NAZARBAYEV UNIVERSITY

School of Engineering

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Capstone project title: Ocean Wave energy extraction

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Abstract

Energy consumption all over the world is increasing rapidly, that is why to fulfill this demand various types of energy sources are needed. During this project, one of the well known type of renewable energy sources wave water energy will be explored. The main aim of this research is to calculate coefficient of efficiency in terms of cost and power dependence and to model new design of ocean wave energy converter. The structure of Sea Slot-cone Generator will be benchmark model for this research and it has several reservoirs, which will have own turbines to produce energy. The data analysis in terms of efficiency and physical behavior will be tested on software ANSYS by making 2D and 3D simulations of a flow. Various shapes of sea slot cone generator will be tested and analysis in terms of pressure and velocity would be made. For preliminary study, the simulation of a flow in 2D will be made and by identifying the velocity profile of the flow ocean wave energy extraction will be tested.

Introduction

Number of people all over the world increasing rapidly, which causes high energy consumption rate. (Chen 2011) That is why, several ways of energy production was developed, to satisfy needs of population around the world. According to the production type and effect to the nature energy production was divided into renewable and non-renewable energy production. (Sharif 2018) There are different types of renewable energy sources, such as hydropower, modern biomass, wave, solar, geothermal etc. According to statistics of Renewable Energy Policy Network for the 21st Century, 14% of total energy was produced by green energy sources. (Panwar 2011). This alternative energy sources helps to decrease the CO_2 emissions to the atmosphere and to increase the cost efficiency of energy production. (Arent 2009). According to Hydropower Status Report statistics in 2018 25.6% of total energy around the world was produced by renewable energy sources, whereas hydropower consisted 15.9% of total energy production. (Scorza 2019) There several types of energy production by using water, such as hydroelectric power, ocean energy and saline water. In every case, different properties of water used as a source of energy. For example, during hydroelectric power production the velocity of water is used, which is wave. Solar ponds and algae production helps to extract energy from salt water, which is based on the composition of a water. In addition, due to the temperature differences and by using ocean thermal energy conversion electricity can be produced between warm and cold water. (Srinvas 2019). During this project wave energy extraction technique will be studied. This project will be focused on the work of Margheritini, who have wrote about sea slot-cone generator in the island of Kvitsoy, Norway.

Figure 1. Sea slot cone generator in Kvitsoy

The mechanism of converting wave energy into electricity will be based on this research, however the model for wave converter will be optimized in this project. Energy efficiency rate and physical behavior will be studied using ANSYS software. According to the results of simulations optimization of design of wave energy converter will be made and new model will be shown.

Literature review

Water at a high speed is a powerful source of energy. That is why the hydropower energy generation one of the fastest growing energy production type.

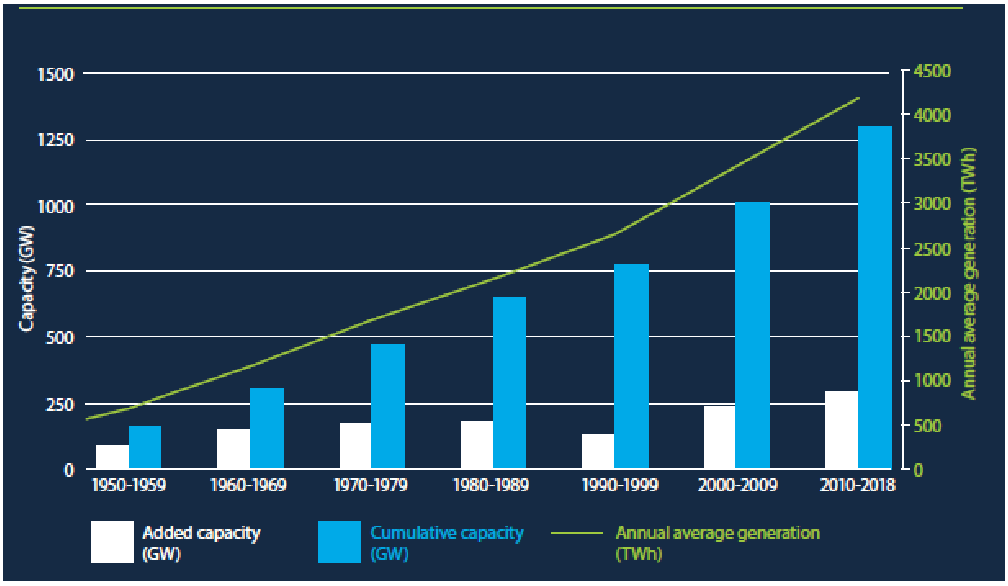

Figure 2. Hydropower generation growth throughout the decades

As it can be seen from the Figure 2, hydropower generation grows 20 times from 1950s. (IHA 2019) As it was discussed before, there are different ways of extracting energy from water. The most effective and widespread type of energy extracting from water is wave energy converter.

