Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 1s (2025)

Construction Of Ocean Wave Generator Test Rig for Wave Energy Harvesting

Mr. Ganesh Korwar[1], Prof Nitin Satpute[2], Shreya Raut[3], Omkar Rasal[3], Rhutu Kulkarni[3], Rudrabhishek Choudhury[4], Atharva Salunkhe.[4]

[1]Research scholar; Faculty of Mechanical Engineering, Vishwakarma University, Pune.
[2]Professor, Faculty of Mechanical Engineering, Vishwakarma University, Pune.
[3]Student, Department of Mechanical Engineering, Vishwakarma Institute of Technology, Pune

Article History:

Received: *25-08-2024*

Revised: *11-10-2024*

Accepted: *31-10-2024*

Abstract:

This study focuses on developing and enhancing a Wave Generator Mechanism utilizing the Scotch yoke mechanism for simulating waves. The research investigates the incorporation of a carefully designed artificial slope into the Scotch yoke system, shedding light on its practical use and effectiveness in mimicking wave patterns. The paper outlines the detailed methodology and production process, analysing the essential components, materials, and factors necessary for precise wave simulation. Through experimentation, it is demonstrated that waves can be successfully generated in a controlled setting, enabling energy dissipation without any wave reflection. The study highlights the efficiency of the integrated mechanism in replicating natural fluid dynamics, offering a cost-efficient, dependable, and adaptable solution for wave simulation systems in scientific and industrial fields. The research concludes by discussing potential future advancements and providing key references for further investigation.

Keywords: Wave Generator Mechanism, Scotch yoke mechanism, wave reflection.

I. INTRODUCTION

The increasing global demand for renewable energy sources has intensified the focus on harnessing ocean wave energy. However, the complex and dynamic nature of ocean waves poses significant challenges in designing and manufacturing wave energy converters (WECs). This paper introduces a novel ocean wave generator test rig designed to address these challenges by providing a controlled and repeatable environment for WEC testing and performance evaluation based on unpredictable ocean currents. A key feature of this test rig is the incorporation of the Scotch yoke mechanism, which is widely recognized for its straightforward design and dependability—attributes that render it a favored option in industrial environments.

The Scotch yoke's robust and direct configuration allows for the accurate conversion of rotational input into linear motion, ensuring consistent and controlled movement within intricate systems. Its efficiency and resilience enable it to endure demanding operational conditions, making it suitable for a diverse range of applications. In the context of wave generation, the Scotch yoke's reliable and smooth motion is fundamental for the precise replication of wave patterns. This mechanism's ability to maintain consistent motion control is crucial for simulating various wave heights and frequencies, which is vital for mimicking the dynamic behavior of natural water bodies.Moreover, the test rig features an artificial slope designed with great attention to detail. Its gently inclined structure reflects the gradual rise of a natural shoreline, effectively dissipating the kinetic energy of the waves. This thoughtfully designed feature prevents the undesirable occurrence of standing waves by redirecting the momentum of the waves, thus creating an environment where wave interactions closely resemble those found in nature. The design of the Scotch yoke also offers benefits such as minimized friction, low maintenance needs, and a relatively simple construction, making it a cost-effective and reliable option for industrial uses. Its versatility and durability in various operational settings establish it as an essential component in systems where precise and controlled linear motion is crucial.

Collectively, the Scotch yoke mechanism and the supplementary artificial slope not only represent advanced engineering solutions but also embody a harmonious integration of functionality. These innovations significantly enhance the realism and reliability of simulations within the ocean wave generator test rig, contributing to the development and optimization of wave energy converters.

Regular wave simulation rigs usually use some sort of wedge-shaped design to produce the sinusoidal waves and the optimal angle as well as depth required to produce accurate sinusoidal waves is just being researched recently [1,2]. While these waves may not be accurate to real-world conditions such as during storms, they help us get data and measure the waves themselves in such a way that it makes adapting the designs and outputs to the real world through calculations possible {3]. The waves in and of themselves can be produced sinusoidal but due to realistic considerations such as possible tank length as well as the principle for conservation of energy it leads to the problem of standing waves being produced as those that reach the end reflect backward [10]. Another factor that has to be considered during the construction of this simulation setup is what types of setups will be tested using it and its future applications.A major interest in energy production recently is trying to harness the potential untapped energy that makes up 75% of the earth's surface. Due to this, there has been a resurgence in innovative ways of extracting this often-overlooked form of energy. Many research papers as well as actual products have surfaced recently that try to rethink the conventional hydro powerplant system into something that can be used on still water, yet which has waves present [8,11,13,15]. While some have designed systems to be used in oceans [4,6,12,14] others have focused on a more shore-based approach [5,9,10].

