INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS

Received: 01.04.2021

Accepted: 20.05.2021

Published: 09.07.2021

Citation: Khankal DV, Edlabadkar RL, Minase JL, Pandhare AP (2021) Design and Analysis of Buoy Geometries for Wave Energy Generator. Indian Journal of Science and Technology 14(23): 1961-1969. https://doi.org/10.17485/IJST/v14i23.543

* **Corresponding author**.

amarppandhare@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Design and Analysis of Buoy Geometries for Wave Energy Generator

Dhananjay V Khankal[1], R L Edlabadkar[1], J L Minase[1], A P Pandhare[1]*

1 Sinhgad College of Engineering, India

Abstract

Objectives/Methods: The main objective here is to make an optimum design of buoy. Wave power generation is one of the extensive research fields all over the world. The ocean waves are usually converted into electrical energy by a device called a wave energy converter (WEC). The electricity generated depends upon the intensity of the waves. In a traditional way, the motion of a buoy that occurred in a vertical direction due to waves in water, can be converted into current generation. Here, the numerical simulation using the Ansys tool is done to find an optimum design of buoy shape to get maximum energy conversion. Findings: The simulations have shown that the drag force for the Oval shape is minimum 0.063 N and the first mode of frequency for the Conical shape is minimum 165 Hz for Point-Absorber type Wave Energy Converter.

Keywords: Buoy; wave energy converter; buoy shapes

1 Introduction

The energy demand grew considerably and is even further increasing. Owing to depletion of fossil fuels and also the emissions caused by the fuels are the major hurdles for its use Thus, the demand for renewable energy sources is increasing. The renewable energy source is clean and available abundantly free of cost in nature. The various available renewable energy sources are wind energy, geothermal energy, solar photovoltaic and wave energy. The selection of renewable energy source varies from region to region(1) depending upon their availability. Ocean energy is consistently available energy with the highest energy density(2–4) throughout the year(5). Wave energy has many advantages available for 24 hours. A number of wave energy devices are available and research is being done for its commercialization(6). The wave energy can be converted into electrical energy by various methods as shown in Figure 1 below(7–20).

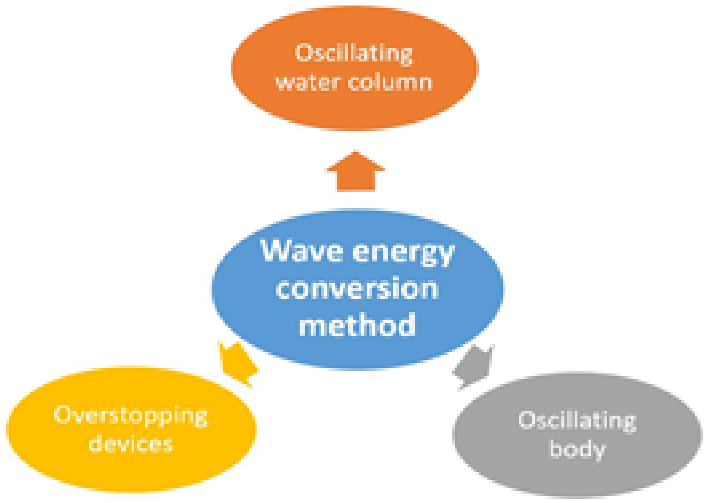


Fig 1. Wave energy conversion method

The point absorber is mostly used to harness wave energy. The multiple numbers of WEC[21] can be arranged in rows and columns to generate good amount of electrical energy. The WEC's are mainly classified as shown in following Figure 2[6,22].

