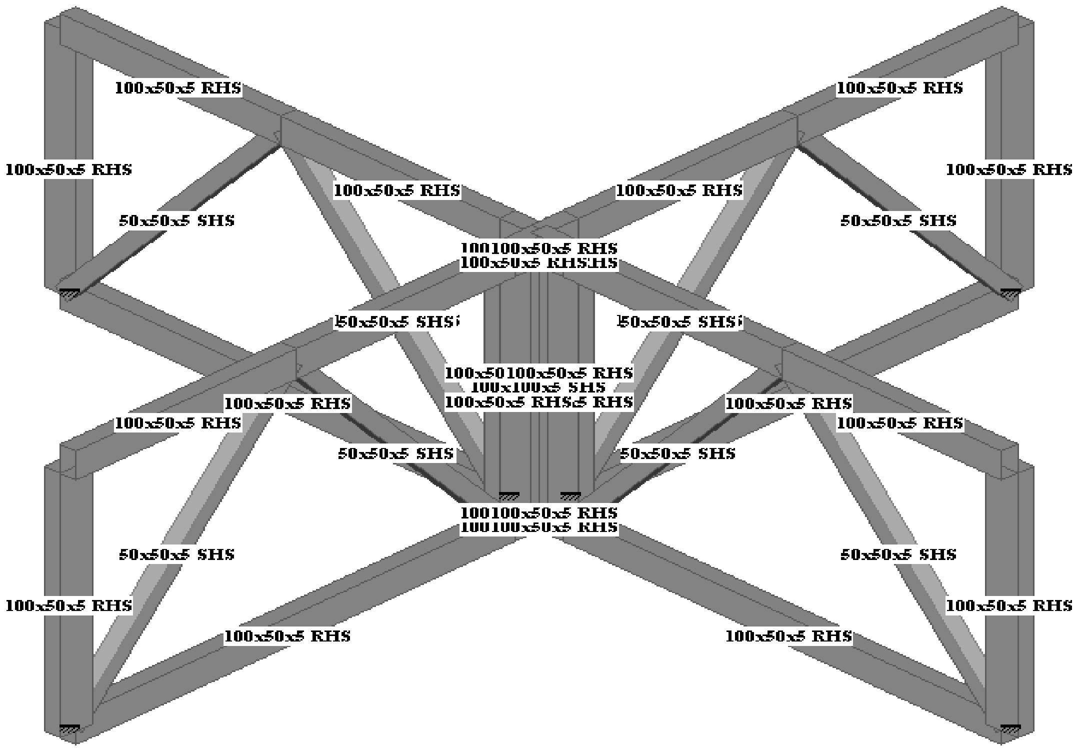


Figure 3.4 Truss system modeling in Multiframe

Table 3.2 Timber section properties

	Property	Value	Units
1	Weight	2.127	kg/m
2	Area	37.980	cm^2
3	D	50	mm
4	B	203.2	mm
5	t	15	mm
6	ρ,density	670	kg/m^3

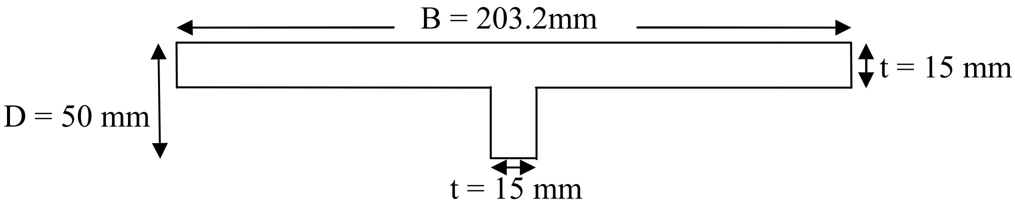


Figure 3.5 Timber section detailing

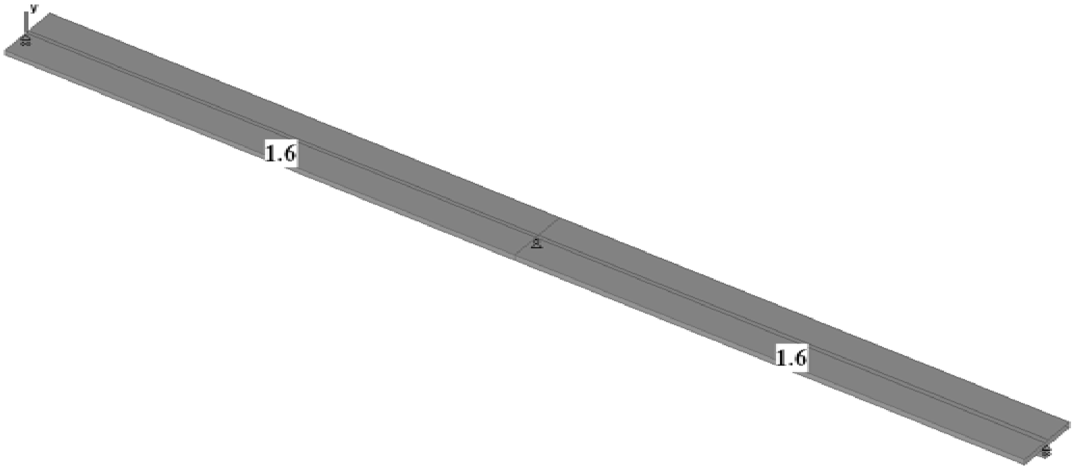


Figure 3.6 Timber section modeling in Multiframe

3.3 Verification

The description of verification is to present a procedure for control for structural detailed design of floating structures. The objective of verification is to guarantee that the final product is in accordance with available compliance and specifications.

3.4 Analyses

The analyses are divided into ferrocement slab capacity check, truss member capacity check, timber section capacity check, Upright Hydrostatic analysis and Large Angle Stability. Three load cases are used in the Longitudinal Strength analysis and Large Angle Stability analysis in Hydromax.

3.4.1 Load Cases

There are three load cases used in Longitudinal Strength analysis and Large Angle Stability analysis in Hydromax. Load Case 1 (Figure 3.7) is designed as four persons with their one day food and drink ration are stayed in the middle of the prototype models. Load Case 2 (Figure 3.8) is designed as four persons with their one day food and drink ration are stayed at corner of the prototype models. Load Case 3 (Figure 3.9) is designed as two persons with their one day food and drink ration are stayed at one corner of the prototype models and another two persons at the opposite corner.

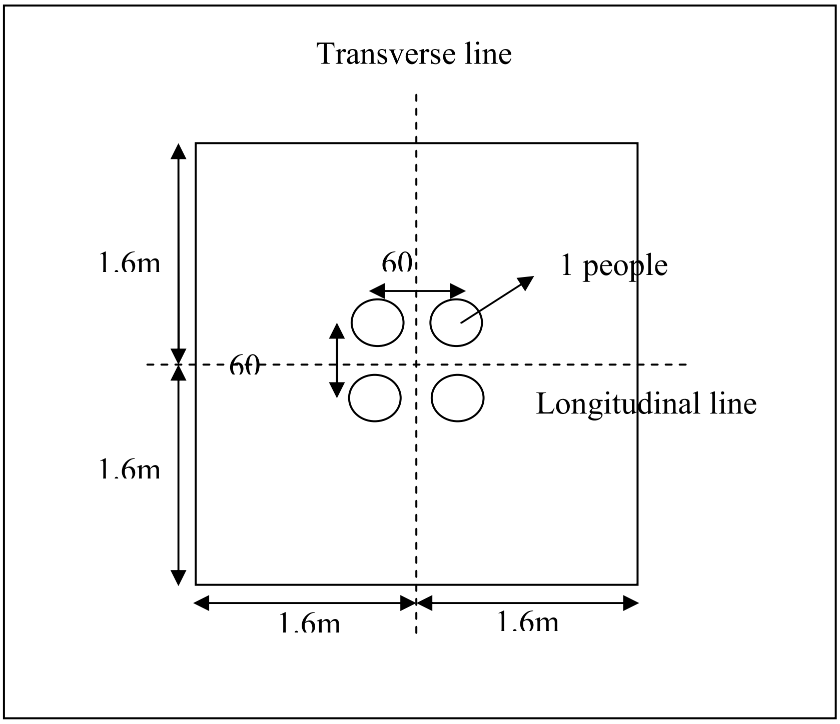


Figure 3.7 Load Case 1

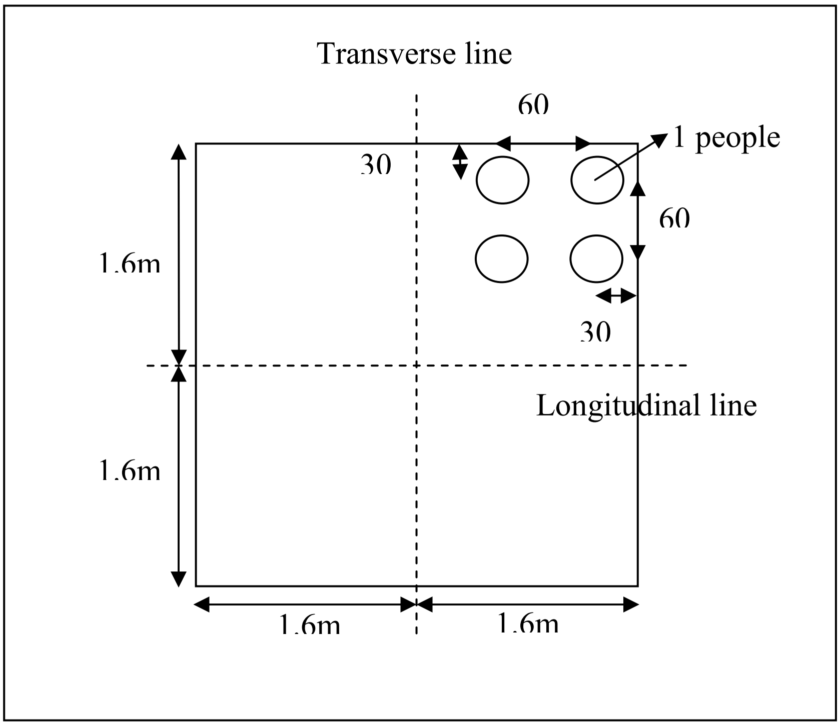


Figure 3.8 Load Case 2

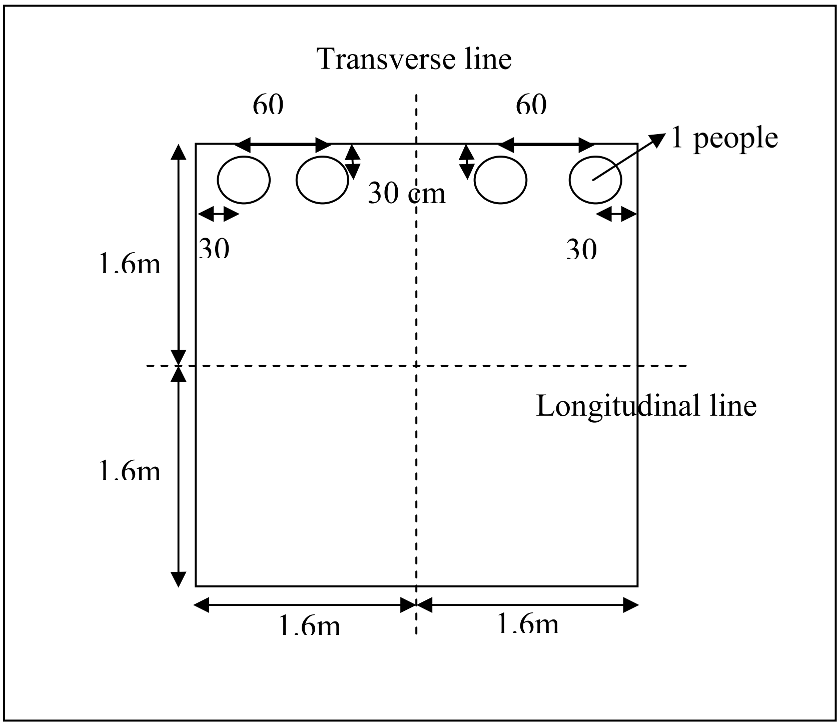


Figure 3.9 Load Case 3

3.4.2 Ferrocement Slab Capacity Check

Ferrocement slab capacity check is divided into Longitudinal Strength analysis, manual calculations for moment and shear due to surface pressure and manual calculations on ferrocement slab capacity.

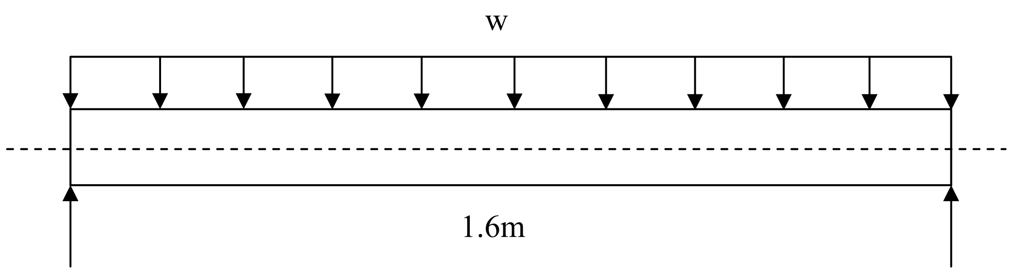
3.4.2.1 Longitudinal Strength analysis

Longitudinal Strength analysis is carried out in Hydromax on the prototype models against the load cases condition stated in Section 3.4.1. The analysis settings are shown in Table 3.3.

Table 3.3 Longitudinal Strength Settings

	Property	Value	Units
1	Water Density	1000	Kg/m^3
2	Wave Height	0.2	m
3	Wave Length	1.2	m
4	DWL	*Refer to floatation Calculation	m
5	Load Case	*Refer to Section 3.4.1	

3.4.2.2 Moment and Shear due to Surface Pressure



Surface pressure, w = ρ_{water} x H x 9.81

Maximum moment, M = $wL^2 / 2$

Maximum Shear, V = wL / 2

where ρ_{water} = water density ($1000 kg/m^3$)

L = Length of span

H = Height of the structure

3.4.2.3 Ferrocement Slab Capacity

The ferrocement slab capacity is calculated manually based on the procedure provided in BS 8110. The calculation steps are like below.