Taking the above experiments into account and expecting similar tests to be performed on the simulation rid in the future, it was deduced that a rig that could simulate conditions found offshore and near the beaches would help in testing a wider variety of setups.

2. Experimental Setup

Experimentation is performed to generate The various wave height d by the prototype. The test is conducted in a container (size: 1200 mm x 500 m x 500 mm) along with the wave generator. The arrangement for wave generation comprises a DC motor (400 W, 20-600 rpm), driving a scotch yoke mechanism. The electric motor drives the eccentric pin of the scotch yoke mechanism, which further ensures harmonic displacement of the follower with an amplitude of 60 mm. The follower is connected to the baffle plate, which finally generates the required waves in the tank. The wave height is influenced by the frequency of the motor and experimentation was carried out with the wave height of 50, 60, and 70 mm.

.The tank needed to be waterproof and robust enough to withstand the water pressure exerted on its walls. Additionally, the tank needed to have a length-to-width ratio greater than 1. For this setup, a ratio of 3.5:1 was chosen, considering factors such as space availability and industry standards for similar applications. Transparency was another critical requirement for the tank, allowing for the visual analysis of wave patterns and comparisons with computer simulations. The final tank dimensions were 1834mm x 485mm x 610mm, constructed from 18mm thick glass. This configuration provided a length-to-width ratio of approximately 3.78:1.
To minimize wave rebound and reduce the likelihood of standing waves, an artificial beach slope was incorporated. This feature is essential for simulating a realistic beach environment. The slope was designed to be waterproof and durable enough to withstand repeated wave impacts. According to a research paper titled "Optimum Coastal Slopes Exposed to Waves: Experimental and Numerical Study," the ideal slope ratio for minimizing wave rebound is 1:5, or approximately 12 to 14 degrees. For this setup, a length of 1826mm and a height of 344mm were selected, resulting in a slope angle of 13.5 degrees. The slope was constructed from galvanized steel.

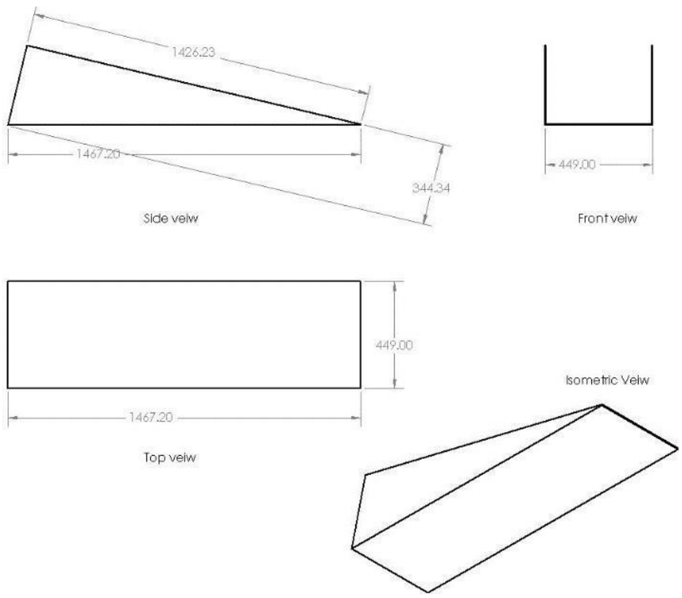

Fig 1The wedge dimensions

The wedge, made from 0.5mm thick galvanized steel, required significant force to move due to its sturdiness. This component was essential for generating uniform waves, necessitating the use of a high-power motor. To oscillate the wedge, a 180V DC motor was employed, accompanied by a DC-regulated power supply to control the current rate and maintain motor speed. The motor's maximum capacity is 5 amps. The selection of this motor was based on its availability and capacity to meet the requirements of the setup. The Scotch yoke mechanism was chosen for its straightforward design and dependability. It allows for the accurate conversion of rotational input into linear motion, ensuring consistent and controlled movement within intricate systems. This mechanism's efficiency and resilience enable it to endure demanding operational conditions, making it suitable for a diverse range of applications, particularly in wave generation.

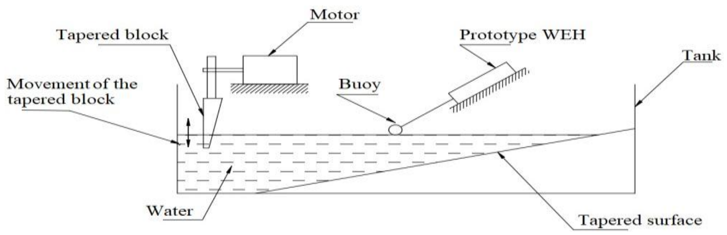

Fig. 2. Schematic arrangement for energy harvesting in a tank.