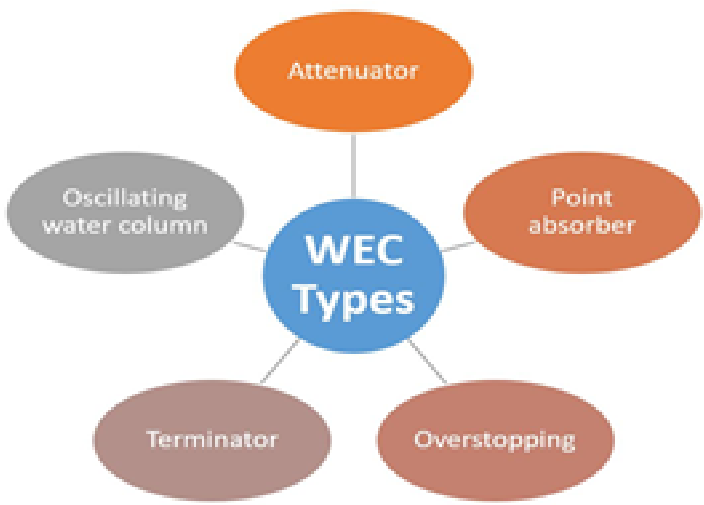


Fig 2. Types of Wind Energy Converter (WEC)

In the point absorber system in resonance with incident waves, the amplitude and speed increase and thus transfers the higher amount of energy[23,24]. Thus, wave energy must be considered a promising source of energy supply. There is a need to find out the suitable devices that are technically feasible and commercially available. The WEC devices that are available require a great deal of investigation in different areas like structural analysis[25], fatigue analysis. This analysis can be done using the Ansys tool which mainly depends upon the wind system[26–28].

The numerical analysis results obtained from the analysis will help to optimize[29–32] the components, enhance the mechanical performance of the components and increase the efficiency of energy conversion. The performance of the buoy is also an important issue in the design of an oscillating buoy wave energy converter. The power output obtained from the buoy is the work with which the buoy has done to overcome the force produced by the system. The amount of work transferred by the buoy to the system is very important. The motion of the buoy depends mainly upon the waves induced.

Thus, this paper focuses on the design and analysis of buoy, from the structural point of view for various buoy geometries so that the efficiency of device also increases.

2 Forces Acting on Buoy

This is the case for the "buoy-type" or "point absorber" [33–36] type of wave energy converter. The buoy will bob up and down on striking with the incoming waves. Whenever a crest of a wave hits the buoy, the buoy will travel up and when a trough comes, it will travel down. This linear movement of buoy is converted into electrical energy.

The various approaches to calculate the forces acting on wave given by Muetze [34,37–39], used are as shown in Figure 3.

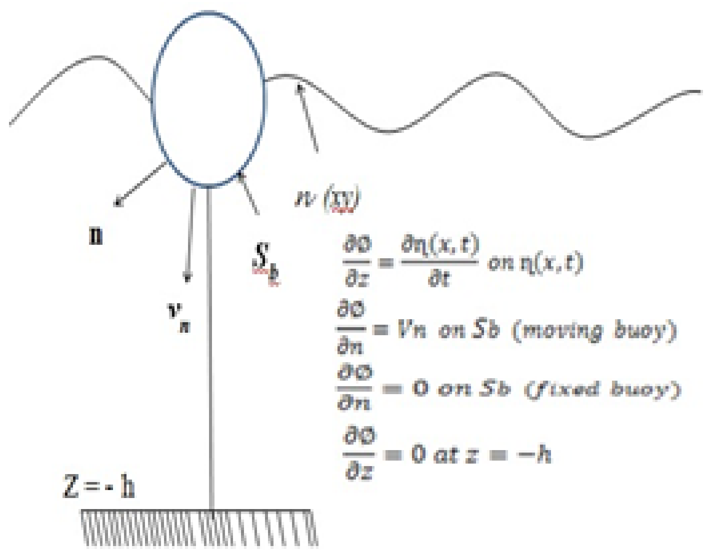


Fig 3. Forces acting on Buoy

A. Selection of Buoy

The buoy is available in various shapes. Based on the previous research by different researchers, we have selected sphere, oval and cone shape of buoy for analysis.