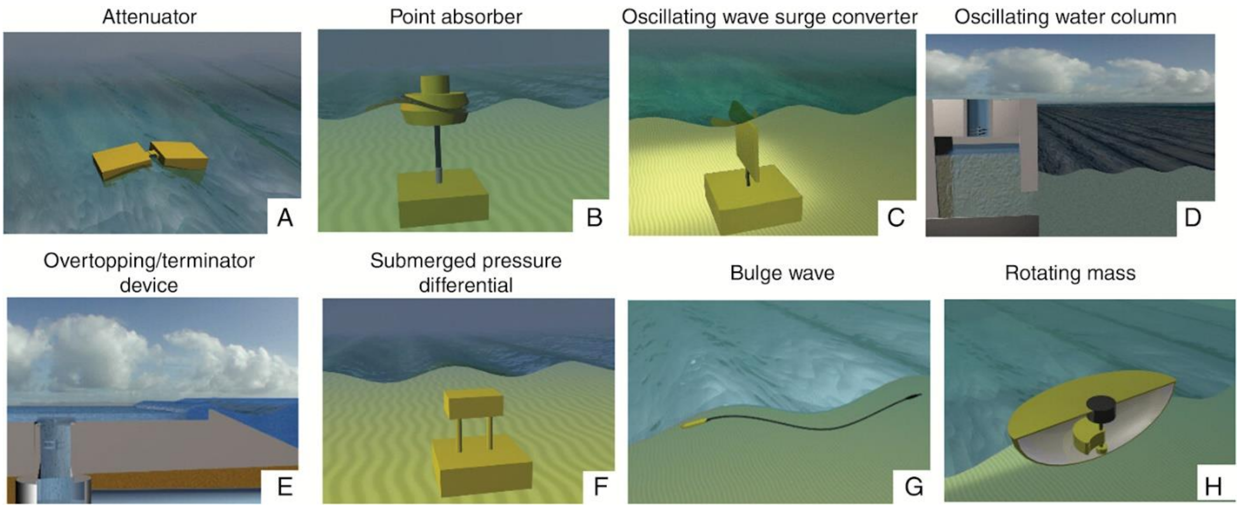

Figure 3. Main categories of wave energy converters

As it can be seen from the Figure 3, there many types of wave energy converters. They have different designs according to their locations and efficiency rate. For ocean wave energy extraction, terminator device(E) should be used, because it has fixed structure and ability to work at different velocities of wave. (Margheritini 2009) Most of these wave energy converter are directed to convert mechanical energy into electricity and they work on the basis of turbines. The main idea behind wave energy converter is gravitational fall of water flow into the reservoir. This gravitational potential energy is converted into mechanical kinetic energy with the help of water turbines. The highest value of kinetic energy during the flow occurs, when the velocity is high. That is why by decreasing the distributor or nozzle size of water turbine high kinetic energy can be produced. There are two main categories of water turbines, such as impulse and reaction. In impulse turbine, all potential energy taken from the wave is converted into kinetic energy in the distributor, whereas in reaction turbines the converting of energy occurs partially in distributor and partially in rotor. (Edward 2015)

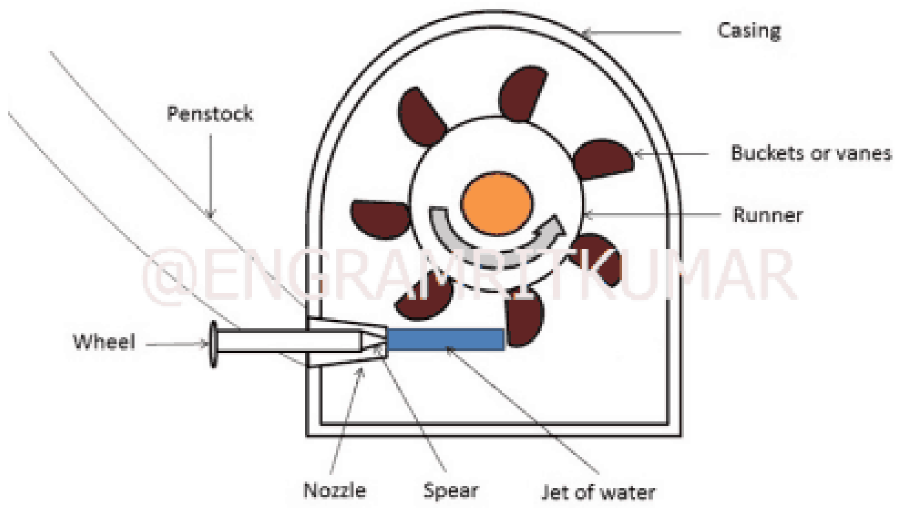

Figure 4. Pelton wheel turbine

Turbine shown in Figure 4 is a classical example of impulse turbine, because the energy converting process occurs at the end of nozzle. This type of hydraulic turbine is used at a high flow rate of water and was invented by American scientist Allan Pelton. The main difference of this kind of turbines is its location in the water. Most of the turbines locate inside the water, whereas vanes of Pelton wheel turbine enters the water, which leads to the rotation of a wheel. Pelton wheel turbines can have different sizes and the power can reach 200 - 250MWh. (Padhy 2009)

As it was discussed before there is also reaction turbines, which converts the energy due to the pressure and moving water. The mechanism of these turbines different from impulse, because reaction turbines are located directly in water flow region and blades every blade of turbine covered with water. That is why, reaction turbines used in places, where pressure is low but the water flow is high. (Adhijit 2009)

Francis turbine is a most known reaction turbine, which has different pressure values at different flow rates. This type of turbine used for a dams where the inlet area of a wave energy converter is high, whereas the outlet is small. This turbine was named after James B. Francis in Lowell, Massachusetts and the geometry was as in Figure 5.

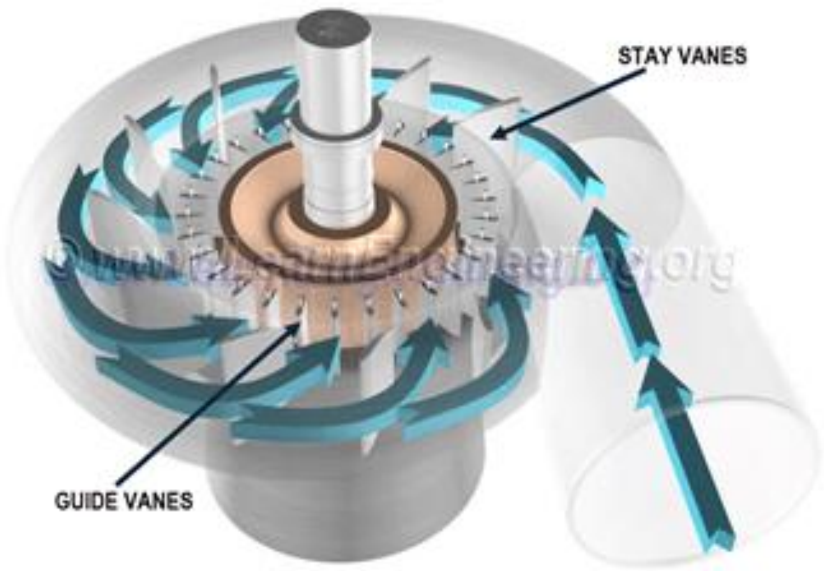

Figure 5. Francis turbine

Advantages and disadvantages of hydropower energy production

As it was discussed before hydropower energy generation one of the fastest growing energy production type. There are several reasons to use this kind of renewable energy sources.

