A Review of Breakwater Integrated Wave Energy Converter

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Abstract- Ocean wave energy is a powerful and predictable source of renewable energy. The use of energy of ocean waves for electricity production can do an important benefaction to the renewable energy stock. Energy of ocean waves is more foreseeable than solar energy or wind energy. Energy of ocean waves has higher energy density. The threat of global climate change is increasing by the ever increasing usage of fossil fuels. Due to this one of the primary policy objectives of the century is to find out an alternative clean energy sources. Wave energy converters (WECs) or Wave energy extractors (WEEs) are machines that have the mechanism to convert ocean wave energy into mechanical energy and then to electric energy. With the massive resource potential, an extensive range of methods have been developed for extracting ocean wave energy. The different devices and systems employ different techniques for extracting the wave energy. Also there is large variety of different methods for converting it to electricity. Breakwaters are structures constructed on coasts as part of coastal protection. The WECs can be integrated to Breakwaters to extract wave energy. This paper aims to review benefits of Breakwater Integrated Wave energy converter on Indian coastal regions, Wave energy assessment of Indian coastal areas, the popular technologies, analysis and model testing of Wave energy converter.

Keywords – Wave Energy, Breakwaters, WECs, Buoy, OWC, CFD, Overtopping device, SSG, OBREC, DEM, RANS.

I. INTRODUCTION

The wave energy is different in different coastal areas of the entire world. The ocean Wave energy extractor technology adopted for a particular zone should be according to the available wave energy of that zone. Different factors should be considered concerned with the current scenario of WECs. 1. The length of the coastal line of a particular coastal region and protection against wave action and wave erosion. 2. Threat of global climate change brought on and air pollution by ever-increasing use of fossil fuels. 3. Scarcity of fossil fuels (gas and oil) in coming decades. 4. Importance of developing alternative energy resource technologies due to increasing population and energy demand. 5. Higher predictively and energy density of wave energy. 6. Immature technologies regarding ocean wave energy extraction. Most the coastal areas of the world are disturbed by wave action and wave erosion. To overcome these situations it is essential to develop an alternative choice. The best choice is the energy from ocean and breakwater integrated Wave energy extractors which will solve the above mentioned factors.

II. HARMFUL EFFECTS DUE TO COASTAL WAVE ACTION AND EROSION

There are various harmful effects on coastal regions due to action of waves and wave erosion. There could have an effect on places further down the coastline, because of long shore drift and build-up of material. Sediment is redirected which means that there is less sediment on the beach to protect the coastline against the waves. The waves can accumulate a lot of energy due to fetch. It will damage the properties of people (especially fishermen) live near coastal area and sometimes it will become difficult to survive the situations. Waves can make the soil/rock weaker which makes it more vulnerable to erosion. The materials will easily eroded by the waves which mean that the cliff is quickly eroded and the waves will become more dominant.

III. BENEFITS OF OCEAN WAVE ENERGY CONVERSION

Extraction of energy from ocean waves does not create harmful by-products like gas, waste and pollution. It reduces the threat of global climate change. The best matter regarding energy from wave is that it will not exhaust. Waves are not limited by a season. Wave energy can be brought directly to electricity-generating machinery and utilize to power nearby generators and power plants. Scarcity of fossil fuels in coming decades can be overcome by this renewable source of energy. World population growth is predicted by 2 billion people in the next 30 years according to the United Nations report. Therefore, the demand for energy will increase day by day. India is the second most populated nation in the world. India is poised to surpass China as the most populated nation by 2024. So the energy demand of India will be more than China by 2024. According to International Monetary Fund estimates India is the third largest economies by PPP GDP (purchasing power parity gross domestic product). India is the third highest importer of crude oil. Indian Crude oil import is about 35% of total import.

Figure 1. Wave action

India will become a developed country very fast by reducing the crude oil import by developing and extracting the renewable energy sources. Coastal cities tend to be largely populated; so many people can take advantage of the wave power plants. Not only it will help to curb air pollution but can also provide the green jobs to millions of people. Energy from wave is safe, clean and one of the preferred method to extract energy. Most of the undeveloped countries use majorities of their income for the generation of energy. The active participation of public in coastal areas by investing them in renewable energy sector like wave energy conversion with the help of Government and Banks will make fast development of coastal area.

Figure 2. Effects of global warming

Breakwaters are structures built on coasts for coastal protection. Breakwaters protect to decrease the magnitude of action of wave in coasts and thus reduce coastal erosion. It also provide a safe harborage. It will create energy concentration of ocean waves (converging waves due to refraction on headland) near the breakwater zone and the dissipation of energy (diverging waves due to refraction in bay) and relative calm water near onshore. Break water integrated wave energy converters have the double advantage of protecting the coast and extracting wave energy.

