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Inland Water and Offshore Aquaculture Technology Systems Series

Edited by
Dr. Sulaiman Olanrewaju Oladokun

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Preface

The vastness of the ocean and its various processes that support life and earth remain a big challenge for humanity. Despite so much achievement in human civilization, logistic, to information technology to multimedia and sensor technology, the knowledge of water and ocean has left man with much more work to do on innovation front and new discovery. Modern day challenges are cluster of alternative energy, protection of the environment, ocean space exploration, sensing technology and material science. The book presents recent studies that have been carried out in maritime research and innovation front. Potential users of the books are library, societies, universities, research centers, professional bodies, government and NGO.

-Dr. Sulaiman Olanrewaju Oladokun

About Author

Dr.O.O.Sulaiman is Associate Professor of Ocean Engineering, and coordinator for Maritime Technology International program, University Malaysia Terengganu. His specialization is in Safety and Environmental risk and reliability for maritime and ocean systems, maritime and ocean energy and environment, sustainable maritime system design. He is chartered engineer with diverse academic and professional background. He has taught and mentor courses and research projects on contemporary issues in maritime and ocean engineering field. He has authored and co-authored a total of about more than 120 publications which include proceeding papers, journal papers, technical report and chapters in book, monograph, seminar papers and other types of academic publications. He has authored more than 60 peer review journals and 6 books. He has patented research work on marine green technology. He is chattered engineer registered under UK Engineering Council. He is the member of royal Institute of Naval Architecture (RINA) and Institute of Marine Engineering, Science and Technology (IMarEST), PIANC, IEEE, ASME.

Acknowledgement

A book that cover wide range of salient information on contemporary sustainable marine maritime technology and systems in coastal and ocean environment owe much appreciation to various individuals, equipment manufacturers and organizations. I am grateful for those who helped in different ways during the preparation of the book.

Introduction

The book will represent a master piece that provides information and guidance on future direction of marine technology and sustainability requirement. The book focuses on various contemporary issues that make its contents richer, more informative and beneficial to the wide number of readers in industry and academic sphere. This book provides the most recent information about proactive approach to sustainable development technology for readers about requirements of sustainable marine system. The book will be useful as followed:

- Reference material for academician, students, researcher, universities library, research institution as well as classroom subject.
- Networking, literature citation
- Useful information for maritime industry and organization Industry and regulatory institution.

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Inland Water and Offshore Aquaculture Technology Systems Series

Sulaiman Olanrewaju Oladokun*

Associate Professor of Ocean Engineering and Coordinator for Maritime Technology International Program, University Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia.

***Corresponding author:** Sulaiman Olanrewaju Oladokun, Associate Professor of Ocean Engineering and Coordinator for Maritime Technology International Program, University Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia Tell: +6096683697; Fax: +6096683149; E-mail: o.sulaiman@umt.edu.my

Preliminary Design and Prototype Scale Model of Offshore Aquaculture Floating Structure

Abstract

Seaweed farming has become one of the natural resources which are economically important. The existing cultivation system for seaweed is not suitable for deployment with most of deep and open water area. Moreover, the current cultivation system are not environmental sustainable and economical unstable. This paper describes the design of the offshore floating structures scientifically based on improvement of the Long Line System for commercializes scale seaweed farming. Some key factors in the design, prototype and testing of floating offshore structures considered in the development of ocean farming technology system are discussed.

Introduction

Recent time shows trend where the concept of VLFS is becoming increasingly popular all around the world, especially in land-scarce island countries and in countries with long coastlines for a number of reasons. VLFSs has been constructed and/or can be built to create floating airports, bridges, breakwaters, piers and docks, storage facilities (for instance for oil), wind and solar power plants, for military purposes, to create industrial space, emergency bases, entertainment facilities, recreation parks, sewerage treatment and waste disposal plants, nuclear power plants, mobile offshore structures and even for habitation. In fact, the last could become reality sooner than one may expect: already different concepts have been proposed for building floating cities or huge living complexes. As a result, this sector has received a lot of research interests in recent years.

Design of very large floating structure for seaweed cultivation project is a socio-economic being carried out as collaboration between UMT, Technip and Bureau Veritas towards developing offshore aquaculture marine technology platform that will provide supplementary income to fishermen in rural areas by selling seaweed as a cash crop and enhanced effective use of ocean resources. Beside the benefits of developing local capabilities and hands-on learning, this study is partly funded using funds for sustainable development.

The project involves design of the mooring system used to anchor and provide station keeping for the seaweed plantation platform to the seafloor in order to prevent tangling of the seaweed and excessive movement of the platform. The project involve technology transfer from offshore industry to design floating platforms for offshore aquaculture carry out model tests at UTM Lab towing tank facility with appropriate equipment and instrument to determine the hydrodynamic coefficients of different components, especially the seaweed for use in design of the mooring system. The determined coefficients are used to design the configuration and appropriately size components of the mooring system.

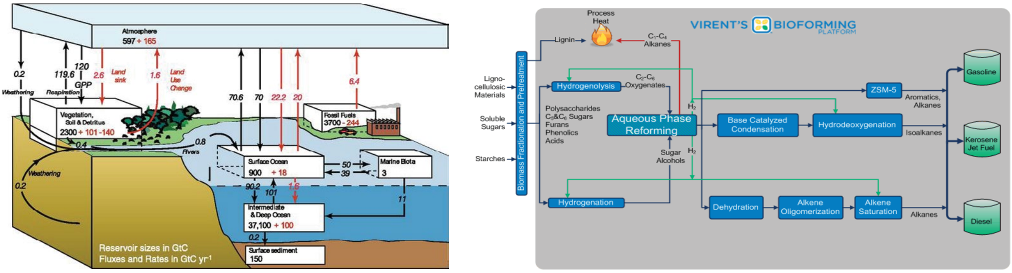
The system design employed industry guidelines such as API RP 2SK, BV and DNV specification on how the data is to be used to design the station keeping (mooring) system including anchor piles and mooring components like shackles, chains, wires, ropes, etc. that make up the system, to assure the system is strong enough to withstand the expected loads and maintain required factors of safety.

Design for ship and offshore performance depends on geometric shape/form factor, load on the system and environmental load on the system factor data, some of which are available from historical and experimental data. However, in case of seaweed, the seaweed interacts directly with the environment compare to other marine structure where the structure has close interaction the environment also available data on the hydrodynamic loading is lacking. Neither are there any known computational tools which can readily simulate the loads on such flexible, buoyant structures. So, the best way to quickly obtain such data is through the use of model tests. For this purpose, samples of seaweed cultures is subjected to static and dynamic tests for the purpose of determining the equivalent added mass and damping coefficients. The test result are then applied in typical software tools to design a mooring system for seaweed which has a good chance of surviving the expected met-ocean conditions for which it has been designed.

Potential of Seaweed

Seaweed farming has become an economically important natural resource. It has wide application potentials similar to other commodities such as palm oil and cocoa. It application found uses product such cosmetic, medicine, gelatine, food, CO_2 sink and biomass energy source (Figure 1). There is currently worldwide requirement to produce large amount. However there is currently no proper system to deliver this demand.

This paper discusses a solution to overcome the problem of deep water and open water environment by proposing a design of offshore floating structure for seaweed farming. This study introduces an appropriate optimized design of the Long-Line Cultivation Method for seaweed cultivation that meets current demand. The new design of floating structure for seaweed ocean farming will improve seaweed culture efficiency and its adoptability and continuity of its operation.



a.CO_2sink b. Biomass energy

Figure 1: Seaweed Application.

Concept of VLFS

The Mobile Offshore Base (MOB) and Mega-Float are typical Very Large Floating Structure (VLFS) with unique concept of ocean structures that with different behavior of from conventional ships and offshore structures. The engineering challenges are associated with:

i. Improvement of fatigue life: VLFS is subjected to constant repetitive load, which lead to fatigues and cracks in interconnected module and in connection points as well.

ii. Detailed structural analysis: The structural designs required to fulfills serviceability and safety requirements in a cost-effective manner. For a novel structure like a Very Large Composite Floating structure (VLCF), the structural design needs a first-principle approach that is based on a rational structural response analysis and explicit design criteria.

iii. Modification of station keeping system: Station keeping system involves numerical modeling.

iv. Parametric study: Parametric study is a also a key requirement to provide design guidelines for the construction of VLFC as well as to identify the improvements that can be made.

Behavior, design procedure, environment and the structural analysis of VLFS required adaptation of conventional ships and offshore structures design knowledge. The design and analysis of VLFS are characterized with unprecedented length, displacement and associated hydro elastic, response. Lots of improvements are currently required in this field to make the application of VLFS more practical. VLFSs, whether built for public use or for industrial facilities is expected to have a long service life (50-100 years) wit preferably low maintenance; and their safety, reliability and survivability are vital for their economic feasibility. VLFSs should also have good fatigue life, corrosion and fracture resistance as well as light structural weight to ensure sustainability [1].

Work on the design of hydro elastic analysis of VLFSs may be found in the review papers mentioned at Kashiwagi M [2], Newman JN [3], Ohmatsu S [4], Suzuki H et al., [5], Watanabe et al., Fujikubo et al., are worked on structural modeling global response analysis and collapse of VLFS. Inoue K [6], work focuses on stress analysis of the system. [7] focus on use of composite e material for VLFS. Mamidipudi and Webster undertook pioneering work on the hydro-elastic analysis of a mat-like floating airport by combining the finite-difference method for plate problem and the Green's function method for fluid problem. Wu et al., solved the two dimensional (2-D) hydro elastic problems by the analytical method using Eigen functions. Yago and Endo analyzed a zero-draft VLFS using the direct method and also compared this with their experimental results. Ohkusu and Nanba analyzed an infinite-length VLFS analytically. Kashiwagi applied the B-spline panels for the analysis of a zero-draft VLFS using the pressure distribution method. Nagata et al., and Ohmatsu [4] analyzed a rectangular VLFS by using a semi-analytical approach based on Eigen function expansions in the depth direction. Che, Xiling [8], work on the hydro elastic analysis of a mat-like floating airport by combining the finite difference method for plate problem and the Green's function method for fluid problem.

In order to couple the problem between the structure part and the fluid part, there exist two competing approaches. These two approaches are sometimes referred to as the modal method and the direct method. In most cases, the direct method is computationally more demanding than the modal method. Thus, the dry-mode superposition method can use for the actual design of VLFS.

Material and Methodology

In the structural design of floating structures, the external load and major load effects, are determine from hydro elastic body motions. The dimensions and arrangement are determined so that the structure has sufficient strength against the given loads and loads effects. Hydro-elastic response analysis dealing with specifies design variable such as structural depth, length, arrangement and size are employed. The characteristic length and frequency derived by Suzuki and Yoshida [5] for VLFS are referenced during this process.

The details of the design consider deterministic analysis of actual structural configurations that have variable of structural characteristic. From the results of global response analysis of mooring components, the local stress response under combined load effects is evaluated. Through the evaluation of strength and serviceability limit states both the arrangement of structural member's analyzed. Figure 2 shows methodology adapted from International Ship Structure Congress.

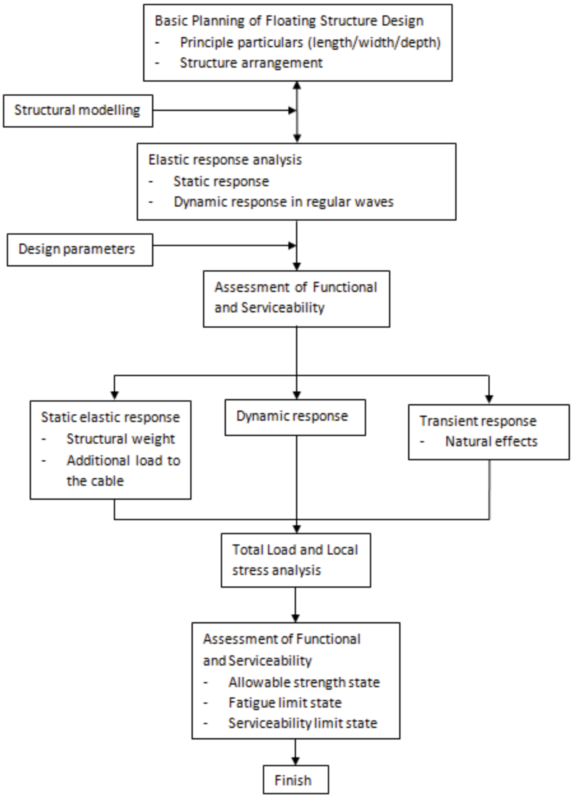


Figure 2: Typical Design Flowchart Modified from the Work of [9].

Model tests involved:

i. Measure drag loads of actual seaweed by towing.

ii. Dynamic tests to measure added mass and damping using PMM. Originally, it was planned to use the Planar Motion Mechanism (PMM). However, the equipment was not functioning. So, this part of the test plan had to be modified. The revised test plan is described below.

iii. Hydrodynamic tests on component tests (Buoy, ropes and float, net) considered available from coefficient of mooring components. Industry data can be substituted for component loading during initial design work.

iv. Complete system tests with scaled seaweed of 1/50 scaled model deployed at UMT

The complete system tests will be used to confirm the adequacy of the preliminary design Instrumentation required:

i. Load cells of suitable size and range will be attached to the seaweed lines

ii. Wave probes

iii. Native carriage speed record

iv. Wave flap signal

The load cells attached to the mooring spring are water-proof aluminum ring strain gauges that measure axial tensile loads. The measured voltage outputs from the load cell strain gauges are connected by cables to the basin's native Dewetron Data Acquisition System (DAQ) to be digitally sampled and stored. Software is used to convert the measured voltage to tension readings. The load cells are appropriately-scaled and calibrated (100N range). Other instruments used in the tests are wave probes fixed at specific locations under the carriage and accelerometers mounted on the model decks. Both are channeled to the DAQ to record measured data output. A video camera was positioned at strategic locations on the carriage for model motion recordings.

Model Test

The model test is required to determine the hydrodynamic loads due to waves and currents acting on seaweed and its mooring system components. The total system loads must be suitable for use in designing a seaweed culture mooring system to avoid failure with potential loss of the valuable crop and possibly requiring costly repairs or replacement of the mooring system components.

Tests for Seaweed Hydrodynamic Coefficients: Tests is carried out to identify hydrodynamic coefficients of an equivalent Morison model of the seaweed which will be suitable for use in typical mooring design and analysis package such as Arianne. Samples (clumps) of dried seaweed, the dried will restore to nearly nominal properties when soaked in water for a period of time. Typical size seaweed clump weigh up to 1.5kg in air, when fully grown. However, the natural buoyancy of the seaweed, make its weight in water almost insignificant. A sample clump of seaweed weight in air 4.1N and the corresponding weight in water is 0.01N in UTM lab (Figure 3).

A sample row of seaweed is attached to a frame and towed from the carriage. To determine the hydrodynamic coefficient, a series of tests including towing in calm water, towing in waves and wave-only tests will be performed. As mentioned, originally, it was planned to use the PMM to perform forced oscillation tests. The resulting loads can be analysed in a straightforward manner to determine the relevant coefficients which give similar hydrodynamic loads (Figure 4).

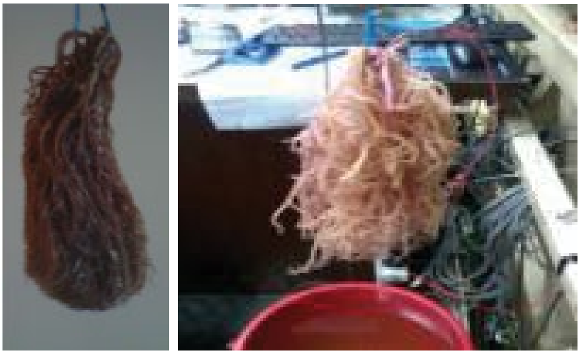


Figure 3: Seaweed.

