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Studying the Hydrodynamic Characteristics of New Type of Artificial Reef

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Abstract - *The hydrodynamic characteristics of new design for artificial reef with low flow drag to provide suitable shelter for fishes and marine organisms in the Malaysian seas, were studied in this paper. The concept used in the design is based on the streamlined bicycle helmet design concept. The flow characteristics and the wave forces (FW) of the helmet and hollow cube artificial reefs (ARs) of the same volume have been studied at a water depth and wave celerties of Malaysia seas using Computational Fluid Dynamics (CFD) RANSE (Reynolds-Averaged Navier-Stokes Eqs.) code Ansys Fluent. The Shear Stress Transport (SST) turbulence model was used in the RANSE code. The streamlined body of the helmet artificial reef provides flow zones with moderate flow speed at this area, which can help fishes and marine organisms to find good shelter. The special shape of the different openings in the body of the helmet artificial reef improves the condition of the flow velocity distribution inside the unit than that of the hollow cube unit, which can increase the amount of the nutrient to the living fishes and organisms inside the reef.*

Keywords: Artificial reefs, Drag force, CFD, Water velocity and Depth variation

1.0 INTRODUCTION

In Malaysia, majority of the citizen that live near sea are operating fisheries industry as their main job. Some of them are involved in touristic activities at some places of have high economic value for recreation activity that may involve snorkeling, diving. Both of these industry mainly very dependent on the existence of marine life for their activity. Due to the activity of irresponsible group of people that practicing illegal fishing method and results to the destruction of natural reefs that used to be the habitat of marine life [1].

The natural reefs naturally provide protection and creates food source as they attract the marine life. Just under a hundred country's natural reefs have been impaired by human activity. If this rate of deterioration continues, 70% of our planet reefs will be annihilated within 60 years, as the result it will cause erosion of coastal shoreline which some serious situation would result in disappearance of small islands. There some other factor that cause the damages, sedimentation, fishing with explosives, cyanide fishing, collection and dredging, water pollution, dumped trash, human run-off, careless recreation and also global warming [2].

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From the current problems, artificial reefs has high potential to act as the early stage of restoration. This will allow the endangered marine life to recover and enrich the population, apart from that it can develop a quality fishing ground that close to access point for the locals, at the same time prevent trawlers to go to the restricted area. To achieve this, a good design of an ARs is needed which concern the hydrodynamic characteristics and thus affecting to the surrounding marine habitats.

2.0 LITERATURE REVIEW

One of the most diverse ecosystem in the world is coral reef where it act as a housing for tens of thousands of marine species. About one-third of marine species live the lives on coral reefs. Normally this animal can be found all over the world in tropical and subtropical oceans. Under normal condition it can be found in shallow areas at depth of less than 150 feet and some other can be find extend up to about 450 feet deep. Figure 1 show the distribution of coral reef all over the world [3].

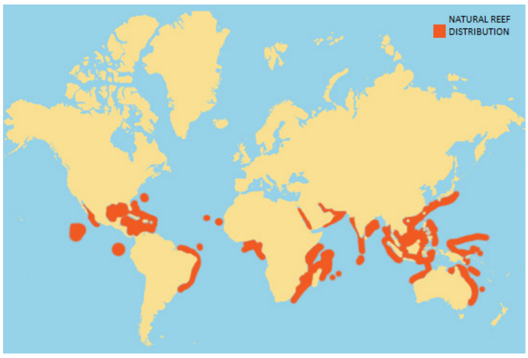

Figure 1: Natural reef distribution around the world [4]

Coral reefs are scattered throughout the tropical and subtropical Western Atlantic and Indo-Pacific oceans. Western Atlantic coral reefs include these areas: Bermuda, the Bahamas, the Caribbean Islands, Belize, Florida, and the Gulf of Mexico. The Indo-Pacific ocean region extends from the Red Sea and the Persian Gulf through the Indian and Pacific oceans to the western coast of Panama. Corals grow on rocky outcrops in some areas of the Gulf of California.

History shows that mankind had destroyed over 35 million acres of coral reefs, it covers 93 country that their reefs has been damages by human activity in the past few decades. If this rate of damage continues without proper action to encounter it another 70% of the world coral reefs will be annihilated within our lifetime. These damages are the major effect from human activity such as sedimentation, fishing with explosives, cyanide fishing, collection and dredging, water pollution, trash, human run-off, careless recreation and also global warming which initially caused from human hand [2].

