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STUDIES ON WAVE ENERGY DISSIPATING STRUCTURE FOR PUDUCHERRY COASTAL REGION

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Abstract-Puducherry coast situated along the East coast of India faces a serious problem of erosion for the past four decades. The problem was aggravated, after the construction of a fishing Harbour at the south of Puducherry. The formation of Puducherry Harbour by a pair of breakwaters has interrupted the movement of Longshore sediment transport and resulted in erosion at Northern side and accretion at the Southern side of breakwaters. The erosion has reached the upland which enrooted the subsidence of land and created a threat among the coastal community. For protection of shoreline erosion, the Puducherry government has built seawalls using boulders of size 0.50 tons to 1.50 tons for a total length of about 3 km. In many places along this seawall, the seabed below the seawall is eroded due to severe wave actions and ground settlement. For the past 10 to 15 years, the seawall is sinking and is replenished from time to time. To combat erosion and to support the incapable boulders from severe wave actions for protecting the Northern side of Puducherry coast, a suitable armour unit placement, both along the slope of seawall and at the toe is contemplated as a possible coastal protective measure, taking into account of existing environment conditions. The scope of this paper is to propose a wave energy dissipating structure (i.e.) armour unit namely Tetrapod for seawall protection. Analysis of a stretch of virgin beach for sediment transport and collection of wave climatic conditions proves to be useful in physical model studies. Creation of similar wave conditions and beach profile as a part of physical model study helps in checking the damage efficiency, energy efficiency, suitability (both quarry stones and Tetrapod) and consequences of armour unit placement in the stretch. The proposal is also believed to effectively support the beach nourishment activities proposed in the coast for regaining back the sandy beach.

Key words: Shoreline erosion, accretion, longshore sediment transport, quarry stones, armour unit.

I. INTRODUCTION

The coastal erosion is caused by the natural and manmade ventures. Natural ventures include wind, tides, longshore drift etc. Manmade ventures include construction of breakwater, groins, dumping of quarry stones in near shore zone etc. In order to reduce the erosion and incoming wave forces an effective energy dissipating structure is required. Here comes the amour unit (Tetrapod) which has to be designed for the site specific condition, to reduce the erosion and immersing of quarry stones into the sea, keeping a step forward to win back the sandy beach.

II. ORIGIN OF BEACH EROSION

Puducherry has lost its natural treasure, this proves that man-made disasters have long term negative effects. In 1986 a Harbour was built, stretching out to the ocean, blocking the movement of sand and taking away the beach. “Beaches are rivers of sand" because each year waves transport huge quantities of sand from north to south and south to north. Beaches are living creatures—winds and waves bring sand in one season and take it away in another. All interventions in this movement change the character of the coasts. In Puducherry the net movement of sand is form south to north. It encounters two monsoon firstly South West monsoon (June to September) when the sand movement is from south to north and secondly North East monsoon where sand is pushed north to south , but since wave action is more during SW monsoon and also since it lasts longer, the net movement is from south to north. Thus, this leads to increased rate of erosion on the northern side of Harbour resulting in loss of sandy stretch along the beach road.

The step taken by the government was building of sea wall using boulders. The size varying from 0.5 to 1.5 tons for a total length of about 3 km. In many places along this seawall, seabed below the sea wall is eroded due to severe wave action and ground settlement. This worsened the situation causing the boulders/quarry stones to slide into the sea and has also accelerated the erosion process resulting in increase in steepness of coast. Thus, this does not prove to be a sustainable solution. Since removal of existing boulders and adopting some protective measure proves to be a costlier affair, a better step forward could be placing of armour units namely Tetrapod on the toe and on the slope of the breakwater. This would cover up the incapability of boulders to face the existing wave climate, resulting in decrease in the rate of transient erosion.

III. METHODOLOGY

VIRGIN BEACH STRETCH

Coast analysis
(Oscillation study, Profile study)

Wave Climate Data

(Wave height, wave period, wave direction)

Physical Model Study by Creation of Existing Coastal Condition

IV. COAST ANALYSIS

Coast analysis involves surveying of a stretch of stable virgin beach in Puducherry. The purpose of survey was to determine the profile of the beach and its oscillations.

A stretch of about 550m near Pillaichavady has been selected to know the exact condition of the beach. Profile surveying was conducted for this stretch, at a regular interval of 30 m. For each 30m interval soil samples were collected for sieve analysis to determine the fineness modulus. By determining the fine modulus (with help of particle distribution) the oscillation of the beach can be evaluated for both southwest (January-September) and northeast (October-December) monsoon.