However, the PMM system is not functioning at present. So, an alternative plan had to be developed. The main difficulty is that the available seaweed samples represent full-scale (prototype) clumps, whereas, the model basin is equipped to generate wave and current kinematics (wave height <0.4 m 0.5 s<Period<2.5 s, and speed<5 m/s) typical of model scale conditions. Therefore, a mismatch exists between the typical body (clump) dimensions and the relative kinematics that can be generated. Some approximations and simplifying assumptions are needed to utilize the available facilities to determine the required coefficients.

The solution chosen at present is to focus on certain key non-dimensional values and try to use the use different scaling factors to apply the results at full scale. In this way, the kinematics available in the towing tank can be used. For example, it is believed that the physical behaviour of seaweed may be similar to that of cylinders in waves and currents. Therefore, the approach closely follows that of the commentary section of the API RP-2A.

For example, the effects on hydrodynamic loading of Keulegan-Carpenter number

$$KC = \frac{2\pi A}{L} \tag{1}$$

Where: A=amplitude of wave particle motion, L=typical length of a seaweed clump

Wave current flow reversal effects (r=ratio of current/wave orbital velocities) are expected to be similar to those for cylinders, though perhaps somewhat more complex and with different regimes for seaweed. Table 1 and 2 below shows the non-dimensional parameters for a series of sea states, typical of the Southeast Asia met-ocean climate. Note it is not envisaged to design the seaweed mooring for extreme environments such as rare 100-year events, typically used for offshore platforms because the consequences of potential failure while still undesirable are considered much less severe.

For the determination of coefficients, the KC number will be preserved. The KC number for all the seastates is KC>12, So, relatively large wave velocities are present. Also, the effect of flow reversal can be maintained, at least in the near surface zone where the seaweed floats, by running the same waves at similar speeds. It is remarkable that the wave kinematics is very similar for all the different sea-states. Therefore it is possible to greatly simplify the tests plan by appropriate choice of the scaling factors for each sea-state. In fact it is sufficient to tests a single wave to produce scaled wave kinematics for all the conditions at least for the important parameter of wave velocity at the surface.

Then what varies between sea-states is actually the current velocity, and resulting ratio r, of wave/current velocities. For the present, tests it is decided to focus on deterministic, regular waves, representing the worst design wave for each sea-state. These waves are characterized by H_{max} and associated period T_{asso}. Therefore the tests can be carried out by using the same wave and changing the current velocity for each sea-state.

Exceedence Prob/Return Period		50%	90%	99%	1 year
Hs	m	0.9	1.8	2.8	5
Hmax	m	1.9	3.6	5.4	9.6
Amax	m	0.95	1.8	2.7	4.8
Tp	s	4.6	6.4	8	10.7
Tasso	s	4.3	6	7.4	10
Uc	m/s	0.21	0.47	0.78	1.61
Mass	g	1500	1500	1500	1500
Length, L	cm	50	50	50	50
Amax/L		1.9	3.6	5.4	9.6
Diameter, D	cm	1	1	1	1
Amax/D		95	180	270	480
Uw	m/s	1.39	1.88	2.29	3.02
U	m/s	1.60	2.35	3.07	4.63
Uc/Uw		0.15	0.25	0.34	0.53
r=Uw/Uc		6.61	4.01	2.94	1.87
KC No.=2π A/L		11.9	22.6	33.9	60.3
Re No.=UL/v		799,073	1,177,478	1,536,257	2,312,964

Table 1: Full scale Seaweed Parameters.

Model Scale		6	12	16	30
Exceedence Prob/Return Period		50%	90%	99%	1 year
Hs	m	0.15	0.15	0.18	0.17
Hmax	m	0.32	0.3	0.34	0.32
Amax	m	0.16	0.15	0.17	0.16
Tp	s	1.88	1.85	2	1.95
Tasso	s	1.76	1.73	1.85	1.83
Uc	m/s	0.09	0.14	0.2	0.29
Mass	g	0.94	0.87	0.37	0.06
Length, L	cm	8	8	8	8
Amax/L		1.98	1.88	2.11	2
Diameter, D	cm	1	1	1	1
Amax/D		15.8	15	16.9	16
Uw	m/s	0.57	0.54	0.57	0.55
U	m/s	0.65	0.68	0.77	0.84
Uc/Uw		0.15	0.25	0.34	0.53
r=Uw/Uc		6.61	4.01	2.94	1.87
KC No=2π A/L		12.4	11.8	13.3	12.6
Re No=UL/v		52,195	54,385	61,450	67,566

Table 2: Proposed Model scale Parameters.

As these tests are currently ongoing, results will be presented as they become available in time for the conference.

Figure 4: UTM Towing Tank and Carriage.

Complete System Tests: The hydrodynamic loads measured will be used to build approximate scale models of the seaweed. The model seaweed will mimic the Froude-scaled properties (mass, dimensions, added mass and damping) of the seaweed measured previously. Suitable material such as plastic ribbon, rubber tubing or even young seaweed seedlings will be used to build a sufficiently quantity of scaled seaweed.

The tests of floating structure in regular and irregular waves will be carried out in the towing tank 120 mx4 mx2.5 m of Marine Technology Laboratory UTM. This laboratory is equipped with the hydraulic driven and computer controlled wave generator which is capable to generate regular and irregular waves over a period range of 0.5 to 2.5 seconds. For this structural experiment, a model of 2 mx2 m per block with 50 scale ration will be used. The floating structure dimension and model are shown in Table 3, Figure 5.

Item	Actual Structure	Model
Length Overall for 10 Blocks, L	1000m	2m
Breath, B	100m	2m
Dimension for Each Block	100m x 100m	2m x 2m
Mooring Depth, D	50m	2.5m

Table 3: Structural Dimension

One of the important task in planning a model test is to investigate the modeling laws required for the system in question to be analyzed. The scaling parameters is very important in designing a model test and a few key areas of consideration in replicating a prototype structure for a physical model test. In order to achieve similitude between the model and the real structure, Froude's law is introduce as the scaling method. Froude's law is the most appropriate scaling law for the free and floating structure tests [10].

The Froude number has a dimension corresponding to the ratio of u^2/gD where u is the fluid velocity, g is the gravitational acceleration and D is a characteristic dimension of the structure. The Froude number Fr is defined as

$$Fr^2 = gD/u \tag{2}$$

The subscripts p and m stand for prototype and model respectively and λ is the scale factor. Assuming a model scale of l and geometric similarity, the Froude model must satisfy the relationship:

$$u^{2}{}_{p/}gD_{p=}u^{2}{}_{m/}gD_{m}\,u \tag{3}$$

Important variable quantities of importance are derived from the equation and dimensional analysis as follows:

Linear	$l_p=\lambda l_m$
Speed	$u_p=\sqrt{\lambda}\ u_m$
Mass	$m_p=\lambda^3\ m_m$
Force	$F_p=(\lambda^3/0.975)*F_m$
Time	$t_p=\sqrt{\lambda}\ t_m$
Stress/Pressure	$S_p=\lambda\ S_m$

Figure 5: Scale model of the physical system.

Environmental load consideration: The weather in Malaysia is mainly influenced by two monsoon regimes, namely, the Southwest Monsoon from late May to September, and the Northeast Monsoon from November to March [11]. However the east coast of peninsular Malaysia is the area that exposed directly to the strong sea currents and periodic monsoon season which is prevalent off the east coast. Furthermore, with the existence of nature elements of the deep and open water environment, seaweed farming is hard to be applied in this area.

Regular waves were considered and generated by the wave maker for a few tests. Random wave's spectrum was based on the Jonswap spectrum for less than 1 Year or for 1 Year or greater, respectively. Froude scaling was applied to establish the relationship between full scale wave height (Hp) and period (Tp) and the corresponding model scale wave height (Hm) and period (Tm), where Hm=Hp/50 and Tm=Tp/√50.

Incident waves will be measured and analyzed prior to the tests. Two wave probes will be installed for calibrations: one in front of the carriage at the basin centerline and one to the side of the nominal position of the model. Wave force vector is generally expressed as the sum of linear wave force proportional to wave height and the slowly varying drift force proportional to the square of the wave height. Table 4

Return Period (Year)	Full Scale Wave Height (m)	Full Scale Wave Period (s)
90%	4.599	9.711
95%	4.850	10.25
1/12th	0.6	1.295
1 Year	5.110	10.79
10 Year	10.7	12.82
100 Year	7.3-13.6	11.1-15.1

Table 4: Full Scale Wave.

Mooring design for offshore platforms makes use of software tools which have been benchmarked against model tests, computational data and full scale measurements for their given applications. Hydrodynamic loading on the platform, risers and mooring system itself due to waves and currents are calculated using a variety of tools such as potential flow, CFD and empirical data.

Design of Offshore Aquaculture Structure for Seaweed Farming: Components of the Floating Structure is as followed (Figure 6)

i. **Frame Line:** This line support the planting line for each block of the structure. It was made from synthetic fibre rope.

ii. **Planting Line:** Planting line is the main part of the structure which contains the planted seaweed. This line must be able to withstand the mature growth of seaweed weight.

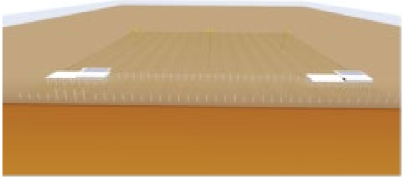
iii. **Separator Line:** When the nature hit floating structure, the planting line tends to tangle. Therefore, this line will act as the separator between each planting line.

iv. **Mooring Line:** This line holds the whole structure at the surface to be in place with connection to the anchor. Since mooring system is a crucial part for floating structure. It must be designed to withstand the natural force and achieve stability through the use of mooring line tension.

v. **Buoy:** Buoy is to provide a convenient means for connection of the floating structure on the surface to the mooring. Through the use of distributed buoyancy for each buoy, floating structures can achieve stability. The buoy also has to withstand the structural weight and additional load from the seaweed.

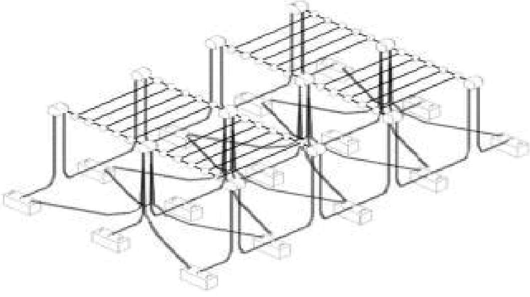
vi. **Sinker:** A sinker is made of concrete and placed on a catenary mooring line to ensure horizontal mooring at anchor, enhance mooring line energy absorption and affect mooring line pretension in a way that can be useful in controlling structural stability.

vii. **Anchor Block:** Anchor is designed in a large mass of concrete to keeps the floating structure at the place also to resists both horizontal and vertical movement.



3D View o first system

Physical system deployed at sea



Mooring configuration

Figure 6: Floating Structure for Ocean Farming System.

The study focuses to produce a design for offshore floating structure of seaweed farming. This design is required to meet the operating conditions, strength and serviceability requirements, safety requirements, durability, visually pleasing to the environment and cost-effective. An appropriate design service life is prescribed depending on the importance of the structure and the return period of natural loads. Its service life is generally expected to be as long as 50 to 100 years with preferably a low maintenance cost.

On logistic, this structure will be operating 200 meters from the shore as a result, the structure is likely to experience more energizes wave action and stronger wind associated with deep water region. This design also considered 1-2 boat lanes within the structure blocks which are about 5 meters wide at the original size.

In the structural design of floating offshore structures, the external load and major load effect, such as cross sectional forces are determined from the rigid body motions. The dimensions of structural members and arrangement are subsequently determined so that the structure has sufficient strength and stiffness against the given loads and loads effects.

Design Challenges: Innovative concept of the floating structure by definition has little or no history of past performance [9]. The factors challenges are:

(1) Incompletely defined structure.

(2) New operating environment.

(3) Lack of verified design criteria.

(4) New materials with different properties of strength and fatigue.

(5) New structure with different load control.

The design has to be reliable at any costs of the environment and risk. It must have the ability to operate without failure in order to gain hundred percent benefits from the operation. The design is required to come with systematic analysis of each component and operational in hydrodynamics condition. This will give the understanding of systematic review on how to implement the structure in the real practice.

The design of this system must determine the pros and cons of the design approaches in an attempt to reach the generic reliable system. Table 1 gives a list of structural design challenge parameters that would impact the performance of a floating structure system.

Each design challenge is evaluated from the three main items of achieving stability using a method of the symbols. The symbols indicate ease with which each challenge might be overcome for each parts of the system. As mention earlier, the structural design is impacted by the choice of each structure components. Therefore, it must be included in the table of design challenge. The design is likely to provide the most efficient floating structure that can stand the high impact from the response of nature. A design such as buoy is likely to be subjected to higher additional loading, which will increase the systems response (motion) to waves. Therefore, the design needs to be made to tolerate larger motion. However, it shall increase the complexity of the systems.

The complexity of the system to create accurate design that will increase the flexibility of the structure for greater responses and motions to wave loading. Predicting wave loads and dynamics for a stable structure require scientific analytical data that are more subject to wave loading. Additional loads from the growth of seaweed along the planting lines are considered part of the analysis in accession of the existing loads. Design of the mooring system is also depends on the water depth. The floating parts of the structure are likely to have catenary mooring lines that are connected directly to the anchors. This system driven by the length of mooring lines which are needed to minimize vertical loading of the anchors. Drag embedded horizontally loaded anchors is associated with a floating part of the structure. The process to identify suitable design for anchor consist of determining anchor holding capacity, burial depth, and drag distance. Moreover, seabed condition as the soil type and soil depth also should also be considered. Once the anchor design has been selected, the anchor size is chosen to satisfy the required holding capacity. The required maximum holding capacity being discussed further in Table 5 [12].

	Main Structure Items		
Structural Design Complexity	**Surface Components**	**Mooring Line**	**Anchor**
Components Buoyancy	●	●	○
Mooring System	○	●	○
Anchors Cost/Complexity		○	●
Seaweed Load	○	○	
Installation Simplicity	●	○	○
Maintainability	●	○	○
Depth Independence	●	○	○
Seabed Condition			●
Wave Sensitivity	○	●	
Maximum Current Load	○	○	○
Structure Weight	○	○	
Structure Motion	●	●	○
Maximum Wave Action Angle	○		

Table 5: Floating Structure Technical Challenges.

Key: ●-Relative Advantage, ○-Relative Disadvantage, Blank-Natural Advantage

Extreme waves are important in designing most of the offshore structures especially for structures that operates in the open sea. Generally, the submerge parts of the structure can easily avoid extreme waves relative to the position at the surface. Compare to the floating parts expose directly to the strong wind and rough waves. Therefore, a floating structure with high tolerant has to be described so it can be placed at a broader range of sites. Each design has a maximum depth that it can operate efficiently. Therefore, the ability to install the structure over a broad range of depths increases the number of sites suitable for that design. This design is more flexible which experiences less force compared to fixed structure and also more economical viable, therefore it can go for greater water depth. Moreover, commonly the floating structure that depends on water plane area can operate in both sites; shallow and deep water sites [13]. As this design structure aims to operates at the deep water area more than 50 m depth.

