Optimization Structure Design of Offshore Oscillating Water Column (OWC) Wave Energy Converter

Khairul Anuar bin Mat Saad and Ahmad Khairil bin Azman

Abstract Oscillating water column (OWC) is one of optional renewable energy device that been used for converting kinetic energy from waves energy into electrical energy. Suitable structural design must be measured and determine to make sure structure is capable to resist wave load. The scope of the research is to design of closed structure of OWC. A model has been set up in Ansys AQWA and Ansys Static Structural which has been undergone through several steps. The model has been run with selected significant wave frequency which is from article finding of the research. Hydrodynamic diffraction analysis has been carried out to identify maximum wave pressure acting on model. Maximum wave pressure be one of component to determine maximum equivalent stress (von Mises) and total deformation of OWC closed structure. There are 4 detail design structure models in this research. Furthermore, there are also 4 different position of maximum wave pressure acting on structure model. Parameter that involve in research including type of material, type of stiffener, number of stiffener and number of frame. Optimization process also carried out by selected suitable detail design structure model to minimize maximum equivalent stress (von Mises) and total deformation. Result shows the optimization process de-creased on structure up to 20–70% at different position for maximum equivalent stress (von Mises). Total deformation also decreased on structure up to 25–80% at different position.

Keywords Oscillating water column (OWC) · Finite element analysis (FEA) · Structural analysis

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K. A. bin Mat Saad · A. K. bin Azman (✉)
Malaysian Institute of Marine Engineering Technology, Universiti Kuala Lumpur, Kuala Lumpur, Malaysia
e-mail: akhairil.azman@s.unikl.edu.my

K. A. bin Mat Saad
e-mail: khairulanuar@unikl.edu.my

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1 Introduction

Green energy development is one of the current issues to reduce the pollution during the operation such as alternative to coal operation. OWC is one of green energy development in industry. The principle of OWC is motion of the wave causes the captured water column to move up and down like a piston thus pressurizing and depressurizing the air though an opening connected to a turbine. Wave impact on structure can cause the device fail to operate in sea. Besides that, to design renewable wave energy converter, suitable structural design must be measured to make sure the structure can operate without fail to resist wave impact load. The structural design use optimization approach and meet the requirement of classification rules. Objective of study research is to analyze and determine structural strength of OWC wave energy converter. It is including optimizing on structural design of OWC wave energy converter. This investigation will give information of concept of OWC. The research also will clarify the difference of several types of OWC based on principle. This investigation also will test and analyze the selected design of OWC on FEA software. It will help the optimization of structural design of OWC. Several parameters of OWC will be change to find best result of design analysis. This research will focus for closed structural design of OWC. The entire test will perform by using FEA software that including equivalent stress (Von-Mises) and total deformation analysis only [10–12].

This project will use existing design of OWC in world. Benchmark model use as reference in FEA to make some comparison between optimization models. Wave data will used for simulate in FEA software. Benchmark model will be design using CAD software. Benchmark model will be design based on limited data from journal or article and guide by classification rules that can be found to validate the structure. In this research, wind and currents will be neglected because wave is the only parameter that will be concentrated.

2 Literature Review

This study presents a comprehensive review of OWC technologies and air turbines [9]. This is followed by a survey of theoretical, numerical and experimental modelling techniques of OWC converters. Its explain types of OWC, location and principle for each type. Study about structure design of BBDB type of OWC [8]. Detail structure on design also identify in this article. In this article, conceptual design for an Oscillating Water Column Wave Energy Converter (WEC) device appropriate for the modeled reference resource site was identified, and a detailed backward bent duct buoy (BBDB) device design was developed using a combination of numerical modeling tools and scaled physical models.

Study about hydrodynamic loads acting on OWC structure [4]. Wave data that used for analysis in this research obtained from this article. This article provides historical development of the OWC device, an explanation of the determination of the hydrodynamic characteristics, a full explanation of a complete motion response formulation, choices regarding device modelling and the presentation of hydrodynamic loads and the resulting transfer functions.