Sectional Area per meter width, As for wire mesh:

$$A_{sw} = \frac{\pi D^2}{4} \text{ x n}$$

where D = diameter of the wire mesh

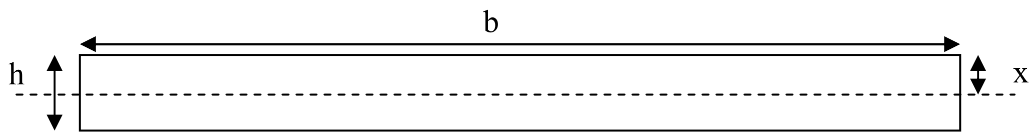
n = no of wire mesh bar per meter

Sectional Area per meter width, As for chicken mesh:

$$A_{sw} = \frac{\pi D^2}{4} \text{ x n}$$

where D = diameter of the chicken mesh

n = no of chicken mesh bar per meter



Moment Capacity, M

$d = h - c - \phi_{bar}/2$

$x = d/ [1 + (0.0022/0.0035]$

$M_{st} = (0.87 f_y As)(d - 0.45x)$

$M_{cc} = (0.405x/d)(1 - 0.45x / d)(f_{cu} bd^2)$

$M = M_{st} + M_{cc}$

Shear Capacity, V

$v_c = 0.79\{100As/(bd)\}^{1/3}(400/d)^{1/4}(f_{cu}/25)^{1/3}/1.15$

$V = v_c bd$

3.4.3 Truss member capacity

Truss member capacity is analysed in Multiframe against the most critical condition with uniform load due to ferrocement cover self weight and 2 point caused by 4 persons and their food and drink for one day. The load case used in the truss member analysis is shown in Figure 3.10.

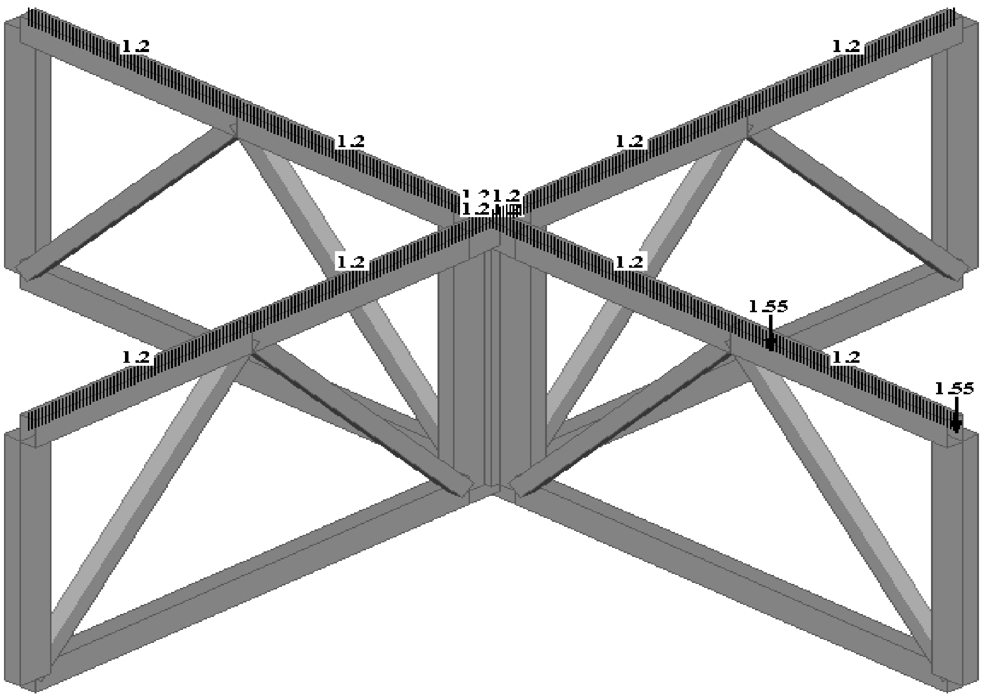


Figure 3.10 Load case used for truss analysis in Multiframe

3.4.4 Timber section capacity

Timber section capacity is analysed in Multiframe against the most critical condition with uniform load due to 2 persons with their food and drink for one day on the same plate of timber. The loadcase used in the timber section analysis is shown in Figure 3.11.

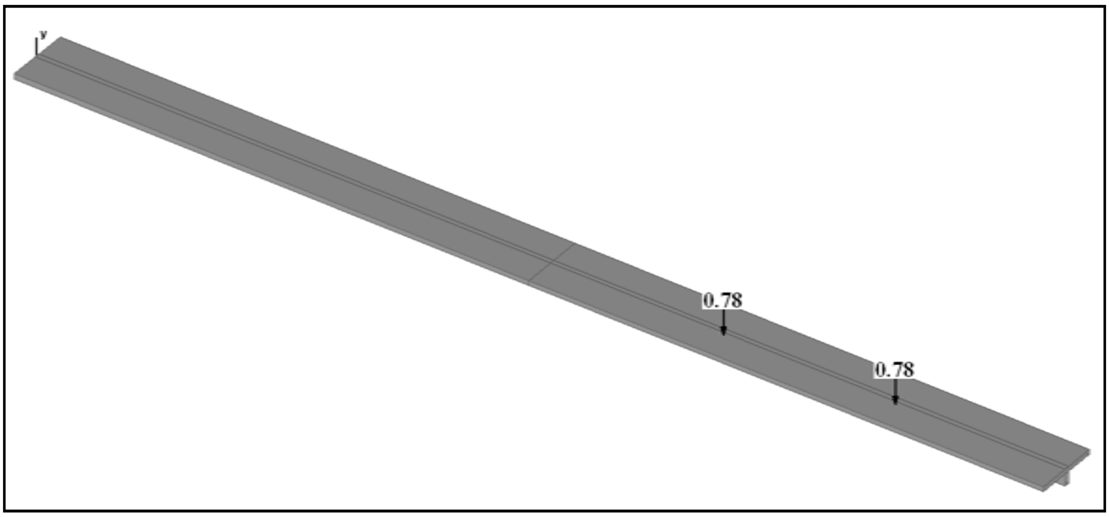


Figure 3.11 Load case used for timber section analysis in Multiframe

3.4.5 Upright Hydrostatic

Upright Hydrostatic analysis gives basic knowledge on floating structures behavior before more detailed analyses are carried out onto the structures. Upright hydrostatic analysis is carried out for all prototype models in Hydromax. The analysis settings are shown in Table 3.4.

Table 3.4 Upright Hydrostatic settings

	Property	Value	Units
1	Water Density	1000	Kg/m^3
2	Wave Height	0.2	m
3	Wave Length	1.2	m
4	DWL	*Refer to floatation Calculation	m
5	Initial draft	0	m
6	Final draft	1	m
7	Number of drafts	10	
8	VCG	*Refer to Table	m

$$\text{Vertical center gravity, VCG} = \Sigma xM / \Sigma M$$

where x = Distance from datum

M = Mass of the respective section

Table 3.5 VCG for each prototype model

Prototype Model	VCG (m)
1	0.5500
2	0.5500
3	0.1029
4	0.1076

3.4.6 Large Angle Stability

Large Angle Stability analysis is carried out onto all prototype models in Hydromax to find out that the stability of each prototype model against the load cases stated in Section 3.4.1. The analysis settings are shown in Table 3.6.

Table 3.6 Large Angle Stability settings

	Property	Value	Units
1	Water Density	1000	Kg/m^3
2	Wave Height	0.2	m
3	Wave Length	1.2	m
4	DWL	*Refer to Floatation Calculation	m
5	Heel angle	0-90	deg
6	Heel direction	Starboard	
8	VCG	*Refer to Table 3.5	m

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The methodology of the research was explained in previous chapter. These include the model prototyping, modeling method and the analyse method on the floating structure. This chapter discussed about the result from the model prototyping and analysis based on materials, geometry, floatation, strength and stability of the floating structures.

4.2 Pontoon's Geometry

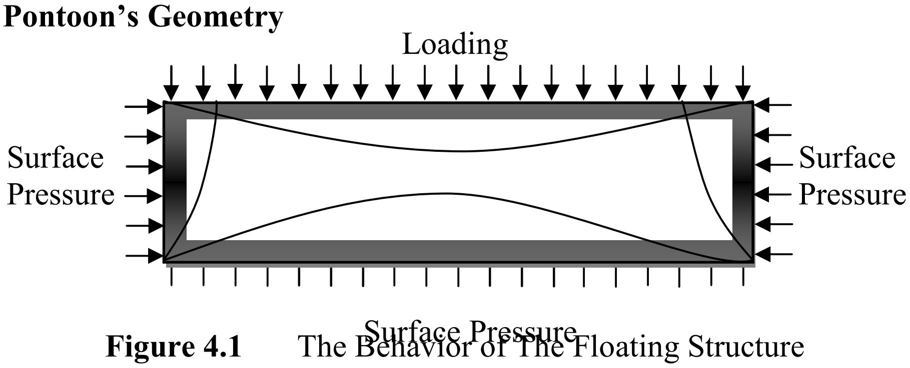


Figure 4.1 The Behavior of The Floating Structure

The schematic of the behavior of the floating structure due to surface pressure and loading is shown in Figure 4.1. The top and bottom ferrocement slab would fail in the middle of the slab due to moment. To avoid failure of slab, the truss showing in Figure 3.4 is placed inside the floating structure. Another reason of using truss as the alternative is for weight reduction of floating structure instead of using ferrocement.

Table 4.1: Results on the floating structure's geometry and materials (Appendix A)

Prototype Model	**1**	**2**	**3**	**4**
Materials	F & S	F & S	F, S & T	F, S & T
Thickness of ferrocement structure (mm)	40	50	40	50
Top Cover Material	F	F	T	T
Top Cover's Mass (kg)	983.04	1228.8	120.65	120.65
Truss Material	S			
Truss Mass	262.08			
Body Material	F			
Body mass (kg)	2269.29	2816.40	2269.29	2816.40
Load (kg)	312	312	312	312
Total Mass without load (kg)	3514.41	4307.28	2652.02	3199.13
Total Mass with load (kg)	3826.41	4619.28	2964.02	3511.13
*F = Ferrocement *S = Steel *T = Timber				

According to Table 4.1, the thickness of the ferrocement structure and the materials used for top cover would affect the weight of the floating structure. By reducing 10mm for the ferrocement structure's thickness, the weight of Prototype Model 1 is reduced as many as 792.87kg when compare to Prototype Model 2 and the weight of Prototype Model 3 is reduced as many as 547.11kg when compare to Prototype Model 4.

The weight of the floating structure would also reduce by replacing the material of the top cover with timber instead of using ferrocement. The weight of Prototype Model 3 is reduced as many as 877.38kg when compare to Prototype Model 1 while the weight of Prototype Model 4 is reduced as many as 1123.14kg when compare to Prototype Model 2.

Therefore, the overall weight of the floating structure can be reduced by reducing the thickness of the ferrocement structure and timber to float the structure at certain appropriate levels.

4.3 Design Water Level, DWL

The design water level (Table 4.2) for the simulation of the floating structure is obtained from manual calculations as shown in Section 3.2.3. The design water level without load would be used in the modeling and analysis through up the research. The detail calculations for the design water level are shown in Appendix B.

Table 4.2: Design Water Level for each prototype model

Prototype Model	1	2	3	4
Total Mass without load (kg)	3514.41	4307.28	2652.02	3199.13
Total Mass with load (kg)	3826.41	4619.28	2964.02	3511.13
DWL without load (m)	0.343	0.421	0.259	0.312
DWL with load (m)	0.373	0.451	0.289	0.343

4.4 Ferrocement Slab Capacity Check

In this section, the maximum shear force and maximum moment acting on the ferrocement floor due to the three load cases (See Section 3.4.1) and surface pressure with wave in 0.2m height and 1.2m length are obtained. Then, the values are compared to the moment and shear capacity of the slab which are calculated manually (See Appendix C). The maximum moment and shear due to load cases are obtained through Longitudinal Strength analysis in Hyromax (Figure 4.2, Figure 4.3 and Figure 4.4).

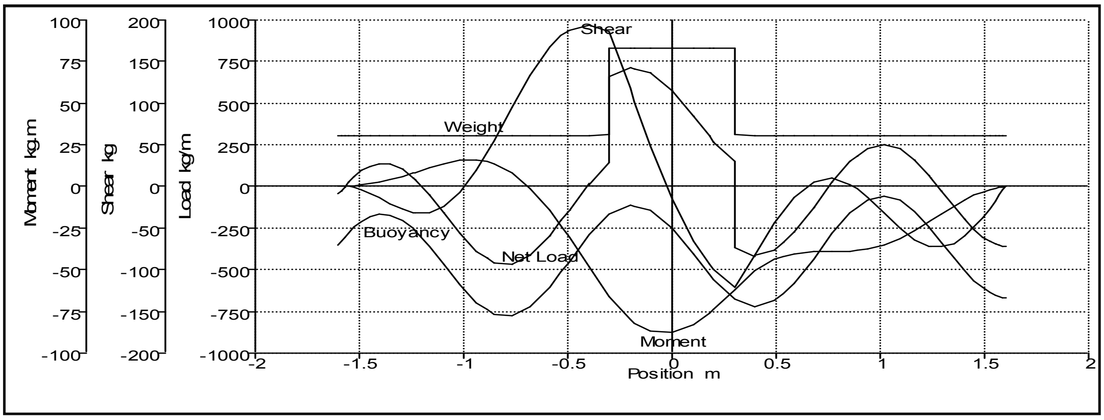


Figure 4.2 Bending Moment and Shear Force Diagram for Sample 1 due to Load Case 1

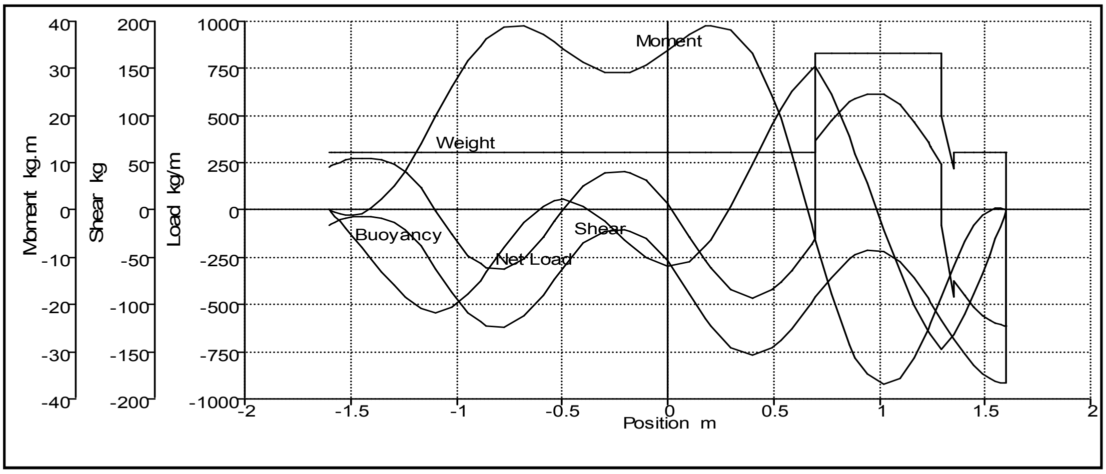


Figure 4.3 Bending Moment and Shear Force Diagram for Sample 1 due to Load Case 2

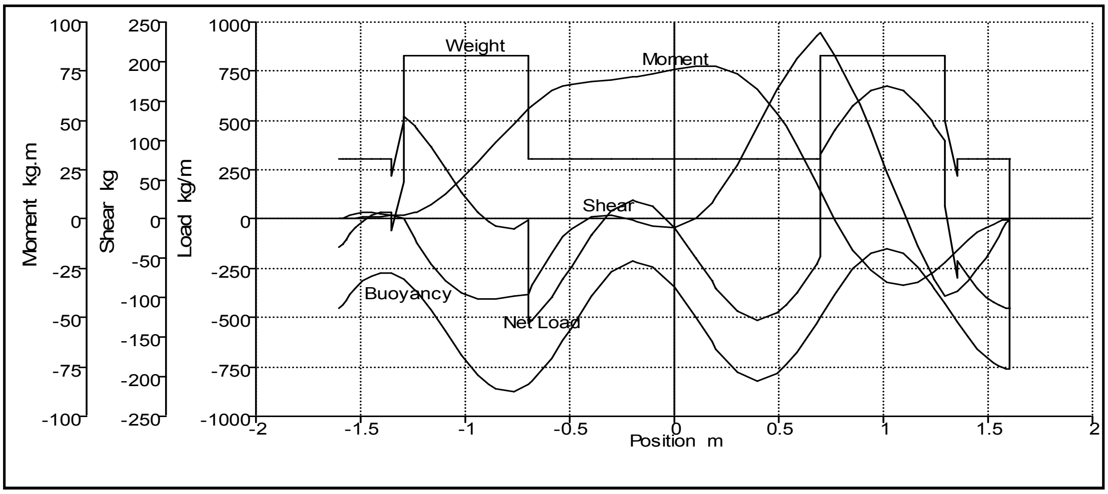


Figure 4.4 Bending Moment and Shear Force Diagram for Sample 1 due to Load Case 3

The maximum moment and the maximum shear that act on the ferrocement structure are 87.5kgm and 240kg. The maximum moment and maximum shear due to surface pressure also obtained through the manual calculation (Appendix D). The overall results are summaried in Table 4.3.