Risk based design requirement

Very large floating structure for fall under new system that needs to be designed based formal safety system approach. After modeling is finished, extensive structural analysis (Elastic response analyses, Stress analyses, collapse analyses, etc) should be carried out in this section to determine various 'Design Limit states' for the proposed VLCFS. The design limit states during structural analysis for marine structures (i.e. VLFS) include the Ultimate Limit State (ULS), the Fatigue Limit State (FLS), the Serviceability Limit State (SLS), and the Progressive Collapse Limit State (PLS). ULS refers to the ultimate event in which structural resistance has an appropriate reserve. PLS refers to the progressive failure of structures when subjected to accidental or abnormal load effects (DNV). PLS for accidental load effects is also called the Accidental Collapse Limit State (ALS) [14]. ULS corresponds to component design verification based on the elastic behavior of the structure, and thus can be examined by the hydro-elastic response analysis. But PLS needs a progressive collapse analysis that considers nonlinear structural behaviors such as buckling and yielding. Safety risk and reliability analysis to address risk over the entire life of the complex system is being applied to the design of the system. Qualitative risk assessment employed the following tools to identify risk in the system. Hazard Identification

i. Checklist
ii. Hazard and Operability Study (HAZOP)
iii. Quantitative risk assessment and analysis method.
iv. Failure Modes and Effect Analysis (FMEA)
v. Fault Tree Analysis (FTA)

Quantitative scientific risk employed analysis related to system failure and consequence related to number of failure of mooring legs, cost, and causal factors emanating from environmental loading. Uncertainty analysis will be addressed during simulation, subsystem level analysis using FTA and ET as well human reliability analysis. In analyzing the failure probability, it is important to bear in mind that a mooring device is failed when the mooring reaction force *W*, due to oscillation of the floating structure, exceeds the yield strength *R*. The floating structure drifts when all its mooring devices are failed. Failure of a mooring device indicates presence of an event satisfying the following condition:

$$\Pr ob\left[\bigcup_{k=1}^{m} Z_K(t) > 0, 0 \ge t \ge T \,\middle|\, X = x_k\,, R_K = r_k\right]$$

$$P_f(T) = \iint dx_i dr_k$$

$$0 \le t \le T$$

$$Z_k(t) = W_k(t; X) - R_k > 0$$

Where, X is natural condition parameters, T duration of the natural condition parameters, and R_k the random variable for the final yield strength of mooring device *k*, *X* and R_k are independent of each other. The probability of a multi-point mooring system being failed by strong wind and waves induced current in specified service life is given by the following equations (Figure 7)

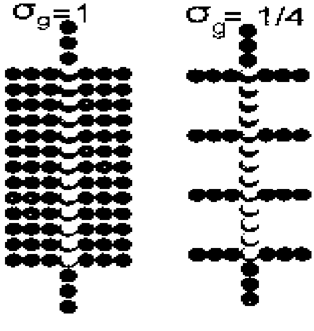


Figure 7: Reliability approach to number of mooring.

Using the extreme-value distribution of the annual maximum values as the distribution of natural condition parameters, the annual reliability is given as:

$$m_{ij}(\infty)$$

The total reliability for years of service life is approximated by the following equation:

$$R_N(T) = \left(1 - P_f(T)\right)^N$$

Mooring force analysis from first principle: The system analysis is best model from deterministic approach and concludes with probabilistic and stochastic approach. First principle system consider for the design is shown in Figure 8. The governing equation for oscillation of the floating structure is defined as follows:

$$F = \left[M_{ij} + m_{ij}(\infty) \right] X(t)'' + F_v(\dot{X}) + \sum_{j=1}^{n} \int_{-\infty}^{t} \dot{x}_j(\tau) L_{ij}(t-\tau) d\tau + F_M(X, \dot{X})$$

$$F = F_{env}(t) + F_{moor}$$

Where $\overline{X}$: displacement vector of horizontal plane response of the floating structure; M_{ij} : inertia matrix of the floating structure $m_{ij}(\infty)$ added mass matrix at the infinite frequency; F_v : viscous damping coefficient vector; L_{ij} : Memory influence function; F_M : Mooring reaction force vector; Fenv : Environmental loading load force, Fmoor: mooring force.

$$\mathrm{Rx}_{(n)} = \mathrm{Rx}_{(n-1)} + \mathrm{Fx}_n$$

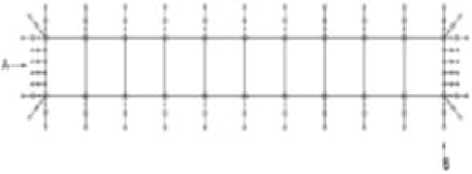
$$\mathrm{Rz}_{(n)} = \mathrm{Rz}_{(n-1)} + \mathrm{Fz}_n \mathrm{T}_n = \left[\mathrm{R}_{X(n)}{}^2 + \mathrm{R}_{Z(n)}{}^2 \right]^{\frac{1}{2}}$$

$$\grave{e}_n = \tan^{-1} \left[\frac{\mathrm{R}_{z(n-1)}}{\mathrm{R}_{x(n-1)}} \right]$$

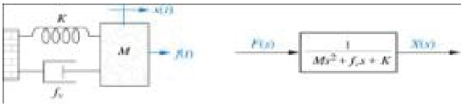
$$s_n = L_n + ▲L_n$$

$$\text{Coordinate } X_{(n)} = X_{(n-1)} + S_{(n)} \cos \quad _{(n)}$$

$$\text{Coordinate } Z_{(n)} = Z_{(n-1)} + S_{(n)} \sin \quad _{(n)}$$



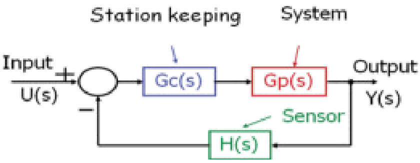
a) Offshore aquaculture System



b) System behavior

$$F(s) = (ms^2 + fs + k)Y(s)$$

$$TF = G(s) = \frac{Y(s)}{F(s)} = \frac{1}{ms^2 + fs + k}$$



c) System control block diagram

Figure 8: System description for deterministic analysis.

The elements immersed weight, WI is defined BY:

$$WI = FB - W$$

WI is positive, the element is positively buoyant (polypropylene subsurface floats), and if it is negative, the element is negatively buoyant (wire rope and shackles).

The drag Q in each direction acting on each mooring element is calculated using:

$$Q_J = \frac{1}{2} P_W . C_{Dt} . A_J U U_J$$

Where Qj is the drag in (N) on element 'i' in water of density rw in the direction 'j' (x,y or z), Uj is the velocity component at the present depth of the mooring element which has a drag coefficient CDi appropriate for the shape of the element, with surface area Aj perpendicular to the direction j. At the depth of the element, the drag in all three directions (j=1(x), 2(y) and 3(z)) is estimated, including the vertical component, which in most flows is likely to be very small and negligible. Figure 9 shows system motion analysis.

Once the drag for each mooring element and each interpolated segment of mooring wire and chain have been calculated, then the tension and the vertical angles necessary to hold that element in place (in the current) can use the equation below to estimate the three (x,y,z) component of each element:

$$Q_{xi} P_f (T) = \iint dx_i dr_k$$

$$Q_{xi} + T_i \cos\theta_i \sin\psi_i = T_{i+1} \cos\theta_{i+1} \sin\psi_{i+1}$$

$$Q_{yi} + T_i \sin\theta_i \sin\psi_i = T_{i+1} \sin\theta_{i+1} \sin\psi_{i+1}$$

$$B_{ig} + Q_{zi} + T_i \cos\psi_i = T_{i+1} \cos\psi_{i+1}$$

$$X_i = X_{i+1} + L_i \cos\theta_i \sin\psi_i$$

$$Y_i = Y_{i+1} + L_i \sin\theta_i \sin\psi_i$$

$$Z_i = Z_{i+1} + L_i \cos\psi_i$$

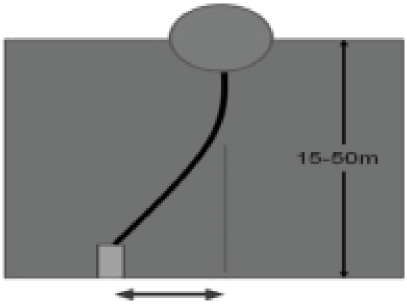


Figure 9: System motion analysis.

Drag coefficients are a function of Reynolds number, Re, as defined as:

$$\mathrm{Re} = \frac{UD}{\nu}$$

Where U is the velocity of the flow, D is the characteristic buoy dimension, and ν is the fluid kinematic viscosity.

By summing the forces at the attachment point, component of the tension is given by

$$T_h = F_d$$

$$T_v = F_b - W$$

$$T_{HV} = \sqrt{{T_H}^2 + {T_V}^2}$$

Where TH and TV are the horizontal and vertical tensions in the submerged element; the forces, FD and FB are the drag and buoyant forces respectively and W is the weight of the buoy. The resultant tension is

Total tension on the mooring lines is the other important aspects that have to be considered. Concentrated loads are spread cross the length of the cable and do not be equal. As they are flexible they do not resist shear force and bending moment. It is subjected to axial tension only and it is always acting tangential to the cable at any point along the length. If the weight of the cable is negligible as compared with the externally applied loads then its self-weight is neglected in the analysis. In the present analysis self-weight is not considered (Figure 10).

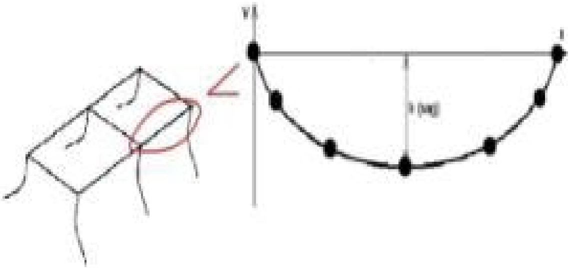


Figure 10: Cable analysis.

Consider a cable ABCDE as loaded in Figure 11. Let assume that the cable lengths, L_1, L_2, L_3, L_4 and sag at B, C, D (h_b, h_c, h_d). The seven reaction components at each point, cable tensions in each of the four segments and three sag values are to be determined. From the geometry, one could write two force equilibrium equations $(\sum F_x = 0, \sum F_y = 0)$ at each of the point A,B,C,D, and E.

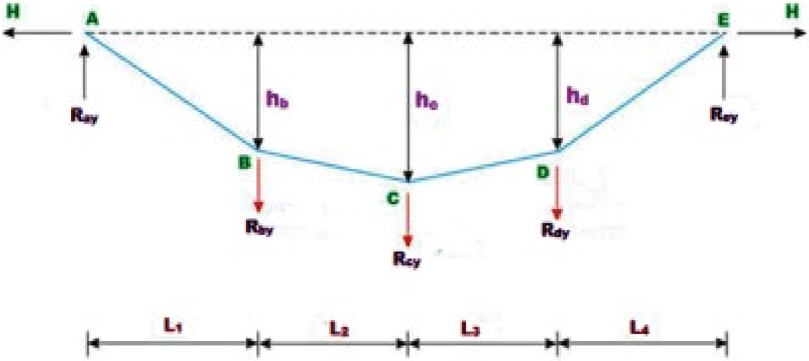


Figure 11: Cable Subjected to concentrated Load.

Where:

$R_{ay}, R_{by}, R_{cy}, R_{dy}, R_{ey}$=Force acting at point A,B,C,D,E

h_b, h_c, h_d=Cable sag at point B,C,D

L_1, L_2, L_3, L_4, L_5=Horizontal cable length.

Since, there are no horizontal loads, horizontal reactions, A and B should be the same. Taking moment about E,

$$R_{ay} x \left(L_1 + L_2 + L_3 + L_4\right) - R_{by} x \left(L_2 + L_3 + L_4\right) - R_{cy} x \left(L_3 + L_4\right) - R_{dy} x \left(L_4\right) = 0$$

Now horizontal reaction H may be evaluated taking moment about point C of all forces left of C.

$$R_{ay} X (L_1 + L_2) - H x h_c - R_{by} X L_2 = 0$$

$$H = \frac{R_{ay}.(L_1 + L_2) - R_{by}.L_2}{h_c}$$

To determine the tension in the cable in the segment AB, consider the equilibrium of joint A

$$\sum Fx = 0 => T_{ab} \cos\theta_{ab} = H$$

$$T_{ab} = \frac{H / L_1}{\sqrt{L_1^{2} + h_b^{2}}}$$

Considering equilibrium of joint B, C and D, one could calculate tension in different segments of the cable. The Total Length of the cable S is given then the required equation:

$$S=\sqrt{L_1^2 + h_b^2} + \sqrt{L_2^2 + (h_c^2 - h_b^2)} + \sqrt{L_3^2 + (h_c^2 - h_d^2)} + \sqrt{L_4^2 + h_b^2}$$

Alternatively, application of catenary curve describes the shape the displacement cable takes when subjected to a uniform force such as gravity. The equation obtained by Leibniz and Bernoulli in 1691 in response to a challenge by Bernoulli and Jacob involve examining a very small part of a cable and all forces acting on it (Figure 12).

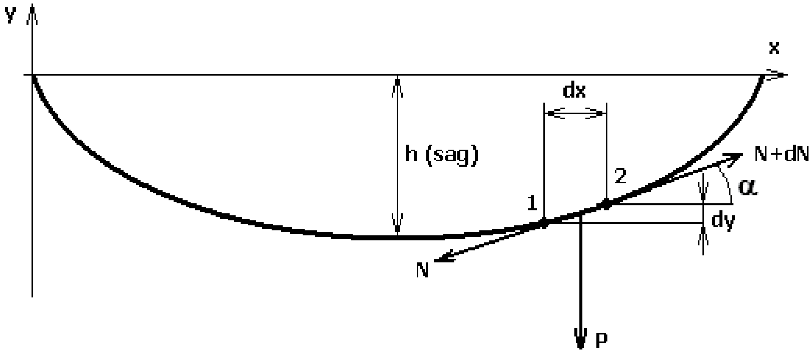


Figure 12: Application of Catenary Curve (Forces Acting at Section 1-2).

The sag (h) of the cable gets under the action of gravitational force. The two points on the cable: points 1 and 2 are further examined. The distance between point 1 and 2 are considered so small, that cable segment 1-2 is linear. *Dx* and *d* will be the projections of section 1-2 length to *X* and *Y* axes respectively.

A tightening force is acting at every point of cable. It is directed at a tangent to cable curve and depends only on the coordinates of cable point. The tightening force at point 1 is N and that at point 2 be N+dN, where dN is a small addition due to difference of coordinates. *P* is the weight of cable section 1-2. Weight is directed downwards, parallel to *Y* axis. Let *a* be the angle between the *X* axis and cable section 1-2. For cable section 1-2 to be at rest and equilibrium with the rest of cable, forces acting on this section need to balance each other. The sum of these forces needs to equal to zero.

Projections of sum of all forces acting at section 1-2 to X and Y axes, give us the value for cable weight P.

$$\begin{cases} -N_x + (N+dN)_x = 0 \\ -N_y - P + (N+dN)_y = 0 \end{cases} \qquad \begin{cases} dN_x = 0 \\ dN_y = P \end{cases}$$

Where, N_X and N_Y are projections of tighting force N to X and Y axes correspondingly. The ratio of tightening force projections (N) represents the slope ratio of the force N. At the same time, cable weight P is cable weight per unit length (q) multiplied by differential of arc (dS).

