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Feasibility Study on Wave Energy Conversion by a Modified Oscillating Water Column Device

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Abstract. Energy conversion from ocean waves has become the need of the hour in view of the renewable energy awakening occurring all over the world. Energy conversion by Oscillating Water Column (OWC) concept has become an established technology in converting mechanical energy of ocean waves to electrical energy. But the limitations of OWC concept call for further research and developments to make the technology commercially an attractive one. In this context Boccotti, the Italian scientist advanced the double chamber concept and the implications of the concept still remains to be investigated through model studies. This paper presents the details of a generic study carried out in a physical model device under regular waves.

Introduction

The environmental problems being generated out of fossil fuel usage have become an issue for concern all over the world. Hence nations had compelled to advance the concept of clean energy production from renewable energy sources. This has generated renewable energy awakening among the nations. Going by the present day trend it is very clear that twenty-first century is about to make revolution in renewable energy production. This can be achieved through the incremental steps in research and development.

In the present day period there exists state of art technology to harness energy from sunlight, wind, biomass, geothermal gradient and ocean. Technology connected with sunlight and wind has already crossed the maturity stage to become commercialised. But the research activities over the ocean related works remains still in the formative stage even though there exists huge potentiality for energy harnessing. Wave energy conversion philosophies emerged over the period of time out of both scientific and speculative intuitions are so diversified that it is very difficult to bring them under a unified conceptual design procedure. Bahaj [1] gives an account of the technological trends appearing commercial projects. In this context, the retrospective analysis of past studies of theoretical and empirical are included just to show the relative significance of OWC concept.

The first patent historians recorded in the eighteenth century [2] for the conversion of wave energy in to mechanical energy by a father and son attests man's ocean energy awakening and his attempts for its utilisation in meeting the daily energy needs. Yoshio Masuda of Japan, the father of wave energy concept [3] started studies in OWC around 1940's and developed first OWC power unit. In its physical form, it was a floating hollow cylinder and the oscillation of cylinder with wave interaction created required pneumatic power for rotating power for rotating the shaft of an electric dynamo. In conformity with the above operating principle navigational buoys were deployed in many parts of the world in the year 1965. Electricity production from waves became a serious research topic with the oil crisis of 1970's. Salter [4] developed the classical Wave Energy

Converter (WEC) called the nodding duck. The shape was so designed that it radiated waves to a lesser extent and was able to achieve to efficiency up to 80%. First model studies conducted for bottom mounted OWC device is reported in 1985 [5]. It was observed that OWC was able to extract energy from a range of wave frequencies and hence named multi-resonant OWC device (MOWC). It was also found that the oscillation amplitudes were improved when parallel harbour walls were added at the mouth of the device. Subsequently there were theoretical studies over the hydrodynamic aspect of OWC concept [6, 7]. McIver and Evans [8] presented the theoretical formulation based on the method of matched asymptotic expansions. The results presented showed that the power absorption capacity of the device depends on mouth opening elevation, wave length and direction of the incident wave. This brings out the fact OWC system response is determined by the magnitude of the dynamic pressure and its excitation period. Evans and Porter [9] developed a theoretical formulation for parametric study of the device. It was observed that maximum energy conversion occurred at resonance. This indicates the pattern similar to that of a forced vibration phenomena. Hence the water oscillation inside the air chamber depends on both the intensity of pressure excitation at the mouth of the device and the natural frequency of the system. In OWC, to increase the natural period of the device the only way possible is to decrease the mouth opening so that the streamline length of flow increases and this causes corresponding increase in natural period also. But as the depth of opening decreases it causes decrease in intensity of pressure excitation and subsequent decrease in oscillation amplitude inside the air chamber. Boccotti [10] proposed a modified concept by incorporating a duct in front of the OWC mouth. Since the device incorporates two chambers in its physical form it is called as Double Chamber Oscillating Water Column (DCOWC). The streamline length of flow can be varied by changing the bottom opening depth and the mouth clearance depth. By theoretical calculations it was predicted that the device was capable of absorbing the incident wave energy up to 100%. Hence this concept offers flexibility in design to bring forth tuning effect in energy conversion by capturing the maximum pressure intensity under the waves.