In marine ecosystem, artificial habitats aims is to restore degraded natural marine habitats and fisheries and at the same time will cover most of the problem stated above. These human-made ecosystem or more specific artificial reefs are designed to cover many aspects, the definition of the artificial reefs itself is a submerge structure positioned on the seabed which designed to mimic some of natural reefs characteristics. Among the aims of these structure are aquaculture or marine ranching, promotion of biodiversity, mitigation of environmental damage,

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enhancement of recreational scuba diving spots, eco-tourism development, expansion of recreational fishing, artisanal and commercial fisheries production, protection of benthic habitats against illegal trawling and also researches. There are also some guidelines for this ecological restoration [3].

ARs are often applied in context of enhancement and improvement of natural level of productivity of a given system. ARs also explained as a natural or a manmade materials that purposely placed in a benthic marine system. The goals stated related to application of this structure are aquaculture and marine ranching, recreational diving, eco-tourism, artisanal fishing, commercial fishing, recreational fishing, research and biodiversity [4]. In term of AR design generally by applying a high-profile structures that suitable for pelagic fish and a low-profile or bottom reefs is to attract mobile fish with its extensive void space that applied on it.

The other thing was stressed out and seem to be affected in the justification of an AR project is environmental impact assessment, expected benefits, evaluation of alternative design and placement methods and also provision for baseline studies [5].

From [6] a study had shown that the algae grazing rate was higher at the nearer region where the AR was placed compared to the further area. They conclude that with the higher grazing rate of macro algae attracting the herbivorous fishes to associate in the AR surroundings. Apart from the source of food region provided by the AR, the main factor of attraction is due to the ability of AR to give protection and shelter. The marine life associate in the AR will became less vulnerable to predation when they stay within its region. Such shelter can maintain the fish ability to escape to the artificial structure.

The first establishment of ARs in Malaysia is in May 1975 at Pulau Telur, Kedah then followed at Pulau Payar in October and at Pulau Aman, Penang in July. This effort is carried until now with various improvement done to the ARs structure, material and costing. The primary objective of this activity is to rehabilitate and conserve the marine habitats which initially mostly affected by the method of fishing such as trawling. Other issue that had been take into consideration is generating the recovery of coastal fisheries resources, whilst improving the caches of the traditional inshore fisherman engaged in the use of artisanal gears [7].

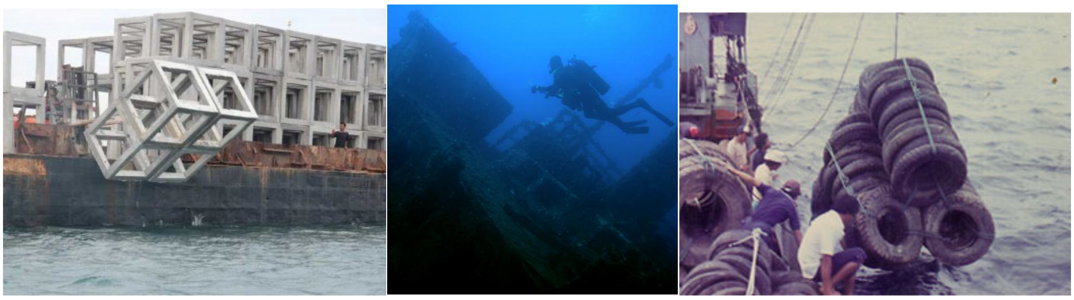

Figure 2: Some of AR developed by DOFM since 1979. Concrete based structure, confiscated vessel and tyres [8].

AR activity in Malaysia is generally for fishery and non-fishery use. For fishery application, they focusing on conservation activity which is in enhancing coastal fisheries resources, protect the marine ecosystem growth and prohibit trawler from get into inshore areas by special designed anti-trawler AR. Secondly for fishing purposes where it can save time and fuel for searching fishing areas. The non-fishery use is basically a recreational activity such as scuba and snorkeling and at the same time it provide firm substrate for marine flora and fauna to

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grow. Observation that has been done shows that the larger size AR are more superior to the smaller ones in attracting more marine flora and fauna [1].

