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The International Conference on Emerging Trends in Engineering

Yukthi-2023

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YUKTHI 2023

Study on effectiveness of tetraPOT as coastal protection structure

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***Abstract*—Tetrapod's are coastal protection structures that are widely used from the time of invention to now. But tetrapod, as a hard structure have certain demerits that includes high cost of production, increase in downdrift erosion, high carbon footprint corresponds to the production of structures etc.… So, a greener alternative which can be implemented on coastal regions for protection from foreshore erosion is a major discussion. To compensate this problem, there are several alternatives found available and mostly looking for a sustainable, greener alternative. But research on these topics are found meager. So, we have conducted a study on TetraPOT structure, a concept created by Taiwanese designer Sheng-Hung Lee and Malaysian designer Wan as a greener and sustainable alternative in 2016. Study was based on how much effective the TetraPOT structure in reducing the wave energy that reaching the coastal region. For that purpose, we have conducted a comparative study on transmission coefficient (Kt) of TetraPOT and tetrapod structure at different configuration and wave heights. By plotting the data obtained, the results are analyzed and effectiveness of TetraPOT is found out.**

Keywords—Tetrapod, transmission coefficient, foreshore soil erosion.

I. INTRODUCTION

Kerala has a large coastline of total length around 570 km with 9 coastal districts. Among these 370 km is protected with sea walls. And 45% of protected coast is subjected to high wave action and subsequent damages. The coastline is subjected to erosion due to hydrodynamic effects of ocean phenomena such as waves, tides, ocean currents, shortage of sediment and deflation etc. This various hydrodynamic effect results in considerable movement of sediment, which ultimately causes changes in the morphology of the coast.

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The wave is one of the major factors which causes erosion and acceleration of this along coast. In such a condition the protection of the coastline is of primary importance. The coastal protection structures include sea walls, bulk heads, groins, jetties, breakwaters etc. But recent studies show that they accelerate the erosion rate. Current artificial sea defense structures tend to be dislodged over time by the forces of the ocean constantly crashing against them. They have also been criticized for destroying the natural scenery along coastlines. As for natural sea defense more than 35% of the world's mangroves are already gone because of the greenhouse effect.

A Tetrapod is a form of wave dissipating concrete block used to prevent erosion caused by weather and longshore drift, primarily to enforce coastal structures such as seawalls and breakwaters. Tetrapod were originally developed in 1950 by Pierre Danel and Paul Angles d'Auriac of Laboratorie Dauphinois d'Hydraulique in Grenoble, France, who received a patent for the design. The name was derived from Greek, with tetra-meaning four and pode meaning foot, a reference to tetrahedral shape. Tetrapod's were first used at thermal power station at Morocco to protect the sea water intake. Tetrapod's are made of concrete, and use a tetrahedral shape to dissipate the force of incoming waves by allowing water to flow around rather than against them, and to reduce displacement by interlocking. Though Tetrapod's are helpful structures, they have also faced a lot of criticism mainly because of the shape. Many people argue that tetrapod's in fact accelerate the beach erosion by disturbing the natural processes that shape the coastal environment. It also been said that the wave action on the on hard structures pulls the sand away from the shore faster than what happens in the natural process.

By combining the natural sea defense system with artificial hard structures can make it effective. They can be considered as a greener alternative for reducing the impact and also increase the sustainable sea defense system. Taiwanese designer Sheng-hung Lee and Malaysian designer Wan Kee Lee (2016) have created a concept for a new kind of sea defense that also functions as a set of giant plant pots. TetraPOT is a seminar shape to the current defenses often made from large concrete blocks called tetrapod's, designed to prevent soil erosion. Created as a hybrid between artificial defenses and mangrove forests- which are rapidly disappearing as sea level rise-TetraPOT's three-pronged concrete shell protects a preceded container, made from compostable material. As the Mangrove seeds inside grow, the designers hope they will create an interlocking barrier made from roots-which can grow through the pot's predrilled holes. TetraPOT's concrete exterior will protect the plants as they're maturing, while fully grown roots will help anchor each block in place. TertraPOT is an eco-friendly alternative to traditional tetrapod sea barriers. Randomly distributed TetraPOT's along coastlines will create trees and roots that eventually will intertwine against soil erosion and creating a natural ecosystem.