Virtual Analysis on Ansys Workbench Version 16.0 (Fluent)- Inputs Parameters -

1. Material= Polyethylene.
2. Mechanism used = Scotch Yoke.
3. Fluid used = Water.
4. Viscosity of Water = 0.0091 poise.
5. Pressure Difference B/w two waves ends crossing buoy= NA.
6. Input Velocity of fluid = 1.5 m/s.
7. Dimensions of Tank (enclosure); L=2.5m; W= 0.5m; H= 0.45m.
8. Head of water = 30 cm.
9. Self-Weight of Buoy = NA.
10. Motor Details = 1 hp single phase DC motor.
11. RPM = 1440 rpm.
12. Iteration Commanded =200

1. Oval Shape: Figure 4 shows the geometry of the oval shape used for analysis.

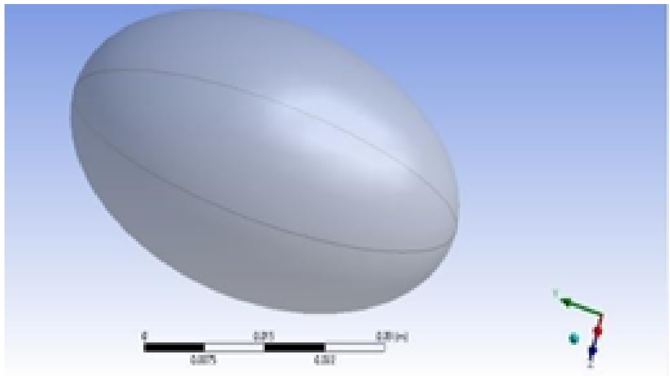


Fig 4. Geometry for OvalBuoy

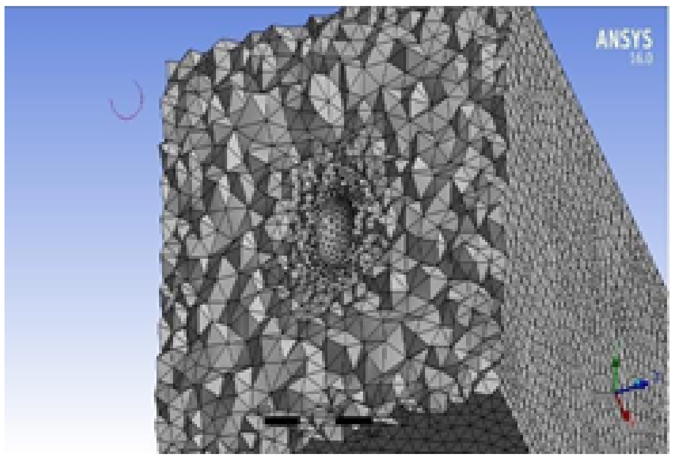


Fig 5. Meshing for Oval shape Buoy

The best element for meshing is the tetrahedral element as shown in Figure 5.
Meshing parameters- Aspect ratio = 1.84, Jacobian 0.8, Element quality 0.88.

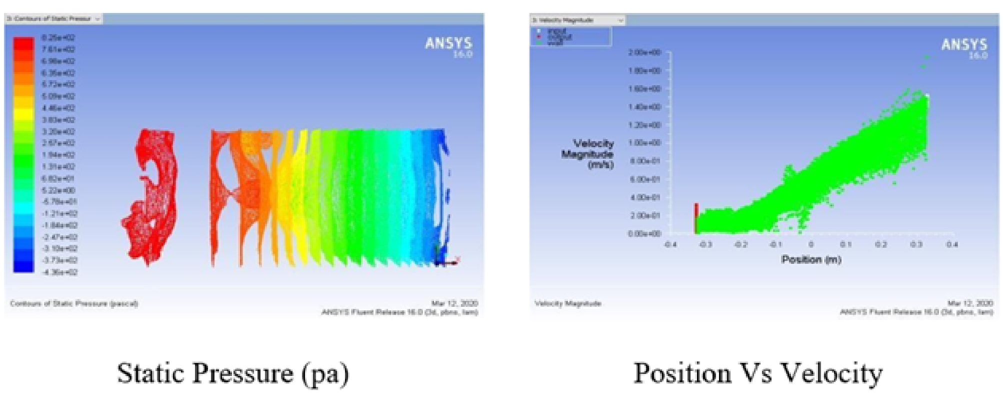


Fig 6. Static Pressure and Velocity for Oval shape

Figure 6 shows static pressure according to position and the velocity at different positions in the container as static pressure graph indicates at starting it has higher static pressure as we go forward in the tank pressure get reduced, exactly opposite to this as to go forward in the tank the velocity of the particle gets increased.