The first derivative of projecting of tightening force to Y axis is the differential of arc.

$$y = a\cosh(\frac{x+c_1}{a}) + c_2$$

$$\frac{dN_Y}{d_X} = \frac{P}{d_x} = q\frac{ds}{dx} = q\sqrt{1+(\frac{dy}{dx})^2}$$

$$P = qds$$

C_1 and C_2 are coefficients that are defined by point of origin in concerned system. We assume this point to be the lowest point of cable, then $C_{1=}0$ and $C_2=1$.

$$h = y(1/2) = a(\cosh(\frac{1}{2a}) - 1)$$

Cable sag (h) is value of cable form equation for point I/2, where l is the straight line distance between the position transducer and the application

The cable length is the length of the catenary curve from point-I/2 to point.

$$S = S(x)_{1/2}^{1/2} = a\sinh(\frac{x}{a})_{1/2}^{1/2} = 2a\sinh(\frac{1}{2a})$$

Environmental loading and station keeping: Mooring loads can be computed by means of static or dynamics analysis. Static analysis is appropriate when dynamic motions are not expected, dynamic analysis. Many successful mooring designs have been designed without a dynamic analysis. Dynamic load IS likely when mooring is exposed to ocean wave attack, large winds, rapids wind shift, large currents and current-induced eddies or macro vortices. Environmental loading additional loads on moored floating structures are considered. Static loads due to wind and current are separated into longitudinal load, lateral load, and yaw moment. Flow mechanisms which influence these loads include friction drag, form drag, circulation forces, and proximity effects. For the current system, wind induced and current induced will have moiré effect on the system.

$$F_{yc} = ½\, \rho_w V_c^2 L\, T\, C_{yc} Sin\ (\theta_c)$$

Where: $F_{yc=}$lateral current load, $\rho_{w=}$mass density of water, $V_{c=}$current velocity, L=structure length, T=draft, $C_{yc=}$lateral current-force drag coefficient, $\theta_{c=}$current angle

Lateral current load is determined using the following equation:

$$F_{yc} = ½\, \rho_w V_c^2 L\, T\, C_{yc} Sin\ (\theta_c)$$

Where, F_{yc} = lateral current load, in pounds, ρ_w =mass density of water , V_c = current velocity, in feet per second, A_c = projected area exposed to current, C_{yc} = lateral current-force drag coefficient, θc =current angle

The lateral current-force drag coefficient is given by:

$$C_{yc} = C_{yc}\left|oo + \left(C_{yc}\right|1 - C_{yc}\left|oo\right) e^{-k\frac{wd}{T}-1}$$

C_{yc} =lateral current-force drag coefficient, $C_{yc}|oo$ = limiting value of lateral current force drag coefficient for large values of $\frac{wd}{T}$, $C_{yc}|1$ = Limiting value of lateral current-force drag coefficient for $\frac{wd}{T} = 1$, *e*=2.718, k=coefficient, T=draft, in feet Longitudinal current load is determined from $F_{xc} = F_{x\,form} + F_{x\,fricion}$

F_{xc} = Total longitudinal current load, $F_{x\,form}$ = Longitudinal current load due to form drag $F_{x\,fricion}$ = Longitudinal current load due to skin friction drag,

Form drag is given by the following equation:

$$F_{x\,form} = -\frac{1}{2}\rho_w V_c^2 BTC_{xcb} \cos\theta_c$$

Where, $F_{x\,form}$ = longitudinal current load due to form drag, ρ_w = mass density of water = 2 slugs per cubic foot for sea water, V_c =Average current velocity, in feet per second, B=Beam, in feet, T=Draft, in feet, c_{xcb} = longitudinal current form-drag coefficient=0.1, θ =current angle

Skin friction drag is given by the following equation:

$$F_{x\,fricion} = -\frac{1}{2}\rho_w V_c^2 SC_{xca} \cos\theta_c$$

Where, $F_{x\,fricion}$ = longitudinal current load due to skin friction, ρ_w mass density of water = 2 slugs per cubic foot for sea water, V_c=Average current velocity, in feet per second, S=wetted surface area, in square feet, C_{xca} =longitudinal skin-friction coefficient

$$\frac{0.075}{(\log R_n - 2)^2}$$

R_n = Reynolds number = VcLWL $cos\theta_c / \gamma$, γ=kinematic viscosity of water (1.4 x 10^{-5} square feet per second), θ_c = current angle

Current yaw moment is from:

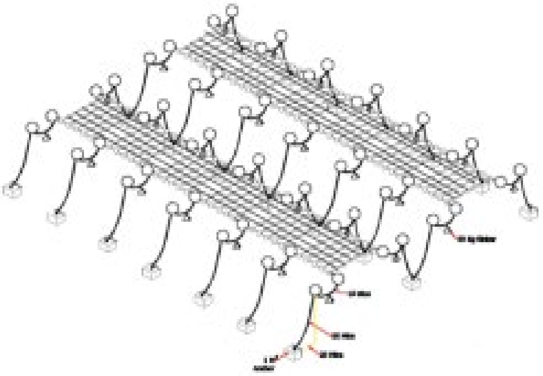
$$M_{xyc} = F_{yc}\left(\frac{e_c}{L_{WL}}\right)L_{WL}$$

M_{xyc} = current yaw moment, in foot-pounds

F_{yc} = lateral current load, in pounds

$\left(\frac{e_c}{L_{WL}}\right)$ = ratio of eccentricity of lateral current load measured along the longitudinal axis of the floating structure from amidships to waterline length, e_c=eccentricity of F_{yc}, L_{wL}= waterline length, in feet

For station keeping each mooring element has a time static vector force balance (in the x, y, and z directions), and that between time dependent solutions the mooring has time to adjust. The forces acting in the vertical direction are: (1) buoyancy (mass (kg)´g (acceleration due to gravity) positive upwards (i.e. floatation), negative downwards (i.e. an anchor), (2) tension from above Newton, (3) tension from below, and (4) drag from any vertical current Figure 13.



a) System to system interaction

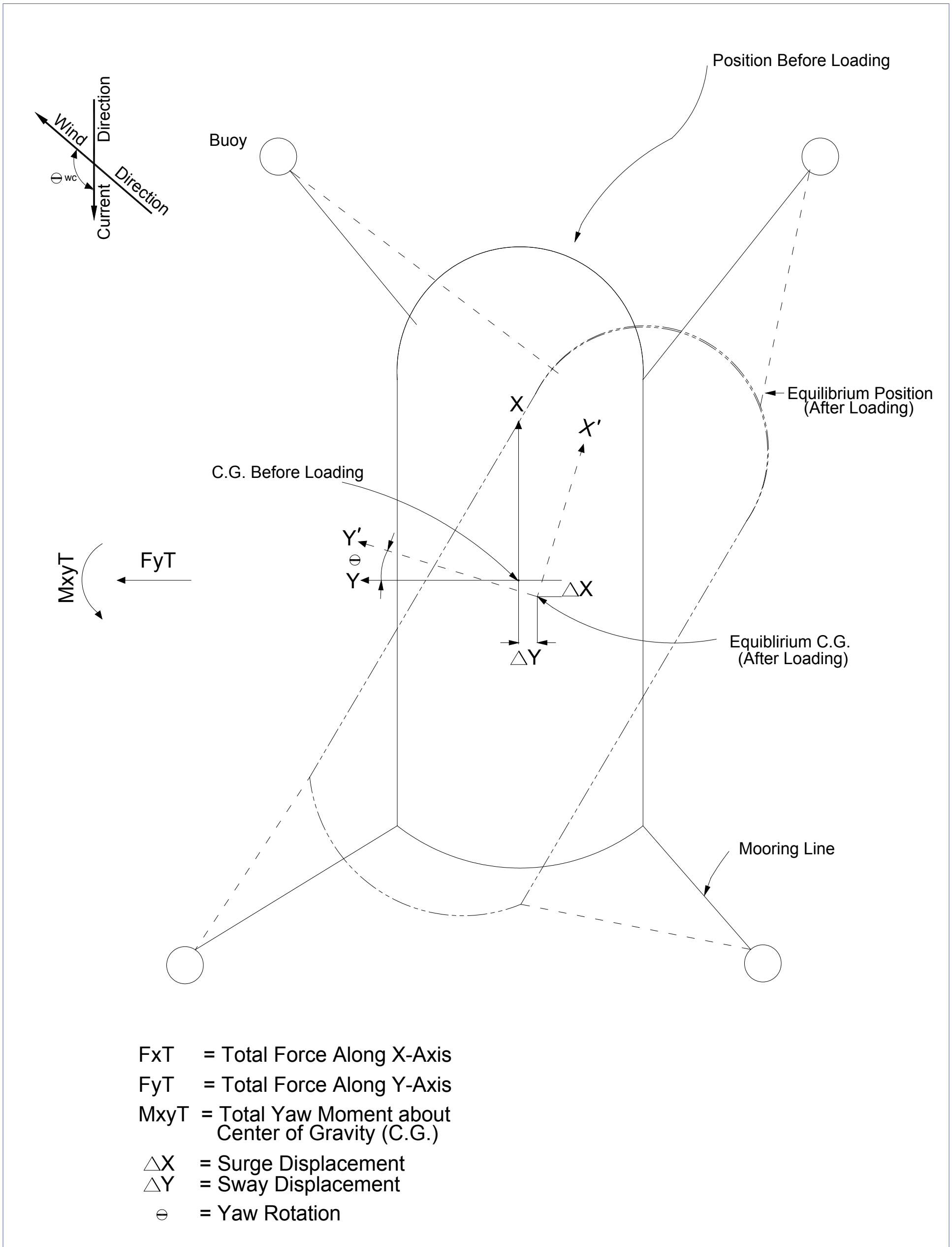
Figure 13: Cable analysis.

In each horizontal direction, the balances of forces are:

(1) Angled tension from above

(2) Angled tension from below and

(3) Drag from the horizontal velocity. Buoyancy is determined by the mass and displacement of the device and is assumed to be a constant (no compression effects and a constant sea water density). Other challenges in this design are system multibody analysis in respect to analysis and keeping the whole system together and system to system interaction (Figure 14).



b) Whole system

Figure 14: Multibody system.

Preliminary result and discussion: Figure 15 shows that there is potential for very large drag force on the seaweed compare to mooring components. The drag is minimal at current speed between 1-1,5, however at current speed 2-3 m/s, there much more drag, the drag at speed above 3 is intolerable for the mooring components and the seaweed (Figure 15).

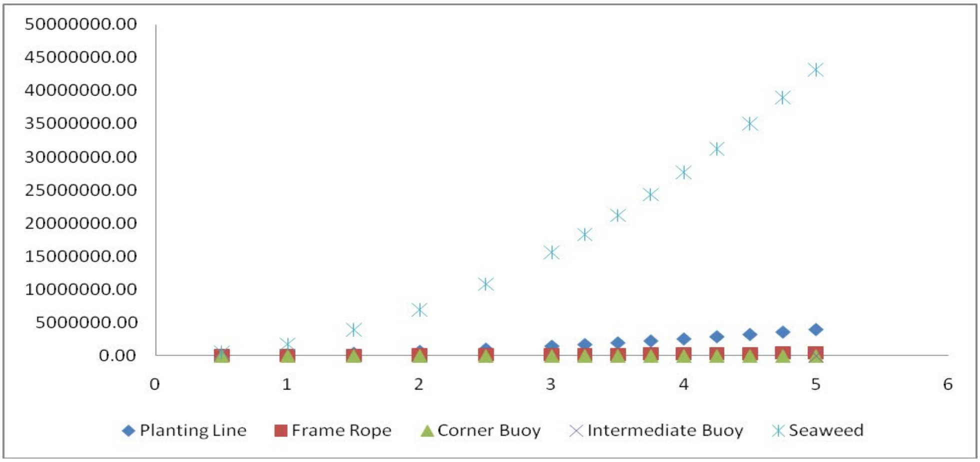


Figure 15: Drag Force Vs Current Speed.

A total drag force estimation equally revealed that there is potential spike for drag force at current speed above 2 m/s Figure 16

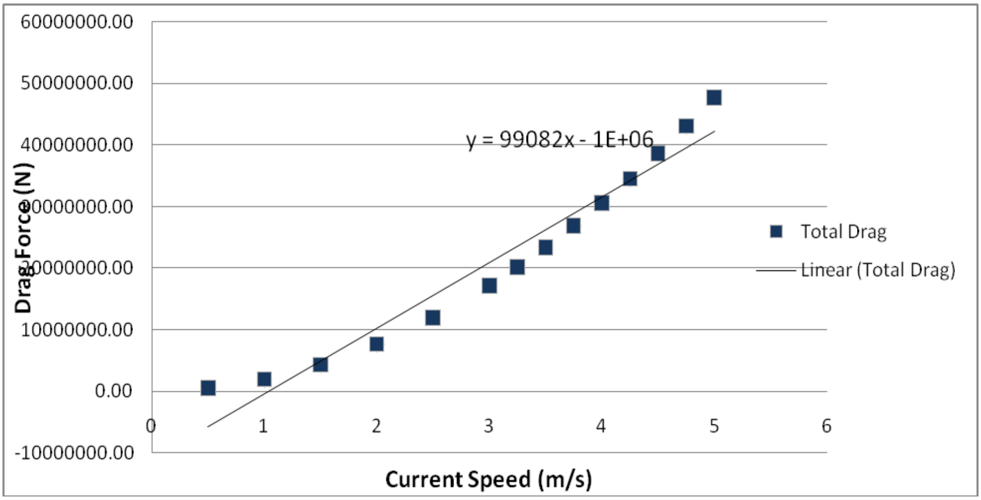


Figure 16: Total Drag Force Vs Current Speed.

All the components on the floating structure contribute to the amount of drag force. This graph shows the comparison of each component that will contribute to the total force experience by the structure. Seaweed as the main contributor of the drag force followed by planting line, frame rope, intermediate buoy and corner buoy. The main factors which contribute to this are the size cross sectional area and drag coefficient of the components. Drag force increase due to the increasing of current speed.

From figure 17, it is important to note that good current historical data for prediction of current direction is useful for deployment of the system and mitigate possible drag; the maximum drag force for ultimate state limit is for current 0-10 degree, while accident limit state design is expected to target current direction of about 90 degree (Figure 17).

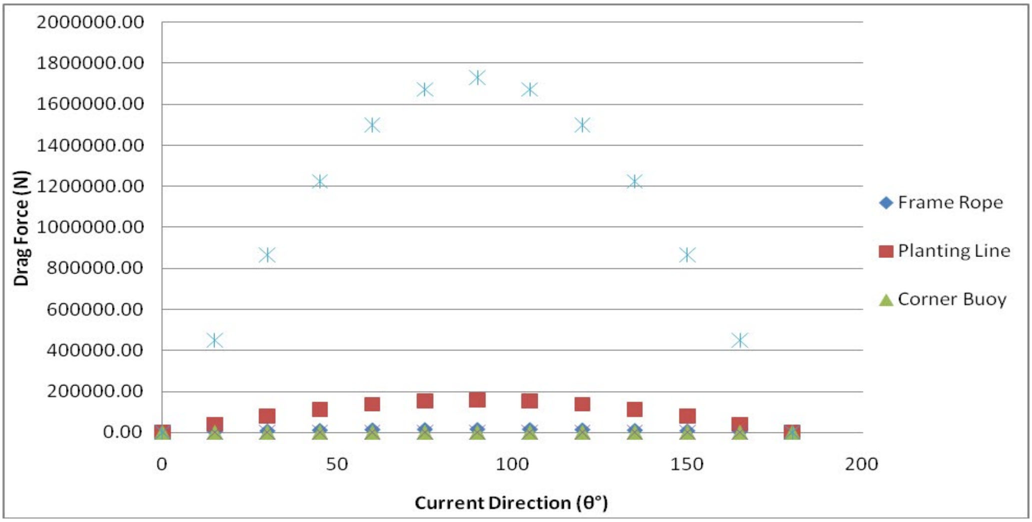


Figure 17: Drag Components Vs Current Direction at 1m/s.

The growth rate represent dynamic situation for the offshore seaweed plantation. Drag force as direct relation with growth of the seaweed and maximum drag force that can leads to removal of the seaweed at full growth is 130 N.