- Renewability of a source of energy. Hydraulic cycle is infinite and the water resources are supplied by precipitation (rain, snow)
- Power produced by hydropower plants can be easily controlled, by changing the velocity of a water flow
- Reservoirs made for energy production can be helpful to build beach and resting zone for tourists. By constructing wave energy converter near the beaches, the velocity of wave can be decreased, because most of power from wave will be directed to produce energy. That is why, safety during the swimming can be improved.
- Decreasing the CO_2 emissions into atmosphere.

Whereas, there are also negative effects of hydropower energy production.

- Big area is needed for construction of hydropower plant. This land can be used for other purposes, such as agriculture, living etc.
- Breaking of reservoirs and dams can lead to the fatal consequences.
- Building water power system depends on the climate of a region.
- Reservoirs decrease the amount of hydrogen of the water, due to the blocking the normal flow of the water in ocean. That is why, natural habitat for fishes can be destroyed.

Modelling

Starting with the design of Sea Slot-cone Generator (SSG) observed in the work of Margheritini, which was the fundamental base structure in designing the ocean sea wave extractor. The dimensions of SSG is 17m (length) x 10m (width) x 6m (height). The SSG model would be benchmark design, whereas the new design will be developed model. The developed model was created with dimensions: 17m (length) x 3m (width) x 6m (height).

Firstly, the design of SSG was created in Solidworks, see Figure 1. Solidworks is the computer software program aimed to design 2D and 3D models of any object.

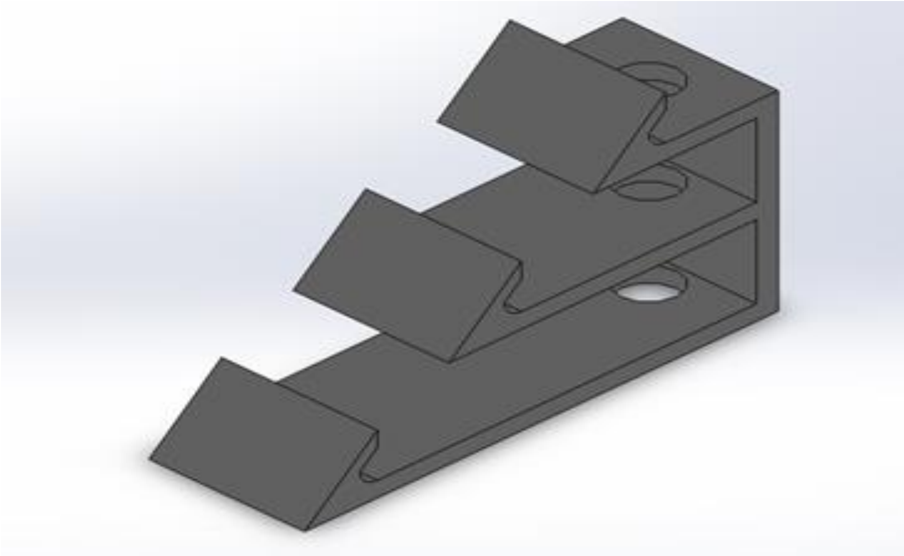

Figure 6. SSG model

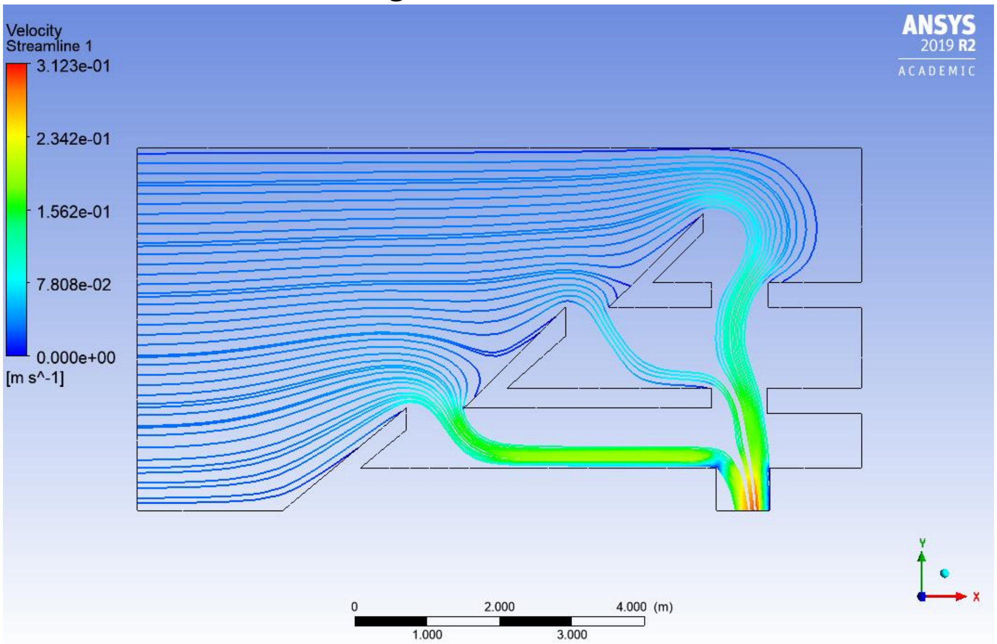

Figure 7. Flow simulation through the SSG model

Making some improvement in design in order to achieve more efficient power generation, the developed model, see Figure 8, was created.