Study about structural analysis on OWC wave energy converter [7]. Measurement of OWC reference model is obtained from this article before detail structure is design. In this article, the dynamic loads determined for the SEA-OWC-Clam wave energy device, treated as a floating offshore structure with six degrees-of-freedom with partial internal sealed-off channels, are applied to assess its structural integrity. This task necessitates the matching of the boundary element determined dynamic pressures to the corresponding Finite Element Analysis (FEA) to determine the effective von Mises stress levels.

Study about understanding of fluid-structure coupled analysis [11]. This research focusing on wave load acting on structure that understanding of fluid- structure coupled analysis is reviewed to achieve the objective. In this study, three design variables (draft, diameter, ballast weight) with 3 levels in the substructure were selected and 9 corresponding models were produced based on design of experiment (DOE). By performing fluid-structure coupled analysis under severe wave conditions with normal current and hydrostatic pressure, they evaluated the dynamic motions (maximum resultant displacement) and maximum von Mises stress and analyzed the influence of those three design variables on the dynamic motion and stress distribution of spar type floating the substructures of spar type floating wind turbines.

3 Methodology

First process of research is to design the reference model by using combination of AutoCAD and Solidworks. AutoCAD will design the model and integrate into Solidworks to check the detail dimension and change the format of analysis software. Then, maximum wave pressure is analyzed and determine by using Ansys AQWA [1, 2]. All the wave data is from journal finding of reference model. This research using coupled analysis to get valid pressure for structural analysis. Maximum wave pressure will be used at analysis of detail structure in Ansys Static Structural. There are 4 design detail structure to identify maximum equivalent stress (von Mises) and total deformation of closed structure. Comparison between various models can identify best model (less equivalent stress and total deformation). Optimization process is continuing by redesign the best model and reanalysis the model to get the final result.

4 Data Collection

OWC design is choose based on the existing OWC that is currently under development. All the information of the model and their wave characteristic is gain from article of [3, 7] (Fig. 1) (Tables 1, 2 and 3).

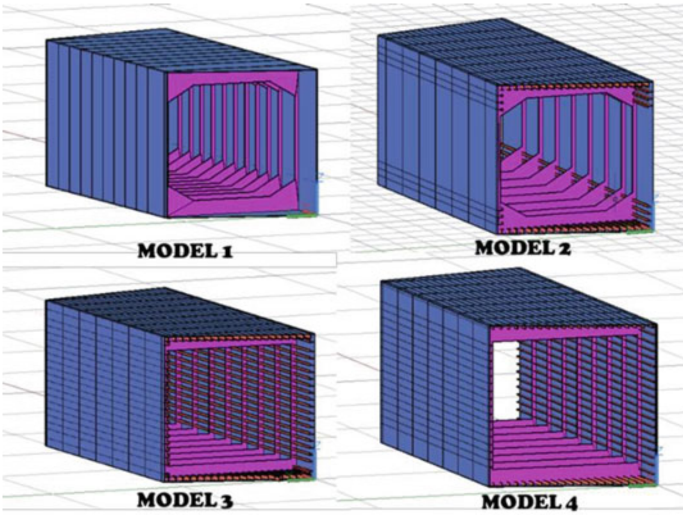

Fig. 1 3D AutoCAD of 4 OWC detail structure design

Table 1 OWC particular

Particular	Full-scale (m)
Length	77.3
Draught	6
Depth	8
Shape	Dodecagon
Type	Multi-device OWC

4.1 Wave Load Configuration

Maximum wave load must be identified as pressure component in FEA analysis [5]. The loads that a floating structure is subjected to are divided in two categories which due to the function on the structure (Functional loads) and due to the environment (Environmental loads). This research only focusing on environmental load which is wave load acting on structure. Other environment load such as wind load or current load not include in this research. The setup of model in this configuration is full body model. This is because full body model can give overall impact of wave into structure. Several mesh element size is compared to generate maximum wave load. The model is modified in order to smoothly be imported into ANSYS Workbench. In AutoCAD, the following modifications to the hull are made:

(i) The body of model is lowered in the coordinate system so the z-axis cuts through the hull on draught level (6 m). The hull is then separated into two

Table 2 Wave data [4]