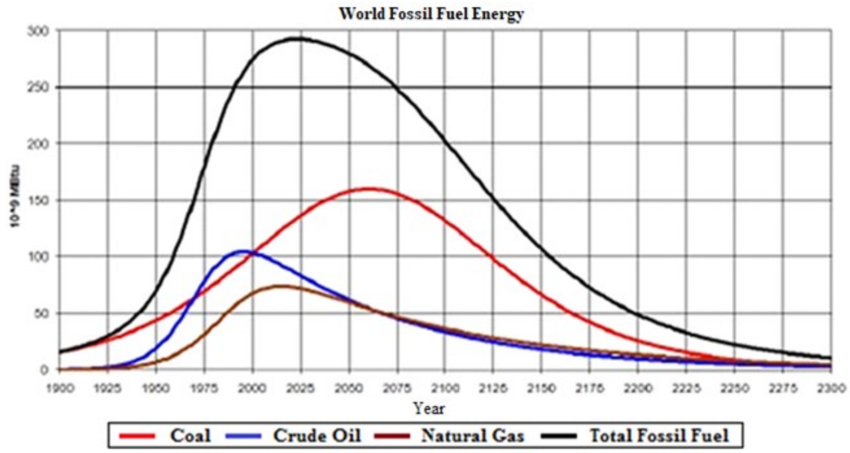


Figure 3. Resource of fossil fuels [Source: World Energy Council]

IV. Wave energy assessment

Wave Energy Assessment is an important component of wave energy extraction. It focuses on the evaluation and characterization of wave energy resources, global resources of wave energy, assessments of aggregate resources and wave energy distribution, and regional and country-wide wave energy resources on the potential of developing wave energy extractors.

Rajesh G et. al (2005) [80] observed the parameters of the ocean as it passed through various tropical cyclones. This was done in 1997 with the proposed local dynamics recorded with the help of the Moore Buoys. In October 1999 Hurricane Orissa observed a maximum wavelength of 13.9 m. in June 2000 near Car. Nicobar observed a speed of 3 m/s. During hurricanes across Arabian Sea, the lowest pressure was recorded at 992 mb (May 2004) and the highest wind speed was 35.26 m / s (May 1999). Sanil Kumar V. et. al (2011) [90] characterized the waves of 15 m of water depth in the northern Arabian Sea for 45 days during the summer rainy season. Significant wave height vary from 1.12 to 4.51 m, with an average of 2.52 m. About 75.5% of the wave height is from the south-west, while the rest is from the south-west to north-west oceans. Remya P G et. al (2012) [82] proposed the MIKE 21 SW model to perform wave hind cast experiments in the Indian Ocean. The Bay of Bengal statistics show a very good agreement with the buoy data, especially in terms of wavelength.

Sivakholundu K.M. et. al (2014) [97] describes the simulation of the growth, decay and transition of offshore and coastal wind-generating waves and swells. In general, the simulated wave height for low-wave heights is a good fit, and it is underestimated in the high oceans at all evaluation points. The maximum significant wave height is 3.5 meters on the coast of Kerala and the minimum value is about 0.5 meters. Using the ERA-Interim Dataset produced by ECMWF, Sanil Kumar V et. al (2015) [88] investigated the change of wave power in 19 locations covering Indian shelf seas. In the western India shelf sea, seasonal oscillations range from the lowest seasonal average value (2.6 kW / m) in the post-monsoon period to the highest (25.9 kW / m) in the south-west monsoon. Significant (10-20%) inter-year variations were found in a few locations.

Based on data measured using Wave rider buoys from the eastern Arabian sea off Vengurla, Amrutha M. M. et. al (2016) [7] examined the near-shore waves in the 5 to 15 m water depth during the 2015 active sea / land wind period (January 1 to April 30) in Coast of India. Examining the temporal variability of the daily wave response, the peak wave duration variability is high (about 8 seconds) at 1 day due to the influence of land / sea breeze. Prior to the sea breeze, swelling (TP> 10 seconds) dominates the wave zone, while during the sea breeze, the wind-sea (TP <5 seconds) is dominated by extreme swelling. The average wave spectrum shows a water depth of 15 and 5 m at 0.075 Hz. The wind-sea peak varies from 0.188 to 0.175 Hz as the waves travel from 15 to 5 m deep. Because of the sea breeze, the intensity of the wind-sea is 15 meters compared to the depth of 5 meters of water.

Table 1. Average value of wave parameters at 15 and 5m water depth in different months

	January		February		March		April	
	15 m	5 m	15 m	5 m	15 m	5 m	15 m	5 m
H_{m0} (m)	0.55	0.46	0.52	0.45	0.63	0.56	0.62	0.55
H_{max} (m)	0.82	0.70	0.80	0.66	0.95	0.86	0.93	0.84
T_{m02} (s)	4.6	5.1	4.2	4.4	4.8	5.1	4.5	4.8
T_{m01} (s)	5.4	6.2	4.8	5.2	5.8	6.3	5.3	5.8
T_p (s)	12.2	13.6	10.0	12.1	12.6	13.3	12.9	13.4
$T_{H_{max}}$ (s)	8.8	10.5	7.2	8.5	9.6	10.8	9.5	10.5
D_m (deg)	240	231	253	235	231	231	226	229
Swell (%)	39	53	32	41	49	58	47	55
Wind-sea (%)	61	47	68	59	51	42	53	44