The maximum moment and shear for the bottom slab is 2594.62Nm and 6277.6N respectively. It means that Prototype Model 1 and 3 would fail due to moment while Prototype Model 2 and 4 are structurally safe.

Table 4.3: Results for ferrocement slab capacity check

<table>
<tr><th>Prototype Model</th><th>Moment Capacity (Nm)</th><th>M_1 (Nm)</th><th>M_2 (Nm)</th><th>Shear Capacity (N)</th><th>S_1 (N)</th><th>S_2 (N)</th></tr>
<tr><td>1 and 3</td><td>841.58</td><td rowspan="2">858.38</td><td rowspan="2">3453.00</td><td>20364.4</td><td rowspan="2">2354.4</td><td rowspan="2">8632.0</td></tr>
<tr><td>2 and 4</td><td>2789.88</td><td>25669.0</td></tr>
<tr><td colspan="7">*M_1 = Maximum moment due to loadcase
*M_2 = Moment due to surface pressure
*S_1 = Maximum shear due to loadcase
*S_2 = Shear due to surface pressure</td></tr>
</table>

4.5 Truss Member Capacity Check

In this section, truss members are designed and analysed in Multiframe. The results of the truss analysis are summaried in Table 4.4 by only mentioning on the critical part of the truss. The critical part of the truss is shown in Figure 4.5 and the behavior of the truss is shown in Figure 4.6. The actual bending stress, shear stress and deflection are average 98% below the capacity of the designed truss. Therefore, the truss sections size of the truss can be reduced at least half of it.

Table 4.4: Steel truss actual and allowable bending stress, shear stress and deflection at major axis (Appendix D)

Member	Section	Major Axis						Status
		Bending Stress (N/mm^2)		Shear Stress (N/mm^2)		Deflection (m)		
		Act	All	Act	All	Act	All	
1	100x50x5 RHS	0.896	163.82	0.079	99.285	0.001	0.333	Ok
5	100x50x5 RHS	2.564	163.82	0.486	99.285	0.012	2.333	Ok
9	100x50x5 RHS	1.602	163.82	0.090	99.285	0.005	3.000	Ok
13	100x100x5 SHS	0.018	163.82	0.001	99.285	0.000	3.000	OK
14	100x50x5 RHS	0.355	163.82	0.020	99.285	0.001	3.000	OK
19	100x50x5 RHS	0.000	163.82	0.000	99.285	0.000	4.667	OK
23	100x50x5 RHS	0.000	163.82	0.000	99.285	0.000	0.333	OK
26	100x50x5 RHS	3.037	163.82	1.818	99.285	0.020	2.333	OK
30	50x50x5 SHS	0.511	163.82	0.014	99.285	0.007	3.801	OK
31	50x50x5 SHS	0.847	163.82	0.028	99.285	0.012	3.801	OK
*Act = Actual *All = Allowable								

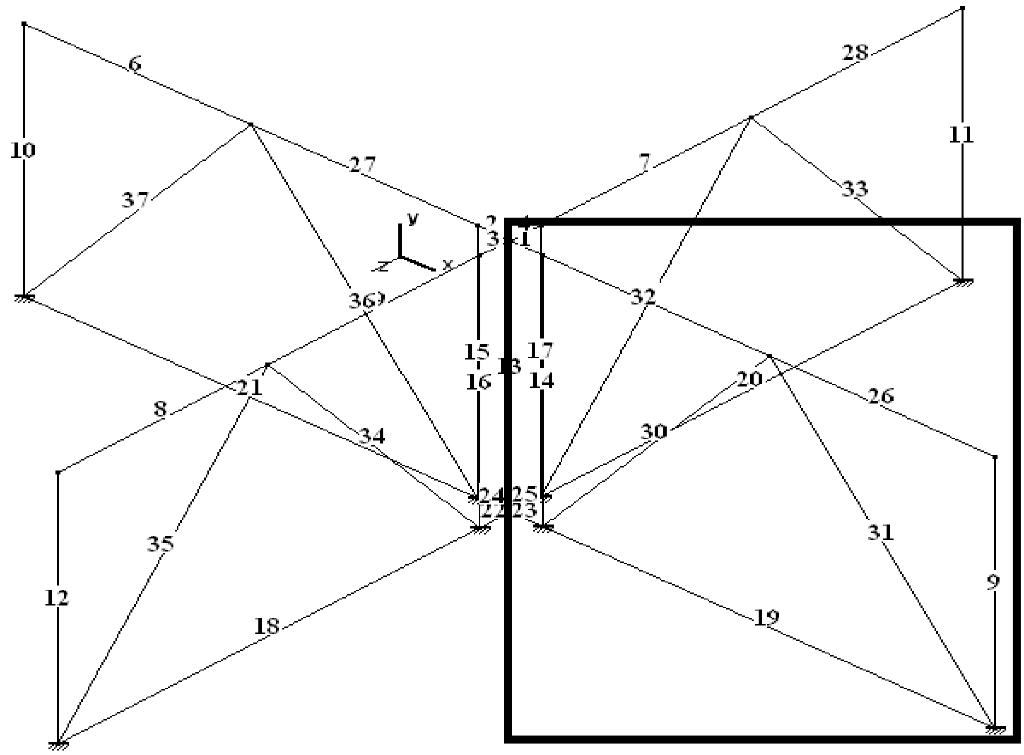


Figure 4.5 Critical part of the truss members

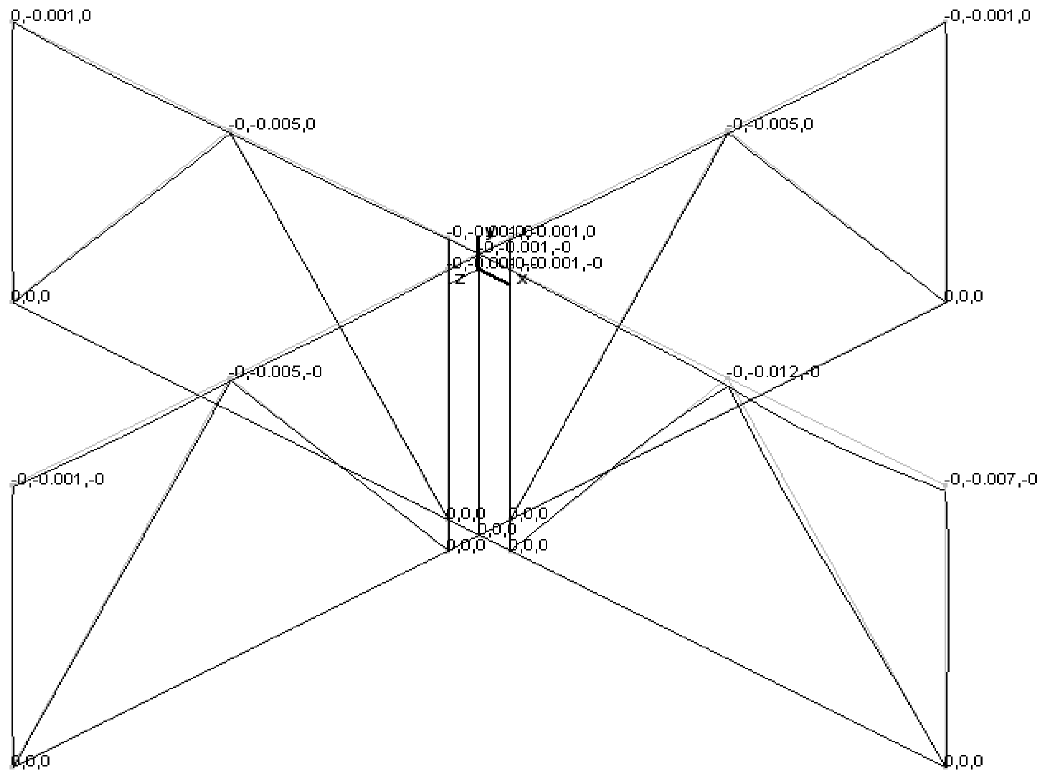


Figure 4.6 The truss deflection due to the load case

4.6 Timber Section Capacity Check

In this section, the timber section used to replace the ferrocement slab is analysed in Multiframe to check its capacity. The results of the analysis are tabulated in Table 4.5. The details of the results are provided in Appendix E. The deflection still 70% under the capacity of the timber section. Therefore, the timber section size still can be minimized. The behavior of the timber section is shown in Figure 4.7.

Table 4.5: Actual and allowable of tensile bending stress, compressive bending stress, shear stress and deflection of the timber section

Member	**Major Axis**								**Status**
	Ten. Bending Stress (N/mm^2)		**Com. Bending Stress (N/mm^2)**		**Shear Stress (N/mm^2)**		**Deflection (m)**		
	Act	**All**	**Act**	**All**	**Act**	**All**	**Act**	**All**	
1	0.929	148.927	3.388	148.927	0.056	99.285	0.707	5.333	Ok
2	5.58	148.927	7.841	148.927	0.594	99.285	1.474	5.333	Ok

*Ten. Bending= Tensile Bending
*Com. Bending = Compressive Bending
*Act = Actual
*All = Allowable

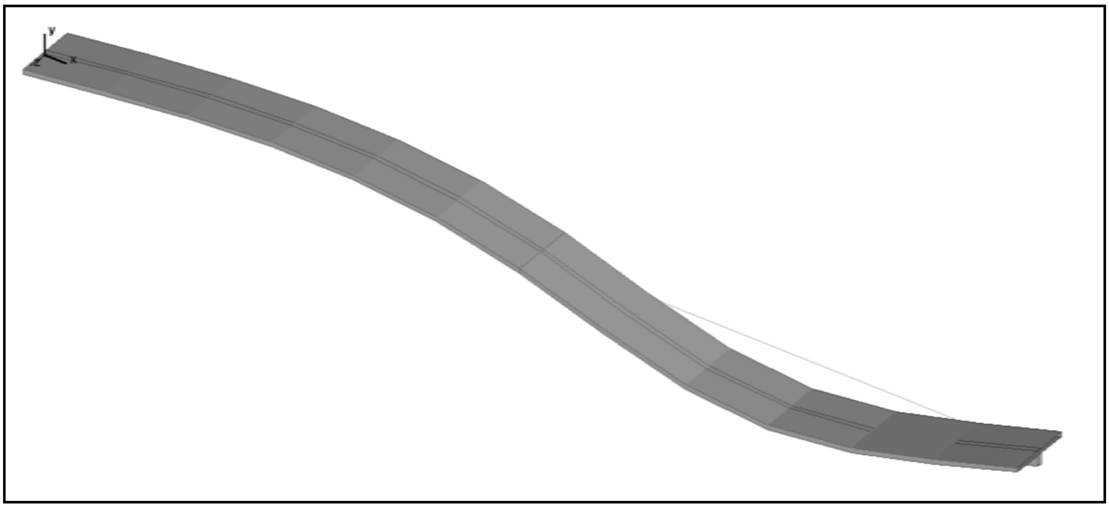


Figure 4.7 Timber deflection due to the load case

4.7 Hydrostatic curves

In this section, hydrostatic data for all prototype models are obtained by using Hydromax. Basically, the behavoiur of the structure can be estimated through the hydrostatic curves. Mainly, the results that can be obtained through the hydrostatic curves based on the known DWL are displacement, tonnef per centimeter immersion and moment to change trim one centimeter.

The results for the prototype models are shown in Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11. The summary of the results is tabulated in Table 4.6.