II. MODELLING AND TESTING

Modelling and testing are fundamental for evaluating the effectiveness of TetraPOT proposal. For this, experimental study should be done to evaluate the effectiveness of this proposal in real life exposure.

Experimental study was done on wave flume located at NIT Calicut with a dimension of 40 m x 2 m x 2 m with wave probes installed at 3 distinct places. One is 2 m Infront of the piston wave generator and other two placed Infront of and beneath the model. Wave probes generate wave output that can be used to evaluate the transmission coefficient of structure.

A. *Modelling and dimensioning.*

Tetrapod and TetraPOT were 3D modelled first with a scaling of 1:10 for experimental study in piston wave generation flume of dimension 40 m x 2 m x 2 m. Tetrapod and tetra-POT are moulded from mentioned 3D model in concrete using M20 specifications proposed by IS 10262 (2009) and mould was made by using clay.

Mangrove modelling was fundamental for evaluating the prop root spatial characteristics while implementing on a TetraPOT structure. Mangrove prop roots are modelled using copper wire with expected shape of occurrence.

Tetrapod and TetraPOT was made separately by using different mould shapes. The dimensioning of TetraPOT were slightly changed from proposed model for effective placing of mangrove plant inside the top leg.

Due to sloping surface of wave flume, an additional mounting structure was also required to provide the effective mounting height and porosity characteristics for the structure. For that, casting of additional frame was done using wooden framework with multi-wood as platform.

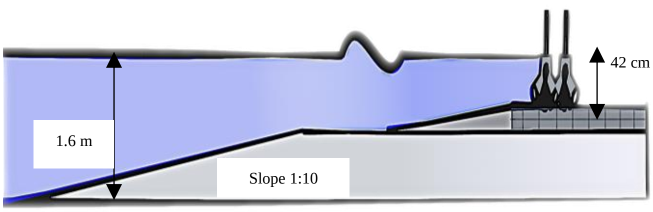


Fig 1: Schematic representation of wave flume and experimental setup with dimensions.

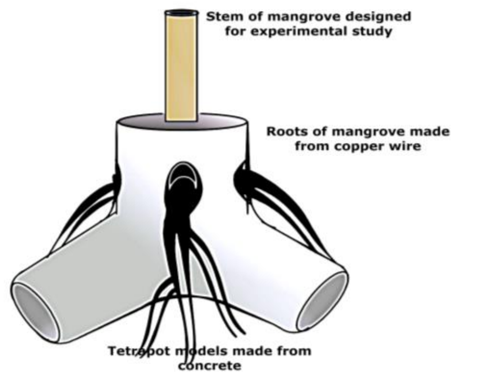


Fig 2: Pictorial representation of tetraPOT with prop roots.

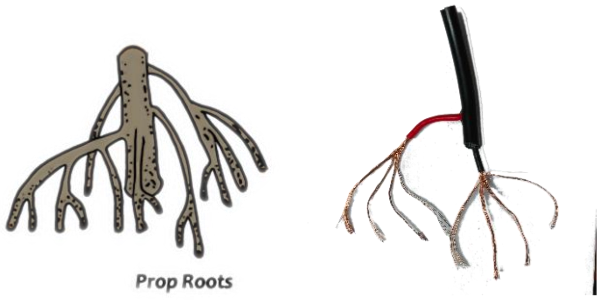


Fig 2.3: Schematic representation of mangrove roots and modelled roots using copper

B. *Testing and evaluation of model*

The tetrapod and TetraPOT have to be separately evaluated for understanding the effectiveness as a coastal protection structure. Also, equal intensity of wave parameters should be imparted to analyse the behaviour of each on different circumstances. For that, we have implemented different spatial arrangements for understanding how much effective can be on each arrangement.

We provided 3 kinds of spatial characteristics.

- The linear-closely packed spatial arrangement
- The non-linear staggered arrangement as per the journal. Sheng Hung Lee (2016)

Each arrangement was subjected to 3 different wave heights generated by EMCOM wave generation apparatus. The wave height was recorded using wave probes mounted to the apparatus and transmission coefficient was evaluated.