No.	Frequency (rad/s)	Wavelength (m)	No.	Frequency (rad/s)	Wavelength (m)
1	0.1	1379.72	11	0.93	71.25
2	0.3	428.23	12	1	61.63
3	0.465	244.52	13	1.035	57.54
4	0.5	219.81	14	1.055	55.38
5	0.522	205.81	15	1.068	54.05
6	0.62	154.89	16	1.085	52.36
7	0.669	135.11	17	1.125	48.7
8	0.75	108.9	18	1.24	40.09
9	0.798	96.51	19	1.375	32.61
10	0.87	81.36	20	1.5	27.39

Table 3 Comparison between various models of OWC

	Stiffener			
	Type	No.	No. of frame	Weight (kg)
Model 1	FLAT BARS	62	11	96,385
Model 2	NAB	54	8	1,06,980
Model 3	NAB	80	8	1,18,490
Model 4	FLAT BARS	84	11	94,603

surfaces with the z-axis separating the two. This is also necessary in order to allow Ansys AQWA to easier analyse the body.

(ii) All the body surface is combined together using the UNION command in AutoCAD software to ease the import process of the hull body in Ansys AQWA.

(iii) The axis is located in the centre of body.

The model is then imported into ANSYS AQWA. On the model, a point mass is added, containing all the necessary mass data.

4.2 Structure Analysis Configuration

Structural analysis is the determination of the effects of loads on physical structures and their components [6]. Maximum stress and deformation are identified for each detail structure model in this analysis. Model that used for this research is single body that consist of detail structure. There are several setups in the outline of the analysis such as direction of pressure, fixed support, mesh and their solution.

Mesh element size is obtained from analysis of maximum wave pressure. For configuration, there are several steps that carried which are setup the mesh sizing, face meshing and method of the mesh. Method of the mesh is Multizone that constructs Hexa mapped mesh type for each model.

5 Results and Discussions

The discussion separated into 2 discussions. First discussion is result obtained from Ansys AQWA that focus on identify the maximum pressure as shown in Figs. 2, 3 and 4. Second result is result obtained from Ansys Static Structural which identifies maximum equivalent stress (von Mises) and total deformation for each model. Furthermore, selection model from comparison study also through optimization process to get better result and achieve objective of research (Fig. 5).