There are already different type of AR design applied in Malaysia water since year 1979 until now such as tyres, confiscated vessel, PVC, ceramics, and also concrete, Figure 2 For year 2006 until 2010, Department Of Fishery Malaysia, DOFM had develop several type of concrete based AR, among them are tetrapod, cuboid, lobster, cube, soft bottom anti-trawler, cuboid bio-active, and cuboid anti-trawler, Figure 3 [8].

Figure 3: reef-ball, tetrapod, soft bottom anti-trawler and cuboid AR [8].

3.0 METHODOLOGY

From the fluid hydrodynamic point of view, different types of reef structure have different hydrodynamic characteristic when discussed in moving water condition. The characteristic that can be define is the frequency property of eddy current, change in strength of vortices and also the AR effective ranges. By testing different type of model, it shows that the higher the frequency of the eddy, the weaker its vibration in strength. Conversely with its greater variation in strength, the frequency are lowered. From this, if we decide to have stronger pressure to effect the organism, then the structure with lower generated should be designed [9].

Transient Navier-Stokes equation are widely used in engineering up until now. The study of hydrodynamic particular around AR closely related to motion of fluid, so it must satisfy the mass and momentum conservation equation. The differential form of continuity equation and momentum equations are defined by the Reynolds-average Navier-Stokes (RANS) equation in the Cartesian rectangular coordinate system as follows:

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

Momentum equation:

$$\rho \frac{\partial}{\partial x_j}(u_i u_j) = -\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_j}(\mu \frac{\partial u_i}{\partial x_j} - \rho u_i' u_j') + s \quad (2)$$

where,

ρ = density of the fluid.

U_i = the average velocity component for x, y, z.

P = is a body of fluid pressure on the micro volume.

In simulation method, to calculate the hydrodynamic particular of the subject studied a fundamental assumption had to be decided upon the model. The usual assumption that had been practiced is that the fluid is incompressible, viscous, and Newtonian fluid to the water, the flows are isothermal which is about the flows studied without regard to heat change in water. Another assumption is that the free water surface is modeled as a “moving wall” with zero shear force and the same speed as the incoming fluid. With this the fluid governing equation that involved are continuity equation, momentum equation, eddy-viscosity relationship, turbulent equation and viscosity coefficient [10, 11].

Materials used must be resistant to deterioration from UV light, wave action and corrosion. Durable materials will maintain the desired structural design and have long life expectancy. The criteria will determine which material is more suitable base on the function of the ARs. The material selection need to be able to give a protection to the marine life and also the material can act as the catalyst in stimulating the growth of micro and macro organism, which result to providing source of food for the marine life. The material chosen for the AR construction should be tested and proven that it cannot create any environmental risk and user conflicts which can result the opposite of AR original function. The user of the AR is mainly marine life, but it also need to consider the other user as well such as diver and not forgetting the fellow natural reefs. This point is important because the movement of big and heavy AR will result to destruction of natural marine life. The consideration of stability must covers both natural and unnatural causes. The natural causes may cause of seabed condition and benthic sea water current, for the unnatural causes is the illegal trawling what can be seem as the main problem.

Main issue of the artificial structures placed in the sea is the corrosion resistance from the environment and also the UV deterioration. Since we desired a long lifespan of the AR, we need to choose s suitable material for the application. Computational fluid dynamics, usually abbreviated as CFD, is a part of fluid mechanics that uses algorithm and numerical methods to solve and analyze problems that involve mainly fluid flows. Computers are used to perform the related calculations to simulate the interaction of liquids and gases with surfaces or body defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. [12-15]

3.1 Software's Involved

3.1.1 Autocad

AutoCAD is software application for 2D and 3D computer aided design (CAD) and drafting that available since 1982 and it first release is in December 1982 as a desktop application. Since 2010 it was available as a mobile web-based and cloud-based application marketed as AutoCAD 360.

3.1.2 Rhinoceros

Like many modelling applications, Rhino also features a scripting language, based on the Visual Basic language, and an SDK that allows reading and writing Rhino files directly. Rhinoceros 3d gained its popularity in architectural design in part because of the Grasshopper plug-in for computational design. Many new avant-garde architects are using parametric modelling tools, like Grasshopper.