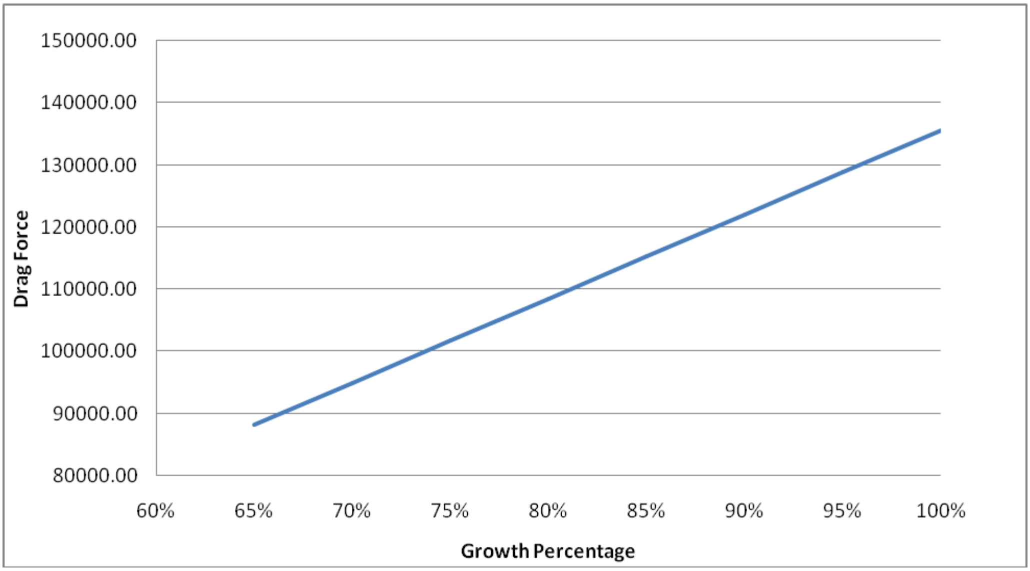


Figure 18: Drag Force with 5% Seaweed Growth.

Figure 18-20 shows some of the result obtained from model test. Figure 18 depicts current speed and acceleration based on Morison model. The test acceleration is maintained at less than 0.05

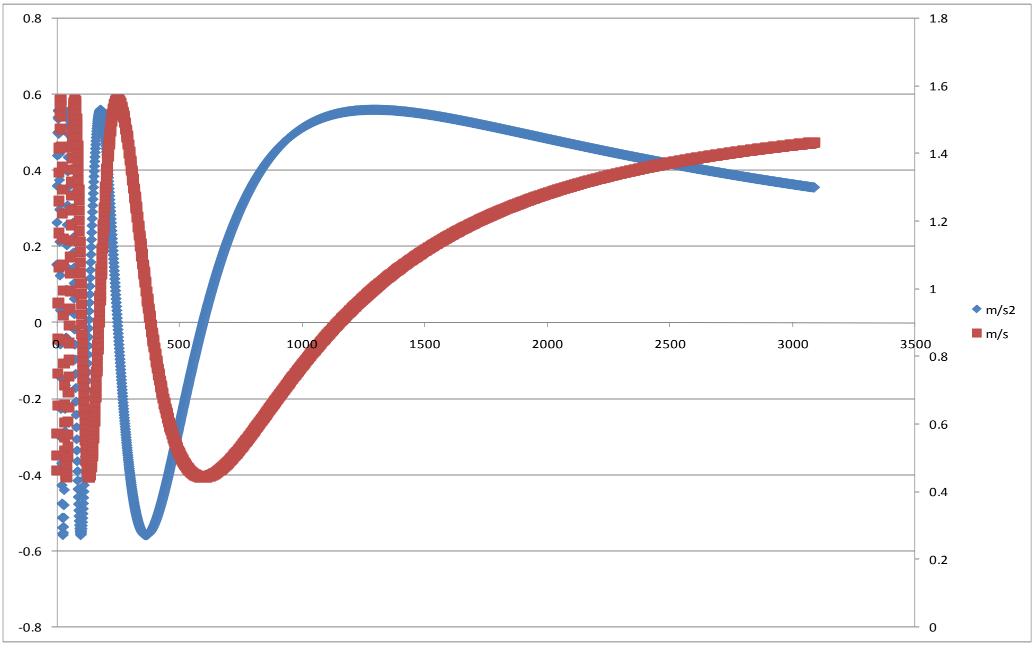


Figure 19: Strain condition at varied velocity, it observed for load balanced load cell of 50 N, the system get overloaded at 0.9.

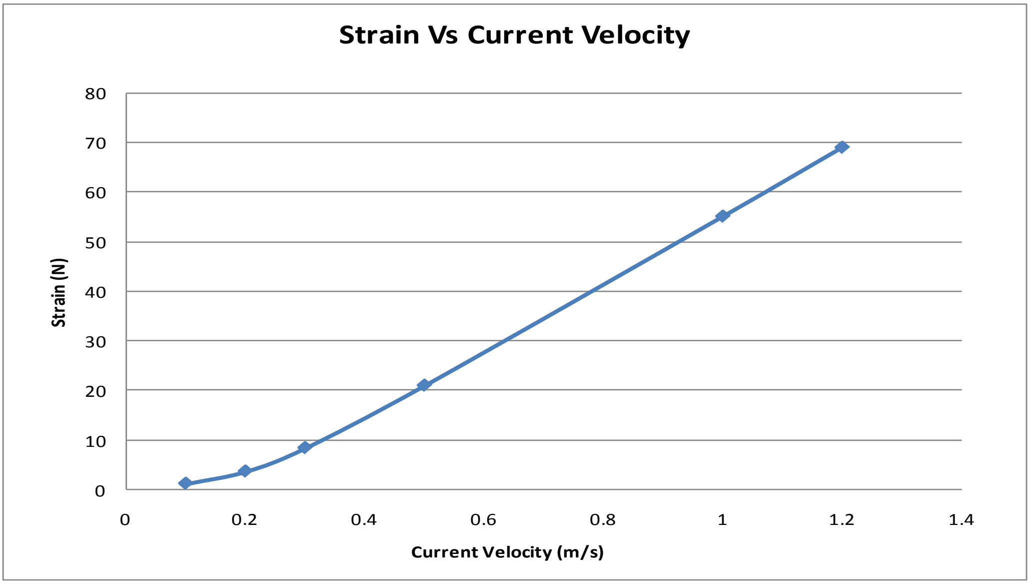


Figure 20: strain v_s velocity.

Figure 19a-19d shows drag and force relations. Ocean current drag and Strain, system overloaded loaded current speed of 1. Drag and drag force, drag force tend to increase at higher current speed Figure 21.

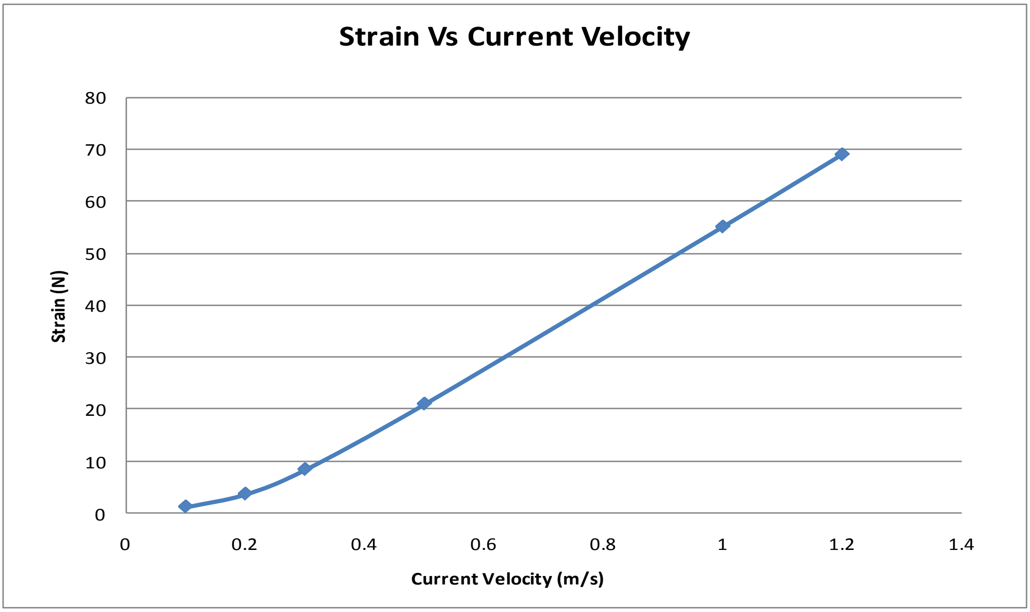


Figure 21: Drag Force with 5% Seaweed Growth.

Figure 22: Cable Tension at Different Current Velocity (90 degree).

(Figure 22) above shows the comparisons of each line tension at different current speed when the line is pull over 90 metre towing tank. At 0.5 m/s, 1.0 m/s and 1.2 m/s the average tension are 69 N, 55 N, and 25 N. Through the comparison of each graph, it can be seen clearly that the difference of strain between each speed is not increase uniformly. This matter probably affected by the properties of cable material use for this experiment is not being considered very well.

Tow Two Line Transverse across Basin (90 Degree) at Different Current Speed

This experiment is conducted by pulling two lines with the frame along 90 meter towing tank. The aim of this experiment is to see the reduction of drag force from the first planting line to the second planting line. From the result we can estimate the percentage of drag reduction after passing each planting line. The outcome can be used to estimate the total reduction for all the planting line of floating structure.

Figure (19a-19d) prove the differences of drag force value acting at first and second planting line. The percentage of reduction can be obtained by calculating the value of reduction from the entire graph.

From the (Graph 4.9a and 4.9b), the difference of tension between first and second planting line is very small due to the slow and medium current speed. The slow speed current produced low drag force to the planting lines and effecting the cable tension. From both graph the range of tension difference is only between 1 to 4 Newton.

Meanwhile, at the high speed current (Figure 9c and 9d), the difference between first and second plating line is higher, which is about 5 to 10 Newton. From this figure value, we can estimate the average reduction for planting line at the current direction of 90 degree is about 0.1 to 0.2%. Using this percentage, we can calculate the total reduction of drag force for complete floating structure when the current facing the structure at 90 degree.

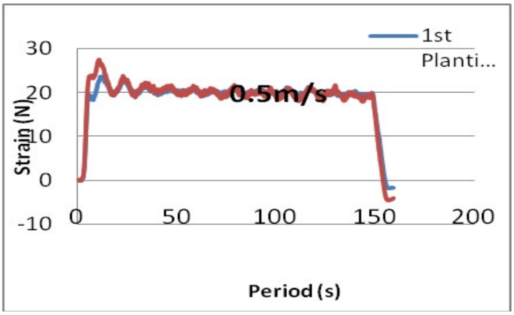


Figure 23: a) Two Planting Line Strain over Period at 0.1m/s, 0.2m/s, 0.3m/s.

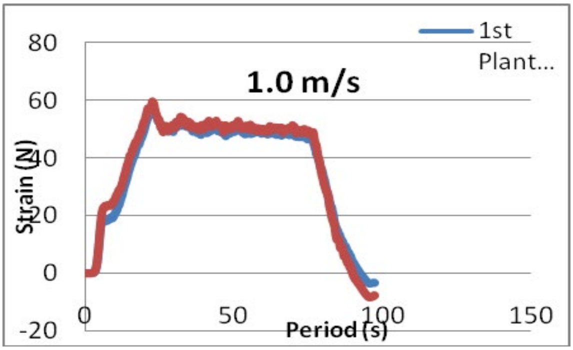


Figure 23: b) Two Planting Line Strain over Period at 0.5 m/s,

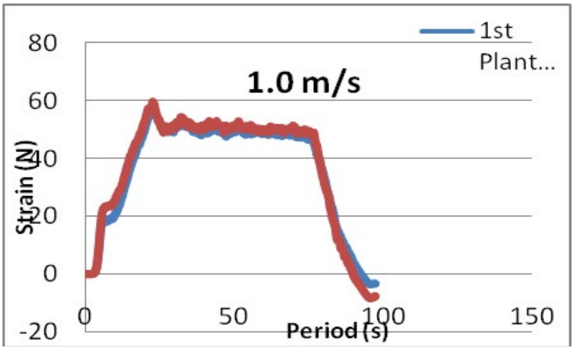


Figure 23: c) Two Planting Line Strain over Period at 1.0 m/s.

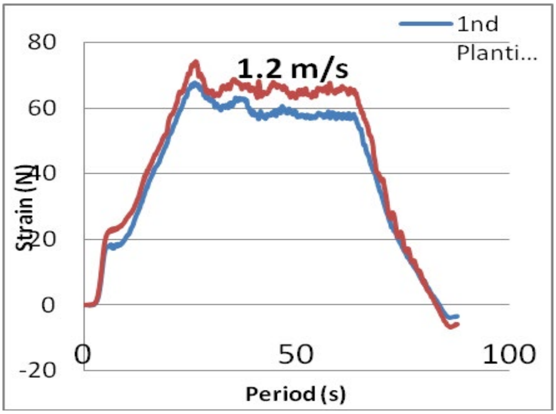


Figure 23: d) Two Planting Line Strain over Period at 1.2 m/s.

Conclusion

The presented the deterministic approach to structural design of very large floating structure for offshore seaweed farming. Towing tank test environmental loading coefficient will be used to check the model from the mathematical model. The design of very large floating structure is challenges with requirement that meet the operating conditions, strength and serviceability requirements, safety requirements, durability, visually pleasing to the environment and cost-effective. An appropriate design service life is prescribed depending on the importance of the structure and the return period of natural loads. Naval architecture of very large floating structure will grow for sustainable exploration of ocean resources. The novel design presented in this paper for the case floating structure for offshore aquaculture structure, describe some of the generic challenges. Integrated approach that hybrid of intuitive deterministic, risk and reliability approach, simulation, experimental as well stochastic methods is a best approach for reliability assurance of the structure.

2. Mooring Analysis for Very Large Offshore Aquaculture Ocean Plantation Floating Structure

Abstract

Aquaculture activities are inherently done at close proximity to coastline and near shore.

Issues and environmental impact concerns and challenges necessitate offshore aquaculture that required reliable structural integrity and mooring system design for ultimate state limit, fatigue state limit and accidental and progressive state limit against environmental loading and accidental loading. To avoid mooring system failure, selecting an appropriate breaking strength and limit state for mooring system components is necessary, this paper describes mooring system design that account for forces and environmental loadings. The paper describe evaluation of optimum mooring performance in wave, wind and current loadings on mooring components anchor, buoy and riser elements that are involved the mooring system dynamics. The paper also discusses establishment of appropriate safety factors and coefficients for the design of very large offshore aquaculture floating structure.

Nomenclature

V-Speed (ms^{-1})

A-Effective area

ρ -Mass density of water

V-Current speed

C_d-Drag Coefficient

N-Newton

Introduction

In Malaysia, commercial seaweed farming was started in Sabah waters in the 1970s. Sabah is still the major producer of seaweed in the country on a commercial scale, and this is mainly in Semporna, LahadDatu, Kudat and Kunak. The recent adoption of the National Aquaculture Centre and the latest announcement of the 2010 Budget on October 23, 2009, included seaweed specifically as one of the most important food farming commodities for the country. Although the sector has developed enormously over the past few years (111,298 tonnes wet weight in 2008), seaweed production and national target by 2010 of 250,000 tonnes (wet weight) is however yet to be achieved. There are several major issues and challenges to this, such as the unavailability of good quality seedlings, pollution in cultivation areas, diseases, shortage of raw materials, lack of capital to venture into the industry, and lack of research and development programmes [15].