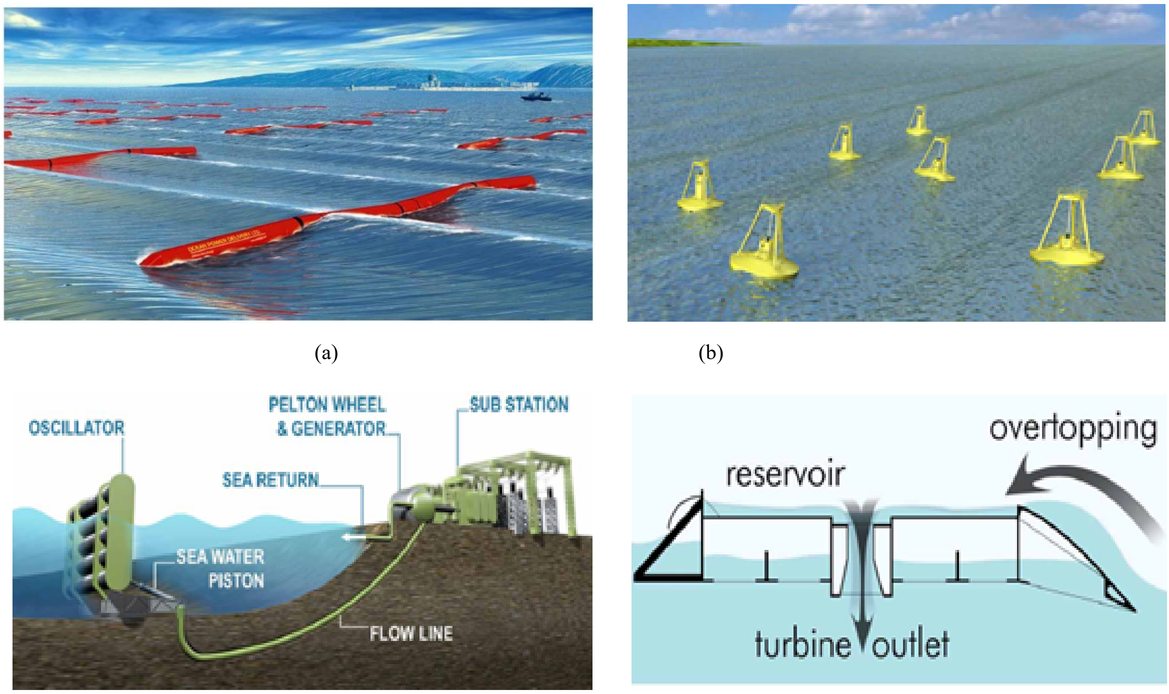
Sannasiraj S.A. et. al (2016) [91] conducted a feasibility study of wave energy resources and their interception technologies in the Indian context. The general estimate of the annual energy potential of the five sites are identified, assuming that 1 km of effective coastal roads can be used in each site. In Indian coast line Koodankulam (Tamil Nadu) reported the largest wave energy density having 29 kW / m. 25.08 KW/m at Trivandrum is the largest wave energy density across coast of Kerala. According to studies, a terrestrial wave energy converter that can be connected to a breakwater will generate more wave energy. The OWC is one of the simplest and best technology in the region. Aboobacker V.M. et. al (2016) [1] focused on the calculation of wave energy in the Bay of East Bengal and the Straits of Malacca. The third generation waveform model was used to simulate wind waves in a domain that crosses the Indian Ocean, the South China Sea and part of the western Pacific Ocean from 1997 to 2008. According to the results, the southern coast of Sumatra and the western coast of the Andaman and Nicobar islands have a high wave energy potential throughout the year. The highest annual average wavelength is 14.54 kW / m 15.77 kW / m. Over time, the SW monsoon has a high potential for wave energy everywhere. The energy potential of the waves before and after the monsoon is the result of tropical cyclones and existing wind systems.

V. Wave energy conversion technologies

According to the studies conducted worldwide, Wave energy converters can be classified on the basis of (1) Horizontal size and orientation of the WEC, (2) Location according to coastline, and (3) Location with according to mean water level. Wave energy can be extracted through one of the three energy conversion processes as (1) Primary conversion which is the first level wherein wave energy is gained by an oscillating system. The examples for these types of systems are a floated body, oscillating water or an oscillating solid in a structure. The oscillating systems should be capable of storing kinetic/potential energy extracted from the wave. (2) Secondary Conversion which is the second level of stored energy converted into some useful form. This level involves utilization of drives and control systems like devices for level control and power take-off which include controllable values, hydraulic rams and pneumatic components as well as electronic hardware and software. This secondary conversion is got by converting the kinetic/potential energy to kinetic energy using a turbine thereby resulting in the rotation of a shaft. (3) Tertiary Conversion which is the last and final level in which the rotary motion is transferred to electric generators which converts the extracted power to electricity.