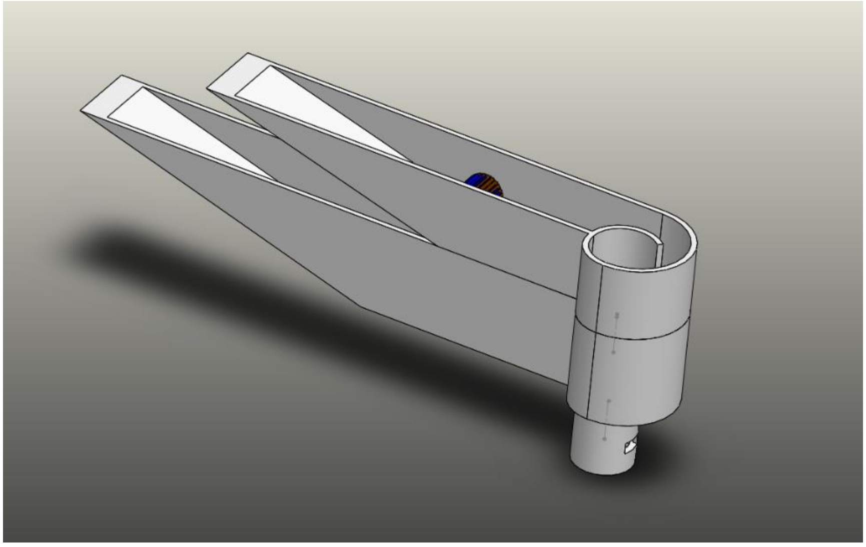

Figure 8. The isometric view of the developed model

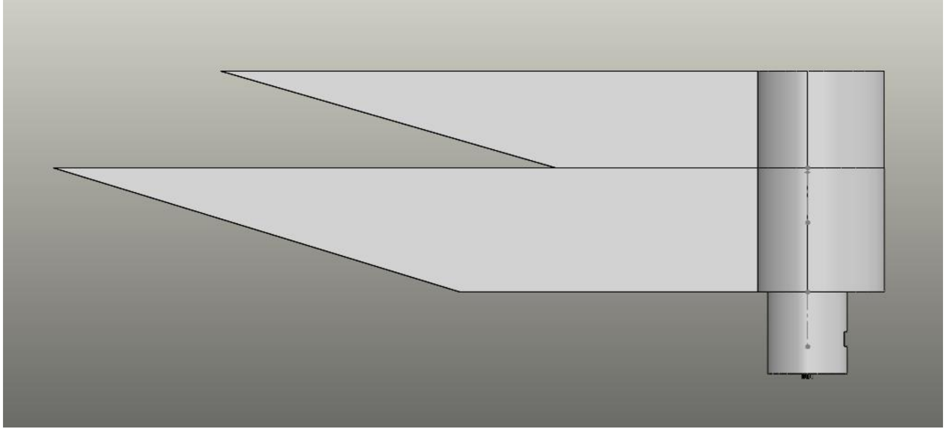

Figure 9. The side view of the developed model

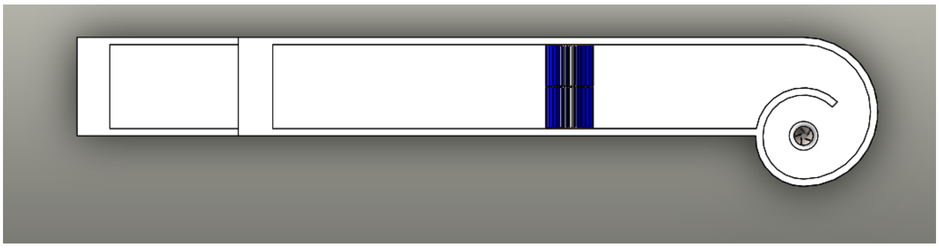

Figure 10. The top view of the developed model

The model consists of three main parts: main body, vertical water turbine and cross flow water turbine.

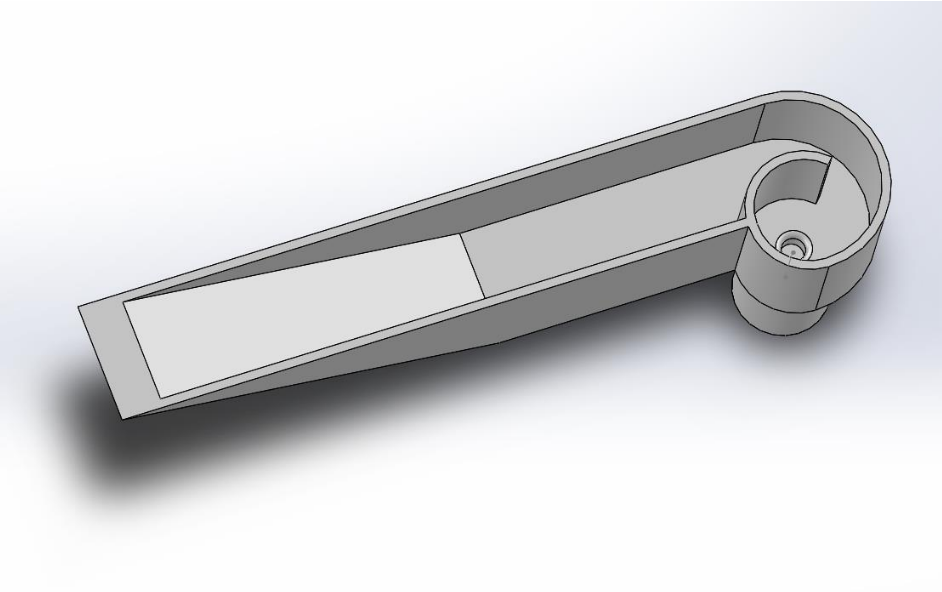

Figure 11. The main body

This kind of structure allows to accelerate the water flow in the place where the turbines are located.