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TABLE I. Fineness modulus of various seasons

Fineness Modulus	
Survey 1	***Survey 2***
2.11	2.04
3.27	2.13
3.20	2.25
1.96	2.18
2.43	2.17
`2.00	2.14
1.97	2.04
1.94	2.13
2.02	1.91
2.00	2.02
2.13	2.04

It may conclude that in January to September, (survey1) the coast is subjected to erosion whereas in October to December (survey2) is subjected to accretion. In the stretch of virgin beach indicate that net sand drift is from south to north and formation of beach was observed.

V. WAVE CLIMATIC ANALSYIS

Waves are predominant factor for physical model test. so significant wave height , wave period are calculated over one year period (2016).

TABLE II. Tabulation of significant wave height

MONTHS	Average wave height (m)
January	0.81
February	0.82
March	0.59
April	0.67
May	0.65
June	0.79
July	0.70
August	1.84
September	0.87
October	0.86
November	0.84
December	0.95

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Fig.1. Stretch of virgin beach- Pillaichavady

Fig.2. Sieve analysis samples

VI. ARMOUR UNIT DESIGN

The armour unit which is concluded to be one of the suitable for the Puducherry coast based on stability number considerations and wave climate comparison is Tetrapod. This considerably proves to reduce overtopping.

A) Weight of armour unit

The **Hudson formula**, written as a function of the stability number, is very often a part of a more recent stability formula containing more parameters. Hudson's formula is commonly adopted in preliminary design to obtain rough initial estimate of rock size. However, this formula has following limitations 1. No account of wave period and storm duration. 2. No account of wave breaking type. 3. Limited description of damage level. 4. No account of permeability of structure and storm duration. 4. The recommended "K_d" values are based on no damage criteria

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Thus, compared with Hudson's formula, **Van der Meer formula** is more site specific, complicated and it is derived from results of a series of physical model tests. They include the consideration of wave period, storm duration, damage level and permeability of structure. The choice of the appropriate formula is dependent on the design purpose (i.e. preliminary design or detailed design).

B) DESIGN PARAMETERS

TABLE III. Parameters

Significant wave height	H_s(m)	1.5 m
Significant wave period	T_s(sec)	4.5 sec
Unit weight of armour unit	γ(N/m3)	0.500 kg

C) Weight of Tetrapod Armour layer

A widely used formula for the design of concrete armour layer is Hudson, by considering the limitations van der Meer formula is used.

Van Der Meer (1988),

$$\frac{H_s}{\Delta D_n} = C_1 + [C_2 + C_3 \frac{N_{od}^{C_4}}{N^{C_5}}] S_{om}^{C_6}$$

Where N -storm duration (number of waves, typically 1000 – 3000)

S_{om}- Wave steepness (Hs= 2π/ (g Tm)).

The values of C1, C2, C3, C4, C5, and C6 are tabulated below for Tetrapod,

TABLE IV. Values of constant

C1	0
C2	0.85
C3	3.75
C4	0.5
C5	0.25
C6	0.2

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TABLE V. Stability values of Tetrapod

Trunk section of Tetrapod		**Head section of Tetrapod**	
Breaking	*Non- Breaking*	*Breaking*	*Non- Breaking*
7	7	4.5	4.5

Where

$$S_{om} = \frac{2\pi H_s}{gTm2}$$

$$= \frac{2\times3.14\times1.5}{9.8\times4.6\times4.6} = 0.045$$

Substituting the s_{om} in vandermeer equation,

$$\frac{H_s}{\Delta D_n} = C_1 + [C_2 + C_3 \frac{N_{od}{}^{C4}}{N^{C5}}] S_{om}{}^{C_6}$$

By simplifying we get,

$$\frac{H_s}{\Delta D_n} = 3.09$$

Hence

$$K_d = (\frac{H_s}{\Delta D_n})^3 \times \frac{1}{\cot\alpha}$$

$$= 19.66$$

$$W_{50} = \frac{w_r\ H^3}{K_D (S_r - 1)^3 \cot\theta}$$

$$= 0.114\ t$$

By scaling down the model to specified scale which is suitable for the physical model study, the weight of Tetrapod will be 0.500 Kg.