VI. Off shore wave energy converters

Off shore wave energy converters are installed in off shore sites. The actuators for the extraction of the wave energy will be in the sea side. The generator for converting electricity may be placed either in sea side or on shore. If the generator is placed offshore the actuators of the WEC will connected to the generator through turbines. The electricity produced will be transmitted through transmission lines that laid through the sea. Transmission losses will be more in this case. If the control of a WEC if perfect the efficiency and hence effectiveness will be increase. Drew B et. al (2009) [28] described the general state of wave energy and assesses the types of equipment that constitute current wave energy conversion technology (WEC). Scope of wave energy potential is very high in India. Taware S.B et. al (2010) [100] provided a brief review of technologies which are used to utilize the abounded amount of energy available in sea waves as well as equipments which are used in wave energy utilization plant. India has a vast coast line with abundant amount of wave energy. That will be the solution to meet the increasing power demand.



(a) (b)

(c) (d)

Figure 4. Off shore wave energy converters (a) Pelamis wave farm (b) Point absorber device (c) Oscillating wave surge converter (d) Wave Dragon

Wave Energy Farms can convert wave energy very effectively. Hyuck-Min Kweon et. al (2012) [43] proposed such a system using the resonating buoys. The buoys heaves with ocean waves. By applying a lifting function to a floating buoy of 3m in diameter and 9 m length, a wave power amplification on a commercial scale is obtained. Buoy farm consists of circular and linear arrays of buoy. As per the numerical results the buoy type floating power farm is very best for practical application. Line absorber with cylindrical floats gives high capture widths in regular and irregular waves in broad frequency range exclusively for offshore sites. Stansby P et. al. (2015) [98] suggested such system with cylindrical floats with bow and middle float strongly connected using a beam. Jeongrok Kim et. al (2015) [49] introduced a double WEC buoy that generates energy through a relative heave movement between two buoys. The WEC contains of two concentric circular floating cylinders (one internal and one external hollow buoy) with multiple resonances. Based on the studies this technology is efficient for ocean sites of low wave energy density. An overtopping system with an offshore buoyant moored device is another method to extract wave energy. Arshit Ambalia et. al. (2016) [10] introduced such a device. It is a floating device in which the upward-downward movement of the swells will drive the pumps. In this mechanism has less transmission loss as the generator unit is placed on onshore. Wassim Chehazea et. al (2016) [108] proposed a new concept of electrical conversion that uses transverse motion of the waves. In this system there is flat plate which actuates and hydraulic power is stored. In the lower side the turbine and generator is placed that generate electric power. Corresponding to an input wave power of 804 W maximum calculated output power generated is 600 W. 75% theoretical efficiency can be obtained by the system.

VII. On shore Wave energy converters

If the generator is placed onshore the hydraulic or pneumatic power will be generated by the actuators and it will be transferred through the hydraulic lines to the turbine which is connected to the generator. Electric transmission losses will be very less in this case. Coastal wave energy conversions are very useful for moderate wave energy models. On shore WECs have many advantages over off shore types. They are very simple in construction, low maintenance cost and less corrosion. They contain mainly tree parts, actuators, chamber and the air or hydraulic turbine. Wave Slot cone Generators (SSG) one of the efficient technology for on shore wave energy extraction. Diego Vicinanza et. al (2012) [26] conducted studies of physical model tests and numerical simulations of SSG. The SSG concept is a novel concept of a multi-stage turbine that reduces start / stop pttern using different levels of water. Even if there is only one reservoir for delivering water, this will work very effectively. 25% to 35% of overall wave-to wire efficiency is expected from SSG. Veigas M et. al. (2014) [105] evaluated optimal position for a coastal wave energy converter (WEC) in terms of power generation. Capacity component value of 0.33 is anticipated, indicating approximately 2628 equivalent hours. Buccino M et. al (2014) [17] indicted an experimental set-up of wave Slot-cone Generators (SSG). The equation for predicting the maximum wave pressure was very satisfactory. Verification of prediction maps against random wave data was favorable. It is found that the absence or lower incidence of impact events is more severe than that observed in vertical breakwaters.

(a) (b)

Figure 5. Onshore wave energy converters (a) Wave Slot cone Generators (b) Heaving-Buoy WEC

Oscillating water column wave energy converter (OWCWEC) is one of the effective method for near shore energy conversion. Irhasa et. al (2014) [44] suggested such a method suitable for wave power plant model which established in Yogyakarta. This tool generates electricity from the oscillation of the water by the waves in a duct. Primary study of OWCWEC was conducted by Sebastian Bruscaa et. al (2015) [93]. The system's energy conversion is a Darius type wind turbine with a straight blade. According to the results obtained from the experiments, the velocity field leads to a velocity peak with a top dead point (end of the piston stroke). The velocity vectors and axis of the air column are nearly aligned. It shows that there is a high interconnection between the turbine rotor and the air flow at the bottom dead center and that the new piston stroke almost interrupts the air flow. A resent technology named as Heaving-Buoy Sea Wave Energy Converter is introduced by Joseph Youssef et. al (2016) [55] on the Lebanese shore. It consists of a float, rack and pinion system. The float heaves on ocean waves that converts the vertical movement of the waves into a rotary movement of pinion. Pinion is connected to generator and produce electricity. Near the Lebanese shore a first prototype tested was conducted. Due to large frictional forces by rack and pinion the efficiency (11%) of this system was very low. But this system can be implemented in a wave and wind hybrid system for electricity generation