It was recognized that demand for seaweed product was outstripping supply and cultivation was viewed as the best means to increase production [15]. Recently, thereis renewed interest in large scale cultivation of seaweed to meet the increasing market demand and at the same time to provide alternative livelihood schemes for local populations as well as increase supply of marine biomass algae for energy production. The large farming expansion near onshore is perceived to bring soomany problems. Sites as sheltered as the original marine farming culture locations are becoming limited, due to pressures from tourist development, urbanization, marine trade and the environmental related consequences. In some cases, unfavorable environmental factors such as near shore pollution from sewage have pushed marine farming sites further offshore to water depths of 50 m or greater [16]. Thus the need to move operations into more exposed sites and in totally unprotected open sea may equally face devastating natural disasters caused by tropical storms. This makes the requirement for robust mooring design and installation a necessity.

In moving offshore, wave, current and wind forces increase rapidly and these effects need to be taken into consideration in the design of mooring system. This means that maximum wave heights of 5-10 m, current speed of 2-3 knots and wind speed of 35 m/s [17] will need to be considered. A requirement is, therefore, that the farming unit may be able to withstand conditions like these. Mooring system design is a trade-off between making the system compliant in consideration to avoid excessive forces on the farming platform, and making it stiff enough to avoid difficulties, such as damage to the structure, that could be caused by excessive horizontal excursions of the farming platform.

This study focus uses the South China Sea, coast of Terengganu as a safety case, since the area is prone to seasonal harsh weather. Thus, the use of strategical location in the area sheltered by a chain of islands forming a good wave breaking point could be advantageous, provided the marine algae can grow there satisfactorily. This will avoid potentially even worse conditions present elsewhere.

Background: Employment of aquaculture farming facilities in offshore will face natural disasters caused by tropical storms. Without reliable design of mooring system, the farming load on the structure can easily damage it during a natural disaster event. That could lead to unacceptable economic loss. Thus, ensuring the security and safe deployment of very large floating structure system is becoming one of the most important issues for industrial marine farm. Because, this comes with requirement to operate offshore aquaculture system in 50 meters of water depths, also, the suspended weight of mooring lines becomes a prohibitive factor. Several parameters need to be considered which include length/weight of mooring line, suitable of material and type of anchoring technique.

Multi-bottom total system analysis that involve use of deterministic, physical, numerical, simulation, model testing and stochastic analysis modeling of such farming platform with position keeping of multiple mooring lines is a challenge to predict the ideal performance of mooring system without ignoring cost effectiveness.

The study of mooring design for VLFS of offshore aquaculture structure aims to develop a mathematical model of mooring system for offshore seaweed farming. The study focuses the investigation on the optimum mooring arrangement for offshore aquaculture marine technology for ocean farming, development of the mathematical model of mooring system offshore aquaculture marine technology for ocean farming, evaluation of the suitability of mooring components for offshore aquaculture marine technology for ocean farming and evaluation of the performance of a catenary mooring arrangement for mooring components of offshore aquaculture marine technology for ocean farming

Material and Method

Environmental Load: For this research, currents are considered because of the dominant contribution of load compared with wave and wind. In addition, it is expected that drag loads will account for a large portion of the wave-driven loads as well. So, by studying the drag loads first, we hope to quickly arrive at an approximate model that is adequate for the design of major system components. Static current loads are discussed in detail below [18]. Static loads due to current are separated into longitudinal load, lateral load [19]. Flow mechanisms which influence these loads include main rope drag, main buoy drag, seaweed drag, and planting lines drag. The general equation used to determine lateral and longitudinal current load are

$$F = \frac{1}{2}\rho V^2 A C_d$$

Static Analysis: This study allows one to predict the geometry of the line between the platform and its anchoring point and the distribution of stresses from top to bottom [19]. The recurrence formulas for carrying out the computation process for the resultant forces applied at the end of any segment n [19]. The tension, the orientation angles, the stretched length and the segment coordinates can now be formulated as

$$Rx_{(n)} = Rx_{(n-1)} + Fx_n$$

$$Rz_{(n)} = Rz_{(n-1)} + Fz_n T_n = \left[R_{X(n)}{}^2 + R_{Z(n)}{}^2\right]^{\frac{1}{2}}$$

$$\grave{e}_n = \tan^{-1}\left[\frac{R_{z(n-1)}}{R_{x(n-1)}}\right]$$

$$s_n = L_n + \blacktriangle L_n$$

$$\text{Coordinate } X_{(n)} = X_{(n-1)} + S_{(n)}\cos\ _{(n)}$$

$$\text{Coordinate } Z_{(n)} = Z_{(n-1)} + S_{(n)}\sin\ _{(n)}$$

Model Test: A towing test is one method of research to determine the hydrodynamic loading coefficients (added mass and damping) in a few different configurations [20]. The samples which are seaweed are dried but will restore to nearly nominal properties when soaked in water for a period of time. In typical practice, the rows of seaweed are held using ropes separated by about 2.6 m between rows. For the drag measurement, the seaweed was attached to towing lines and the lines were towed from the moving carriage. A frame consisting of aluminum channel sections attached to the towing carriage is used. The seaweed clumps in turn attach to a rope line. Tension load cells will be attached between the line and the frame and the measured forces recorded on the model basin's data acquisition system (Figure 24 and 25).

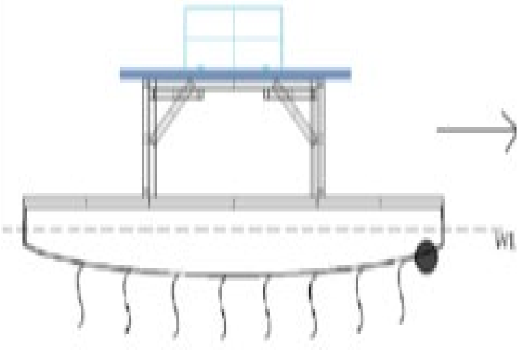


Figure 24: Model test system.

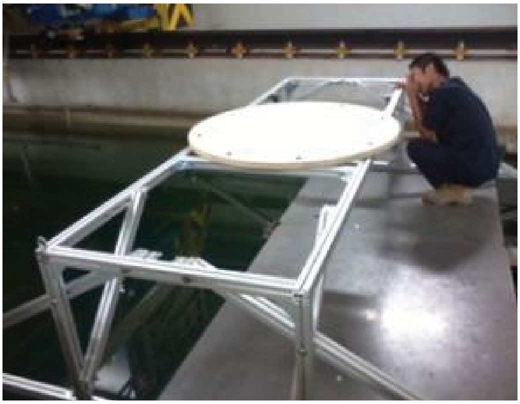


Figure 25: Test frame construction and deployment.

Prototype System: Component of the full-scale platform and mooring cable characteristic first need to be clarified. A typical block has an overall length of 100 meter and the breadth is 100 meter. One block of seaweed farming contains four main ropes for the frame, four main buoy and 30 load lines on which is the seaweed will be planted. Table 6 shows the structural properties of one block of seaweed farming.

structural properties (one block)	No/Quantity	unit
length overall	100	m
Breadth	100	m
main buoy	4	
main rope	4	
load line rope	30	
sea water density	1025	Kg/m^3

Table 6: Structural properties

Result

Environmental Load: Four samples of current speeds are taken the current speeds starts with 0.5 m/s, 1 m/s, 1.5 m/s and 2 m/s. The maximum lateral current load occurs when the structure is subject to2 m/s of current speed which has the value just over 20,000 N, as shown in the figure.

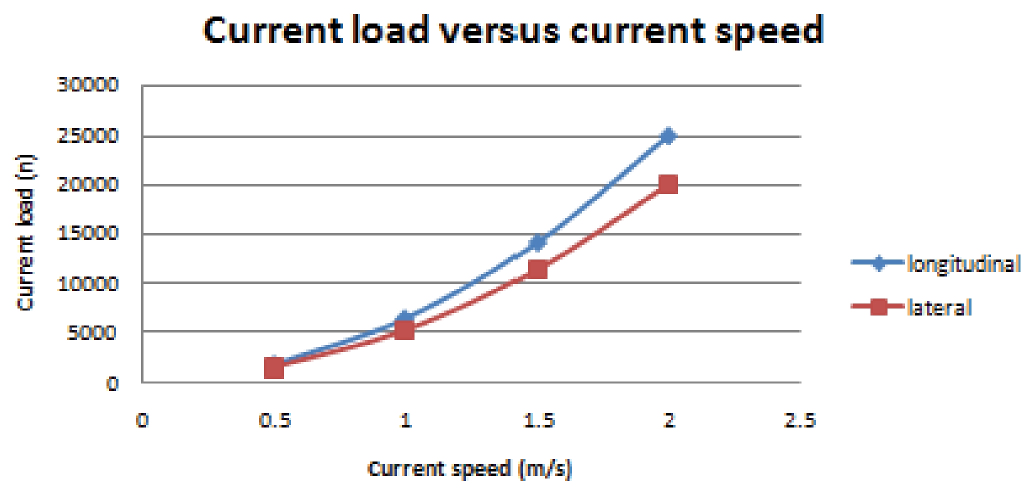


Figure 26: Graph current load versus current speed.

Figure 26 shows that the current load increases when the current speed increases for both longitudinal and lateral load. The graph indicates that the longitudinal loads are higher than the lateral load. This is because the longitudinal current speed is moving horizontally to the x-axis of the structure (up and down in the figure) which results in the bigger load from the planting lines.

Spread Mooring Analysis for One Block

The mooring consists of H_3, H_4, H_6, and H_7 mooring lines, which resist longitudinal load, and four mooring lines, H_1, H_2, H_4 and H_5 placed perpendicularly to the longitudinal axis of the structure, which resist lateral load [21]. The maximum allowable working load, T break is 39,865.6 N

Deadweight anchor was selected and it is a large mass of concrete or steel which relies on its own weight to resist lateral and uplift loading. Lateral capacity of a deadweight anchor will not exceed the weight of the anchor and is more often some fraction of it [22]. Deadweight-anchor construction may vary from simple concrete clumps to specially manufactured concrete and steel anchors with shear keys. Several advantages of deadweight are anchor has large vertical reaction component, permitting shorter mooring-line scope. Also, it is simple to construct using means which are readily available, even in fairly remote locations (Figure 27 and 28).

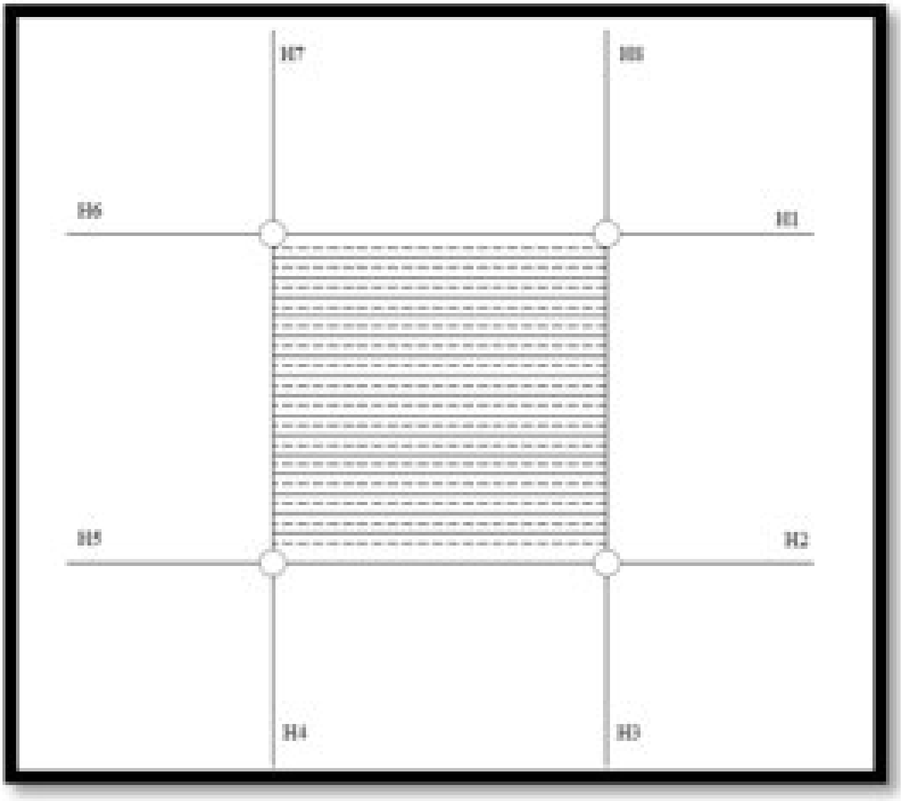


Figure 27: Force diagram for the mooring system.

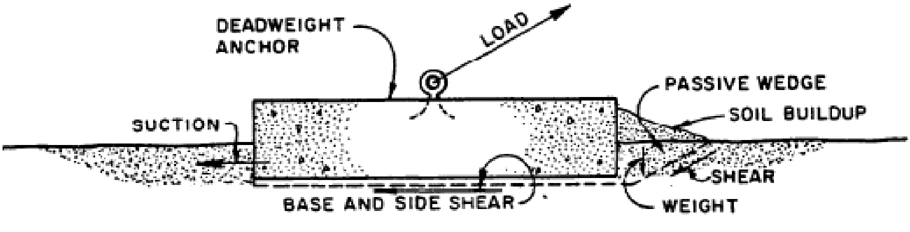


Figure 28: Deadweight anchor.

Model Test: The data were recorded on the basin's native Data Acquisition System (DAQ) at a frequency of 25 Hz. The load cells attached to the mooring lines measure the tension (strain) in the line. These are water-proof aluminum ring strain gauges that measure axial tensile loads [23]. The measured voltage outputs from the load cell strain gauges are connected by cables to the basin's native Dewetron Data Acquisition System (DAQ) to be digitally sampled and stored. Figure 29 below shows the result of several typical tests which indicates the drag value of seaweed in different current speeds.

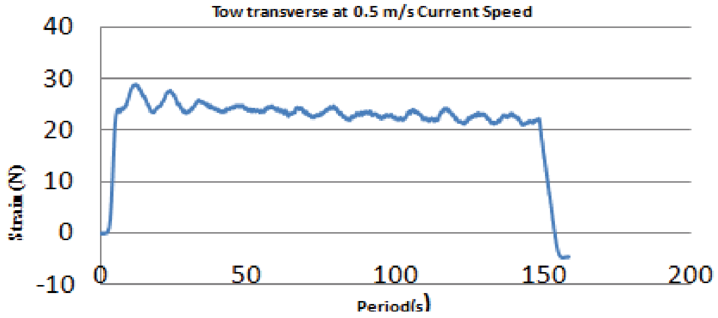


Figure 29: Tow transverse at 0.5 m/s Current Speed.

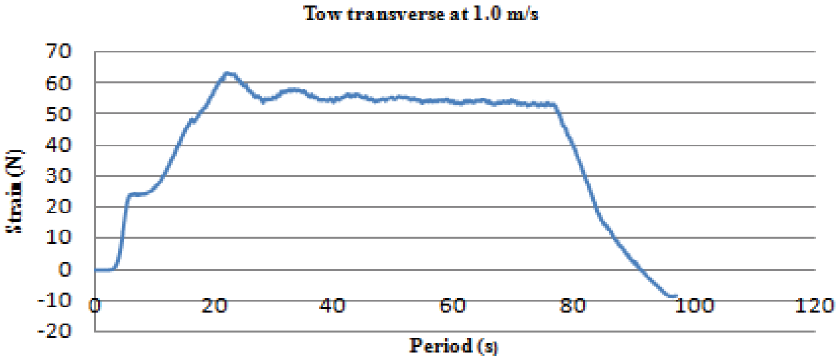


Figure 30: Tow transverse at 1.0 m/s Current Speed.