Table 4.6: Results summary for Upright Hydrostatic analysis

Prototype model	DWL (m)	Δ (kg)	TPc (52one/cm)	MTc (52one.m)
1	0.343	3470	0.102	0.023
	0.373	3760	0.102	0.023
2	0.421	4250	0.102	0.023
	0.451	4570	0.102	0.023
3	0.259	2590	0.102	0.028
	0.289	2904	0.102	0.028
4	0.312	3140	0.102	0.028
	0.343	3460	0.102	0.028

DWL = Design Water Level
Δ = Displacement
TPc = Tonnef per centimeter immersion
MTc = Moment to change trim one meter

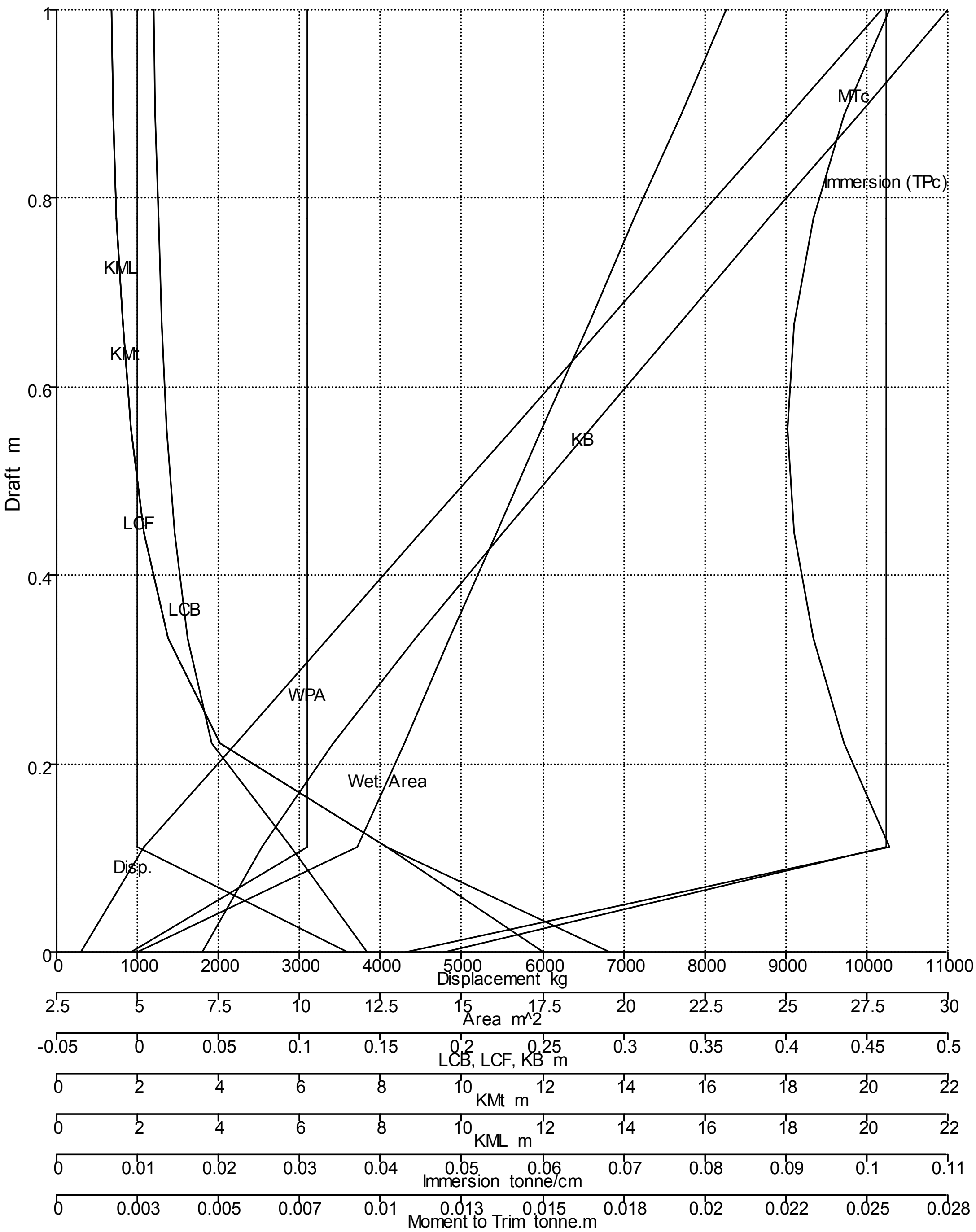


Figure 4.8 Hydrostatic curves for Prototype Model 1

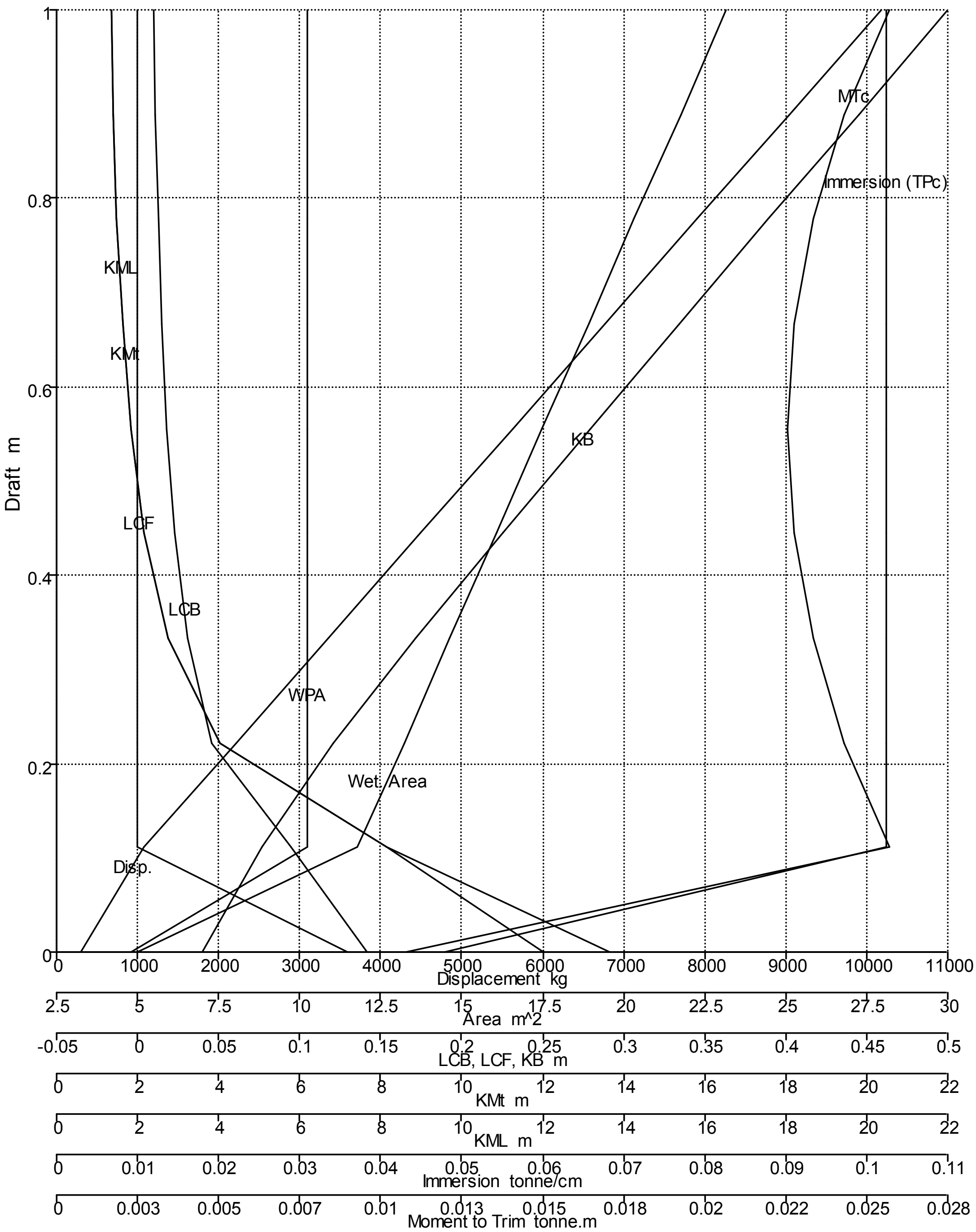


Figure 4.9 Hydrostatic curves for Prototype Model 2

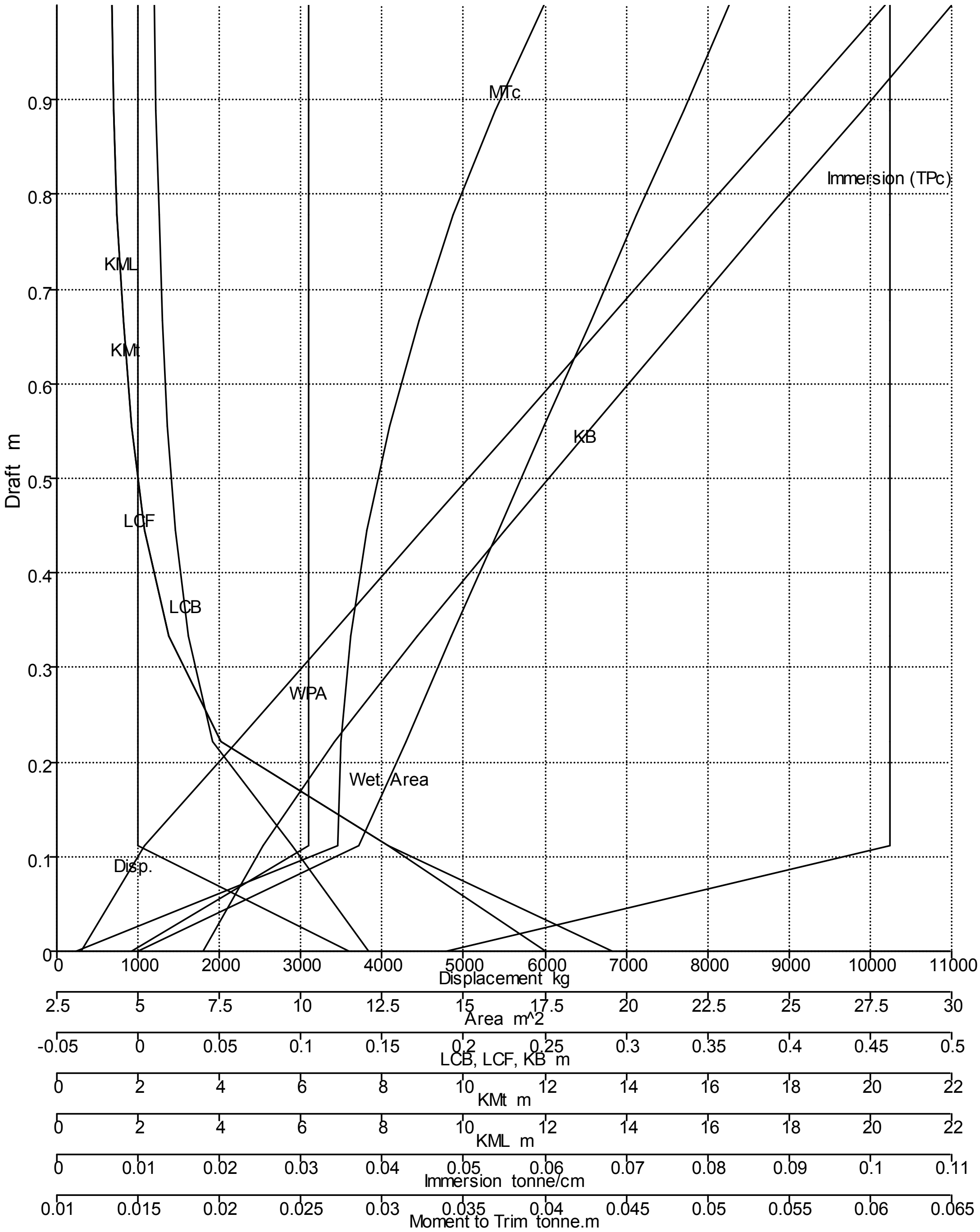


Figure 4.10 Hydrostatic curves for Prototype Model 3

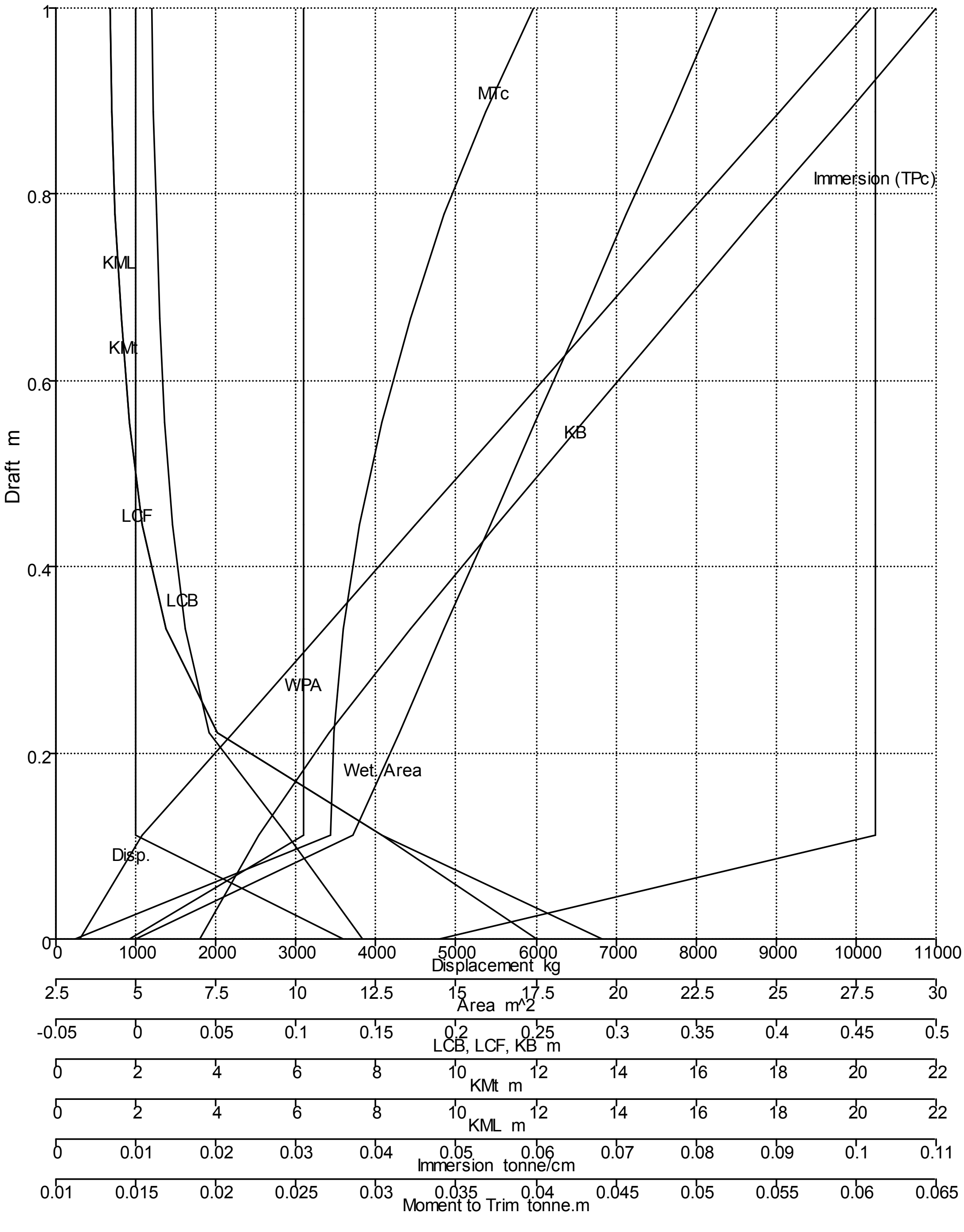


Figure 4.11 Hydrostatic curves for Prototype Model 4

4.8 Statical Stability Curve

In this section, Large Angle Stability analysis is carried out on the prototype models using Hydromax. The prototype models were analysed for three load cases (See Section 3.4.1).

Results for different prototype models are tabulated in the Table 4.6, Table 4.7, Table 4.8 and Table 4.9. The result details are provided in Appendix F. According to the results, the most critical condition is the condition stimulated in Load Case 3 where the maximum steady heeling moment is the smallest.

When comparing between the prototype models, the most stable prototype model is Prototype Model 2 with the highest maximum steady heeling moment when it was analysed in Load Case 3 condition. That means heavier structure would be more stable. As conclusion, all prototype models are stable in all condition.