3.1.3 Ansys icem

ANSYS ICEM is a meshing software that starts with an advance CAD or geometry reader with variety of geometry-tolerant mashers and can produce high-quality volume or surface meshes. With advance mesh diagnostics, automated mesh editing, output to a wide variety of CFD and finite element analysis solver and multi physics post-processing tool makes the usage of this software will be advantageous for this research.

3.1.4 Ansys fluent

ANSYS Fluent software contains the broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications ranging from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from clean room design to wastewater treatment plants. Special models that give the software the ability to model in-cylinder combustion, aeronautics, turbo machinery, and multiphase systems have served to broaden its reach.

4.0 NEW ARTIFICIAL REEF DESIGN

The main idea of this study is to design new streamlined AR of low drag and good flow distribution inside the unit. A bicycle helmet Figure 4 concept was chosen for this purpose [16]. Figures 5 and 6 show the final design of the artificial reef that has been used in this research work based on the idea of bicycle helmet. The flow field patterns around and inside the new artificial reef and hollow cube artificial reef Figure 7 of the same volume (Table 1) were studied by employing FVM code Ansys Fluent.

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Figure 4: Examples of bicycle helmet. [16]

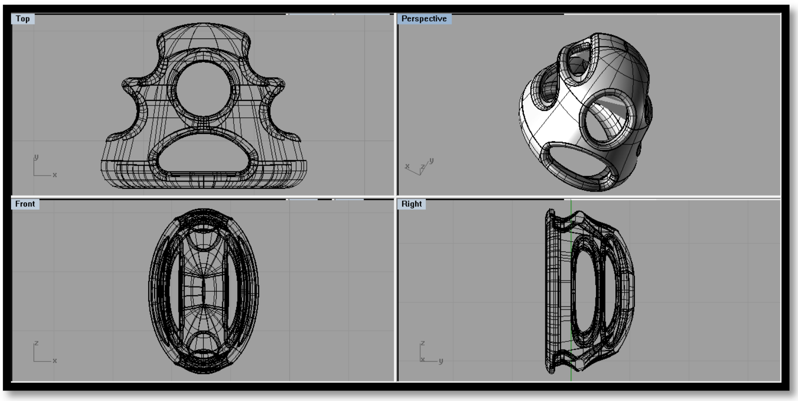

Figure 5: New artificial reef design.

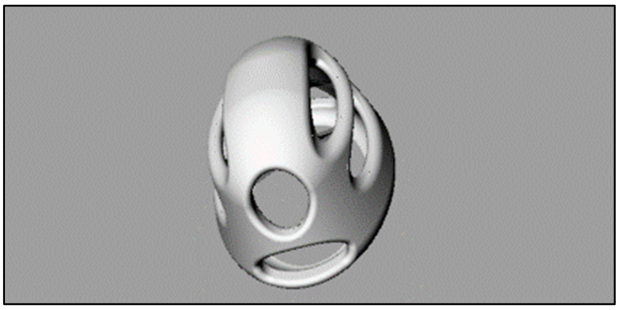

Figure 6: Prospective view of the new AR design

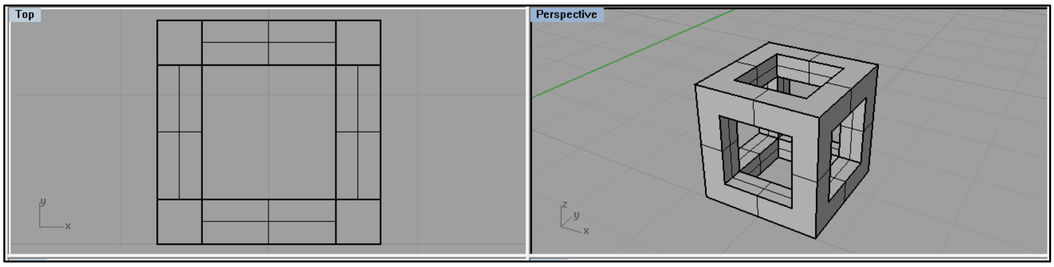

Figure 7: Hollow cube design

Table 1: Main dimensions of helmet and hollow cube ARs

Parameters	Helmet AR	Hollow Cube AR
Max length	2.8 m	1.5 m
Max width	1.9 m	1.5 m
Max height	1.5 m	1.5 m
Area projected to flow direction	1.5 m^2	**1.44 m^2**