Experimental Set-up

The physical model consists of three smaller DCOWC units and one bigger unit integrated together. One DCOWC unit has two parts, the portion which is in contact with the incident wave is known as energy absorption unit and the chamber where the pneumatic power is known as energy conversion unit. The size of energy conversion chamber for the smaller unit is 0.30mx0.60mx1.45m and the same for bigger unit is 1.0mx0.60mx1.45m. The dimensions of the energy absorption chamber for the smaller unit are 0.[illegible]x0.30m and for bigger unit it is 1mx0.30m. The parameters of interest considered in the investigation are the bottom opening (O) and the incident wave period (T). In the present set of 'O' for the smaller units were in the order of 0.15m, 0.30m and 0.45m while the same for bigger unit was 0.30m. The adjacent units were separated by plywood partitions to avoid the interference effect between them while performing the simultaneous testing. The plan and section of the model units are shown in **Fig.1**. An air vent of circular shape having a cross sectional of 0.65% of energy conversion plan area is provided to simulate the air damping induced by the turbine in prototype device. The model units were made of fibre reinforced plastic sheets. Enough care had been taken to avoid sharp corners in the fabrication of the units. The top of the energy conversion units were covered by 12mm transparent perspex sheets to facilitate viewing the water surface oscillations inside the chamber.

The present experimental study was carried out in a wave flume of 72.5m long, 2.0mwide and 2.7m deep, in the Department of Ocean Engineering, Indian Institute of Technology Madras, India. The depth of water (d) in the flume was maintained at 1m. Regular waves of period varying between 1.3s and 2.2s in steps of 0.3s were employed for the tests. For each of the period, four wave heights (H) of 0.045m, 0.055m, 0.065m and 0.095m were considered.