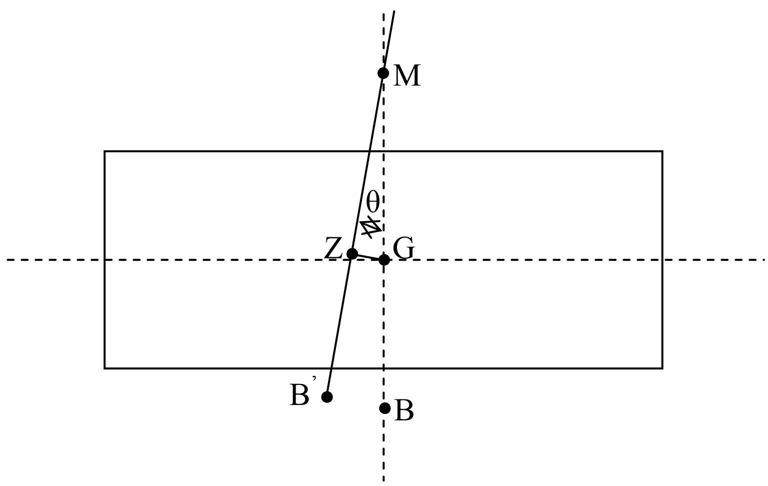


Table 4.7: Large Angle Stability results for Prototype Model 1

Loadcase	Max. GZ (m)	Heel to Starboard, θ (deg)	Max. steady heeling moment (kg.m)
1	0.685	31.8	2575.6
2	0.608	31.8	2286.1
3	0.595	32.7	2237.2

Table 4.8: Large Angle Stability results for Prototype Model 2

Loadcase	Max. GZ (m)	Heel to Starboard, θ (deg)	Max. steady heeling moment (kg.m)
1	0.627	30.9	2865.39
2	0.562	31.8	2568.34
3	0.552	31.8	2522.64

Table 4.9: Large Angle Stability results for Prototype Model 3

Loadcase	Max. GZ (m)	Heel to Starboard, θ (deg)	Max. steady heeling moment (kg.m)
1	0.733	30.9	2128.63
2	0.637	30.9	1849.85
3	0.617	32.7	1791.77

Table 4.10: Large Angle Stability results for Prototype Model 4

Loadcase	Max. GZ (m)	Heel to Starboard, θ (deg)	Max. steady heeling moment (kg.m)
1	0.704	31.8	2435.84
2	0.622	31.8	2152.12
3	0.606	32.7	2096.76

CHAPTER 5

CONCLUSION AND RECOMMEDATIONS

5.1 Conclusion

The conceptual multi-purpose floating structure had been designed using basic ship theory. Truss system and combination of various materials in the structures has been used to optimize the structure's utilization. Variation of mass due to different materials had been compared through manual calculations and simulation. Next, Longitudinal Strength analysis and manual calculation for maximum moment and maximum shear had also been done on the ferrocement slab. Then, manual calculation based on BS8110 had been carried out on the ferrocement slab's capacity. After that, the truss member and timber‘s capacity and behavior had been analysed in Multiframe. Finally, the behavior of the floating structures had been analysed on Upright Hydrostatic and Large Angle Stability in Maxsurf.

The conclusions that can be drawn from the parametric studies are:

(a) The truss system is suitable in restraining the floating structure design to avoid buckling of walls and makes the structure lighter without weakening the structure.

(b) Ferrocement with appropriate concreting technology is suitable in floating structure design in term of making the structure lighter with an acceptable strength

(c) Timber is a replacement of the floating structure cover instead of using the ferrocement because the weight reduction is as many as 20% by using timber. The timber can also sustain the load without failure.

(d) The overviews of the structures are displayed in Figure 5.1 and 5.2. The behaviors of each prototype are summary as below (Table 5.1):

Table 5.1: Behaviours of each prototype model

Prototype Model	**1**	**2**	**3**	**4**
Moment Capacity (Nm)	841.58	2789.88	841.58	2789.88
Shear Capacity (N)	20364.4	25669	20364.4	25669
Timber bending capacity (N/mm^2)	/	/	148.927	148.927
Timber shear capacity (N/mm^2)	/	/	99.285	99.285
Timber deflection capacity (N/mm^2)	/	/	5.333	5.333
Water Level (m)	0.343	0.421	0.259	0.312
TPc (tonne/cm)	0.102	0.102	0.102	0.102
MTc (tonne.m)	0.023	0.023	0.028	0.028
Stability (kg.m)	2237.2	2522.64	1791.77	2096.76

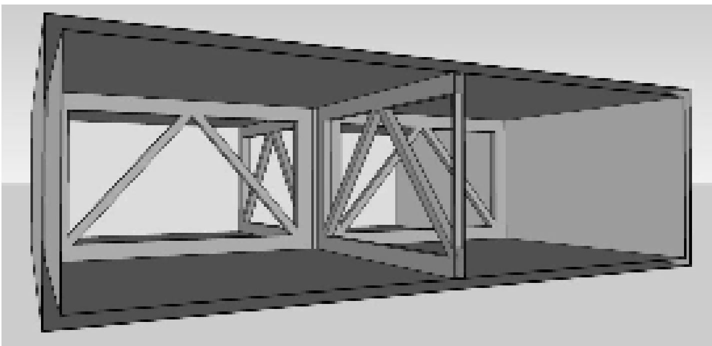


Figure 5.1 Prototype Model 1 and 2's overview

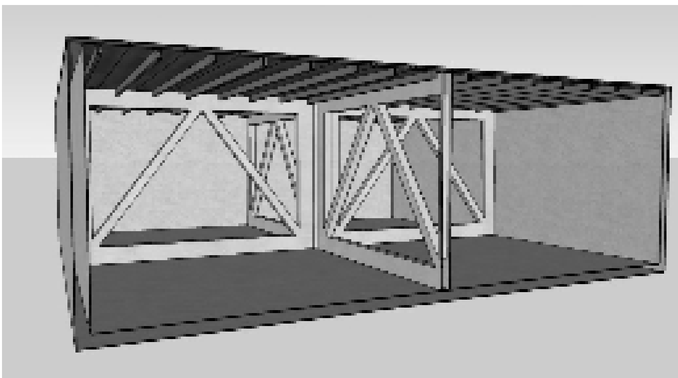


Figure 5.2 Prototype Model 3 and 4's overview

5.2 Recommendations

Several recommendations are outlined below to improve the study of multi-purpose floating structure in the future.

(a) For this study the proposed multi-purpose structure is analysed using software application. Thus, it is recommended that the structure should be analysed through experimental to obtain the real behavior of the structure under various load conditions.

(b) The structures in this study are assumed as a water tight structure. Thus, study on special concrete mix for water tightness of the structure can be carried out in the future.

(c) The study on making the structures into IBS components also can be carried out for specific site assembly.

(d) The structures are multi-purpose structures. Thus, it is recommended analysis and experiments on possible application should be done.

(e) The structure can be used as a pontoon for jetty and floating house. It also can be used as a tank for rain harvesting, fish pond, agricultural, as damper for earthquake purposes and as raft foundation.

REFERENCES

Associate Professor Dr Abdul Kadir Marsono.*Tall Building System: Analysis and Design*.

ACI Committee 549, Ferrocement (1979).*FERROCEMENT (Materials and Applications).* USA: American Concrete Institute, Detroit.

British Standard Institute (BSI) (1997) BS 8110-1:1997. *Structural use of concrete.* London.

British Standard Institute (BSI) (2002) BS 5268-2:2002. *Structural use of timber.* London.

C.M.Wang et al (2006). *Marine Structures*. Pg 70-82.

D.G.M.Watson (1998). *Practical Ship Design.*New York: Elsevier

Formation Design Systems (1990-2005).*Maxsurf Pro User Manual*

Formation Design Systems (1990-2005).*Hydromax User Manual*

FormSys. *MULTIFRAME (Integrated Structural Engineering Software)* from http://www.formsys.com/multiframe

FormSys. *MARINE (Design.Production.Collaboration)* from http://www.formsys.com/maxsurf

J.A.Desai (2008). *Ferrocement for Future Generations.*

Judith Anne Gunther (1995). *Design House "Boats"*. USA: Popular Science Magazine

K.J.Rawson and E.C.Tupper (1994).*Basic Ship Theory.*England: Longman Scientic & Technical.

Michael Carr (2004). *Waves and Boat Stability* from http://www.sailnet.com/forums/seamanship-articles/19301-waves-boat-stability.html

Mohammed Saleem (1988). *Flexural Behaviour of Ferrocement Sandwich Panels.* Master of Science in Civil Engineering. King Fahd University of Petroleum & Minerals

National Academy Of Sciences (1973). *Ferrocement: Application in developing Countries.*Washington,D.C: National Academy Of Sciences.

P.J.Nedwell and R.N.Swamy (1994).*Ferrocement.* London: E & FN Spon.

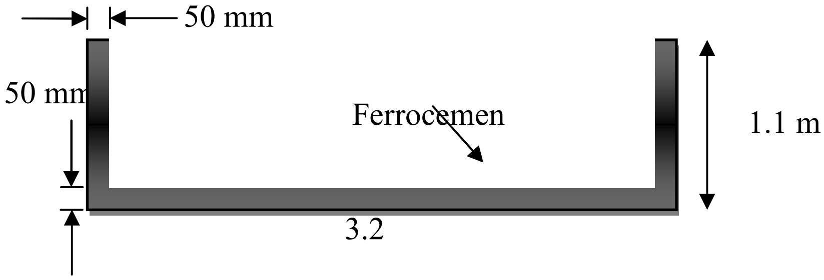
P.Kumar Mehta (1991). *Concrete in the Marine Environment.*USA: Elsevier Science Publishers.

Winston International Corporation (2005-2009). *LAND-LOCKED FLOATING HOUSE* from http://floodproofhousing.com/home.html

Wikipedia, the free encyclopedia (2009). *Boat* from http://en.wikipedia.org/wiki/Boat

APPENDIX A

Pontoon's Mass



Ferrocement Cover (Prototype Model 2)

Specification:

Thickness of ferrocement structure = 50mm

Volume of ferrocement cover, V_{cf} = 3.2 x 3.2 x 0.05
= 0.512 m^3

Mass of ferrocement cover, M_{cf} = 0.512 x 2400
= 1228.8 kg

Ferrocement Structure

Volume of void space, V_{void} = 1.05 x 3.1 x 3.1
= 10.0905 m^3

Volume of whole structure, V_{total} = 3.2 x 3.2 x 1.1
= 11.264 m^3

Mass of the ferrocement structure, W_F $= (V_{total} + V_{void})* \rho_{cement}$

$= (11.2640 – 10.0905) \times 2400$

$= 1.1735 \times 2400$

$= 2816.4$ kg

Truss

Volume of truss beam void space, V_{bv} $= 1.49 \times 0.09 \times 0.04$

$= 0.0054\ m^3$

Volume of truss beam, Vtb $= 1.5 \times 0.1 \times 0.05$

$= 0.0075\ m^3$

Mass of hollow truss beam, V_{hb} $= 8(V_{tb} – V_{bv})* \rho_{steel}$

$= 8(0.0075 – 0.0054) \times 7800$

$= 131.04$ kg

Volume of truss column void space, V_{cv} $= 0.79 \times 0.09 \times 0.04$

$= 0.0029\ m^3$

Volume of truss column, Vtc $= 0.8 \times 0.1 \times 0.05$

$= 0.004\ m^3$

Mass of hollow truss beam, V_{hc} $= 8(V_{tc} – V_{cv})* \rho_{steel}$

$= 8(0.004 – 0.0029) \times 7800$

$= 68.64$ kg

Volume of truss center column void space, V_{ccv} $= 0.79 \times 0.09 \times 0.09$

$= 0.0064\ m^3$

Volume of truss center column, V_{tcc} = 0.8 x 0.1 x 0.1

= 0.008 m^3

Mass of hollow truss center column, V_{hcc} = $(V_{tcc} - V_{ccv})* \rho_{steel}$

= (0.008 – 0.0064) x 7800

= 12.48 kg

Volume of truss brace void space, V_{bbv} = 0.88 x 0.04 x0.04

= 0.0014 m^3

Volume of truss brace, V_{tbb} = 0.89 x 0.05 x 0.05

= 0.0022 m^3

Mass of hollow truss brace, M_{hbb} = 8 (0.0022 – 0.0014) x ρ_{steel}

= 49.92 kg

Mass of the whole truss, M_T = $M_{hb} + M_{hc} + M_{hcc} + M_{hbb}$

= 131.04 + 68.64 + 12.48 + 49.92

= 262.08 kg

Pontoon's Mass

Total structure mass, M = $M_F + M_T + M_{cf}$

= 2816.4 + 262.08 + 1228.8

= 4307.28 kg

Total structure mass with load, M_L = M + L

= 4307.28 + 312

= 4619.28 kg

APPENDIX B

Sample Calculation (Prototype Model 1)

DWL without load $= \frac{D}{LxWx\rho}$

$= 3514.41/ (3.2 \times 3.2 \times 1000)$

$= 0.343m$

DWL with load $= \frac{D}{LxWx\rho}$

$= 3826.41/ (3.2 \times 3.2 \times 1000)$

$= 0.373m$

APPENDIX C

Section Area Per Meter Width for various bar spacings (mm^2)

For wire mesh (150mm x 150mm x 4.2mm),

$$A_{s1} = \frac{\pi D^2}{4} \times \frac{L}{W}$$

$$= \frac{\pi(4.2)^2}{4} \times \frac{1000}{150}$$

$$= 92.33 \text{ mm}^2$$

For chicken mesh (50mm x 50mm x 1.5mm),

$$A_{s2} = \frac{\pi D^2}{4} \times \frac{L}{W}$$

$$= \frac{\pi(1.5)^2}{4} \times \frac{1000}{50}$$

$$= 35.35 \text{ mm}^2$$

Total section area per meter, A_s = 92.33 + 35.35
= 127.68mm^2

Sample Calculation of Slab Capacity (Prototype Model 1)

$$d = h - c - \frac{\text{Øbar}}{2}$$

$$= 40 - 25 - 5.7$$

$$= 9.3 \text{ mm}$$

$$x = \frac{d}{1+(\frac{0.0022}{0.0035})}$$

$$= \frac{d}{1.63}$$

$$= 5.71 \text{ mm}$$

$$M_{st} = \text{Fst Z}$$

$$= (0.87 f_y A_s)(d - 0.45x)$$

$$= 0.87(500)(127.68)(9.3 - 0.45 \times 5.71)$$

$= 373.82$ Nm

$M_{cc} = F_{cc}\, Z$

$= (\frac{0.405x}{d})\,(1 - \frac{0.45x}{d})\,(f_{cu}bd^2)$

$= (\frac{0.405 \text{ x } 5.71}{9.3})\,(1 - \frac{0.45 \text{ x } 5.71}{9.3})\,(30)(1000)(9.3^2)$