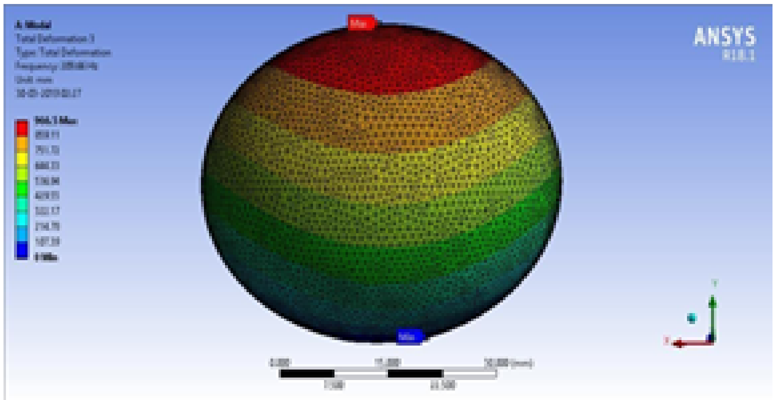


Fig 7. Displacement Contour of oval shape

Figure 7 shows the modular analysis of an oval buoy. It shows the displacement at various point of the buoy when the first mode frequency wave is used for simulation.

First Mode: 209.66 Hz

Second Mode: 266.61 Hz

2. Spherical Shape:

Fig 8. Geometry of Spherical buoy

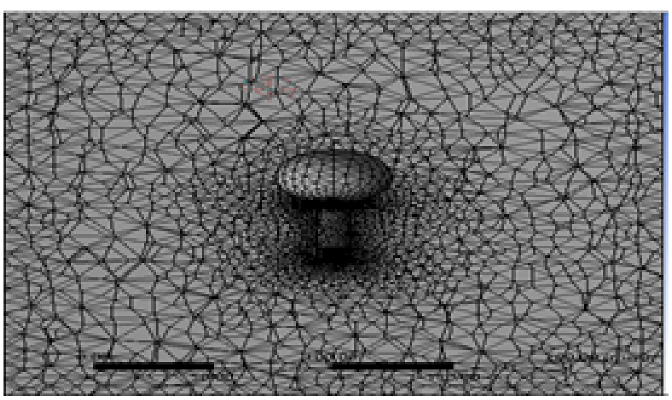
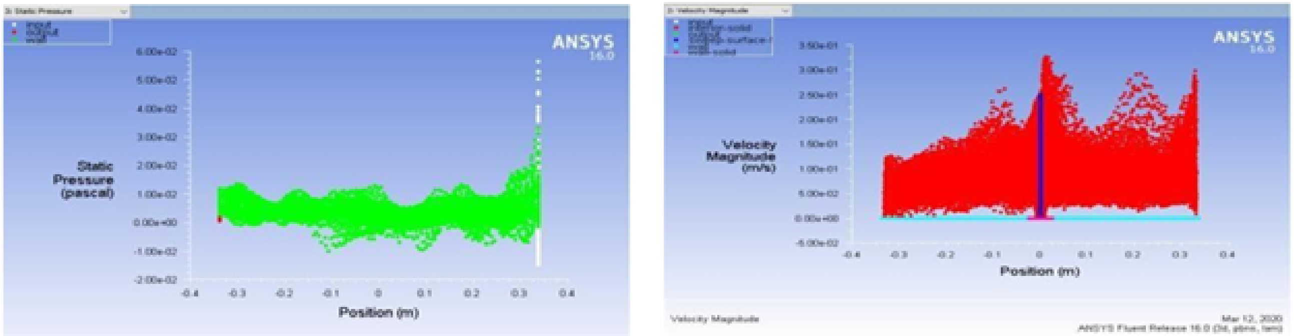


Fig 9. Meshing of Spherical Buoy

Figures 8 and 9 shows the geometry and meshing of Spherical Buoy.