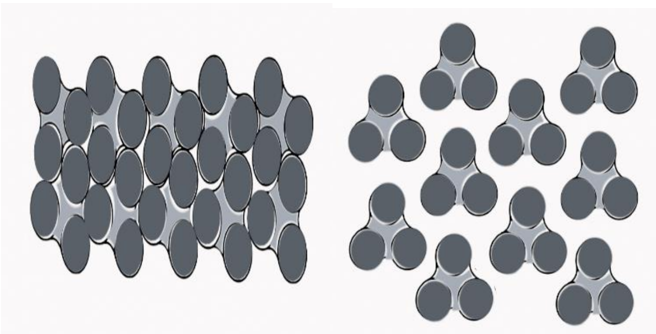
Transmission coefficient can be evaluated as:

$$K_t = \frac{\text{Wave height transmitted from the mounted structure(Ht)}}{\text{Wave height incident on to the mounted structure(Hi)}}$$

If the transmission coefficient is found to be low, the armour layer can be evaluated effective against wave surges or vice versa. By evaluating the transmission coefficients, a comparative graph was generated and found out the arrangement of TetraPOT that could be effective in reducing the wave impact force.

III. ANALYSIS OF DATA

After obtaining the experimental data, the data was analysed and results were generated as graphs. By comparing the transmission coefficient obtained by different spatial arrangement of tetrapod and tetraPOT, following results were obtained.



(a) (b)

Fig 3.1: Graphical representation of (a) linear arrangement (b) staggered arrangement

Table 3.1: K_t data for TetraPOT

Wave input parameter*	Hi (mm)	Ht (mm)	Hp (mm)	Ht/Hi
Input 1	9.057	7.023	10.82	0.725226
Input 2	10.05	8.026	10.066	0.776272
Input 3	12.01	11.035	14.025	0.942818
Input 4	9.057	8.02	12.025	1.155333
Input 5	10.05	8.033	10.015	0,978942
Input 6	12.01	10.022	14.066	1.011766

Table 3.2: K_t data for Tetrapod

Wave input parameter*	Hi (mm)	Ht (mm)	Hp (mm)	Ht/Hi
Input 1	9.057	8.558	19.6	0.752749
Input 2	10.05	8.205	12.067	0.784642
Input 3	12.01	11.278	15.864	0.814296
Input 4	9.057	8.8235	11.0854	0.766954
Input 5	10.05	8.8546	13.378	0.738992
Input 6	12.01	10.2056	16.576	0.798123

*****_Input corresponds to the EMCON wave generator input values for wave generation._

Case 1: Comparison of normal and staggered arrangement of tetrapod

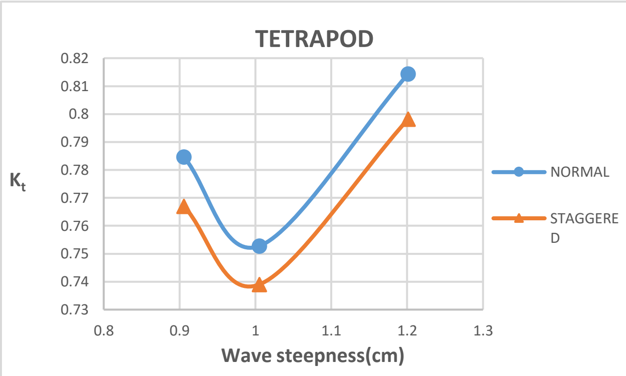


Fig 3.1: Variation of K_t for Tetrapod

The data obtained from the experiment shows Tetrapod is showing similar transmission properties while in normal and staggered arrangement. That means there is no variation on the behaviour of transmission coefficient by change in arrangement. The transmission values found lower for staggered arrangement.

Case 2: Comparison of normal and staggered arrangement of tetraPOT

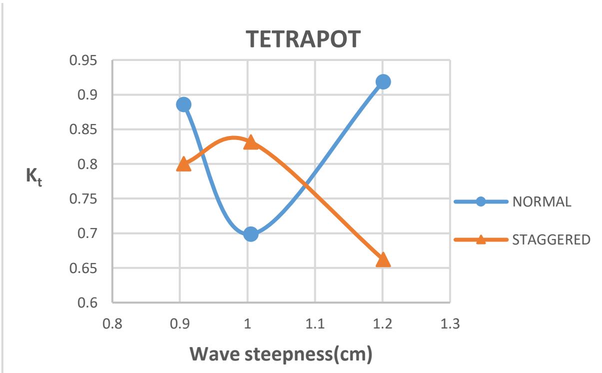


Fig 3.2: Variation of K_t for TetraPOT

TetraPOT shows inverse relation while in normal and staggered arrangement. As the wave intensity increases, the TetraPOT with staggered arrangement have high ability to reduce the energy of waves. For normal arrangement, it shows exactly similar property corresponds to tetrapod arrangement.