$= (0.249)\,(0.724)\,(30)\,(1000)\,(9.3^2)$

$= 467.76$ Nm

Total Moment Capacity $= M_{st} + M_{cc}$

$= 373.82 + 467.76$

$= 841.58$ Nm

$v_c = 0.79[\frac{100(127.68)}{1000(9.3)}]^{1/3}(\frac{400}{9.3})^{1/4}(\frac{30}{25})^{1/3}/1.15$

$= 0.79\,(1.111)\,(2.561)\,(1.063)/1.15$

$= 2.078$ N/mm^2

Shear Capacity, V $= v_c b_v d$

$= 2.078\,(1000)\,(9.3)$

$= 20364.4$ N

Moment and Shear due to Surface Pressure

Surface pressure, w = 1000 x 1.1 x 9.81

= 10.79 kN/m^2

Maximum moment, M $= (10.79)\,(1.6)^2 / 8$

= 3.453kNm

Maximum Shear, V = (10.79)(1.6) / 2

= 8.632 kN

APPENDIX D

Checking member 1

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2
On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2
F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2
Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*100/35,1*100/19.9)=5.025
F_a=(1-(KL/r)^2/(2*Cc^2)*Fy/FS=(1-5.025^2/(2*126.116^2)*248.211/1.682=147.487 N/mm^2
Major Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2
Minor Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 1, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 15.101 _ 163.82 OK 91% under
Compressive Bending Stress:
f_b _ F_b, 15.101 _ 163.82 OK 91% under

Member 1, Load Case 1, Major shear
f_v _ F_v, 1.555 _ 99.285 OK 98% under

Member 1, Load Case 1, Major deflection
d _ L/300, 0.022 _ 100/300=0.333 mm OK 94% under

Member 1, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 1, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 1, Load Case 1, Minor deflection
d _ L/300, 0 _ 100/300=0.333 mm OK 97% under

Member 1, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 1, Load Case 1, Slenderness
K_x*Lx/rx=1*100/35=2.857 _ 200 OK 99% under
K_y*Ly/ry=1*100/19.9=5.025 _ 200 OK 97% under

Member 1, Load Case 1, Compression
f_a _ F_a, 0.156 _ 147.487 OK 100% under

Member 1, Load Case 1, Bending & tension
$f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}$=0/199.948+15.101/163.82+0/163.82=0.092 _ 1 OK 91% under
Member 1, Load Case 1, Bending & compression
f_a/F_a=0.156/147.487=0.001 _ 0.15 \
$f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}$=0.156/147.487+15.101/163.82+0/163.82=0.093 _ 1 OK 91% under
Member 1, Load Case 1, Sway
D _ Y/300, 0 _ 5000/300=16.667 mm OK 100% under

Checking member 5

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2
On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2
F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2
Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*700/35,1*700/19.9)=35.176
F_a=(1-(KL/r)^2/(2*Cc^2)*Fy/FS=(1-35.176^2/(2*126.116^2)*248.211/1.769=134.888 N/mm^2
Major Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2
Minor Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2
Member 5, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 23.315 _ 163.82 OK 86% under
Compressive Bending Stress:
f_b _ F_b, 23.315 _ 163.82 OK 86% under
Member 5, Load Case 1, Major shear
f_v _ F_v, 6.754 _ 99.285 OK 93% under
Member 5, Load Case 1, Major deflection
d _ L/300, 0.09 _ 700/300=2.333 mm OK 96% under
Member 5, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Member 5, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under
Member 5, Load Case 1, Minor deflection
d _ L/300, 0 _ 700/300=2.333 mm OK 97% under
Member 5, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under
Member 5, Load Case 1, Slenderness
K_x*Lx/rx=1*700/35=20 _ 200 OK 90% under
K_y*Ly/ry=1*700/19.9=35.176 _ 200 OK 82% under
Member 5, Load Case 1, Compression
f_a _ F_a, 0.404 _ 134.888 OK 100% under
Member 5, Load Case 1, Bending & tension
$f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}$=0/199.948+23.315/163.82+0/163.82=0.142 _ 1 OK 86% under
Member 5, Load Case 1, Bending & compression

f_a/F_a=0.404/134.888=0.003 _ 0.15 \
$f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}$=0.404/134.888+23.315/163.82+0/163.82=0.145 _ 1 OK 85% under

Member 5, Load Case 1, Sway
D _ Y/300, 0.002 _ 5000/300=16.667 mm OK 100% under

Checking member 9

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2
On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2
F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2
Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*900/35,1*900/19.9)=45.226
F_a=(1-(KL/r)^2/(2*Cc^2)*F_y/FS=(1-45.226^2/(2*126.116^2)*248.211/1.795=129.361 N/mm^2
Major Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2
Minor Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 9, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 14.139 _ 163.82 OK 91% under
Compressive Bending Stress:
f_b _ F_b, 14.139 _ 163.82 OK 91% under

Member 9, Load Case 1, Major shear
f_v _ F_v, 0.796 _ 99.285 OK 99% under

Member 9, Load Case 1, Major deflection
d _ L/300, 0.04 _ 900/300=3 mm OK 97% under

Member 9, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 9, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 9, Load Case 1, Minor deflection
d _ L/300, 0 _ 900/300=3 mm OK 97% under

Member 9, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 9, Load Case 1, Slenderness
K_x*Lx/rx=1*900/35=25.714 _ 200 OK 87% under
K_y*Ly/ry=1*900/19.9=45.226 _ 200 OK 77% under

Member 9, Load Case 1, Compression
f_a _ F_a, 6.448 _ 129.361 OK 95% under

Member 9, Load Case 1, Bending & tension
$f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}$=0/199.948+14.139/163.82+0/163.82=0.086 _ 1 OK 91% under

Member 9, Load Case 1, Bending & compression
f_a/F_a=6.448/129.361=0.05 _ 0.15 \
$f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}$=6.448/129.361+14.139/163.82+0/163.82=0.136 _ 1 OK 86% under

Member 9, Load Case 1, Sway
D _ Y/300, 0.004 _ 5000/300=16.667 mm OK 100% under

Checking member 13

Group: SHS
Section: 100x100x5 SHS

Load Case: Load Case 1

F_y=248.211 N/mm^2

On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2

On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2

F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2

Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*900/38.7,1*900/38.7)=23.256

F_a=(1-(KL/r)^2/(2*Cc^2)*Fy/FS=(1-23.256^2/(2*126.116^2)*248.211/1.735=140.626 N/mm^2

Major Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Minor Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 13, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 0.026 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0.026 _ 163.82 OK 100% under

Member 13, Load Case 1, Major shear
f_v _ F_v, 0.002 _ 99.285 OK 100% under

Member 13, Load Case 1, Major deflection
d _ L/300, 0 _ 900/300=3 mm OK 97% under

Member 13, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 13, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 13, Load Case 1, Minor deflection
d _ L/300, 0 _ 900/300=3 mm OK 97% under

Member 13, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 13, Load Case 1, Slenderness
K_x*Lx/rx=1*900/38.7=23.256 _ 200 OK 88% under
K_y*Ly/ry=1*900/38.7=23.256 _ 200 OK 88% under

Member 13, Load Case 1, Compression
f_a _ F_a, 3.278 _ 140.626 OK 98% under

Member 13, Load Case 1, Bending & tension
f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}=0/199.948+0.026/163.82+0/163.82=0 _ 1 OK 100% under

Member 13, Load Case 1, Bending & compression
f_a/F_a=3.278/140.626=0.023 _ 0.15 \
f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}=3.278/140.626+0.026/163.82+0/163.82=0.023 _ 1 OK 98% under

Member 13, Load Case 1, Sway
D _ Y/300, 0 _ 5000/300=16.667 mm OK 100% under

Checking member 14

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2

On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2

On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2

F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2

Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*900/35,1*900/19.9)=45.226

F_a=(1-(KL/r)^2/(2*Cc^2)*Fy/FS=(1-45.226^2/(2*126.116^2)*248.211/1.795=129.361 N/mm^2

Major Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Minor Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 14, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 6.083 _ 163.82 OK 96% under
Compressive Bending Stress:
f_b _ F_b, 6.083 _ 163.82 OK 96% under
Member 14, Load Case 1, Major shear
f_v _ F_v, 0.345 _ 99.285 OK 100% under
Member 14, Load Case 1, Major deflection
d _ L/300, 0.018 _ 900/300=3 mm OK 97% under
Member 14, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Member 14, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under
Member 14, Load Case 1, Minor deflection
d _ L/300, 0 _ 900/300=3 mm OK 97% under
Member 14, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under
Member 14, Load Case 1, Slenderness
K_x*Lx/rx=1*900/35=25.714 _ 200 OK 87% under
K_y*Ly/ry=1*900/19.9=45.226 _ 200 OK 77% under
Member 14, Load Case 1, Compression
f_a _ F_a, 4.813 _ 129.361 OK 96% under
Member 14, Load Case 1, Bending & tension
$f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}$=0/199.948+6.083/163.82+0/163.82=0.037 _ 1 OK 96% under
Member 14, Load Case 1, Bending & compression
f_a/F_a=4.813/129.361=0.037 _ 0.15 \
$f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}$=4.813/129.361+6.083/163.82+0/163.82=0.074 _ 1 OK 93% under
Member 14, Load Case 1, Sway
D _ Y/300, 0 _ 5000/300=16.667 mm OK 100% under

Checking member 19

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2

On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2

On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2

F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2

Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*1400/35,1*1400/19.9)=70.352

F_a=(1-(KL/r)^2/(2*Cc^2)*F_y/FS=(1-70.352^2/(2*126.116^2)*248.211/1.854=113.039 N/mm^2

Major Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Minor Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 19, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Member 19, Load Case 1, Major shear
f_v _ F_v, 0 _ 99.285 OK 100% under
Member 19, Load Case 1, Major deflection
d _ L/300, 0 _ 1400/300=4.667 mm OK 97% under
Member 19, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Member 19, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under
Member 19, Load Case 1, Minor deflection
d _ L/300, 0 _ 1400/300=4.667 mm OK 97% under
Member 19, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under
Member 19, Load Case 1, Slenderness
K_x*Lx/rx=1*1400/35=40 _ 200 OK 80% under
K_y*Ly/ry=1*1400/19.9=70.352 _ 200 OK 65% under
Member 19, Load Case 1, Compression
f_a _ F_a, 0 _ 113.039 OK 100% under
Member 19, Load Case 1, Bending & tension
f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}=0/199.948+0/163.82+0/163.82=0 _ 1 OK 100% under
Member 19, Load Case 1, Bending & compression
f_a/F_a=0/113.039=0 _ 0.15 \
f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}=0/113.039+0/163.82+0/163.82=0 _ 1 OK 100% under
Member 19, Load Case 1, Sway
D _ Y/300, 0 _ 4100/300=13.667 mm OK 100% under

Checking member 23

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2

On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2

On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2

F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2

Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*100/35,1*100/19.9)=5.025

F_a=(1-(KL/r)^2/(2*Cc^2)*F_y/FS=(1-5.025^2/(2*126.116^2)*248.211/1.682=147.487 N/mm^2

Major Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Minor Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 23, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 23, Load Case 1, Major shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 23, Load Case 1, Major deflection
d _ L/300, 0 _ 100/300=0.333 mm OK 97% under

Member 23, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 23, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 23, Load Case 1, Minor deflection
d _ L/300, 0 _ 100/300=0.333 mm OK 97% under

Member 23, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 23, Load Case 1, Slenderness
K_x*Lx/rx=1*100/35=2.857 _ 200 OK 99% under
K_y*Ly/ry=1*100/19.9=5.025 _ 200 OK 97% under

Member 23, Load Case 1, Compression
f_a _ F_a, 0 _ 147.487 OK 100% under

Member 23, Load Case 1, Bending & tension
f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}=0/199.948+0/163.82+0/163.82=0 _ 1 OK 100% under

Member 23, Load Case 1, Bending & compression
f_a/F_a=0/147.487=0 _ 0.15 \
f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}=0/147.487+0/163.82+0/163.82=0 _ 1 OK 100% under

Member 23, Load Case 1, Sway
D _ Y/300, 0 _ 4100/300=13.667 mm OK 100% under

Checking member 26

Group: RHS
Section: 100x50x5 RHS

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2
On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2
F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2
Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*700/35,1*700/19.9)=35.176
F_a=(1-(KL/r)^2/(2*Cc^2)*F_y/FS=(1-35.176^2/(2*126.116^2)*248.211/1.769=134.888 N/mm^2
Major Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2
Minor Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 26, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 23.996 _ 163.82 OK 85% under
Compressive Bending Stress:
f_b _ F_b, 23.996 _ 163.82 OK 85% under
Member 26, Load Case 1, Major shear
f_v _ F_v, 7.412 _ 99.285 OK 93% under
Member 26, Load Case 1, Major deflection
d _ L/300, 0.12 _ 700/300=2.333 mm OK 95% under
Member 26, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Member 26, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under
Member 26, Load Case 1, Minor deflection
d _ L/300, 0 _ 700/300=2.333 mm OK 97% under
Member 26, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under
Member 26, Load Case 1, Slenderness
K_x*Lx/rx=1*700/35=20 _ 200 OK 90% under
K_y*Ly/ry=1*700/19.9=35.176 _ 200 OK 82% under
Member 26, Load Case 1, Compression
f_a _ F_a, 0.573 _ 134.888 OK 100% under
Member 26, Load Case 1, Bending & tension
f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}=0/199.948+23.996/163.82+0/163.82=0.146 _ 1 OK 85% under
Member 26, Load Case 1, Bending & compression
f_a/F_a=0.573/134.888=0.004 _ 0.15 \
f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}=0.573/134.888+23.996/163.82+0/163.82=0.151 _ 1 OK 85% under
Member 26, Load Case 1, Sway
D _ Y/300, 0.004 _ 5000/300=16.667 mm OK 100% under

Checking member 30

Group: SHS
Section: 50x50x5 SHS

Load Case: Load Case 1

F_y=248.211 N/mm^2

On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2

On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2

F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2

Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*1140.176/18.3,1*1140.176/18.3)=62.305

F_a=(1-(KL/r)^2/(2*Cc^2)*Fy/FS=(1-62.305^2/(2*126.116^2)*248.211/1.837=118.638 N/mm^2

Major Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Minor Axis:

F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 30, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 0.516 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0.516 _ 163.82 OK 100% under

Member 30, Load Case 1, Major shear
f_v _ F_v, 0.012 _ 99.285 OK 100% under

Member 30, Load Case 1, Major deflection
d _ L/300, 0.043 _ 1140.176/300=3.801 mm OK 97% under

Member 30, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 30, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 30, Load Case 1, Minor deflection
d _ L/300, 0 _ 1140.176/300=3.801 mm OK 97% under

Member 30, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 30, Load Case 1, Slenderness
K_x*Lx/rx=1*1140.176/18.3=62.305 _ 200 OK 69% under
K_y*Ly/ry=1*1140.176/18.3=62.305 _ 200 OK 69% under