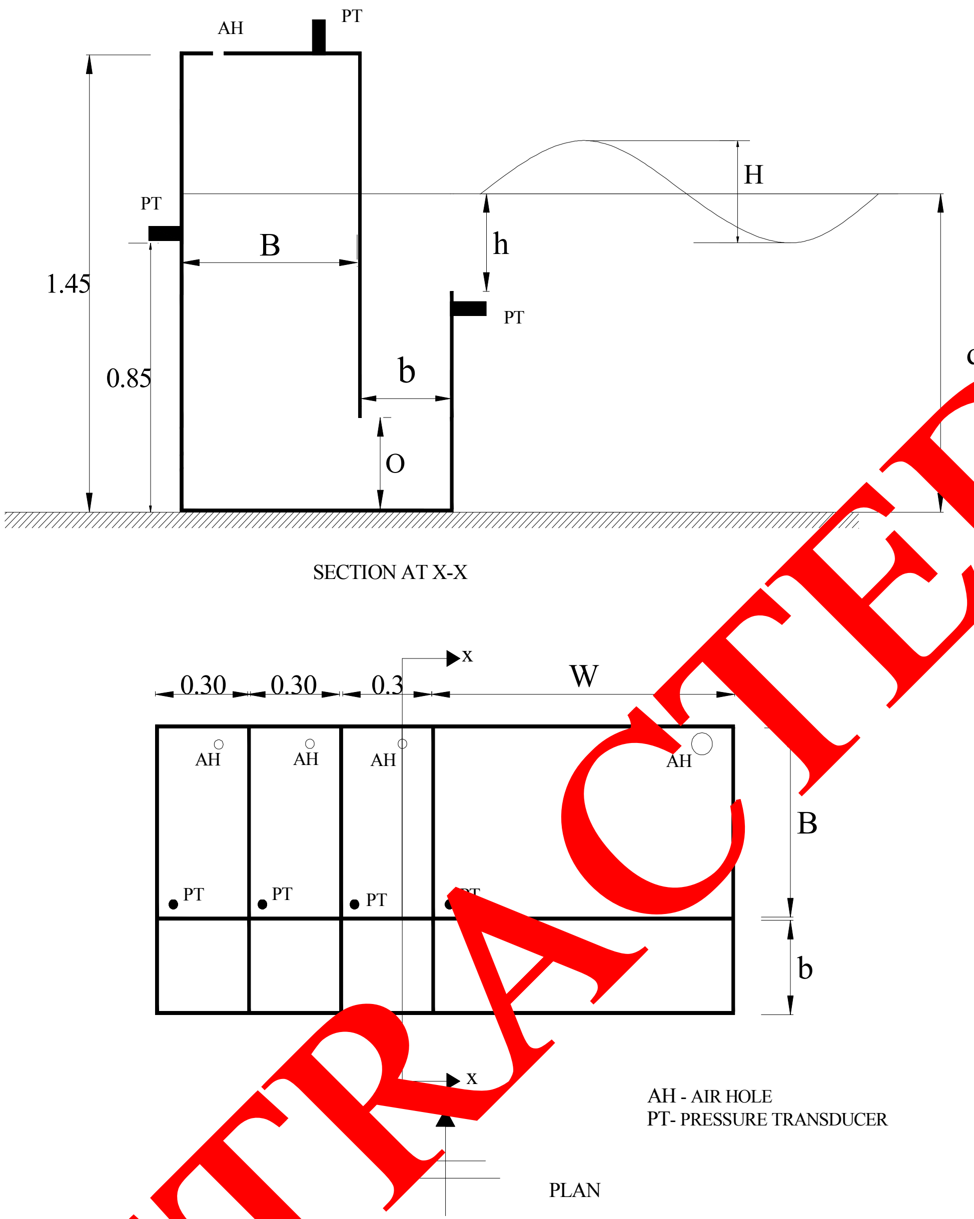

Fig. 1 Plan and section of the model

Hydrodynamics

For assessing the energy conversion efficiency, the different hydrodynamic aspects considered here are energy conversion efficiency (λ) inside the air chamber and phase difference (ϕ) between incident pressure and wave pressure. They are calculated as follows.
The incident wave power (P_{in}) across the width 'W' normal to the wave crest for a wave of height 'H' and celerity 'C' in a water depth of 'd' by linear wave theory is

$$P_{in} = \frac{\rho g H^2}{8} \cdot \frac{C}{2}\left(\frac{2kd}{\sinh 2kd} + 1\right)W. \tag{1}$$

where k=2π/L, L is the wave length.

$$\lambda = \frac{\frac{1}{T}\int_{t}^{t+T} p_a A v dt}{P_{in}} \times 100. \tag{2}$$

where, T=Time period of the wave, p_a air pressure of the energy conversion module, A is the plan area of the air chamber and v is the velocity of water surface oscillation inside the energy conversion module.

$$\phi = 360 \times \frac{T^*}{T}. \quad (3)$$

where T^* is the time difference between pressure excitation at mouth and air pressure. It is obtained from the maximum value of cross correlation between the two time series.

Results and discussions

The measurements were carried out such that at least three steady state cycles in the pneumatic pressure variation could be captured during a particular test. The hydrodynamic power was calculated as the average of the three steady cycles. The velocity of water surface oscillation inside the energy conversion module is obtained by the numerical differentiation of the difference between rear wall pressure and air pressure.

Effect of bottom opening. The results presented in **Fig.2** brings out the effect of bottom opening depth in energy conversion capacity of the device while it is subjected to same intensity of forcing at the mouth. It is clear that for the same opening depth the energy conversion capacity of the device increases with wave period. This is the characteristic feature of an oscillating system where the amplitude of oscillation increases as the excitation frequency approaches the resonance region. The lower values of energy conversion at O/d=0.15 indicates that natural frequency of the system lags far behind the excitation frequency which is the incident wave period in the present case. The variation in energy conversion can be attributed to streamline flow length variation and the corresponding change occurring in the natural period of the system. The pattern in performance attests that it is possible to alter the natural period of the device by controlling the depth of opening.

Phase variation. Phase angle variations marked against wave frequency parameter d/L in **Fig.3** represents the effect of system parameters in bringing tuning effect in energy conversion. In line with the fundamental principles when the oscillating system approaches resonance region correspondingly phase angle decreases so that as it reaches resonance, phase angle becomes zero. The trend seen here agrees with pattern observed over energy conversion.