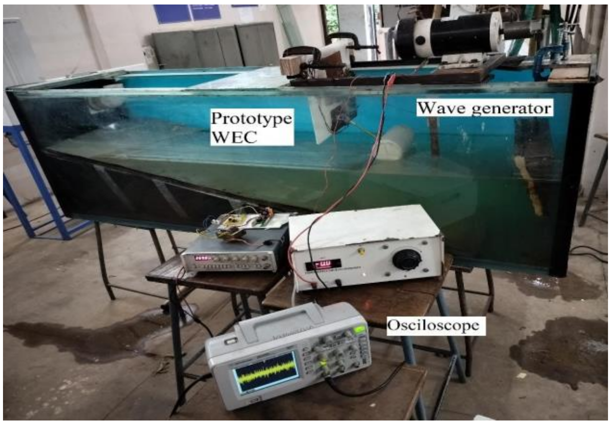

Fig. 3. Experimental arrangement for energy harvesting in a tank.

4. RESULTS

The wave characteristics significantly influence the average power generated by the Wave Energy Converter (WEC). In cases of higher wave height, the time required for the completion of the energy storage mode (winding the spiral spring in the Energy Storage Element (ESE) through 90°) is reduced. The average power generated by the WEC is defined as the electric energy generated by the electric generator in one cycle divided by the time required to complete one cycle.

Experimental and simulation results for the average wave height, shown in Figure 5 reveal that the average power increases with the wave height. The wave vertical force for an 80 mm wave height is illustrated in Figure 6. This force lifts the buoy, transferring the wave energy to the ESE.

As shown in Figure 2, the buoy gets lifted, and the wave energy is converted into ESE strain energy when the wave vertical velocity reaches the threshold limit of 0.07 m/s. When the wave velocity reaches this threshold limit, the force becomes sufficient to overcome the torque in the ESE due to the initial deflection of the helical spring. The minimum value of the wave vertical force required for energy to be stored in the ESE depends on the helical spring stiffness and initial deflection, calculated as πKt/2l for the prototype.

It can be noted that the proposed WEC will utilize wave energy when the wave vertical velocity exceeds the threshold value of 0.07 m/s. This feature makes the WEC design suitable for both periodic and non-periodic random wave forces, efficiently harvesting wave energy when the wave vertical velocity is higher than the threshold.

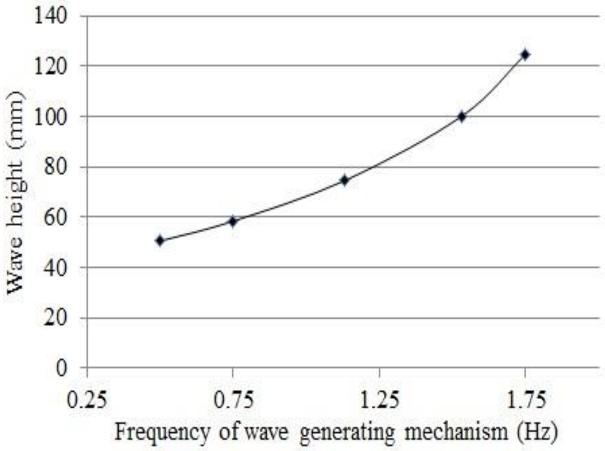

Fig. 3. Variation in the wave height.

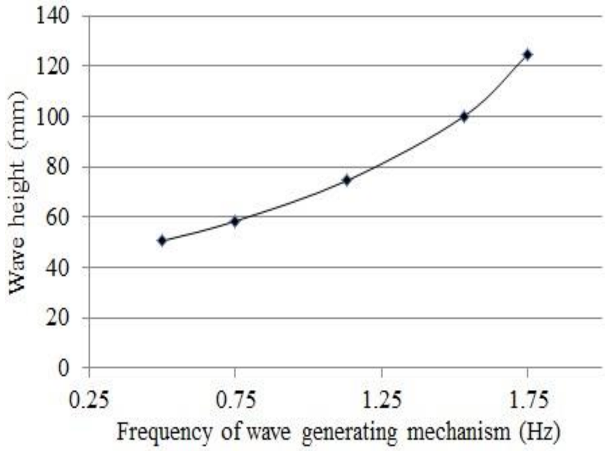

Fig. 4. Variation in the wave time period.