5.0 COMPUTATIONAL DOMAIN AND GRIDS

The computational domains for the two ARs were chosen to be in a box shape in Ansys Fluent. The heights of the computational domain had been set to be 20 m depending on the water depth data for Malaysian seas (H). The width of the domain was nearly 7L (L is the maximum length of the unit), the domain inlet boundary was at a distance of *L* ahead of the artificial reef, while the outlet boundary was located at approximately 4L from the end of artificial reef, as shown in figure 8. The computational domains and the surfaces of the artificial reef models are meshed used tetrahedral mesh elements. A grid dependency study was performed to make sure the solution is independent of the mesh elements size. A size of 0.05 m mesh elements was used the surfaces of helmet (figure 9) and hollow cubic ARs, while a size of 0.5 m was used for the rest of the domain (figure 10).

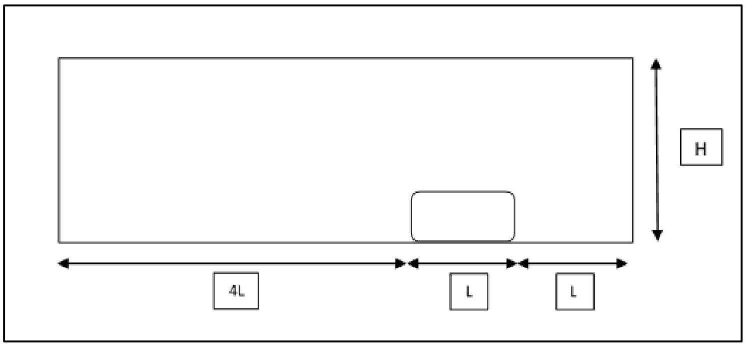

Figure 8: ARs computational domain main dimensions

6.0 RESULTS AND DISCUSSION

Based on the linear wave theory, the wave velocity (*V*) has been found in the range of 0.5 to 1.2 m/ based on the environmental data for Malaysia seas. The calculated values of *V* for water depth *H* = 20 m were used for defining the inlet speed in Ansys Fluent. The volume of fluid (VOF) was used in the finite volume code to describe the sea waves. The numerical results for the wave force (F_W) that acted on the hollow cube and helmet artificial reef units at 0° (Figure 11) for water depths of 20 m are given in figure 11. Generally, the streamlined body of the

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helmet artificial reef led to less final wave force FW at all flow directions (results of 0o were the same as for 90o for hollow cube artificial reef due to the geometrical similarity at these two angles), as shown in Figure 12. The reduction in the value of F_W reaches to nearly 53%, 59% and 45% at 0^{o}, 45^{o} and 90^{o} of flow direction respectively. This show the improvement in the flow pattern due to the use of helmet artificial reef.

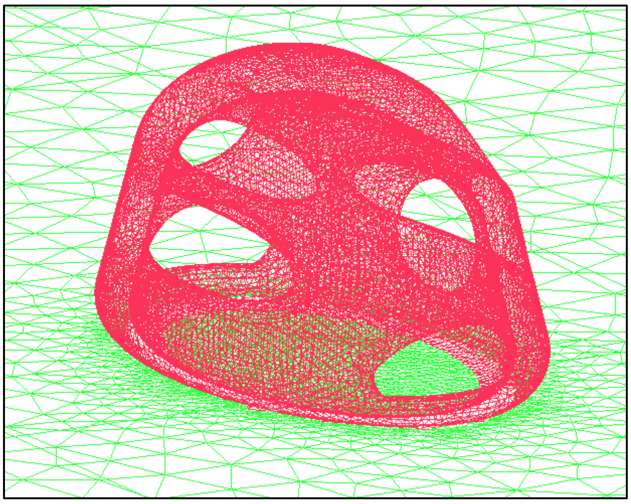

Figure 9: Refined mesh elements of helmet AR.