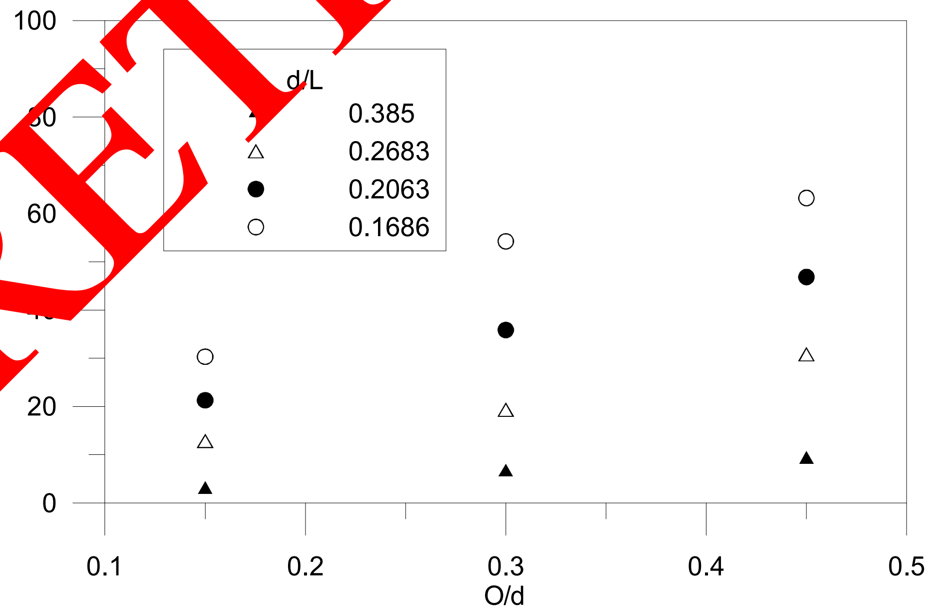

Fig.2 Variation of energy conversion with relative bottom opening

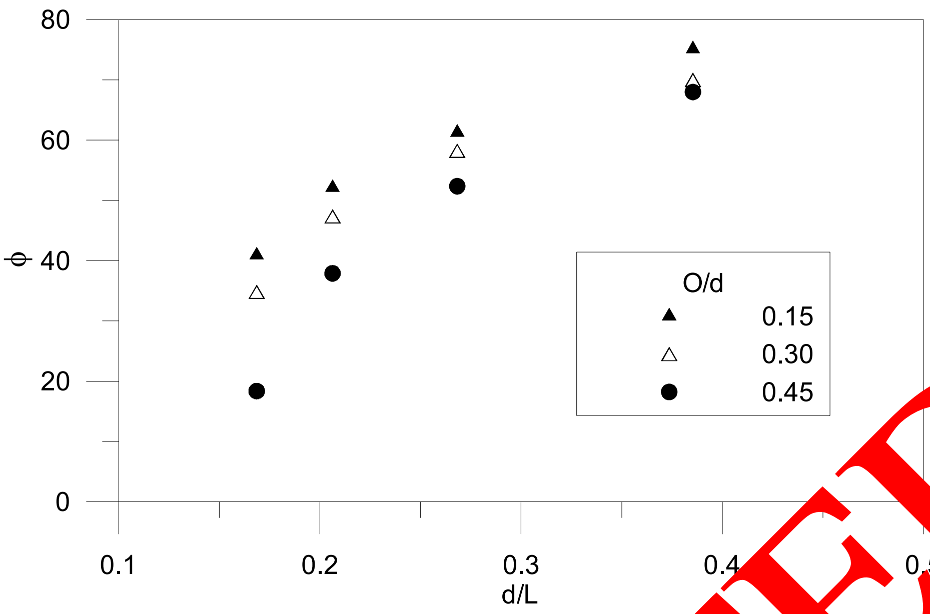

Fig.3 Phase variation with system parameters

Conclusions

The detailed experimental investigation carried out on the physical study establishes that DCOWC concept is a feasible one for primary energy conversion from ocean waves. The results clearly emphasises the effect of system parameters influence on bringing positive changes in performance conditions of the device.

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