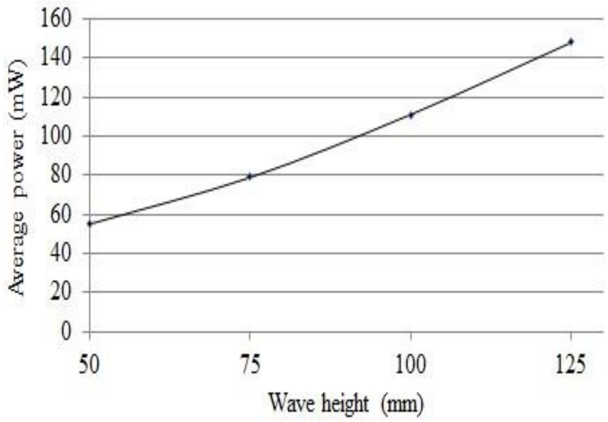

Fig. 5. Variation of average power with wave height for prototype WEC.

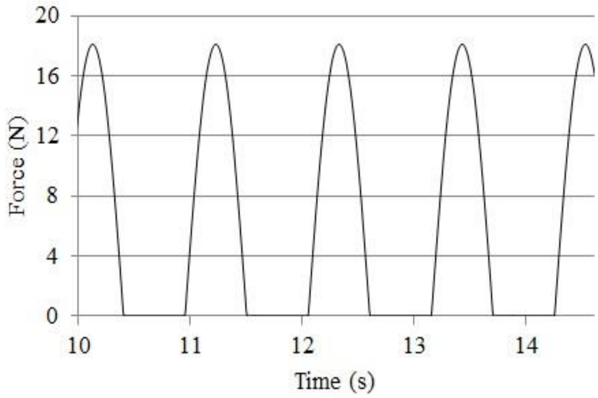

Fig. 6. Wave vertical force for 80 mm wave height.

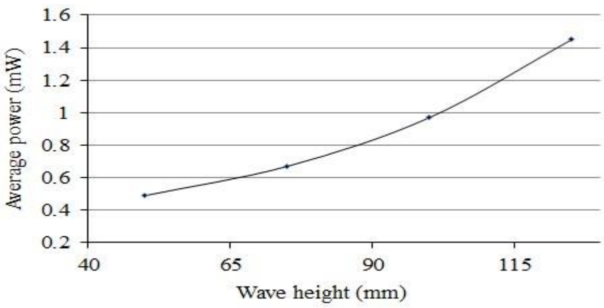

Fig.7. Voltage generated by conventional WEC for 50 mm wave height.

5. CONCLUSION

In our previous design, we constructed a wave generator within a 0.3 m^3 tank. This generator utilizes a DC motor and a tapered wedge to produce waves. The DC motor drives the tapered wedge vertically through a scratch yoke mechanism, generating simple harmonic waves within the tank. To prevent wave reflections, the tank incorporates a tapered bottom with a 13-degree angle.

Our experiments demonstrate that this mechanism effectively generates waves without reflections, maintaining a simple harmonic motion pattern. We employed a prototype energy harvester to test the system's power output, achieving a peak power of 150 mW with wave heights ranging from 50 to 125 mm.

By varying the frequency of the tapered wedge's vertical movement, we discovered the ability to generate waves within a wider range, from 40 to 140 mm. The energy harvester successfully converted these waves into electricity, demonstrating its potential for power generation.

REFERENCES

[1] The wave forces acting on a floating hemisphere undergoing forced periodic oscillations by A.HULME Department of Mathematics, University of Manchester, Oxford Road, Manchester M13 9PL (Received 21 October 1981).

[2] Experimental and numerical study on the wave force calculation of a partially immersed horizontal cylindrical float Bijin Liu a, Danjuan Fu a, *, Youquan Zhang b, Xiaoyun Chen a School of Civil Engineering and Architecture, Xiamen University of Technology, Xiamen, 361024, China b Fujian Marine Forecasts, Fuzhou, 350500, China.

[3] A TRIDENT SCHOLAR PROJECT REPORT NO. 237 "WAVE INTERACTIONS WITH VERTICAL WAVE BARRIERS' UNITED STATES NAVAL ACADEMY ANNAPOLIS, MARYLAND This document has been approved for public release and sale; its distribution is unlimited.

[4] Gilbert, J, M; and Balouchi, F; Design and optimization of a footfall energy harvesting system. Journal of Intelligent Material Systems and Structures, 2014,25(14), 1746-1756.

[5] Z. Liu, C. Xu, K. Kim, J. Choi, and B. Soo Hyun, “An integrated numerical model for the chamber-turbine system of an oscillating water column wave energy converter,” Renew. Sustain. Energy Rev., vol. 149, no. June, p. 111350, 2021, doi: 10.1016/j.rser.2021.111350.