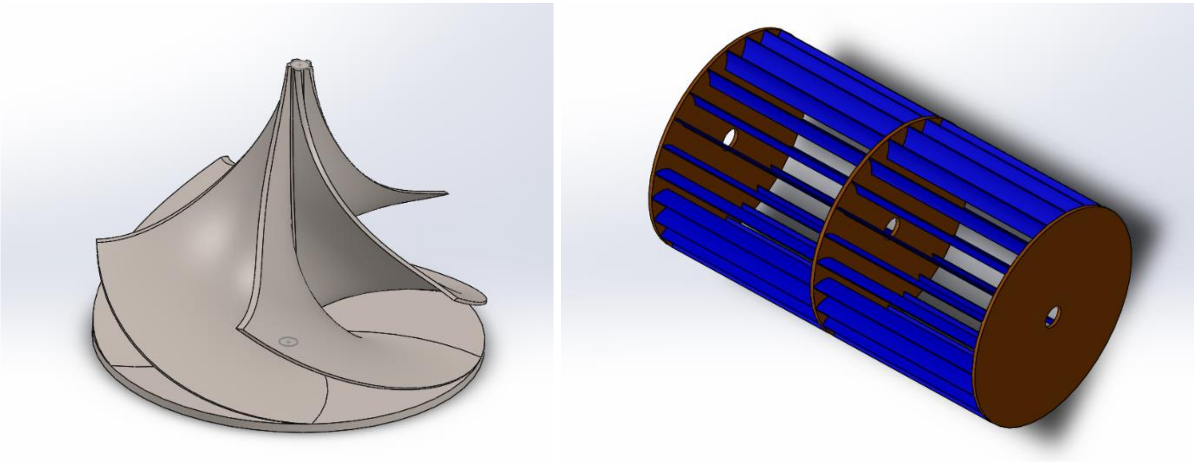

Figure 12. The vertical (left) and horizontal (right) water turbines.

The horizontal water turbine structure is a cross flow water turbine also known as Michell-Banki turbine. (Sinagra 2014)

The differences of this model from SSG are modified main body, additional two horizontal turbines and more efficient vertical turbines.

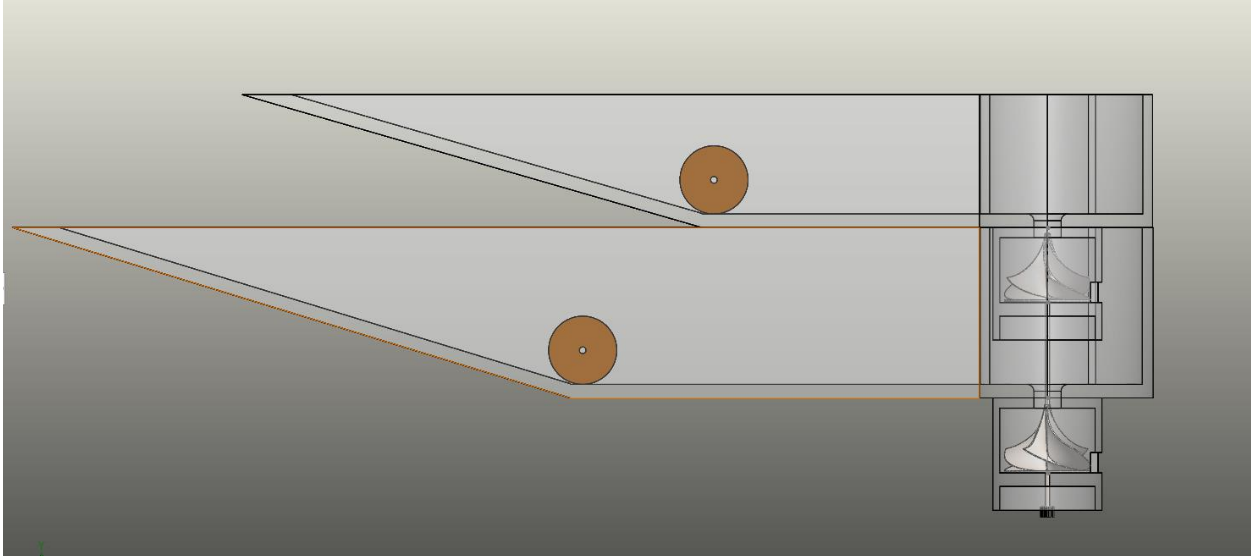

Figure 13. The sectional view of the developed model

From the Figure 13, it can be seen that the cross-flow water turbines are located at the end of the inclined inlet. The water goes through the horizontal turbines and makes circular motion when they pass the loop structured pathway. The vertical turbines located under another inlet that is placed in the middle of the circular pathway. These two vertical turbines are connected to each other and have one common generator.

Simulation

Mesh verification

At the beginning of the simulation, the mesh verification process was completed. The mesh verification is the process when the mesh size is decreasing until the point when the results of previous and last simulation will not change significantly. It completes to obtain the more accurate result during the simulation.