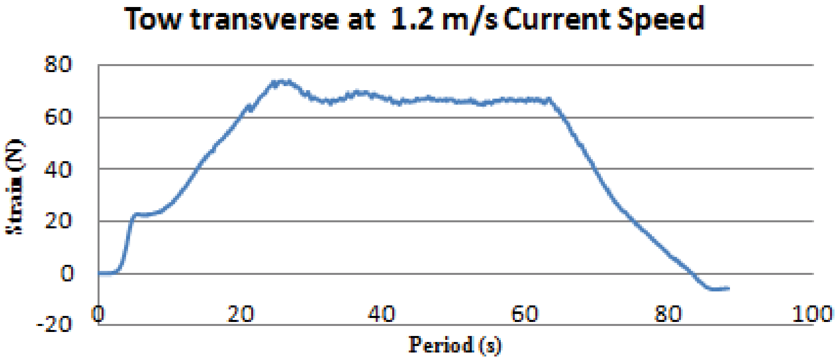


Figure 31: Tow transverse 1.2 m/s Current Speed.

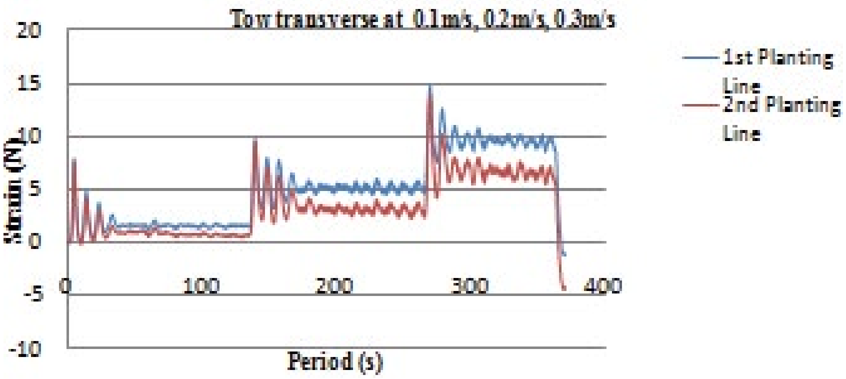


Figure 32: Tow transverse at 0.1 m/s, 0.2 m/s, 0.3 m/s (two lines).

Figure 29-32 shows that the strain values are nearly constant at the middle part of the graphs but the strains have different values for each graph which increase for increasing current speed. The increasing strain values presented in this result are mainly used to validate the accuracy of theoretical calculation which has been developed for this study. Note that the initial pretension in the strain (40 N) was zeroed for measurement purposes. The value has to be added to the results in the figures to obtain the total tension in the lines.

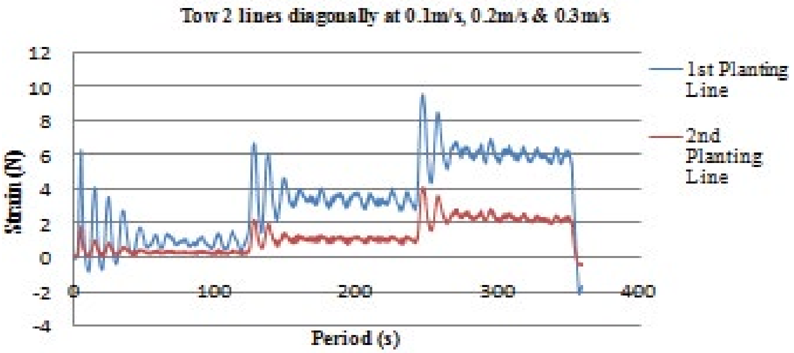


Figure 33: Tow diagonally at 0.1 m/s, 0.2 m/s, 0.3 m/s (two lines).

a

For smaller towing speeds, it is possible to combine several towing speeds in a single test run to reduce waiting time. Figure 32 and 33 shows test results for such tests. The results sow that strain increases with the increasing of current speed. The graph indicates that the second planting lines has a lower value compares to the first lines. This is due to the shielding effect which results from the wake deficit acting on second line resulting in the lower drag.

Mooring Line Dynamic: This part will discuss the mooring line analysis when experienced increasing current velocity to the dynamic of mooring line. Figure 34 shows the behaviour of mooring line profile at different current speed.

In this analysis, three samples of current values are taken. The current speeds start with 0.5 m/s, 1.0 m/s and 2.0 m/s. Figure 34 shows the behavior of mooring line profile when experiencing an increasing of current speed. From the graphs, obviously we can see the movement of mooring line is increased when the current speed increases. It means that, the horizontal excursion of mooring line distance is increasing simultaneously decreasing in line angle. Another logical behavior from this analysis is that, the buoy point which attaches the mooring line to the structure keep on moving downwards towards the seabed when there is an increase of current speed. This means that, the mooring lines pull the platform downward.

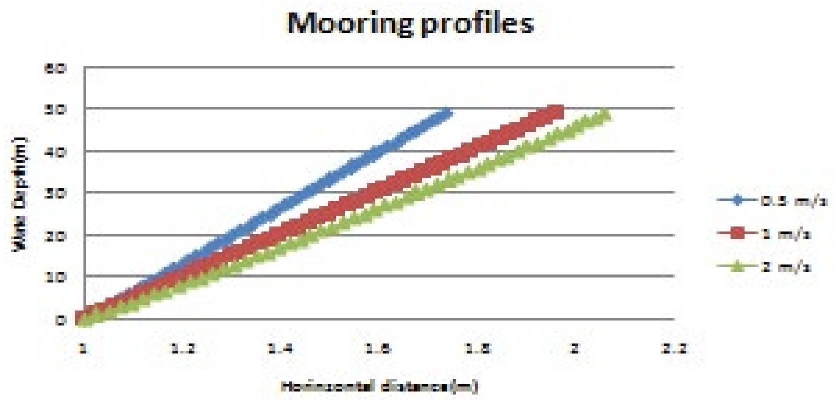


Figure 34: Mooring profile.

Conclusion

As for conclusion, the objectives stated in this report are achieved. This numerical model is developed by the formulas to determine the suitable mooring component to be equipped on the seaweed farming. Mooring behavior and its design requirements have been determined for the feasibility of moving many similar floating structure used for offshore aquaculture to more exposed sites.

In addition, modeling can serve as the basis for comparing and evaluating different mooring systems before purchasing and installation. Modeling will be an essential tool for choosing larger mooring systems for commercial-sized facilities.

Performance of catenary mooring line such as tension and the suspended length required are obtained easily by entering the initial values into the input file data and will be calculated.

The initial results presented here are based on current drag load calculations only, which are expected to comprise the majority of loading on the aquaculture structure. As a next step, calculations are planned which will include the additional drag loading due to waves.

Further studies including unsteady dynamic testing need to be carried out to adequately determine the additional loading components needed for completely robust design.

It is hoped that this effort will lead to more full scale prototype systems being deployed from which much more is yet to be learned. Adequate feedback from actual systems to the design process will remain an essential part of an improved design process, leading to more robust and cost-effective aquaculture systems helping to meet the national goals of increased production.

Study of Properties of Components for Offshore Aquaculture Technology Farming

Abstract

This study outlines analysis about selection of suitable material for offshore technology farming in general, especially in seaweed farming. This has occurred because in most cases, floating structures proved to have economical and dependable, operational advantages and it emerge to be more acceptable from an environmental point of view. Generally, floating structure is used for the construction of various facilities and accommodations. Study of properties of components for offshore aquaculture technology farming involved the properties of material selection that is suitable for floating offshore structure and is conducted based on the case study area which is in Setiu, Terengganu. The materials are two types of rope, manila and polyester, and SHE-20 type of buoy. The result from the tensile test showed that manila rope has better usage for larger force and polyester rope can be use within smaller scale of force. The result from water absorption test showed that the buoy absorbed water with lower percentage, which means it can be used for longer period. This study is also involved other tasks; for example data gathering, experimental test, field works, and prototype modeling. The result of the study hopes to contribute to ocean farming, especially seaweed farming in the future.

Nomenclature

DNV-Det Norske Veritas
JTM-Jabatan Teknologi Maritim
ISOS-International Ship and Offshore Structures
NMIF-National Marine Industries Forum
UTS-Ultimate Tensile Strength
VLFS-Very Large Floating Structure

Introduction

Floating structure in general have been used for the construction of floating houses, storage for liquid and dry bulk materials, bridges, airports, golf courses and miscellaneous industrial facilities [24]. In maritime industry, there are many activities that can be done and give back benefit for community, especially in Shipyard industry, Marine leisure, and Support services. Nowadays, the world seems to look forward to the present fast-developing seaweed farming [25].

Seaweed farming was first devoted in Japan at least 1500 years ago, based on the early written records. It started in Japan in early 1670 in Tokyo Bay. In autumn of each year, farmers would throw bamboo branches into shallow, muddy water, where the spores of the seaweed would gather. A few weeks later these branches would be changed place to a river estuary. The nutrients from the river would assist the growth of seaweed. In the 1940s, the Japanese enhanced this technique by placing nets of synthetic material tied to bamboo poles. This efficiently doubled the production. A lower cost alternative of this technique is known the hibi technique; simple ropes stretched between bamboo poles. In the early 1970s demand for seaweed and seaweed products, outstripping supply and cultivation was seen as the best way to increase productions [26].

On the other hand, the production itself is giving some useful information. It is almost entirely derived from culture in floating cages, which is essentially an open system. The open nature of this culture system allows the outputs to participate in exterior biological, chemical and ecological systems, where they may cause unwanted effects. These effects are often complex, varying by orders of scale on temporal and spatial scales [27].

Commercial seaweed farming in Malaysia started in Sabah coastal area in the 1970s. Sabah is tranquilly the main manufacturer of seaweed in Malaysia on a commercial scale, and this is primarily in Semporna, Lahad Datu, Kudat and Kunak. Besides, the recent implementation of the National Aquaculture Centre, and the latest declaration of the 2010 Budget on October 23, 2009, has seaweed being mentioned specifically as one of the most important food farming production for the country.

Although the sector has developed extremely over the past few years (about 111,298 tonnes wet weight in 2008), seaweed production national target by 2010 of 250,000 tonnes in wet weight is however yet to be achieved. There are some major issues and challenges to this, for example the unavailability of good quality seedlings, pollution in cultivation areas, diseases, shortage of raw materials, lack of capital to venture into the industry, lack of research and development agenda listed by the government itself.

This research involved the study of properties of components for offshore aquaculture technology farming. System and structure will go through the sources from seaweed farming, the regulation of offshore aquaculture with respect to the components within technology seaweed farming, together with some of models that have been developed, the relationships with other coastal users and finally consideration for site selection and some commercial aspects.

Significant of study

Based on the general view, the study about properties of components for offshore aquaculture technology farming has wide range of area. It needs to be justified so that it is related with the research. For that purpose, scope of study is focused on some areas which is field work, experimental set up and validation for standard based on the classification society recommendation.

The fieldwork is within Kuala Terengganu and Setiu area to provide environmental data the components used for offshore aquaculture technology farming, especially seaweed farming. The components that are used are ropes and buoy. One of the most important parts is the experimental set up. This is required to provide data to achieve the aim and the objectives of the research.

The experiment is done at JTM laboratory using Go tech Universal Testing Machine as shown in Figure 35 and also Kampung Pak Tuyu area, which are to test the properties of components. The tests that have been done are Tensile Test and Water Absorption Test.

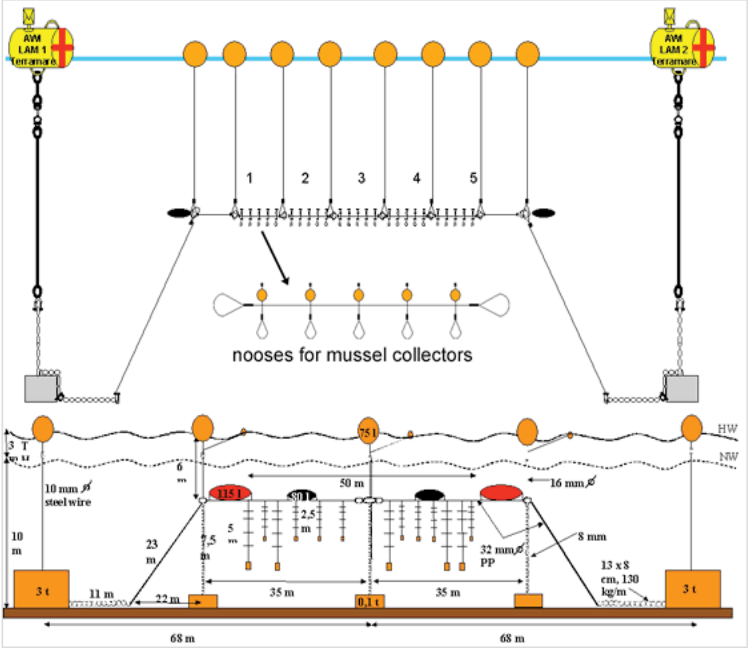


Figure 35: Long Line System.

Offshore Aquaculture: Open ocean aquaculture or offshore aquaculture is an up and coming approach to Mari culture or marine farming where fish farms operations some distance offshore. The offshore aquaculture involves farms that are located in deeper and less sheltered waters, where ocean currents are stronger than they are inshore. One of the concerns with inshore aquaculture especially fish farming is that unnecessary nutrients and feces can resolve beneath the farm on the seafloor and harm the benthic ecosystem [28]

Proponents the wastes from aquaculture that has been moved offshore tend to be swept away from the site and diluted with it. However, moving aquaculture offshore also provides more gaps where aquaculture production can enlarge to meet the increasing demands for fish. Moving aquaculture offshore avoids numerous of the conflicts that arise with other marine resource users in more crowded inshore waters, there can still be consumer conflicts offshore.

Beside this, there is criticism regarding issues such as the ongoing consequences of using antibiotics and other drugs and the potential of cultured fish evasion and distribution of disease among feral fish. Furthermore aquaculture is the most swiftly growing food industry in the world, resulting from the declining of wild fisheries stocks and profitable business. In 2008, aquaculture provided 45.7% of the fish produced worldwide for human consumption; increasing at a mean rate of 6.6% a year since 1970 [29].

Nonetheless, using some of the offshore Very Large Floating Structures (VLFS) technology system as well as suitable material is much better. VLFS are artificially man-made floating land parcels on the sea. The system appears like giant plates resting on the sea surface. VLFS may be broadly categorized into the semisubmersible type and the pontoon type. The semisubmersible-type VLFS has a raised platform above sea level by using column tubes and is suitable for deployment in high seas with large waves. On the contrary, the pontoon-type VLFS platform rests on the water surface and is intended for deployment in calm waters such as in a cove, a lagoon or a harbor [30].

Seaweed Farming

Seaweed farming is defined as the perform act of cultivating and harvesting seaweed. In its most simple outline, it involves the management of naturally found batches. In its most sophisticated form, it involves fully controlling the life cycle of the plant. The main seaweed species grown by aquaculture in Japan, China and Korea include Gelidium, Pterocladia, Porphyra and Laminaria.

The Long Line system allows for culture of shellfish (in mussel collectors) as well as seaweed growing on ropes suspended from the surface line [31]. Figure 35 shows the Long Line System that is used for the seaweed farming.

Seaweed farming has commonly been developed as an alternative to improve economic conditions and to decrease fishing pressure and over exploited fisheries. In addition, seaweeds have been harvested throughout the world as a food source as well as an export product for manufacture of agar and carrageenan products. [32]. The offshore ring system consists of a submerged ring with culture lines descending from it, surface flotation and anchoring system. The rigging is adjusted to maintain the growing lines below the surface at the optimum light depth for growth. This system continues to undergo tests and improvements and should be watched as a potential large-scale seaweed cultivation platform [33]. The ring system can be completed rigged on-shore then towed to the location and anchored, decreasing the need for costly construction at sea [15]. Figure 36 shows the Offshore Ring system.