Static Pressure (pa) Velocity

Fig 10. Static Pressure and Velocity for spherical shape

Figure 10 shows static pressure according to position and the velocity at different positions in the container as static pressure graph indicates at starting it has higher static pressure as we go forward in the tank pressure get reduced, exactly opposite to this as we go forward in the tank the velocity of the particle gets increased.

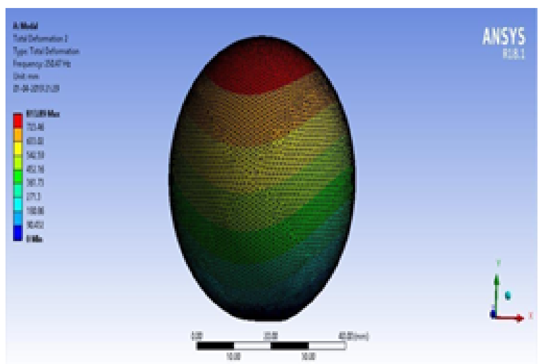


Fig 11. Displacement Contour

Figure 11 shows the modular analysis of a spherical buy. It shows the displacement at various point of the buoy when the first mode frequency wave is used for simulation.

First Mode:249.68 Hz

Second Mode: 250.47 Hz

3. Conical Shape:

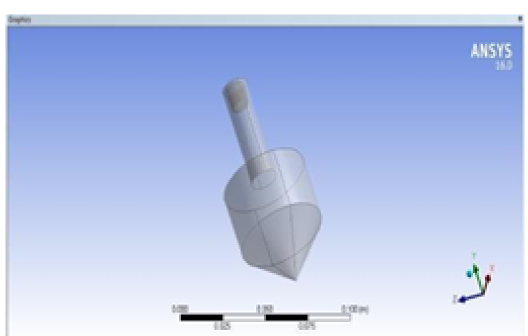


Fig 12. Geometry of Conical Buoy

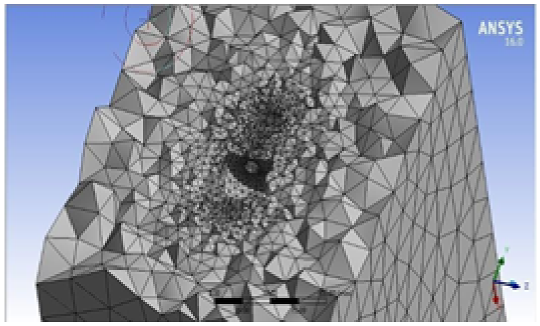


Fig 13. Meshing of Conical Buoy

Figures 12 and 13 shows the geometry and meshing of Conical Buoy

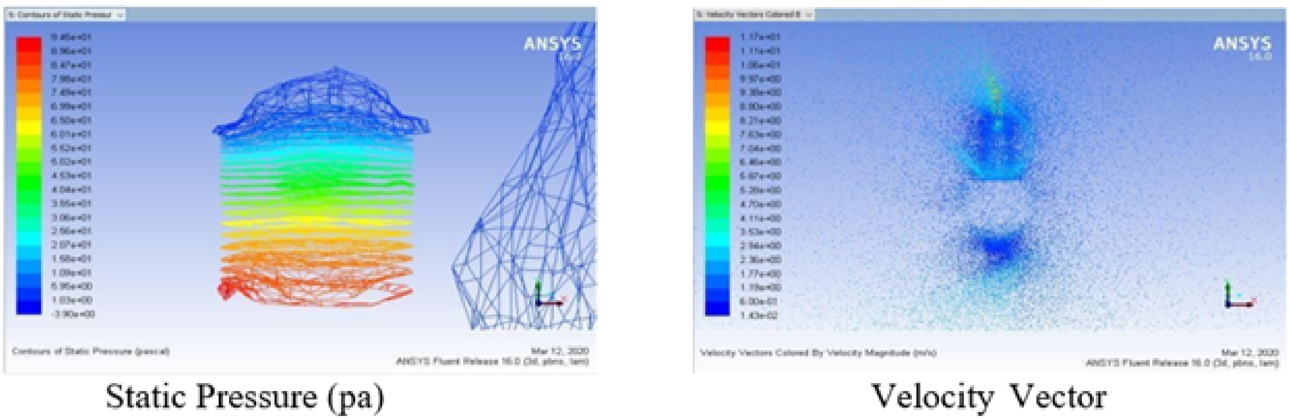


Fig 14. Static pressure and Velocity Vector of conical buoy

Figure 14 shows static pressure according to position and the velocity at different positions in the container. As the static pressure graph indicates at starting it has higher static pressure as we go forward in the tank pressure get reduced, exactly opposite to this as we go forward in the tank the velocity of the particle gets increased.