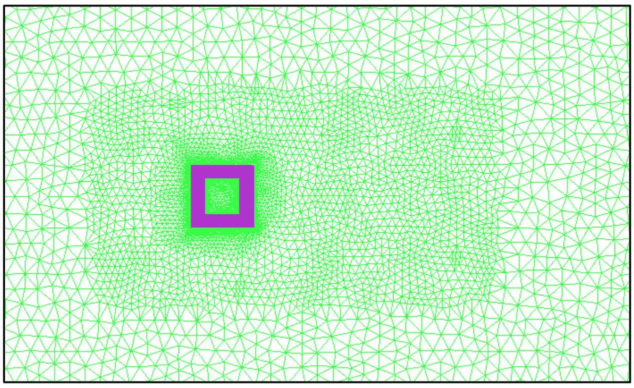

Figure 10: Plan view for the mesh elements on and around the hollow cubic AR

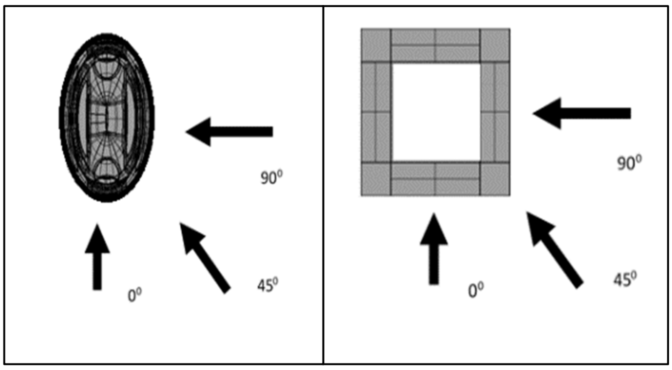

Figure 11: Direction of Flow Applied onto AR's Body (The direction of the flow against the ARs units (helmet and hollow cube)

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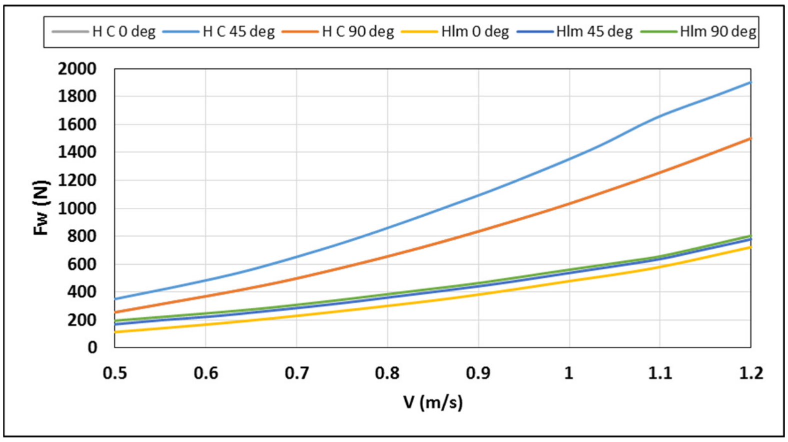

Figure 12*:* F_W for helmet (Hel) and hollow cube (H C) ARs at different flow directions for water depth of 20 m

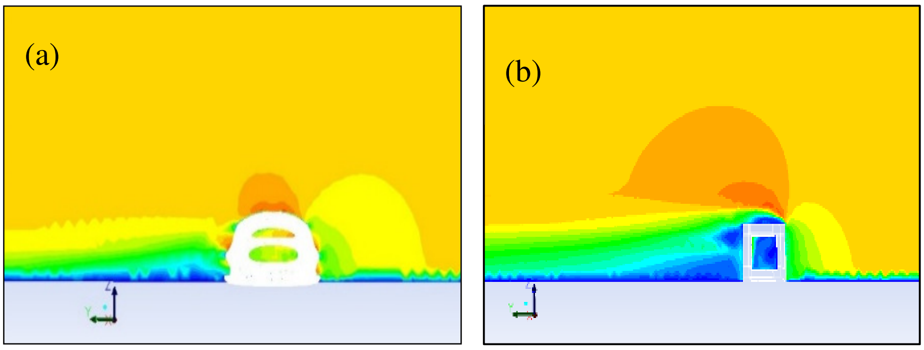

Figure 13: Velocity contours for the two ARs (0°)