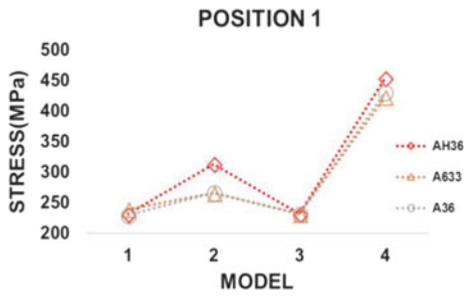

Fig. 2 Line chart of maximum equivalent stress between materials of position 1

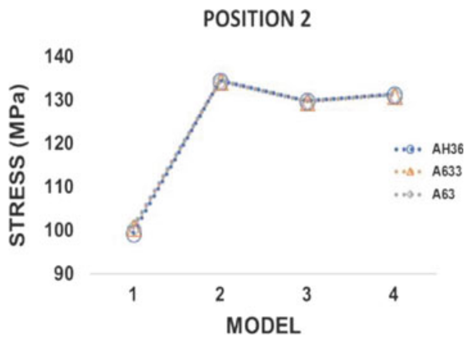

Fig. 3 Line chart of maximum equivalent stress between materials of position 2

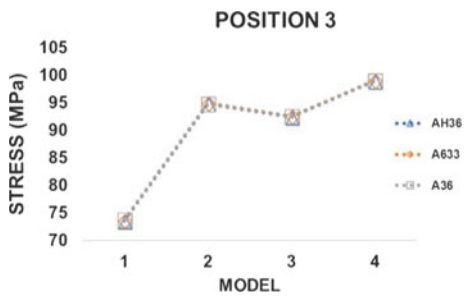

Fig. 4 Line chart of maximum equivalent stress between materials of position 3

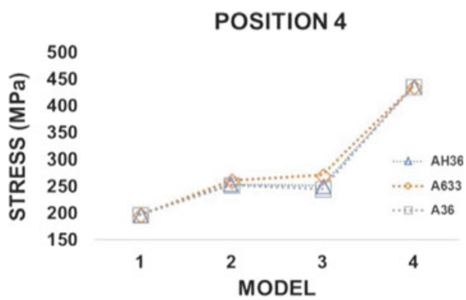

Fig. 5 Line chart of maximum equivalent stress between materials of position 4

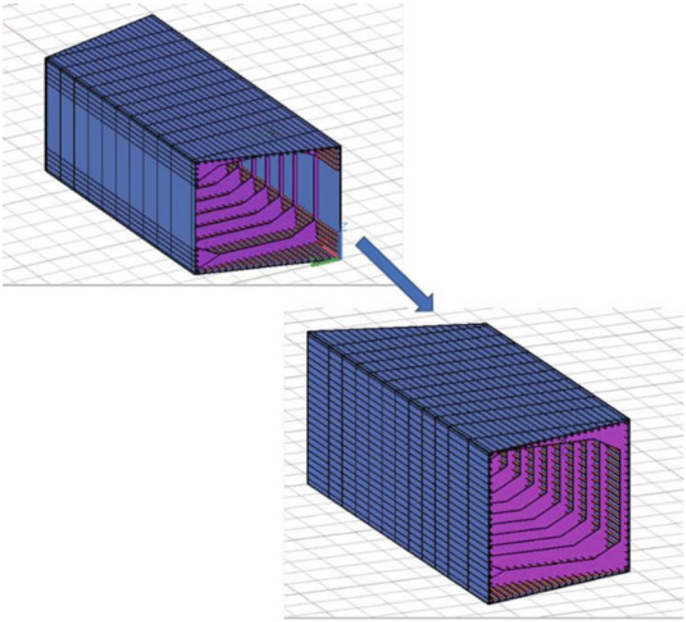

Fig. 6 Optimization of model 1 detail structure

5.1 Optimization of Selection Model

From observation, Model 1 with material of A633 is selected for optimization process. Model 1, referred to Fig. 6, has shown positive result for both maximum equivalent stress and total deformation but for material of A633, there are opposite view that total deformation shows A36 has low total deformation compared to other material. Material A633 can be selected based on result at all Model 1 that use material A633. It shows low result of deformation for Position 1, 2 and 4 as shown in Figs. 7, 8, 9 and 10.

Optimization process is started with redesign the detail structure. Maximum equivalent stress and total deformation can be reduced by optimization process. Stiffener is added to side structure from 62 stiffeners to 84 stiffeners. After stiffener is added, the weight of structure is increase to over 6 tones but the added weight is not exceeded compare to weight of Model 3.

Optimization process has decreased the structure up to 20–70% of Maximum Equivalent Stress. Others, total deformation also decreased up to 25% into 80%.