Member 30, Load Case 1, Compression
f_a _ F_a, 10.173 _ 118.638 OK 91% under

Member 30, Load Case 1, Bending & tension
f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}=0/199.948+0.516/163.82+0/163.82=0.003 _ 1 OK 100% under

Member 30, Load Case 1, Bending & compression
f_a/F_a=10.173/118.638=0.086 _ 0.15 \
f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}=10.173/118.638+0.516/163.82+0/163.82=0.089 _ 1 OK 91% under

Member 30, Load Case 1, Sway
D _ Y/300, 0.002 _ 5000/300=16.667 mm OK 100% under

Checking member 31

Group: SHS
Section: 50x50x5 SHS

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6*F_y=0.6*248.211=148.927 N/mm^2
On net area F_t=0.5*F_u=0.5*399.896=199.948 N/mm^2
F_v=0.4*F_y=0.4*248.211=99.285 N/mm^2
Kl/r=max(K_x*l/rx,K_y*l/ry)=max(1*1140.175/18.3,1*1140.175/18.3)=62.305
F_a=(1-(KL/r)^2/(2*Cc^2)*Fy/FS=(1-62.305^2/(2*126.116^2)*248.211/1.837=118.639 N/mm^2
Major Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2
Minor Axis:
F_b=0.66*F_y=0.66*248.211=163.82 N/mm^2

Member 31, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 1.999 _ 163.82 OK 99% under
Compressive Bending Stress:
f_b _ F_b, 1.999 _ 163.82 OK 99% under

Member 31, Load Case 1, Major shear
f_v _ F_v, 0.073 _ 99.285 OK 100% under

Member 31, Load Case 1, Major deflection
d _ L/300, 0.05 _ 1140.175/300=3.801 mm OK 97% under

Member 31, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 163.82 OK 100% under

Member 31, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 31, Load Case 1, Minor deflection
d _ L/300, 0 _ 1140.175/300=3.801 mm OK 97% under

Member 31, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 31, Load Case 1, Slenderness
K_x*Lx/rx=1*1140.175/18.3=62.305 _ 200 OK 69% under
K_y*Ly/ry=1*1140.175/18.3=62.305 _ 200 OK 69% under

Member 31, Load Case 1, Compression
f_a _ F_a, 9.787 _ 118.639 OK 92% under

Member 31, Load Case 1, Bending & tension
f_a/F_t+f_{bx}/F_{bx}+f_{by}/F_{by}=0/199.948+1.999/163.82+0/163.82=0.012 _ 1 OK 99% under

Member 31, Load Case 1, Bending & compression
f_a/F_a=9.787/118.639=0.082 _ 0.15 \
f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}=9.787/118.639+1.999/163.82+0/163.82=0.095 _ 1 OK 91% under

Member 31, Load Case 1, Sway
D _ Y/300, 0.002 _ 5000/300=16.667 mm OK 100% under

APPENDIX E

Checking member 1

Group: Custom 1
Section: Papan 3

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6∗F_y=0.6∗248.211=148.927 N/mm^2
On net area F_t=0.5∗F_u=0.5∗399.896=199.948 N/mm^2
F_v=0.4∗F_y=0.4∗248.211=99.285 N/mm^2
Kl/r=max($K_{x*l/rx}$,$K_{y*l/ry}$)=max(1∗1600/26.204,1∗1600/48.085)=61.059
F_a=12∗π$^{2*E/(23*(KΛ/ρ)2)=12*π2*10000/(23*61.0592)=13.812\ N/μμ2}$
Major Axis:
F_b=0.6∗F_y=0.6∗248.211=148.927 N/mm^2
Minor Axis:
F_b=0.6∗F_y=0.6∗248.211=148.927 N/mm^2

Member 1, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 0.929 _ 148.927 OK 99% under
Compressive Bending Stress:
f_b _ F_b, 3.388 _ 148.927 OK 98% under

Member 1, Load Case 1, Major shear
f_v _ F_v, 0.056 _ 99.285 OK 100% under

Member 1, Load Case 1, Major deflection
δ _ L/300, 0.707 _ 1600/300=5.333 mm OK 87% under

Member 1, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 148.927 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 148.927 OK 100% under

Member 1, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 1, Load Case 1, Minor deflection
δ _ L/300, 0 _ 1600/300=5.333 mm OK 97% under

Member 1, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 1, Load Case 1, Slenderness
$K_{x*Lx/rx}$=1∗1600/26.204=61.059 _ 200 OK 69% under
$K_{y*Ly/ry}$=1∗1600/48.085=33.274 _ 200 OK 83% under

Member 1, Load Case 1, Compression
f_a _ F_a, 0 _ 13.812 OK 100% under

Member 1, Load Case 1, Bending & tension
$f_a/F_t+f_{bx}/F_{bx}+f_by/F_{by}$=0/199.948+0.929/148.927+0/148.927=0.006 _ 1 OK 99% under

Member 1, Load Case 1, Bending & compression
f_a/F_a=0/13.812=0 _ 0.15 ∴
$f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}$=0/13.812+3.388/148.927+0/148.927=0.023 _ 1 OK 98% under

Member 1, Load Case 1, Sway

Δ _ Y/300, 0 _ 0/300=0 mm OK 100% under

Checking member 2

Group: Custom 1
Section: Papan 3

Load Case: Load Case 1

F_y=248.211 N/mm^2
On gross area F_t=0.6∗F_y=0.6∗248.211=148.927 N/mm^2
On net area F_t=0.5∗F_u=0.5∗399.896=199.948 N/mm^2
F_v=0.4∗F_y=0.4∗248.211=99.285 N/mm^2
Kl/r=max($K_{x*l/rx}$,$K_{y*l/ry}$)=max(1∗1600/26.204,1∗1600/48.085)=61.059
F_a=12∗$\pi^{2*E/(23*(K\Lambda/\rho)2)=12*\pi 2*10000/(23*61.0592)=13.812\ N/\mu\mu 2}$
Major Axis:
F_b=0.6∗F_y=0.6∗248.211=148.927 N/mm^2
Minor Axis:
F_b=0.6∗F_y=0.6∗248.211=148.927 N/mm^2

Member 2, Load Case 1, Major bending
Tensile Bending Stress:
f_b _ F_b, 5.58 _ 148.927 OK 96% under
Compressive Bending Stress:
f_b _ F_b, 7.841 _ 148.927 OK 95% under

Member 2, Load Case 1, Major shear
f_v _ F_v, 0.594 _ 99.285 OK 99% under

Member 2, Load Case 1, Major deflection
δ _ L/300, 1.474 _ 1600/300=5.333 mm OK 72% under

Member 2, Load Case 1, Minor bending
Tensile Bending Stress:
f_b _ F_b, 0 _ 148.927 OK 100% under
Compressive Bending Stress:
f_b _ F_b, 0 _ 148.927 OK 100% under

Member 2, Load Case 1, Minor shear
f_v _ F_v, 0 _ 99.285 OK 100% under

Member 2, Load Case 1, Minor deflection
δ _ L/300, 0 _ 1600/300=5.333 mm OK 97% under

Member 2, Load Case 1, Tension
On gross area f_t _ F_t, 0 _ 148.927 OK 100% under
On net area f_t _ F_t, 0 _ 199.948 OK 100% under

Member 2, Load Case 1, Slenderness
$K_{x*Lx/rx}$=1∗1600/26.204=61.059 _ 200 OK 69% under
$K_{y*Ly/ry}$=1∗1600/48.085=33.274 _ 200 OK 83% under

Member 2, Load Case 1, Compression
f_a _ F_a, 0 _ 13.812 OK 100% under

Member 2, Load Case 1, Bending & tension
$f_a/F_t+f_{bx}/F_{bx}+f_by/F_{by}$=0/199.948+5.58/148.927+0/148.927=0.037 _ 1 OK 96% under

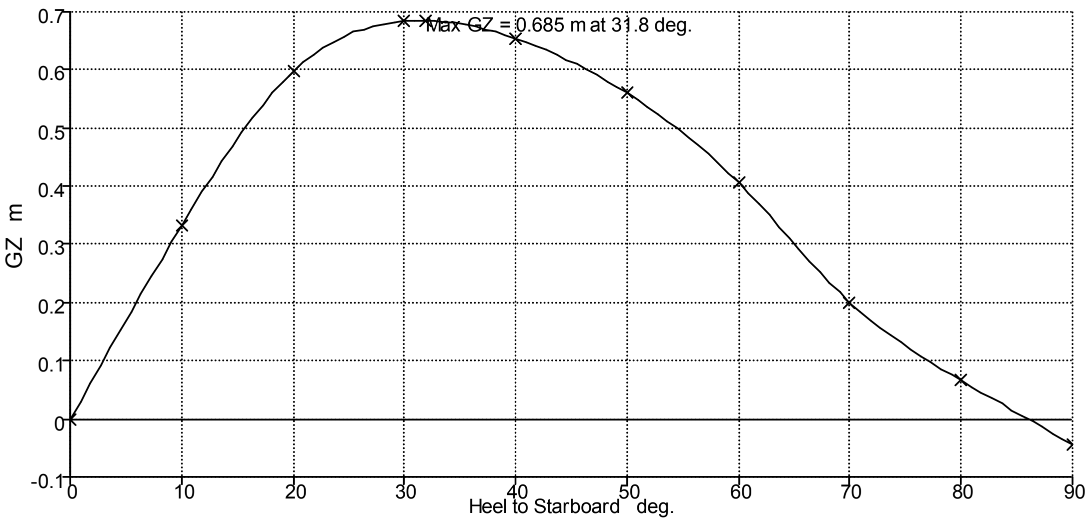
Member 2, Load Case 1, Bending & compression
f_a/F_a=0/13.812=0 _ 0.15 $\therefore$
$f_a/F_a+f_{bx}/F_{bx}+f_{by}/F_{by}$=0/13.812+7.841/148.927+0/148.927=0.053 _ 1 OK 95% under

Member 2, Load Case 1, Sway
Δ _ Y/300, 0 _ 0/300=0 mm OK 100% under

APPENDIX F1

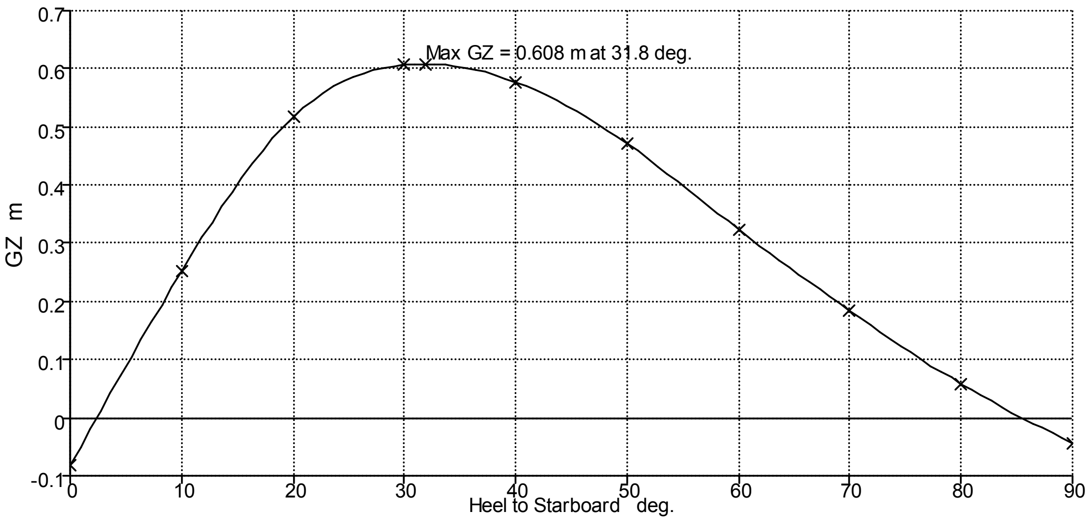
Prototype Model : 1
Load Case : 1

Graph GZ (m) versus Heel to Starboard (deg)

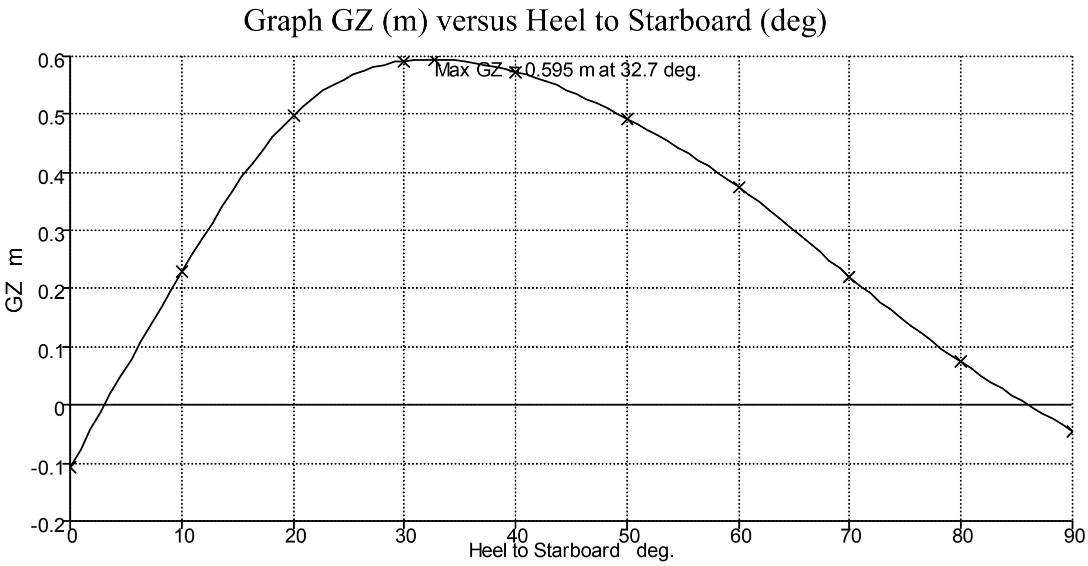


Prototype Model : 1
Load Case : 2

Graph GZ (m) versus Heel to Starboard (deg)