Case3: Comparison of normal arrangements of tetrapod and tetraPOT.

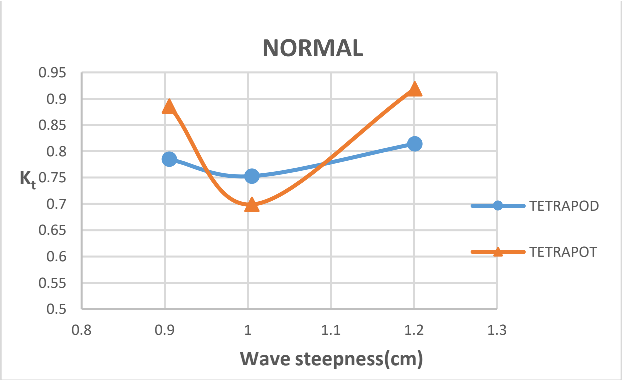


Fig 3.3: Variation of K_t for normal arrangement

The value of transmission coefficient of tetrapot is higher for high and low values. As the wave height increases, the transmission coefficient of tetrapot also increases.

Case 4: Comparison of staggered arrangements of tetrapod and tetra-POT.

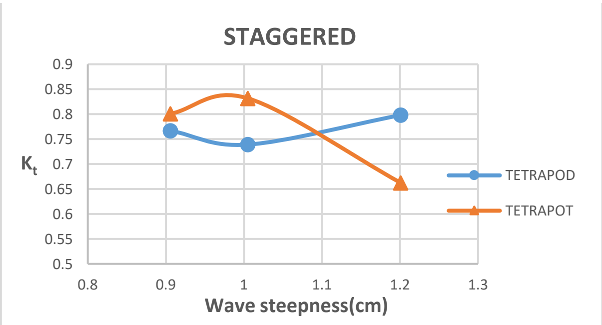


Fig 3.4: Variation of K_t for staggered arrangement

The value of transmission coefficient is high for tetrapot than tetrapod for initial values. As there is increase in wave height, transmission coefficient of tetrapot decrease compared to tetrapod.

By comparing the data obtained for normal arrangement in Tetrapod and TetraPOT, the transmission coefficient value decreases on increasing wave heights.

RESULTS AND DISCUSSION

The Experimental Observations are plotted for the normal and staggered arrangement for the tetrapod and tetra pot and following observations were made.

Case 1: Tetrapod with normal and staggered arrangement:

Transmission coefficient is showing similar characteristics while on normal and staggered arrangement. The change in arrangement of structures does not produce any influence on transmission of waves.

Case 2: Tetrapot with normal and staggered arrangement:

The staggered arrangement allows low transmission of waves for higher wave heights. That shows the staggered arrangement of TetraPOT provide more effective protection.

Case 3: Comparison of normal arrangement: -

Transmission coefficient of TetraPOT was higher for initial values and then decreases towards intermediate points. Then again, the value of TetraPOT increases.

Case 4: Comparing the Staggered arrangement of tetrapot: -

For higher values of wave amplitude, the transmission coefficient values of TetraPOT found lower than Tetrapod. It shows that the TetraPOT is highly effective in reducing energy of waves compared to Tetrapod.

TetraPOT showing good amount of reduction in wave energy of waves approaching the shore than tetrapod in high wave amplitudes. The root projections found in tetra-POT produces more vortex shredding compared to tetrapod that have provided the low transmission of waves. As the wave steepness increases, the chance of vortex shredding also increases, but the applicability of tetra-POT on very large wave steepness are yet to be clarified.

It shows that TetraPOT have a great future towards sustainable, cost-effective alternative on coastal protection, especially in Kerala were a large amount of coastal protection materials required for hotspot regions.

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