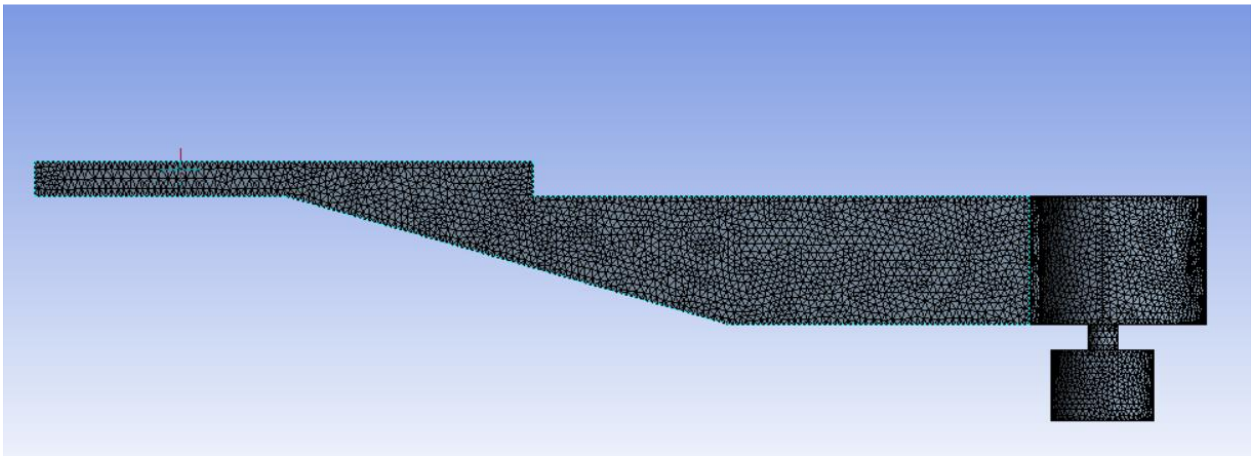

Figure 14. The mesh of the developed model

Table 1. The mesh verification data

Element size [m]	Nodes	Elements
0.1	95806	51750

0.07	186776	104556
0.05	374137	213502

The physics preference was set as “Mechanical”. The “tetrahedron” method of meshing was chosen. The span angle center set as “Medium”. Quality of mesh was equaled to 0.8.

The first mesh check was at element size of 0.1m, then it was decreased to 0.07. The difference in results were more than 5%. The mesh with element size of 0.05m was checked. The difference was about 1% comparing with 0.07m.

Boundary conditions

The velocity of the flow was installed as 1.97m/s, according to IPCC report , it is the average value for the wave speed. (IPCC 2018) Fluid was set as water-liquid. Temperature of the water is 283K. The wall is in no slip condition. The simulation was completed under different flow conditions: laminar and turbulent.

Results

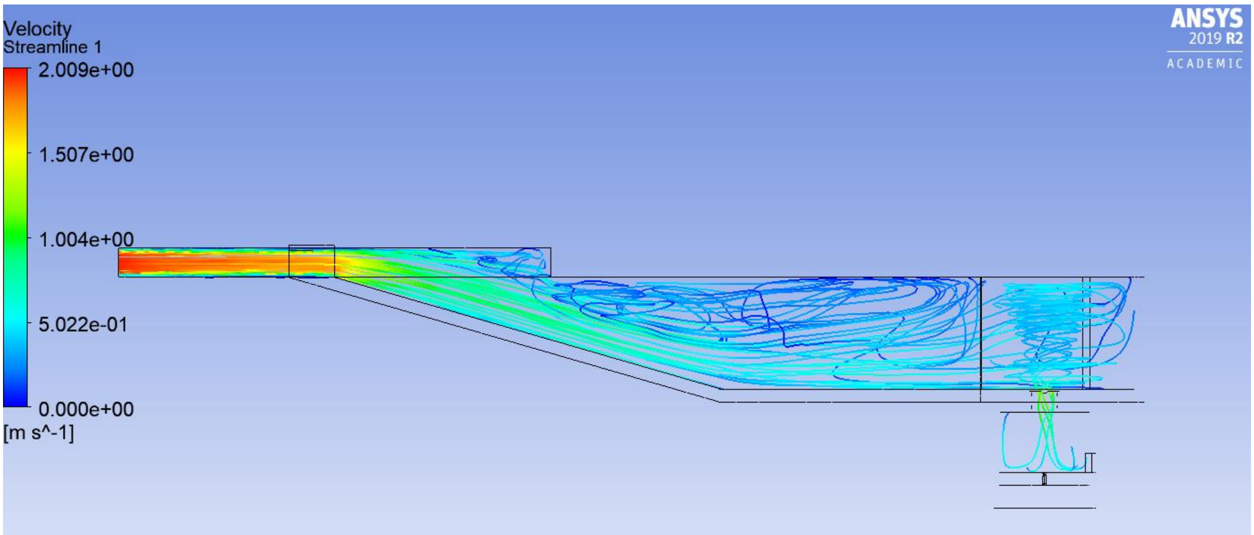

Figure 15. The velocity profile for laminar flow

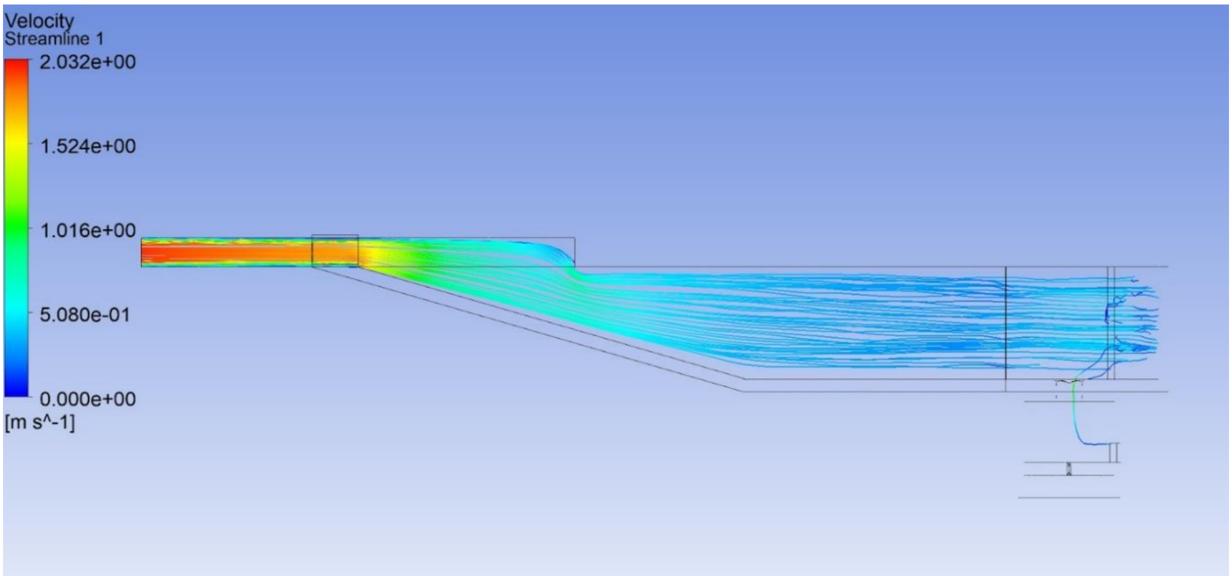

Figure 16. The velocity profile for turbulent flow (k-epsilon)