VIII. BREAK WATER INTEGRATED WECS

Break water is used to reduce the energy of incoming waves by reducing wave energy and / or reflecting all wave energy to protect some coastal areas from wave attacks. The breakwater can be functioned as wave energy hot spots from where the wave energy can be extracted. Such an update is important for the marine environment, since renewable energy represents a significant investment. Riccardo Briganti et. al. (2008) [83] described a new station to completely measure the surge of the waves on the rubble mounded breakwater of the tourist port of Rome in Ostia (Italy). The first measurement made in winter 2003-2004. When attacks of large waves occur at the top of the structure associated with intense braking on the ground, the overflow rates can be mainly affected by the breaking during storms. Koutitas C.G et. al. (2008) [59] developed a mathematical model of wave energy conversion on the port side by a breakwater and WEC with a low head turbine. The breakwater configuration, which has an armored slope in the open sea, is about 2 times more efficient than vertical orientation. The fraction of extracted power is in the order of 10-30% of the incident wave.

As per the studies combination of rubble mound breakwaters with wave energy converters is very effective for on shore wave energy extraction. Diego Vicinanza et. al. (2014) [27] suggested the coastal infrastructure that is economically and environmentally sustainable. At the University of Aalborg, the 2-D model physical tests were conducted. Rate of average wave overtopping and wave loadings were discussed based on the test. Overtopping breakwater for energy conversion (OBREC) shows an average reflection coefficient similar/reduced compared to conventional breakwater by the rubbles. With the same overall dimensions OBREC cannot guarantee a level of safety similar to the conventional breakwater. Using model physical studies, Bikas G.S et. al. (2014) [12] studied the performance of the wave power converter used together with the conventional rubble mounted breakwater. In the turbine consists of a Savonius rotor. According to experiments, the efficiency of the rotor is more when the horizontal distances X/d is in the range 22.5 to 30 and depth is equal to 55 mm for submerged case.

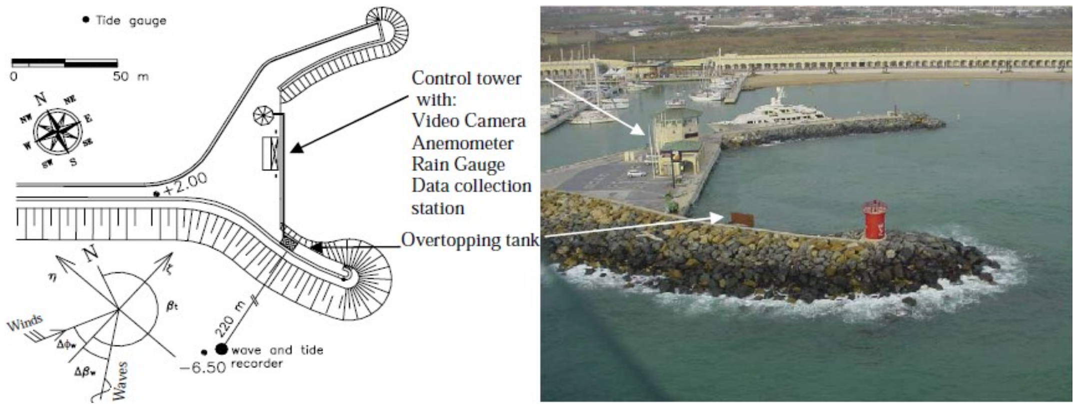


Figure 6.   Overtopping measurement station

To find out optimal economic configuration of an innovative OBREC, Pasquale Contestabile et. al. (2016) [75] [76] performed an analysis. Construction of prototype from small scale to full scale was carried out for OBREC in 2015 in port of Naples. According to the study, most get-away energetic waveforms lead to a saturated tank state, so a large amount of overtopping is reflected as outgoing. In low and mild wave condition OBREC will give best performance. OBREC will be a brilliant solution to reduce the high construction costs of the wave energy converters. To increase the effectiveness, integration of hybrid devices into breakwaters is appreciated very well.