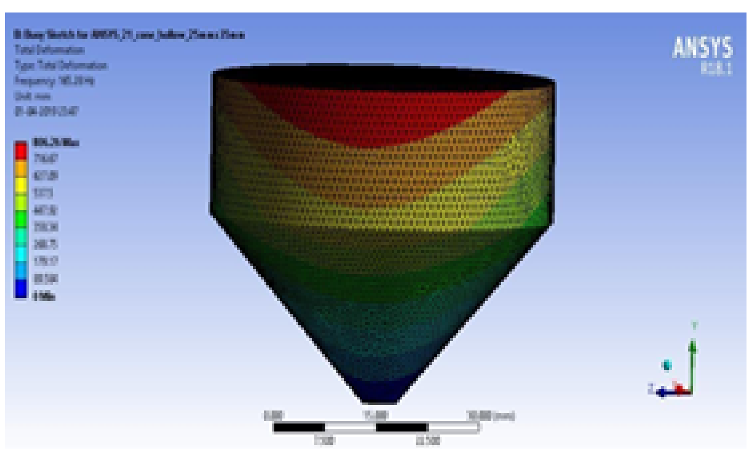


Fig 15. Displacement Contour

Figure 15 shows the modular analysis of a conical buoy. It shows the displacement at various point of the buoy when the first mode frequency wave is used for simulation.

First Mode: 165.28 Hz

Second Mode: 165.58 Hz

3 Conclusions

The commercial code in Finite element analysis is used to perform structural calculations to understand the behaviour of three different buoy geometries when subjected to wave forces. Based on the CFD readings given above, the drag force for the shapes in increasing order can be seen as follows:

Oval Buoy → Conical Buoy → Spherical Buoy

The drag force for the Oval shape is minimum 0.063 N for Point-Absorber type Wave Energy Converter.

The first two modes of frequencies for all the shapes can be arranged in the increasing order as follows:

Conical Buoy → Oval Buoy → Spherical Buoy

The first mode of frequency for the Conical shape is minimum 165 Hz for Point- Absorber type Wave Energy Converter.

Base on the above two analysis we can say that the oval shape or conical shape buoy are the best to get the optimum energy conversion. In future work, the performance will be verified in deep sea water with more depth.