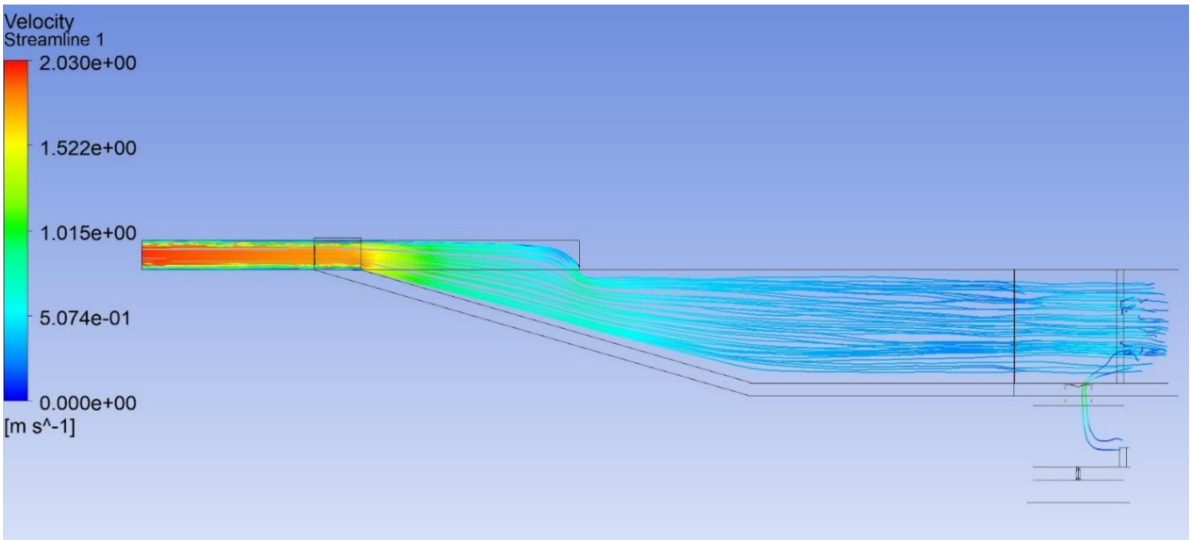

Figure 17. The velocity profile for turbulent flow (k-omega)

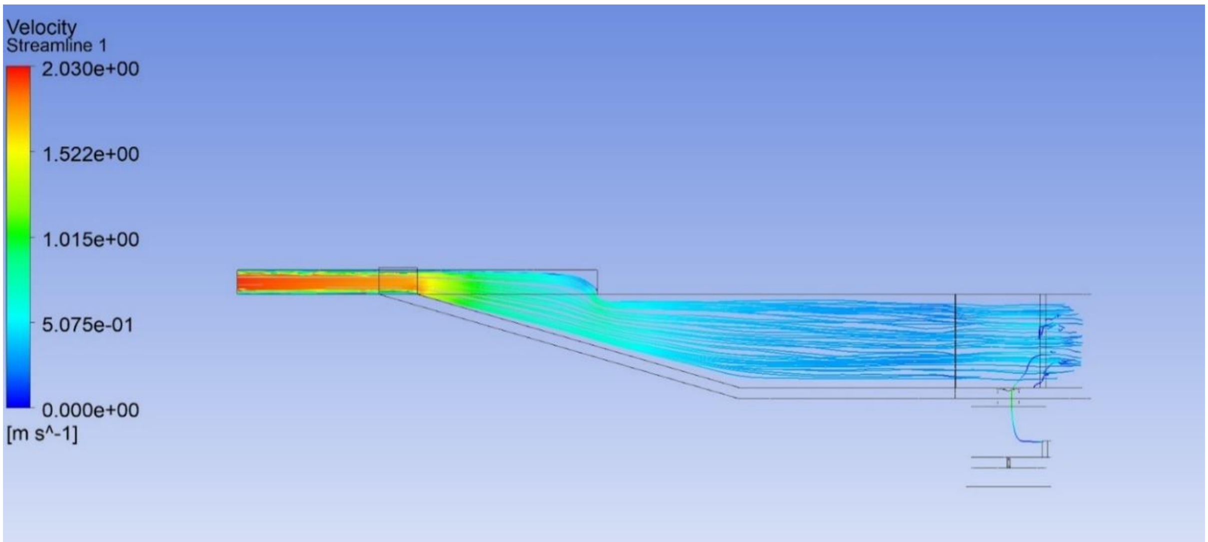

Figure 18. The velocity profile for turbulent flow (SST)

The results were obtained for laminar flow and turbulent flow calculated with three different equations (k-epsilon, k-omega, SST). According to the research of Douvi, the k-epsilon and k-omega are two-equation modes, whereas the SST is the four-equation mode. (Douvi 2012) The k-epsilon calculates well the results far from wall, whereas the k-omega does it near the wall. The SST combines the advantages of both equations. That's why for further calculations the results obtained by SST equation will be used.

As it can be seen from the Figure 15-18, the velocity of the flow at the place, where horizontal turbine is located, is decreasing. However, the circular motion adds the velocity to the flow, and at the second inlet, the velocity increases almost to its initial value.

Energy analysis

The energy calculation was completed following the formula:

$$Power\ [kVA] = Q \times \rho \times H \times g \times \eta \quad \text{(Eq. 1)}$$

Where, Q – flow rate m^3/s

ρ – density of the water

H – waterfall height

g – gravitational acceleration

η – total efficiency of the turbine

The data for calculation was given as:

Hydro resources:

Flow rate = velocity*inlet area = 2.364 m^3/s

Diameter = 40 cm

Inlet width = 175 cm

Gravitational acceleration = 9.81 m^2/s

Waterfall height = 1m; 2m;

Density = 997 kg/m^3

Losses and real electrical power (approximately)

Efficiency of turbine = 0.8

Pressure drop factor = 0.9

Other losses = 0.98

Days: 365

Power production by SSG = 320 MWh/year

Power production by developed model = 450 MWh/year

The efficiency $\eta = \frac{450-350}{450} * 100\% = 30\%$

The efficiency increases up to 30% compared to SSG model according to the simulation results.