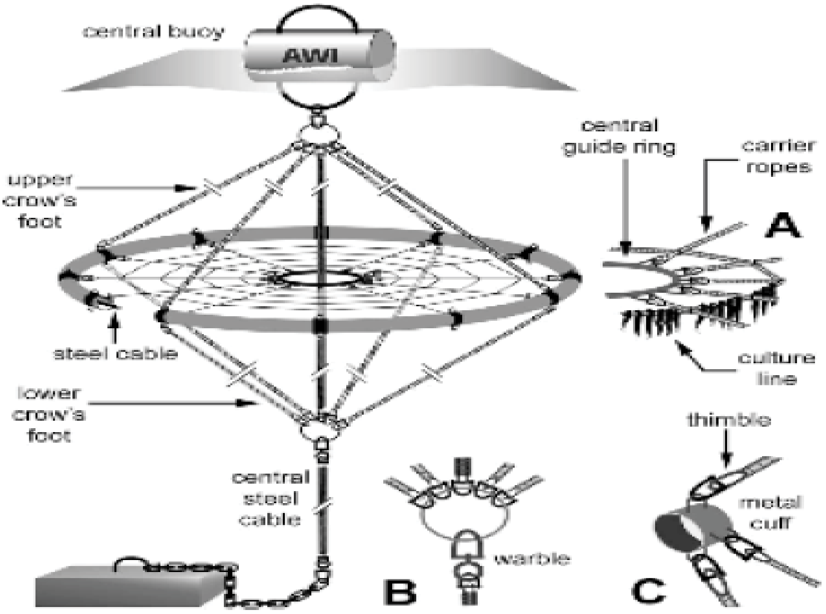


Figure 36: Offshore Ring system.

Offshore system design: For specific reasons, the analysis and design of floating structures need to account for some special characteristics [34] when compared to land-based structures; namely:

i. Horizontal forces due to waves are in general several times greater than the (non-seismic) horizontal loads on land-based structures and the effect of such loads depends upon how the structure is connected to the seafloor.

ii. It is distinguished between a rigid and compliant connection; a rigid connection virtually prevents the horizontal motion while a compliant mooring will allow maximum horizontal motions of a floating structure in the order of the wave amplitude.

iii. Structures which are piled to the seafloor, the horizontal wave forces produce extreme bending and overturning moments as the wave forces act near the water surface.

iv. The structure and the pile system need to carry virtually all the vertical loads due to self-weight and payload as well as the wave, wind and current loads.

v. If a floating structure has got a compliant mooring system, consisting for instance of catenary chain mooring lines, the horizontal wave forces are balanced by inertia forces.

vi. If the horizontal size of the structure is larger than the wave length, the resultant horizontal forces will be reduced due to the fact that wave forces on different structural parts will have different phase (direction and size).

vii. A particular type of structural system, denoted tension-leg system, is achieved if a highly pretensioned mooring system is applied additional buoyancy is then required to ensure the pretension.

viii. Sizing of the floating structure and its mooring system depends on its function and also on the environmental conditions in terms of waves, current and wind. The design may be dominated either by peak loading due to permanent and variable loads or by fatigue strength due to cyclic wave loading.

ix. It is important to consider possible accidental events such as ship impacts and ensure that the overall safety is not threatened by a possible progressive failure induced by such damage.

x. Due to the corrosive of sea environment, floating structures have to be provided with a good corrosion protection system.

xi. Possible degradation due to corrosion or crack growth (fatigue) requires a proper system for inspection, monitoring, maintenance and repair during use.

In spite of these, the allowable strength limit state is intended to confirm that a structure has strength for safe use throughout a service period with appropriate reserve. Buckling and yielding strengths of principal structural members are evaluated on their elastic responses. The first class environmental load that corresponds to a return period of at least double the number of service years is considered a characteristic value.

As well as representing DNV's recommendations of good engineering practice for general use by the offshore industry, the offshore standards also provide the technical basis for DNV classification, certification and verification services. Buoys designed, built, installed, tested and intended to be followed up in-service under supervision of the Society in compliance with the requirements of this standard will be entitled to the Class Notation: Offshore Loading Buoy. Due to the particular nature of offshore loading buoys' operations and ownership, the precise scope of classification shall be decided on a case-by case basis after agreement with the client [35].

Functionality and safety criteria are key issues that dominate the structural design. The excessive structural response could lead to the sinking of the floating structure due to progressive flooding and drifting of the floating structure due to the failure of system. However, the motions of a floating structure become large when the length of mooring line is rather long. Moreover, the tension leg system is adopted to which the pretension is applied to the mooring line in order to restrain heaving motion especially in deep seas. In such a station keeping system, it is difficult to restrain the horizontal motion and usually the mooring lines experience significant tension forces [36].

Result and Analysis

Figure 37 shows the graph for tensile stress-strain test of manila rope. When the load was applied, stress of the rope was higher and at point of 5.3117 kN/mm² stress, the value was constant. Until it reached its highest load which is 1.0023 of strain, it was sharply decreased. That means the rope was broken that it cannot withstand higher load any more. At that point, it was its ultimate strength.

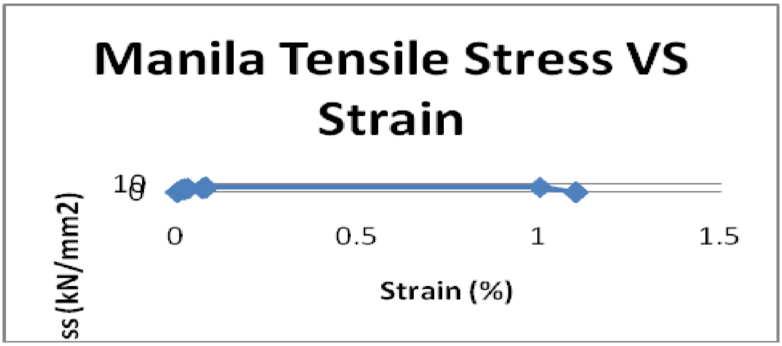


Figure 37: Graph for Manila Rope's Tensile Stress-Strain.

When the load was applied, stress of the rope was higher and at point of 5.3117 kN/mm^2 stress, the value was constant. Until it reached its highest load which is 1.0023 of strain, it was sharply decreased. That means the rope was broken that it cannot withstand higher load any more. Figure 38 shows the graph of modulus of elasticity and break elongation for Manila rope.

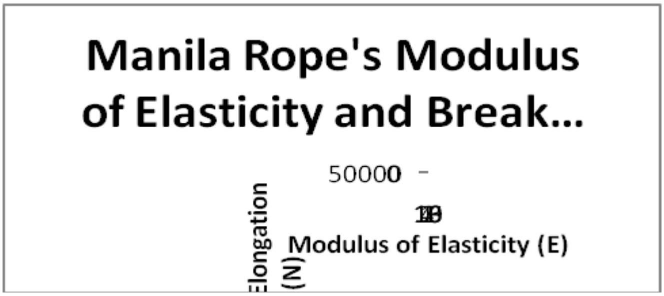


Figure 38: Graph of Modulus of Elasticity and Break Elongation for Manila Rope.

The highest point of which the rope was broken when time is 37.112 s and load applied on the rope is 3906.213 kN. The result was that the stress is 4.4311 kN/mm^2 and the strain is 0.0621%. Figure 39 shows the graph for tensile stress-strain test of polyester rope.

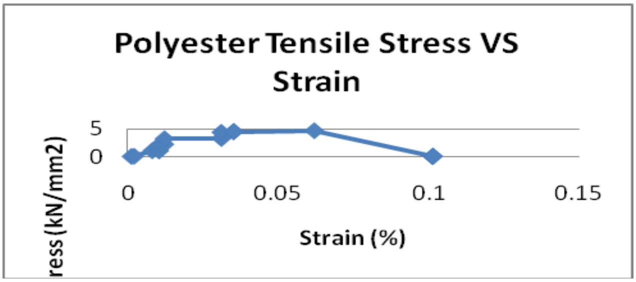


Figure 39: Graph for Polyester's Tensile Stress-Strain.

Stress of the rope was higher and at point of 4.4355 kN/mm^2 of stress, the value was started constant. Until it reached its highest load which is 1.0023 of strain, it was sharply decreased. The rope was broken that it cannot bear the higher load applied onto it any more. It was recorded that it was the ultimate strength. Figure 40 shows the graph of modulus of elasticity and break elongation for Polyester rope.

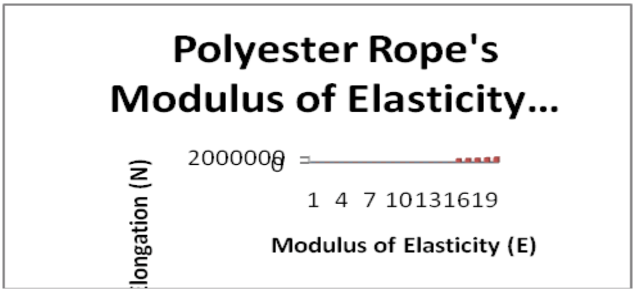


Figure 40: Graph of Modulus of Elasticity and Break Elongation for Polyester Rope.

Figure 41 and 42 below show the graph for differences between manila with polyester's modulus of elasticity and break elongation.

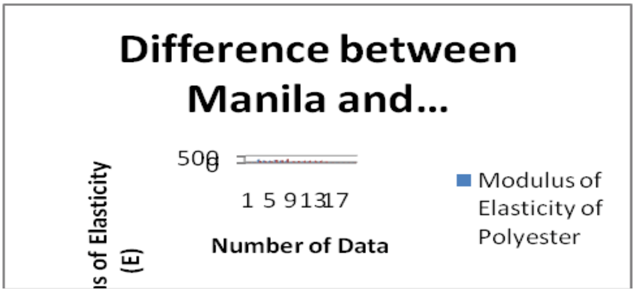


Figure 41: Graph for Difference between Manila and Polyester's Modulus of Elasticity.

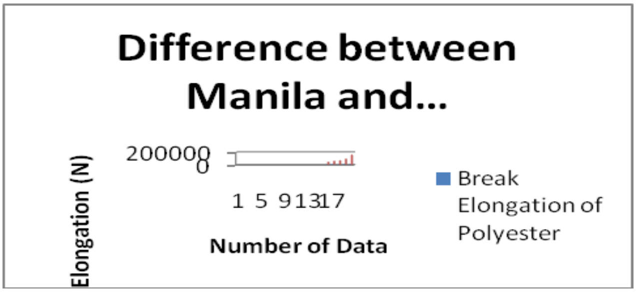


Figure 42: Graph for Difference between Manila and Polyester's Break Elongation.

Each of the figures indicates the difference in capability of two types of rope that could be used in two different situation and usage. The figures show that Manila rope has higher modulus of elasticity and break elongation than Polyester rope.

Conclusion

This study is about the study of floating material for offshore aquaculture technology farming. The outcome of the study is aimed to provide a recommendation for development of seaweed farming in local coastal area. Some parts of this study have the ability to develop better system. In this study the validation with the standard of classification society to meet its expectation is important. The study uses the classification society as bench mark for criteria.

The experiment in this study was carried out with no harmful incident. The properties of the material were investigated and determined by the calculation of each part of the test theory. Data analysis is major part to ensure the student achievement of the research aim and objectives. Observed error or other circumstances is given and recommendation is provided for future research. Laboratory test provides the required data to validate the result, and the theoretical analysis can be useful generally for seaweed farming.

As future baseline, the rule and regulation development was about to avoid any error that could bring any bad incident to take place. For example, risk assessment approaches are now available tools to use for developing rules and regulations for better workplace. Getting more experience from offshore and other marine industries will give the student better knowledge towards the industries.

Recommendation

Based on this study, it is recommended to continue for further research that focuses on the following issues:

i. Environmental impact study or green technology.

ii. Cost of the material.

iii. Other properties that can be determined such as corrosion resistivity and fatigue analysis.

iv. Other material that involved in the seaweed farming such as anchor, shackle and chain.

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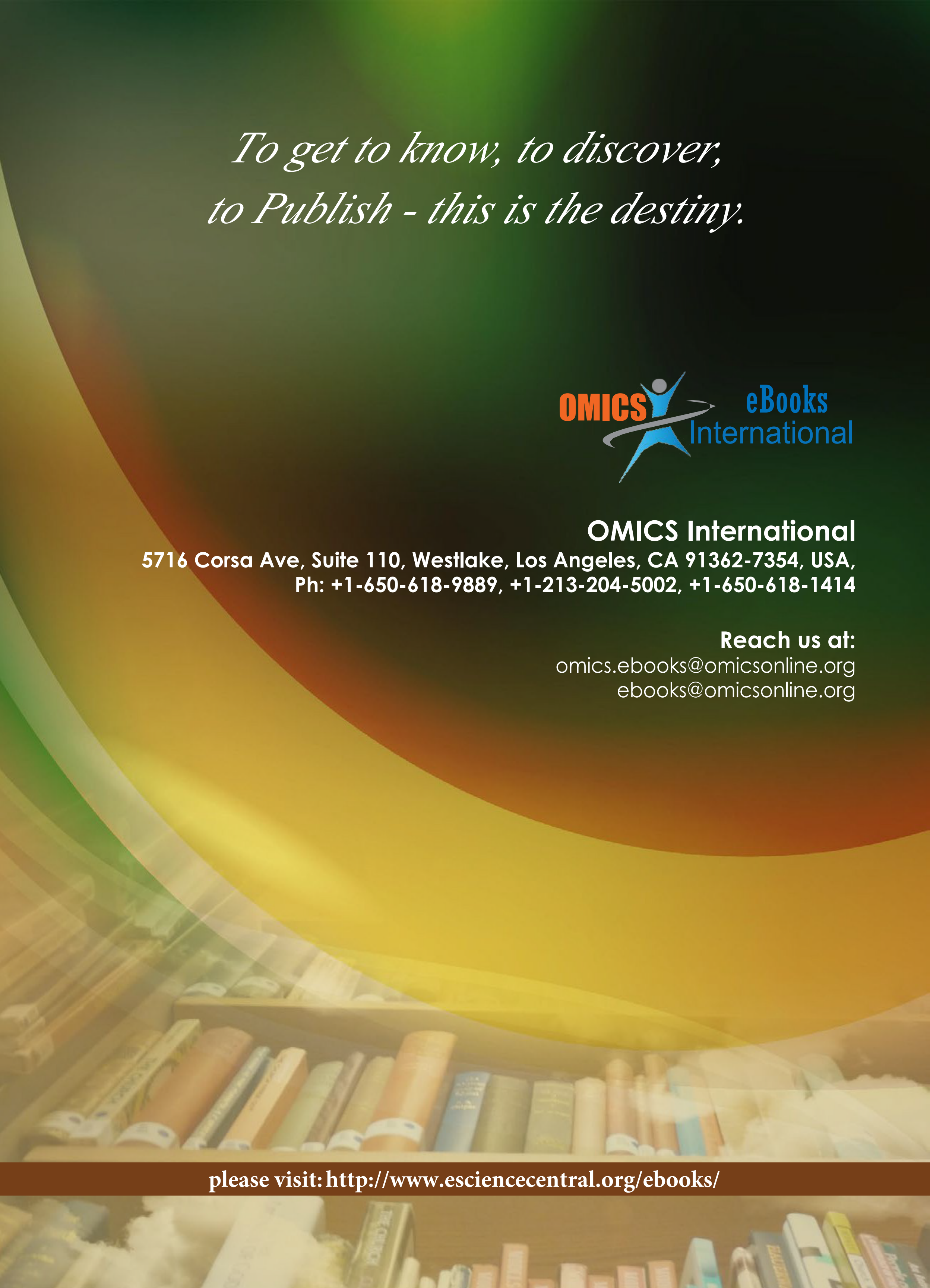

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