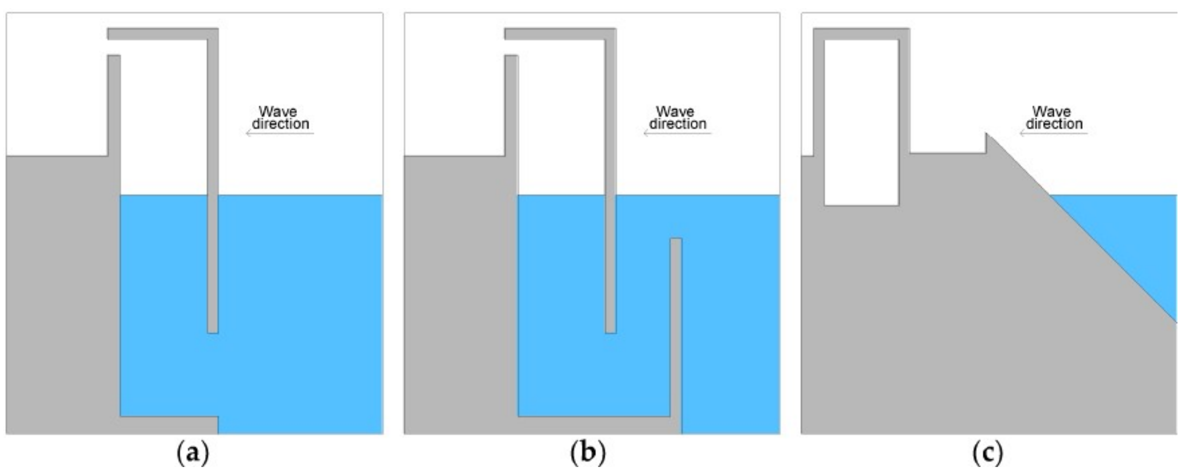


Figure 7.   Different WEC systems (a) OWC, (b) U-duct OWC, (c) OBREC

The integration of Oscillating Water Column Wave Energy Converters (OWCWECs) to the vertical breakwater is one of the best method for on shore wave energy extraction. Stefania Naty et. al. (2016) [99] conducted a feasibility study of such system for moderate wave energy level. The configuration is capable to convert maximum wave energy with the minimum wave reflection. Accurate prediction of the wave loads on the front wall can be done for such an optimized configuration. The current scenario regarding the integration of breakwater to WEC was conducted by Mustapa M.A et. al. (2017) [69] considering several factors like effectiveness, performance and reliability. During both medium and high wave condition integration of WEC with existing breakwater structure improves WEC device workability and improved device lifetime.

IX. Analysis of Break water & Break water integrated WECS

Various methods are adopted for analyzing the Break water & break water integrated WECs concerned with its hydrodynamic behavior, response of the structure against wave action, dissipation and concentration of wave energy, analyzing the durability etc. wave load calculation on breakwater walls is also important in this regards. Concerned with this Francisco L. Martin et. al. (1999) [39] suggested a new method for load calculation of random waves through the equivalence hypothesis. It turns out the generation of dynamic pressures during the abrupt change of direction of the front of the bore due to the wall of the crown. John-Paul Latham et. al. (2008) [52] carried out a modeling of the stability problems of the breakwater armor coupled with 3D. Computational fluid dynamics was found to be a powerful method for coastal engineers who want to capture breaking wave and interaction of structure when combined with finite element method (FEM) or discrete element (DEM). Ghassan Elchahal et. al. (2009) [40] proposed optimization problem which involves the design of a floating breakwater which is able to dissipation of the waves energy within the minimum port and creating various constraints relating to stability buoyancy, and resistance of structure. The coefficient of transmission for long wave periods is approximately equal to the various optimal structures. Small structures are the worst due to low transmission coefficients for a small range. These structures also have high resonance peaks over the remaining period range. Enlarging the structure with the increase in the wave period is preferred.

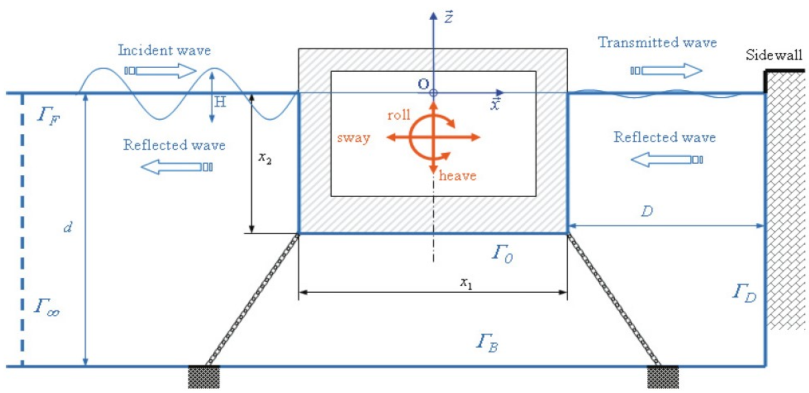


Figure 8. Definition sketch for theoretical analysis with a sidewall

Fabio Dentale et. al. (2014) [31] combine CAD and CFD with a new procedure to analyze the hydrophobic aspects of the breakwater and waves interaction generated by the waves. The structure of the numerical domain is modelled using overlapping tetrapods. Tetrapods are individual three-dimensional elements. It resembles like a physical laboratory testing. The assessment of flow of fluid in the gap between the blocks of concrete is carried out by integrating the Reynolds-averaged Navier-Stokes (RANS) equations. Currently in the design stage of breakwater, this innovative approach validates that different design solutions can be compared at relatively low cost. Effects of oblique waves on the rock inclination stability and cube armored rubble mound breakwater were carried out by Marcel R.A. Van Gent (2014) [62]. It was found that the influence of the oblique waves on the rock slope is large for the long-crested waves and it can significantly reduce the required armor size compared to the shear size required for vertical wave attack. The size of the reinforcement required can be reduced compared to the size of the reinforcement required for the attack of the perpendicular wave. A study on the stability of the tip of the rock using physical model tests was conducted to find out the size of the rock required for the structure by Marcel R.A. van Gent et.al. (2014) [61]. He recommended that toe structures that consist of concrete units may be a good alternative to the use of rocks. For the shore protection purpose, construction of submerged breakwater can be done by geo-synthetic tubes as an alternative method. Kiran A.S et. al. (2015) [58] introduced such design by using geo-synthetic tubes having a 200 kN/m tensile strength. A tensile strength of 75% of the real strength was attained by the geo synthetic material after exposure to UV radiation for 500 hours. The wave load of 45 kN per meter of breakwater was approximated by the methods.