References

1) Leijon M, Danielsson O, Eriksson M, Thorburn K, Bernhoff H, Isberg J, et al. An electrical approach to wave energy conversion. *Renewable Energy*. 2006;31(9):1309–1319. Available from: https://dx.doi.org/10.1016/j.renene.2005.07.009.
2) Pelc R, Fujita RM. Renewable energy from the ocean. *Marine Policy*. 2002;26:471–479. Available from: https://dx.doi.org/10.1016/s0308-597x(02)00045-3.
3) Thorpe TW. A brief review of wave energy, Technical report no. R120, Energy Technology Support Unit (ETSU). 1999.
4) ment AC, Mccullen P, nio Falcão A. Wave energy in Europe: current status and perspectives. *Renewable and Sustainable Energy Reviews*. 2002;6(5):405–431.
5) Drew B, Plummer AR, Sahinkaya MN. A review of wave energy converter technology. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*. 2009;223(8):887–902. Available from: https://dx.doi.org/10.1243/09576509jpe782.
6) Mekhiche M, Edwards K, Bretl J. System-level approach to the design development testing and validation of wave energy converters at ocean power technologies. In: ASME 2014 33rd International Conference on Ocean Offshore and Arctic Engineering. 2014.
7) Drew B, Plummer AR, Sahinkaya MN. A review of wave energy converter technology. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*. 2009;223(8):887–902. Available from: https://dx.doi.org/10.1243/09576509jpe782.
8) Falnes J. A review of wave-energy extraction. *Marine Structures*. 2007;20:185–201. Available from: https://dx.doi.org/10.1016/j.marstruc.2007.09.001.
9) Falca F, De O. Wave energy utilization: A review of the technologies. *Renewable and Sustainable Energy Reviews*. 2009;14(3):899–918. Available from: 10.1016/j.rser.2009.11.003.
10) Brekker T, Joanne A, Han H. Ocean wave energy overview and research at Oregon State University, Power Electron. Mach. In: Wind Application;vol. 6. 2009;p. 24–24.
11) Martins-rivas H, Mei CC. Wave power extraction from an oscillating water column along a straight coast. *Ocean Engineering*. 2009;36(6-7):426–433. Available from: https://dx.doi.org/10.1016/j.oceaneng.2009.01.009.
12) Malmo O, Reitan A. Wave-power absorption by an oscillating water column in a channel. *Journal of Fluid Mechanics*. 1985;158:153–175. Available from: https://dx.doi.org/10.1017/s0022112085002592.
13) Pizer DJ. Maximum wave-power absorption of point absorbers under motion constraints. *Applied Ocean Research*. 1993;15(4):227–234. Available from: https://dx.doi.org/10.1016/0141-1187(93)90011-l.
14) Vantorre M, Banasiak R, Verhoeven R. Modelling of hydraulic performance and wave energy extraction by a point absorber in heave. *Applied Ocean Research*. 2004;26(1-2):61–72. Available from: https://dx.doi.org/10.1016/j.apor.2004.08.002.
15) Margheritinia L, Vicinanzab D, Frigaarda P. SSG wave energy converter: Design, reliability and hydraulic performance of an innovative overtopping device. *Renewable Energy*. 2009;34:1371–1380. Available from: 10.1016/j.renene.2008.09.009.
16) Amarkarthik A, Chandrasekaran S, Sivakumar K, Sinhmar H. Laboratory experiment on using non-floating body to generate electrical energy from water waves. *Frontiers in Energy*. 2012;6:361–365. Available from: https://dx.doi.org/10.1007/s11708-012-0210-1.
17) Chandrasekaran S, Harender. Power Generation Using Mechanical Wave Energy Converter. *The International Journal of Ocean and Climate Systems*. 2012;3(1):57–70. Available from: https://dx.doi.org/10.1260/1759-3131.3.1.57.
18) Stephen TN. Deep Ocean Wave Energy Converter. 2011.
19) Harender. Power Generation using Mechanical Wave Energy Converter. India. 2012. Available from: https://doi.org/10.1260/1759-3131.3.1.57.
20) Chandrasekaran S, Heo M. Mechanical wave energy converter, Report to Human Resource Development in Offshore and Plant Engg, HOPE. 2010.
21) Falcão A. Wave energy utilization: a review of the technologies. *Renew Sust Energ Rev*. 2010;14:899–918. Available from: 10.1016/j.rser.2009.11.003.
22) Soares CG, Bhattacharjee J, Karmakar D. Overview and prospects for development of wave and offshore wind energy. 2014.
23) Budar K, Falnes J. A resonant point absorber of ocean-wave power. *Nature*. 1975;256(5517):478–479. Available from: https://dx.doi.org/10.1038/256478a0.
24) Falnes J. Ocean waves and oscillating systems: linear interactions including wave-energy extraction. Cambridge. Cambridge University Press. 2002. Available from: 10.1017/9781108674812.
25) Sun P, Hu S, He H, Zheng S, Chen H, Yang S, et al. Structural optimization on the oscillating-array-buoys for energy-capturing enhancement of a novel floating wave energy converter system. *Energy Conversion and Management*. 2021;228. Available from: 10.1016/j.enconman.2020.113693.
26) Jshoele K, Prowell I, Zhu Q. Dynamic and structural modelling of a floating wind turbine. *Int J Offshore Polar*. 2011;21:155–160.