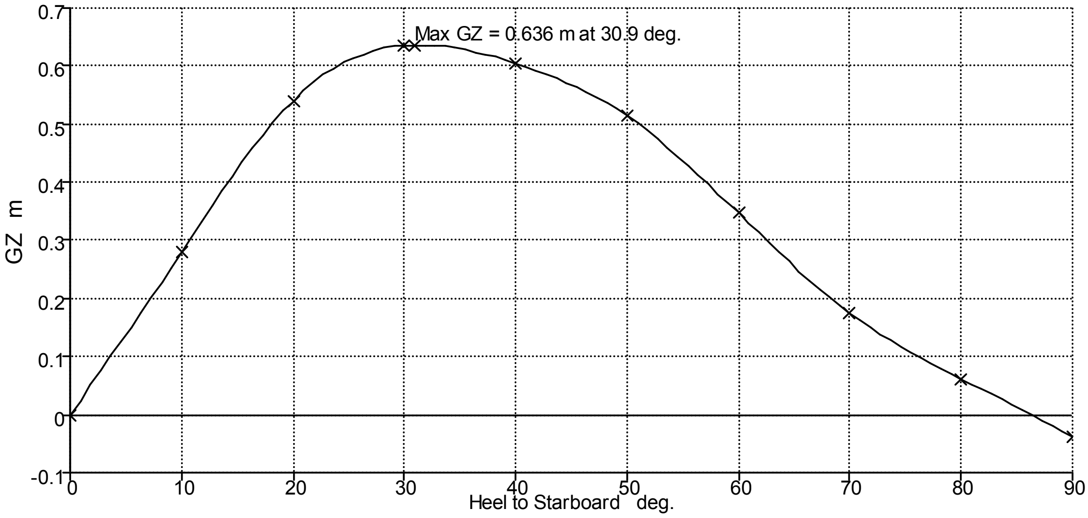
Prototype Model : 1
Load Case : 3



APPENDIX F2

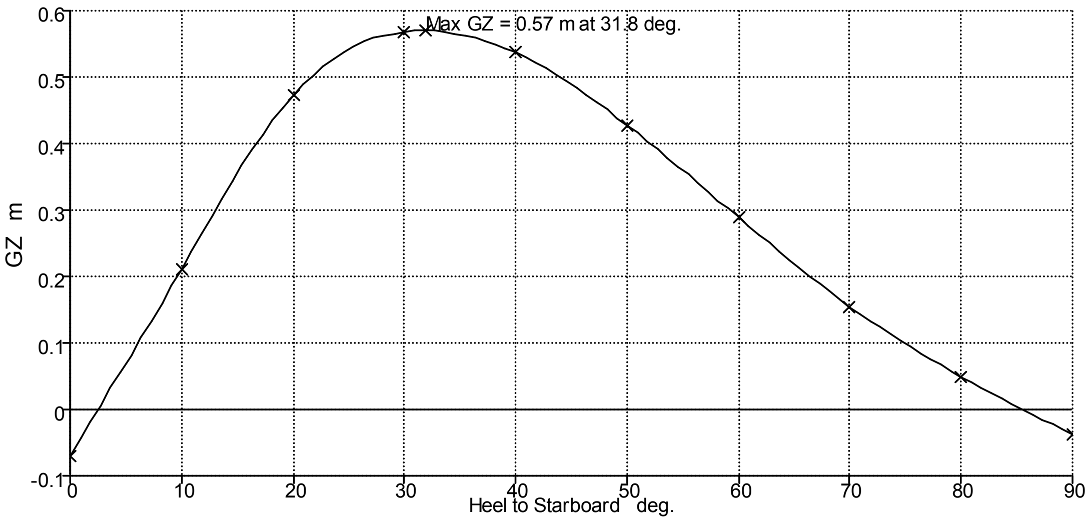
Prototype Model : 2
Load Case : 1

Graph GZ (m) versus Heel to Starboard (deg)



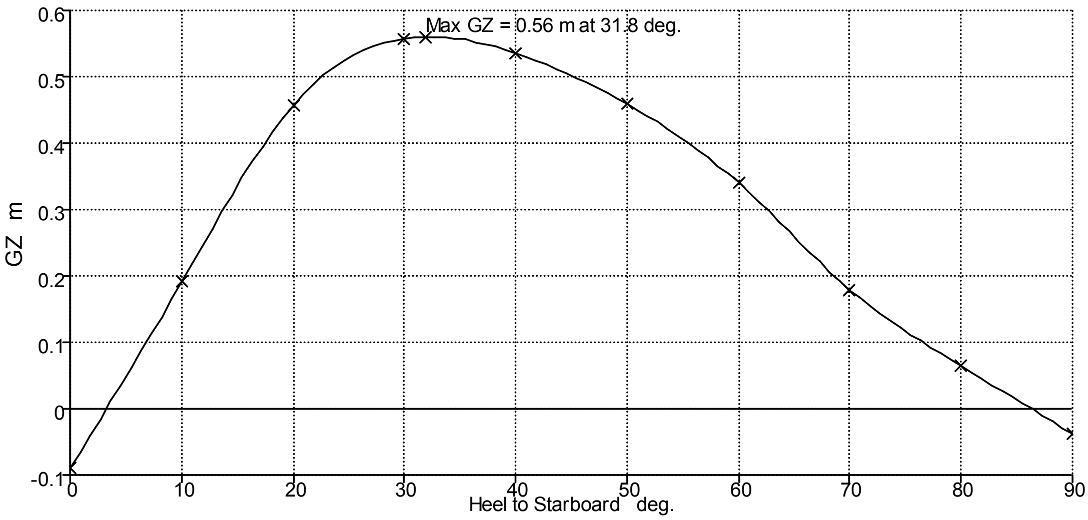
Prototype Model : 2
Load Case : 2

Graph GZ (m) versus Heel to Starboard (deg)



Prototype Model : 2
Load Case : 3

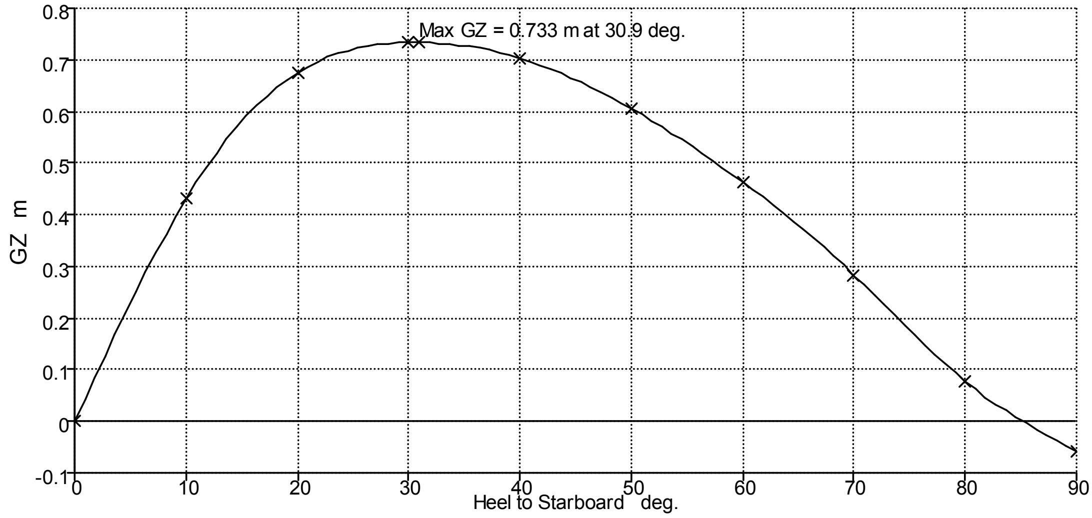
Graph GZ (m) versus Heel to Starboard (deg)



APPENDIX F3

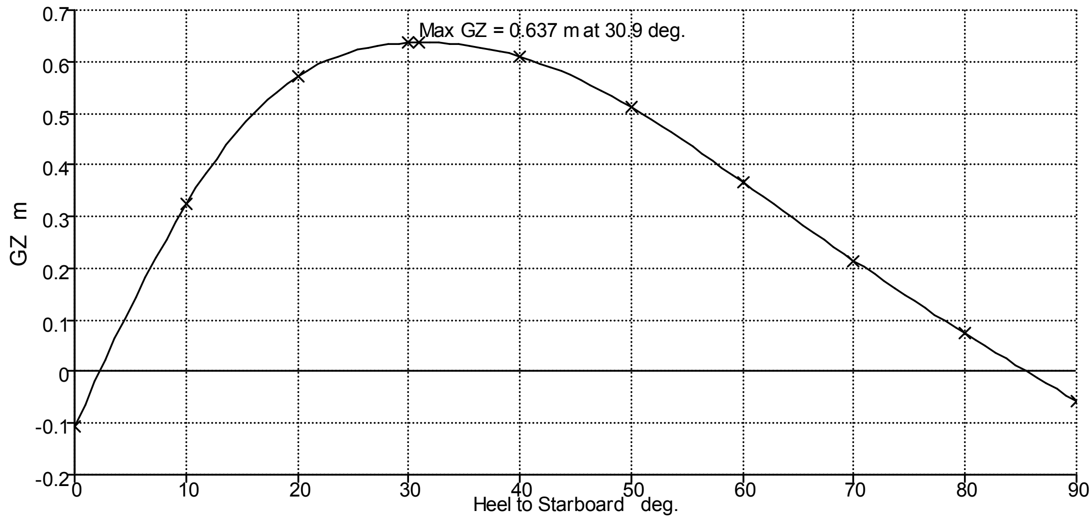
Prototype Model : 3
Load Case : 1

Graph GZ (m) versus Heel to Starboard (deg)



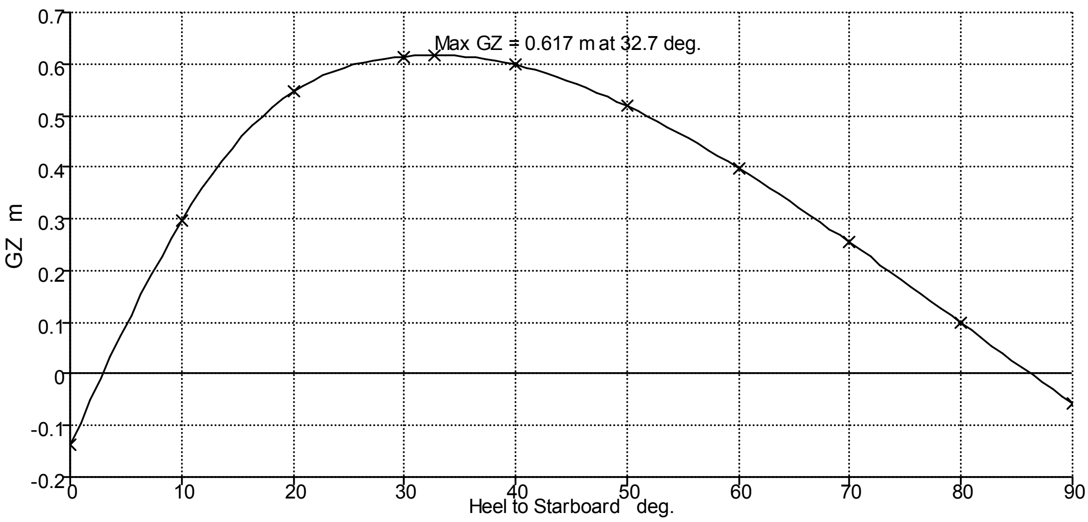
Prototype Model : 3
Load Case : 2

Graph GZ (m) versus Heel to Starboard (deg)



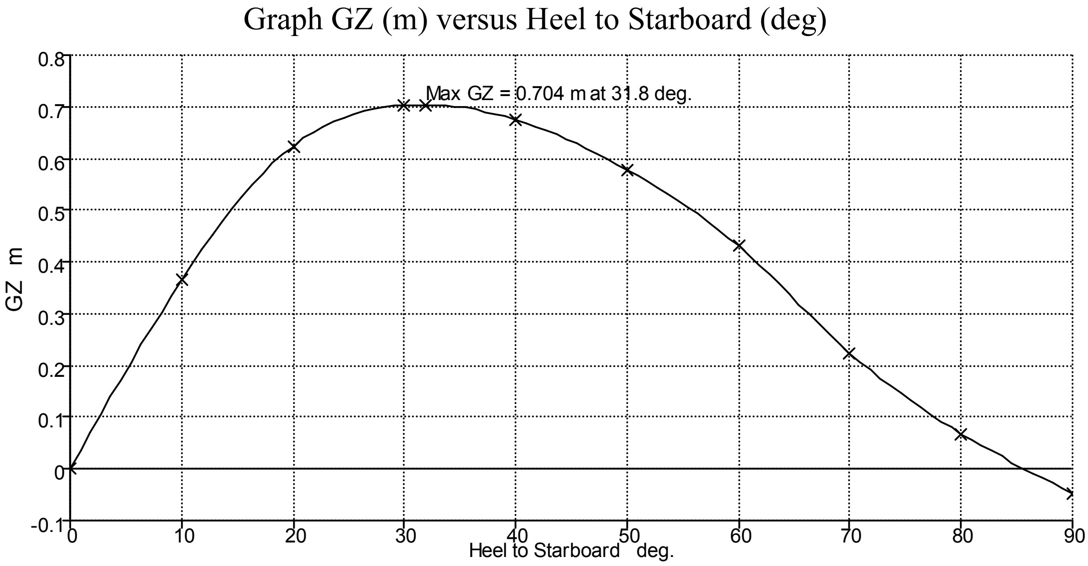
Prototype Model : 3
Load Case : 3

Graph GZ (m) versus Heel to Starboard (deg)

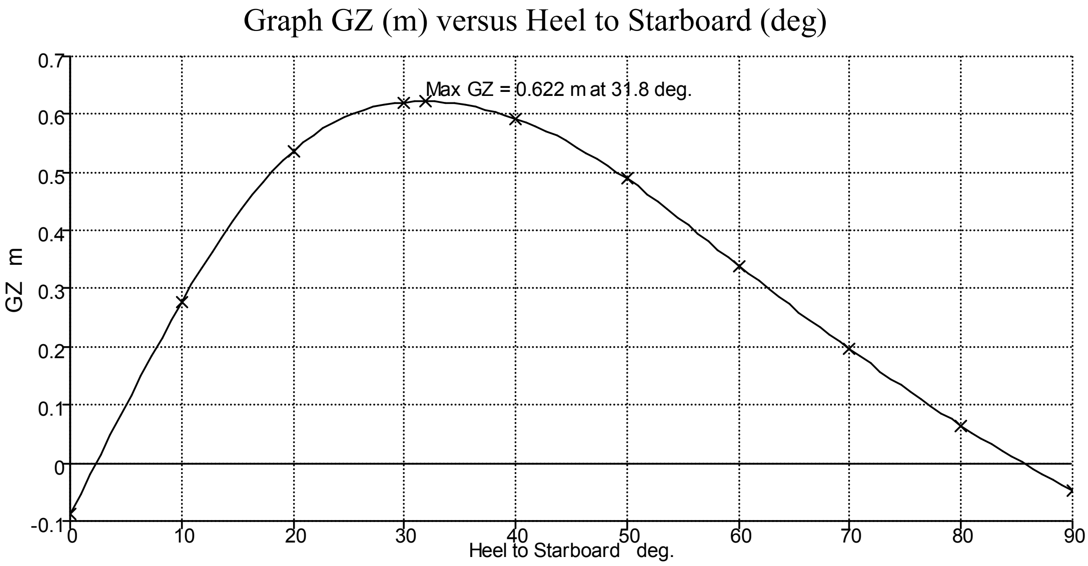


APPENDIX F4

Prototype Model : 4
Load Case : 1



Prototype Model : 4
Load Case : 2



Prototype Model : 4
Load Case : 3

Graph GZ (m) versus Heel to Starboard (deg)