Numerical simulation concerned with the interaction between breakwater and solitary waves was carried out by Ching Piao Tsai et.al. (2016) [20]. This was done using CFD based on the Reynolds-Navier-Stokes Average (RANS) equations and on the turbulent reorganization group (RNG) model. When the solitary waves pass through the breakwater a jet-like flow phenomenon was revealed in the simulation results. This was due to the difference in water level between the breakwater downwind sides and the weather. In addition, considerable vorticity developed in the jet-like flow region and generates relatively appreciable turbulent energy dissipation. Farzad Milanian et. al. (2016) [37] explained the effect of wave run-up on berm type breakwater. Using a technique of CAD and CFD integration carried out 200 number of tests to calculate the effect of wave period, wave height and berm width during the wave run-up. Increasing the berm width by about 36%, the wave run-up could be reduced. If the wave height is increased by 53% and wave period by 36%, the wave run-up can be increased considerably.

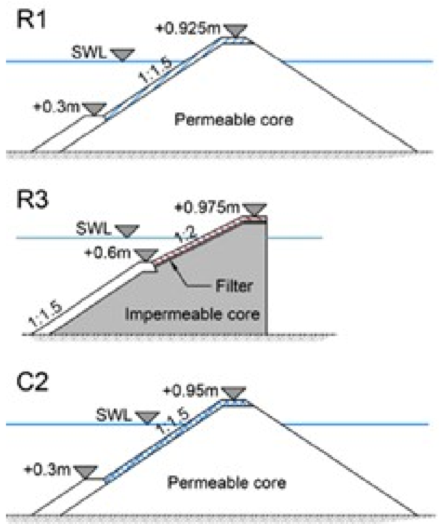


Figure 9. Tested cross-sections with rock (R1, R2 and R3) and cubes (C1, C2 and C3); levels are relative to the seabed (0 m); the still water level SWL varied between 0.65 m and 0.8 m.

To study the flow over breakwater Vivek kumar Gope et. al. (2016) [107] adopted CFD to analyze the variations of different properties like glow properties, temperature etc. by semicircular breakwater geometric models. These models can be effectively used to predict flow and proves as a rapid and alternative approach. Hydrodynamics behavior of ocean waves on break-waters can be analyzed based on the theory of linear potential flow and matching the technique of Eigen-function expansion. De Zhi Ning et. al. (2017) [25] suggested such an analytical model of dual-pontoon floating breakwater working as oscillating buoy WEC. He found that the reflection coefficient, transmission coefficient and the total capture width ratio of a system with two identical pontoons strongly depends on the spacing between them and natural frequency in heave mode. The single-pontoon system and two-pontoon system are compared with each other based on the comparison between the capture width ratio and transmission coefficient. Better performance is given by the system of two small pontoons.