[6] G. Moretti *et al.*, “Resonant wave energy harvester based on dielectric elastomer generator,” *Smart Mater. Struct.*, vol. 27, no. 3, 2018, doi: 10.1088/1361-665X/aaab1e.

[7] H. M. Chen and D. R. Delbalzo, “Linear sliding wave energy converter,” *MTS/IEEE Ocean. 2015 - Genova Discov. Sustain. Ocean Energy a New World*, vol. 107, pp. 1–6, 2015, doi: 10.1109/OCEANS-Genova.2015.7271686.

[8] H. M. Chen and D. R. Delbalzo, “Electromagnetic spring for Sliding Wave Energy Converter,” *Ocean. 2015 - MTS/IEEE Washington.*, no. 2, pp. 1–5, 2016, doi: 10.23919/oceans.2015.7401829.

[9] T. Bin Abdul Akib, M. I. Iqbal, and F. Mehedi, “Numerical design and analysis of ocean wave energy generator,” *Int. Conf. Energy Power Eng. Power Progress, ICEPE 2019*, no. 3, pp. 31–34, 2019, doi: 10.1109/CEPE.2019.8726781.

[10] J. Graves, Y. Kuang, and M. Zhu, “Counterweight-pendulum energy harvester with reduced resonance frequency for unmanned surface vehicles,” *Sensors Actuators, A Phys.*, vol. 321, p. 112577, 2021, doi: 10.1016/j.sna.2021.112577.

[11] Chandrasekhar Arunkumar, Vivekananthan Venkateswaran, and Kim Sang-Jae, “A Fully Packed Spheroidal Hybrid Generator for Water Wave Energy Harvesting and Self-powered Position Tracking,” Nano Energy, 2019. Vol. 69, p. 104439. 10.1016/j.nanoen.2019.104439.

[12] Y. Yang, P. Chen, and Q. Liu, “A wave energy harvester based on coaxial mechanical motion rectifier and variable inertia flywheel,” *Appl. Energy*, vol. 302, no. August, p. 117528, 2021, doi: 10.1016/j.apenergy.2021.117528.

[13] Wang; Hengyu; Weimin Wu; Lixun Zhu; Eftichios Koutroulis; Kaiyun Lu; and Frede Blaabjerg. Design and Experiment of a New Wave Power Conversion Device for Self-Powered Sensor Buoy. IECON 2021– 47th Annual Conference of the IEEE Industrial Electronics Society, 2021,1-5

[14] Karayaka; Bora.H; Hugo, Mahlke; Darek., Bogucki; and Mehrube; Mehrubeoglu. "A rotational wave energy conversion system development and validation with Real Ocean wave data." IEEE Power and Energy Society 2011, 1-7.

[15] Li, yunfei; qiyu, guo; manjuan, huang; xin, ma; zhaohui, chen; huicong, liu; and lining sun. study of an electromagnetic ocean wave energy converter driven by an efficient swing body toward the self%02powered ocean buoy application. ie, 2019, 129758-129769.

[16] Khatri; pooja; and xu, wang. a comprehensive review of a linear electrical generator for ocean wave energy conversion." It Renewable Power Genre, 2020, 949-958

[17] Henriques, j. c. c.; juan cc portillo; l. m. c. gato; r. p. f. gomes; d. n. Ferreira; and A. f. o. falcão., "Design of oscillating-water-column wave energy converters with an application to self-powered sensor buoys." energy 112, 2016, 112 852-867.

[18] . Fraunhofer. Available online: https://www.bu.edu/fhcmi/Projects/02.html (accessed on 14 February 2022).

[19] Liang; Changwei; Junxiao, Ai; and Lei Zuo. Design, fabrication, simulation, and testing of an ocean wave energy converter with mechanical motion rectifier." Ocean Engineering 2017, 136,190-200.

[20] Wavestar Energy. Available Online: https://wavestarenergy.com/(accessed on 14 February 2023).

[21] Liang, X.; Liu, S.; Yang, H.; and Jiang, T. Triboelectric Nanogenerators for Ocean Wave Energy Harvesting: Unit Integration and Network Construction. Electronics, 2023, 12(1), 225

[22] . Yu, Y.; Tian, X; Jia, Y; Cong, L; Mi, Z; and Fan, Z; An integrated scheme of speed control and vibration suppression for spiral spring energy storage system driven by PMSM based on backstepping control with minimum electrical loss. Advances in Mechanical Engineering, 2020, 12(3)