Conclusion

To sum up, the new developed model of ocean wave energy extractor was designed and water flow in it was simulated. The developed model was compared with the SSG model made by Margheritini and his team. According to the results of simulation, the developed model with extra two horizontal turbines and redesigned main body should be able to generate 450 MWh energy per year. Although the simulation results show the efficiency increase up to 30%, the real experimental results could be different. The energy absorption simulation should be completed using the Simulink/Matlab software. The further studies on this topic and testing of real model will be completed in the future.

Reference list

Arent et al. 2009. “Renewable energy. Renewable Energy Sources and Potential Energy Supplies”

Babarit, Aurélien. 2017. Ocean Wave Energy Conversion. 1st ed. Ecole Centrale de Nantes, Nantes, France: ISTE Press - Elsevier. https://www.elsevier.com/books/ocean-wave-energy-conversion/babarit/978-1-78548-264-9

Chen, Z., & Chen, G. (2011). An overview of energy consumption of the globalized world economy. Energy Policy, 39(10), 5920-5928. doi: 10.1016/j.enpol.2011.06.046

Dina Silva, Eugen Rusu and Carlos Guedes Soares. 2013. “Evaluation of Various Technologies for Wave Energy Conversion in the Portuguese Nearshore” https://www.researchgate.net/publication/235922774_Evaluation_of_Various_Technologies_for_Wave_Energy_Conversion_in_the_Portuguese_Nearshore

Douvi C. Eleni (2012). Evaluation of the turbulence models for the simulation of the flow over a National Advisory Committee for Aeronautics (NACA) 0012 airfoil. *Journal of Mechanical Engineering Research*, 4(3).

Falnes, J. (2007). A review of wave-energy extraction. Marine Structures, 20(4), 185-201. doi: 10.1016/j.marstruc.2007.09.001

Frey, G., & Linke, D. (2002). Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. Energy Policy, 30(14), 1261-1265. doi: 10.1016/s0301-4215(02)00086-1

G. de F. Retief, F.P.J. Muller, G.K. Prestedge, L.C. Geustyn, D.H. Swart. 1984. “DETAILED DESIGN OF A WAVE ENERGY CONVERSION PLANT. https://icce-ojs-tamu.tdl.org/icce/index.php/icce/article/view/3952

James Rattray Joubert. 2013. “Design and development of a novel wave energy converter” https://www.crses.sun.ac.za/files/research/completed-research/ocean/JR_Joubert_Novel_WEC.pdf

James Tedd. 2007. “Testing, Analysis and Control of Wave Dragon,Wave Energy Converter” PhD Thesis defended in public at Aalborg University http://vbn.aau.dk/files/12994787/Wave_Energy_Converter

Kofoed. 2006. “VERTICAL DISTRIBUTION OF WAVE OVERTOPPING FOR DESIGN OF MULTI LEVEL OVERTOPPING BASED WAVE ENERGY CONVERTERS” https://www.worldscientific.com/doi/abs/10.1142/9789812709554_0395

Leszek Chybowski, Bolesław Kuźniewski. 2015. “An overview of methods for wave energy conversion”. Ph.D, Maritime University of Szczecin. https://www.researchgate.net/publication/275196605_An_overview_of_methods_for_wave_energy_conversion

Margheritini, L., D. Vicinanza, and P. Frigaard. 2009. "SSG Wave Energy Converter: Design, Reliability And Hydraulic Performance Of An Innovative Overtopping Device". Renewable Energy 34 (5): 1371-1380. doi:10.1016/j.renene.2008.09.009.

Ocean wave climate. (1981). *Applied Ocean Research*, 3(4), pp.205-206.

Panwar, N., Kaushik, S., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. Renewable And Sustainable Energy Reviews, 15(3), 1513-1524. doi: 10.1016/j.rser.2010.11.037

Pasquale Contestabile, Vincenzo Ferrante, Enrico Di Lauro, Diego Vicinanza. 2016. “Prototype Overtopping Breakwater for Wave Energy Conversion at Port of Naples” https://www.onepetro.org/conference-paper/ISOPE-I-16-418

Rusu, E., & Onea, F. (2018). A review of the technologies for wave energy extraction. Clean Energy, 2(1), 10-19. doi: 10.1093/ce/zky003

Sinagra, M., Sammartano, V., Aricò, C., Collura, A. and Tucciarelli, T. (2014). Cross-flow Turbine Design for Variable Operating Conditions. *Procedia Engineering*, 70, pp.1539-1548.

Scorza Luis. 2019. “Hydropower status report 2019” https://www.hydropower.org/status2019

Sharif, A., Raza, S., Ozturk, I., & Afshan, S. (2019). The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: A global study with the application of heterogeneous panel estimations. Renewable Energy, 133, 685-691. doi: 10.1016/j.renene.2018.10.052

WATERS, RAFAEL. 2008. "Energy From Ocean Waves. Full Scale Experimental Verification Of A Wave Energy Converter". Ph.D, Uppsala University. https://uu.diva-portal.org/smash/get/diva2:172943/FULLTEXT01.pdf

Appendices

Item type/ name	Title	Description	Responsible person
WP1	Design and simulation of the energy extraction device	Literature review (kinetic energy extraction, collision of the objects, behaviour of the waves, previous wave energy extraction concepts and their results, opportunity of this concept); Design of systems in Solidworks and analysize in ANSYS FLUID; Simulation of the fluid flow; Results, benchmarking and discussion;	Akylbek Satybaldy
WP2	Literature review of sea wave energy extraction and comparision of different energy converting devices.	• Brief information about ocean wave • Principle of converting water energy into mechanical energy • Different types of mechanism for converting energy • Advantages and disadvantages of using water for energy extraction	Yerkin Yernazarov