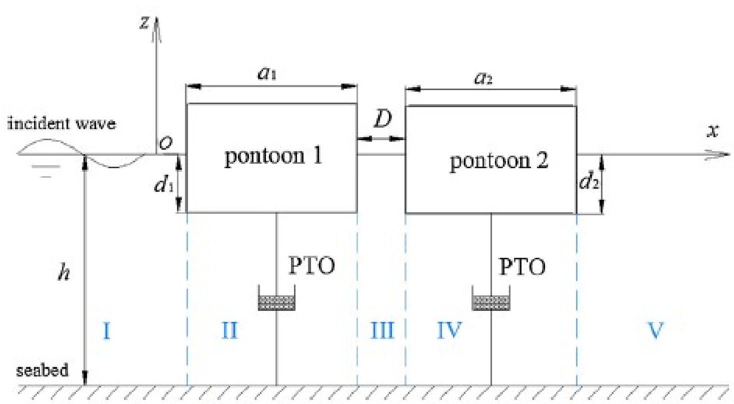


Figure 10. Sketch of the floating structures with the PTO systems

Fang Hai et al. Alabama. (2017) [36] carried out wave-flume experiments at regular wave condition to test the extraction of wave energy from a floating box breakwater with double pneumatic chambers. The power is extracted from the oscillation of the water column inside the chamber. Planned natural period differentiation in the double chambers could expand the bandwidth of the energy extraction efficiency. The oscillation of the water column depended more on the wave period than being controlled by the dispersion of the wave at different depths of the water. Large-scale movement leads to poor quality mesh in computational domain and this can be removed by Divide the entire processing domain into multiple parts. Zonal hybrid RANS method or laminar method based on strategy of improved mesh updating is the method to overcome this. Using this method Jie-min Zhan, et. al. (2017) [51] conducted a numerical analysis concerned with nonlinear interaction of irregular waves or regular waves on inverse T-type free surface breakwater. Based on the results and comparison between the fixed breakwater and floating breakwater models, the phenomenon of redistribution of wave energy is more evident for floating type. Also the movement of the floating breakwater leads to radiation of wave energy, which can improve the transfer of energy from low to high frequency waves in addition to the dissipation and reflection of waves. The assessment for optimal configuration was conducted by Pasquale Contestabile et. al. (2017) [73] [74] based on the OBREC financial returns. Analysis model was a high resolution coastal propagation type. The analysis of the wave climate with off and near shore was studied. Due to the presence of ocean states in the more efficient regions of OBREC, plants located in high energy zones produce fewer than average wave power. He studied the nature and extent of wave loads concerned with overtopping wave energy conversion in different parts of rubble mound breakwater. He considered two configurations of the device. First one was the front curved ramp (curved configuration) and second one was front inclined ramp (flat configuration). The results show that in almost all tests, the flat ramp loading acting is 30-40% higher than the curved ramp. There were no important differences between the two configurations for the loading of the base and the vertical crown wall.

A modified method of OWC is introduced by Ching-Piao Tsai et. al. (2018) [21]. In this method caisson breakwater is integrated with vertically submerged open OWC in which the front wall is composite and perforated. For hydrodynamic performance examine, both numerical and experimental evaluations are carried out on the typical OWC and the modified devices. In the case of typical OWC, perforation is absent on the front wall. The 3D numerical model based upon RANS equations. Based on the simulated results hydrodynamic efficiency is very well effected by OWC chamber width. As the OWC chamber width increases, resonant frequency decreases. If the front wall porosity is in between 25 to 70%, hydrodynamic efficiency will be greater than 80%. Based on linear potential flow theory, a theoretical model was introduced by Siming Zhenga et. al. (2019) [95]. Performance of an OWC integrated with a vertical breakwater was carried out in the study. Thin wall restriction was not provided in on the breakwater. Because of wave reflection from breakwater, OWC integrated with breakwater has the efficiency about twice as that of the theoretical maximum efficiency of offshore type. Wave power capturing will increase with perpendicularity of the direction of incident wave relative to Breakwater.

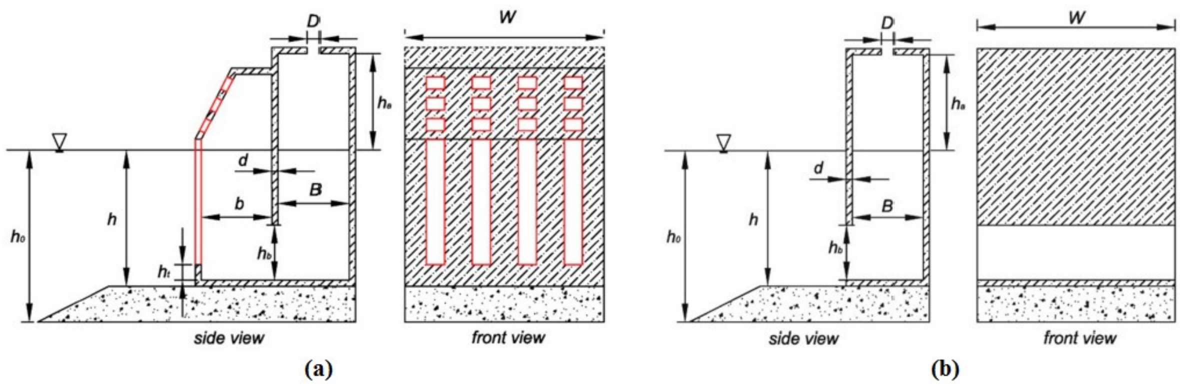


Figure 11. The geometry of OWC (a) present OWC device (b) typical OWC devices

X. CONCLUSION

The paper describes harmful effects due coastal wave action and erosion and benefits of Breakwater Integrated WEC on Indian coastal regions. It also goes through the research efforts in the fields of the areas of interest such as wave energy assessment of Indian coastal areas, various wave energy conversion technologies including off shore, on shore and Break water integrated WECs and Analysis of break water & break water integrated WECs. Based on this following factors are worth noting. There are several types of WEC technologies available worldwide. But there are only two technologies (oscillating water column WEC and over toping type WEC) having the advantages of both coastal protection and wave energy extraction. But both of the technologies have their own limitations also. Oscillating water column WEC uses the pressure and vacuum created by the oscillation of water column only for the extraction of energy of ocean wave. The upward thrust of wave is not extracted by devise. Over toping type WEC only extract energy from downward flowing water through its ducts. Breakwater integrated WEC is a better technology for both coastal protection and wave energy extraction. But the geometry and design optimization of the same for maximum wave energy extraction are still not done. Based on the above mentioned factors it can be inferred that the optimization of breakwater integrated WEC will be a committed work which will enable the efficient extraction of wave energy and protection of the coastal area from action and erosion of ocean wave.

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