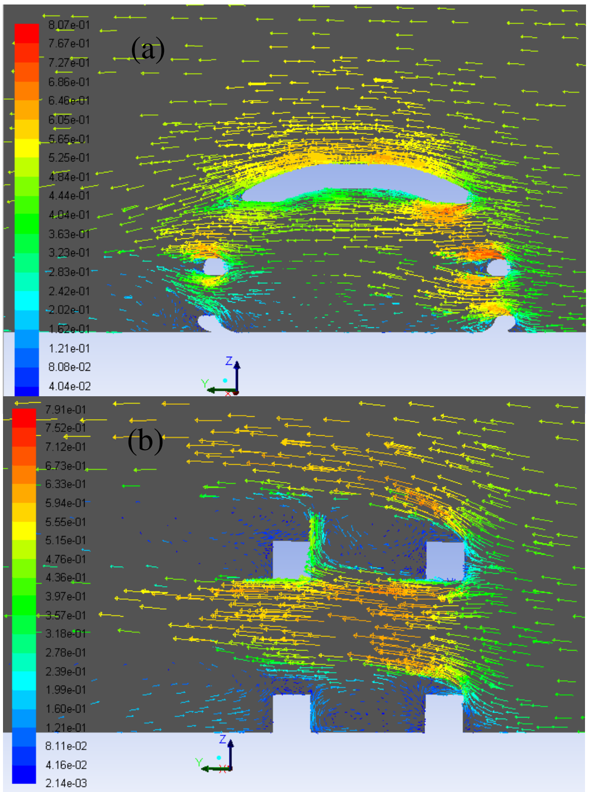

Figure 14: Velocity vectors in and around the two ARs (0°)

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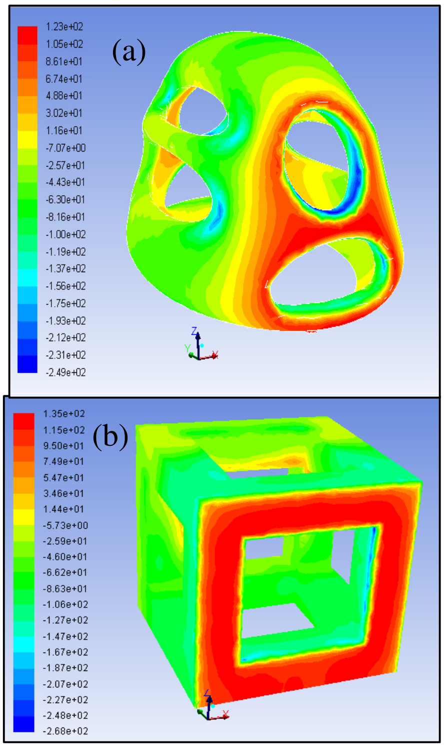

Figure 15: Velocity contours of in and around the two ARs (0°).

Figures 13 and 14 shows the contours and vectors of water velocity around and inside the two ARs for the most common flow direction at 0°. The results show that, there are areas of low flow velocities in front of the two ARs due to the effect of the geometry of the two units on the flow field in this region. The streamlined body of the helmet artificial reef improves the flow distribution at the front area and decreases the stagnation pressure area. Furthermore, Figure 15 shows that helmet artificial reef improved the flow separation and the low velocity flow field at the downstream of the reef, which can provide fishes and marine organisms with a more suitable shelter in this environmental condition.

7.0 CONCLUSION

In this study, a new type of streamlined artificial reef based on the concept of bicycle helmet has been introduced. The wave force that is acting on the new artificial reef and the hollow cube artificial reef of the same volume; which is one of the widely used ARs around the world, was calculated numerically using Ansys Fluent code at water depth of 20 m for a range of wave velocities from 0.5 to 1.2 m/ based on the environmental data for Malaysia seas. The results show that the hollow cube artificial reef is always subjected to higher F_W than the helmet artificial reef for all flow directions. The reduction in the value of F_W reaches to nearly 53%, 59% and 45% at 0°, 45° and 90° of flow direction respectively. This show the improvement in the flow pattern due to the use of helmet artificial reef.

The flow pattern in front of the helmet reef is always subjected to less resistance than that of the hollow cube artificial reef, which led to the reduced area of the stagnation pressure on the unit body in front of the water flow. The streamlined body of the helmet artificial reef improves the flow pattern at its rear region and provided zones with moderate flow, which can help fishes and marine organisms from finding good shelter. The different openings in the body of the helmet artificial reef improves the condition of the flow velocity distribution inside the unit than that of the hollow cube unit, which can increase the amount of the nutrient to the living fishes and organisms inside the reef.

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