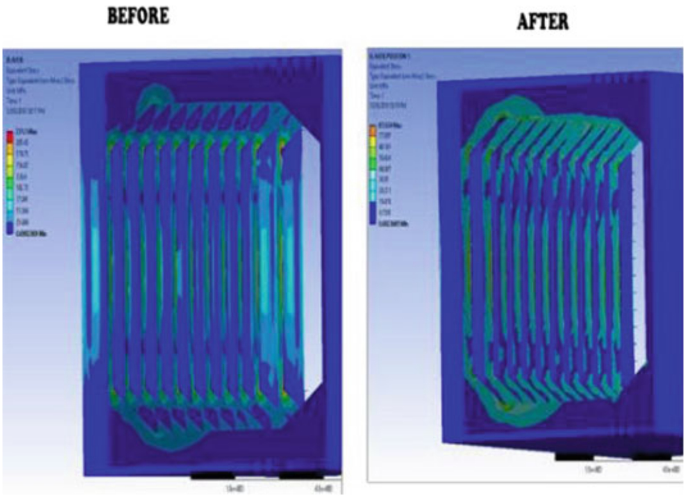

Fig. 7 Before and after optimization for position 1 of model 1

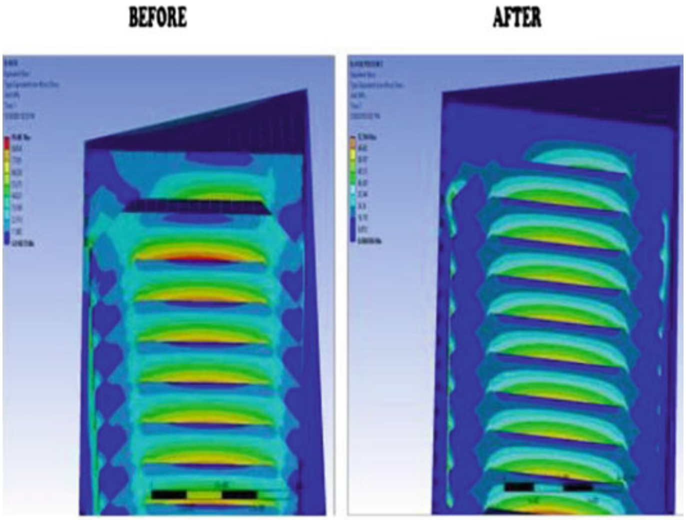

Fig. 8 Before and after optimization for position 2 of model 1

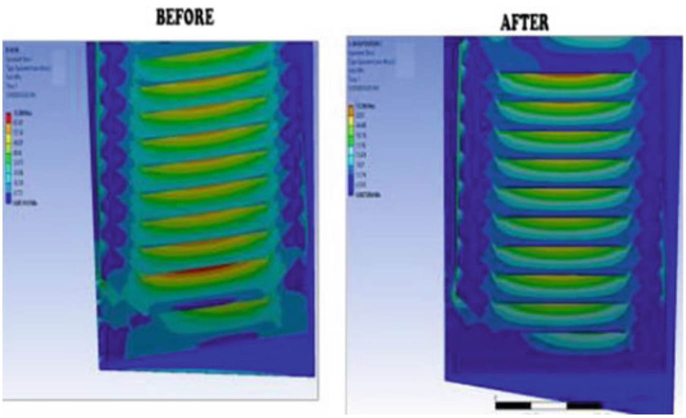

Fig. 9 Before and after optimization for position 3 of model 1

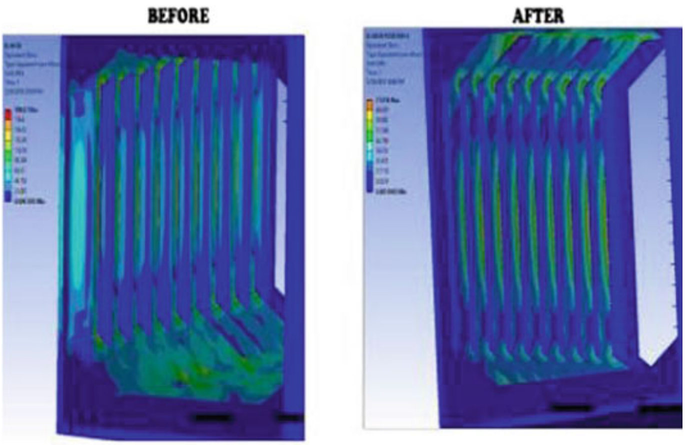

Fig. 10 Before and after optimization for position 4 of model 1

6 Conclusion

In this study, the simulation has been conducted using OWC model with environmental data related to reference actual condition. The objective of the study is successfully achieved. Based on analysis and results obtained in this project, the following conclusions can be made:

1. The Computational Aid Design (CAD) which is AutoCAD and Solidworks is use to model the OWC model and detail structure based on reference article [7]
2. The maximum wave pressure acting on OWC model is successfully identify using Ansys AQWA software

3. Structural strength of OWC is analyze by maximum equivalent stress (von Mises) and total deformation
4. Maximum equivalent stress (von Mises) and total deformation of OWC is successfully conduct and determine using Ansys Static Structural
5. Based on result and discussion, detail structure of Model 1 has less stress impact on structure
6. Redesign detail structure of Model 1 to optimize the maximum equivalent stress (von Mises) and total deformation
7. Optimization process decreased on structure up to 20–70% at different position for maximum equivalent stress (von Mises). Total deformation also decreased on structure up to 25–80% at different position.

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