27) Robertson A, Jonkman J. Loads analysis of several offshore floating wind turbine concepts. In: Proceedings of the 21th International Offshore and Polar Engineering Conference (ISOPE). 2011.
28) Aubault A, Cermelli C, Roddier D. WindFloat: a floating foundation for offshore wind turbines-Part III: Structural analysis. In: Proceedings of the 28th International Conference on Ocean, Offshore and Arctic Engineering. 2009.
29) Thorburn K, Karlsson KE, Wolfbrandt A, Eriksson M, Leijon M. Time stepping finite element analysis of a variable speed synchronous generator with rectifier. *Applied Energy*. 2006;83(4):371–386. Available from: https://dx.doi.org/10.1016/j.apenergy.2004.10.016.
30) Yueh CY, Chuang SH. A boundary element model for a partially piston-type porous wave energy converter in gravity waves. *Engineering Analysis with Boundary Elements*. 2012;36(5):658–664. Available from: https://dx.doi.org/10.1016/j.enganabound.2011.11.011.
31) Nader JR, Zhu SP, Cooper P, Stappenbelt B. A finite-element study of the efficiency of arrays of oscillating water column wave energy converters. *Ocean Engineering*. 2012;43:72–81. Available from: https://dx.doi.org/10.1016/j.oceaneng.2012.01.022.
32) Wang S, Soares CG. Numerical study on the water impact of 3D bodies by an explicit finite element method. *Ocean Engineering*. 2014;78:73–88. Available from: https://dx.doi.org/10.1016/j.oceaneng.2013.12.008.
33) Barbarelli S, Amelio M, Castiglione T, Florio G, Scornaienchi NM. Design and analysis of a new wave energy converter based on a point absorber and a hydraulic system harvesting energy from waves near the shore in calm seas. *International Journal of Energy Research*. 2021;45(1):661–690. Available from: https://dx.doi.org/10.1002/er.5799.
34) Ribeiro AS, deCastro M, Rusu L, Bernardino M, Dias JM, Gomez-Gesteira M. Evaluating the Future Efficiency of Wave Energy Converters along the NW Coast of the Iberian Peninsula. *Energies*. 2020;13. Available from: https://dx.doi.org/10.3390/en13143563.
35) Qiao D, Haider R, Yan J, Ning D, Li B. Review of Wave Energy Converter and Design of Mooring System. *Sustainability*. 2020;12. Available from: https://dx.doi.org/10.3390/su12198251.
36) Rodrigues C, Nunes D, Clemente D, Mathias N, Correia JM, Rosa-Santos P, et al. Emerging triboelectric nanogenerators for ocean wave energy harvesting: state of the art and future perspectives. *Energy & Environmental Science*. 2020;13(9):2657–2683. Available from: https://dx.doi.org/10.1039/d0ee01258k.
37) Muetze A, Vining JG. Ocean Wave Energy Conversion-A_Survey. 2006.
38) Shrinivasan C, Harender. Power Generation Using Mechanical Wave Energy Converter. *Journal of Ocean and Climate: Science, Technology and Impacts*. 2012. Available from: https://doi.org/10.1260/1759-3131.3.1.57.
39) Santhosh N, Baskaran V, Amarkarthik A. A review on front end conversion in ocean wave energy converters. *Frontiers in Energy*. 2015;9(3):297–310. Available from: https://dx.doi.org/10.1007/s11708-015-0370-x.