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Height of the model (h) = 10 cm
Nominal diameter (D_n) = 0.65 h = 0.65*10 = 6.5 cm

D) Thickness of the Armour layer

The thickness of the Armour layer can be calculated from the below formula

$$t = n\, K_d \left(\frac{W_r}{\Upsilon_r}\right)^{1/3}$$

W_r = 0.113 tons

Υ_r = 2.4 m

N = 1

K_d =19.66

Substituting in the above equation we get,

T = 13 cm (by scaling down)

The average number of armour units per unit area (Na) may be determined by the formula

$$\frac{N_r}{A} = n\, K_d\, (1\text{- P})\left(\frac{\Upsilon_r}{W_r}\right)^{2/3}$$

For random placement of Tetrapod, simplifying the above formulae,

Na = 50 units /m2

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Fig.3. **Miniature models**

VII. EXPERIMENTAL SETUP

The experimental work was carried out in the 11 m long, 3 m wide and 1.8 m high wave basin with the test section installed at 10 m from the wave generator. To measure the incident waves and the transmitted waves after hitting armour units, a pressure sensor was used that reads based on energy hitting it. It is also used for measuring of the reflected waves.

The tetrapod blocks i.e. miniature models had an average mass of 500 g, an average height of 9.8 cm, and a nominal diameter of $0.65h$ = 6.5 cm. The blocks were placed by hand on the section, which had a slope of 1:1.5. The core and the under layer material was chosen such as to represent the coast. Bags of beach sand were placed into the basin at one end and the beach profile was created with the slope 1:1.5. The slope of the core was covered with small sized granite pieces representing the boulders in the coast. A similar arrangement as that existing in the coast was generated. The boulders were initially tested with regular waves of varying wave height pertaining to maximum values in various seasons for determining the pressure acting on them and also to determine the relative damage occurrence. This step was also used as trials to verify the beach profile change of the main coast (by movement of sand) for confirming that the wave climate is a scaled down version of what exists in the coast. The miniature Tetrapod were then placed on the slope in interlocking pattern and waves was passed to verify whether the same pressure as that of boulders acted on it(calibration step). Then the Tetrapod were also placed on toe as well on the complete slope and wave heights of different seasons where passed with different mean period and the pressure values were noted. A one meter line was marked for the purpose of determining number of boulders and armour unit that got displaced. And also the sand subsidence was also observed.

For better verification Tetrapod was placed as a mound with an interlocking pattern and waves were made to pass in order to check the reduction in wave height. Several trials were performed. After every trial, the core and armour layer was rebuilt. Each test was performed with a fixed cross-section, water depth, period and height. The cross-section was

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completely rebuilt before a new test was run. Each test was run in two stages: a first stage consisting of 100 waves with the damage being recorded at the end, followed by a second stage consisting of 200 waves and a cumulative damage recording.

Fig.4. Wave basin (3*11 mts)

VIII. TEST ON QUARRY STONES

The stability of the models was tested with different wave for various climatic conditions. The wave heights is about 50 % of the significant wave height and increased gradually in steps of 25% up to 125 % of the significant wave height . The duration of the test was for 200 waves, which is about 20 minutes for the prototype of 3 sec and 30 minutes for prototype of 5 sec wave period . The details of the testing program are provided in the Table. The stability of the quarry stones models in terms of damage assessment were evaluated from the visual observation during the action of waves and after 200 waves.

TABLE VI. Testing schedule for the quarry stones

(d=0.65 m, Number of waves =200)

Wave direction (degree)	Wave height (cm)	Wave Period (sec)
85	12	3
90	20	5

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A) DAMAGE ASSESMENT FOR QUARRY STONES

The damage to the quarry stones section is in terms of number of stones, which have been usually dislodged from the layer . This can be expressed in percentage of the total number of units displaced on the armour layer

The order of the damage for armour layer has been assessed using the formula ,

$$\% \text{ of damage} = \frac{\textit{Number of stones displaced}}{\textit{total number of units in armour layer}} \times 100$$

B) *TRAIL 1*

Different trials of wave height corresponding to peak values in each season were passed and the subsidence of boulders was noted. The result corresponding to maximum condition:

Total number of boulders placed in 1m stretch = 120

No of boulders displaced = 42

For the test with a wave period of 3secs, and significant wave height of 12cm, the maximum damage to the structure is found to be 33.33%

No overtopping of the crest was observed in this case.

C) *TRAIL 2*

Total number of boulders placed in 1m stretch = 120
No of boulders displaced = 50

For the test with a wave period of 5secs , and significant wave height of 20cm , the maximum damage to the structure is found to be 41.67 %

Spilling over the crest was observed when continuously exposed to about 200 waves or more.

The limit of maximum allowable percentage of damage is **5%.** Hence it is not acceptable to use the quarry stone in Puducherry coast.

TABLE VII. Damage efficiency of quarry stones

Wave height (cm)	**Wave period (sec)**	**Damage efficiency (%)**

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12	3	33.33%
20	5	41.67%

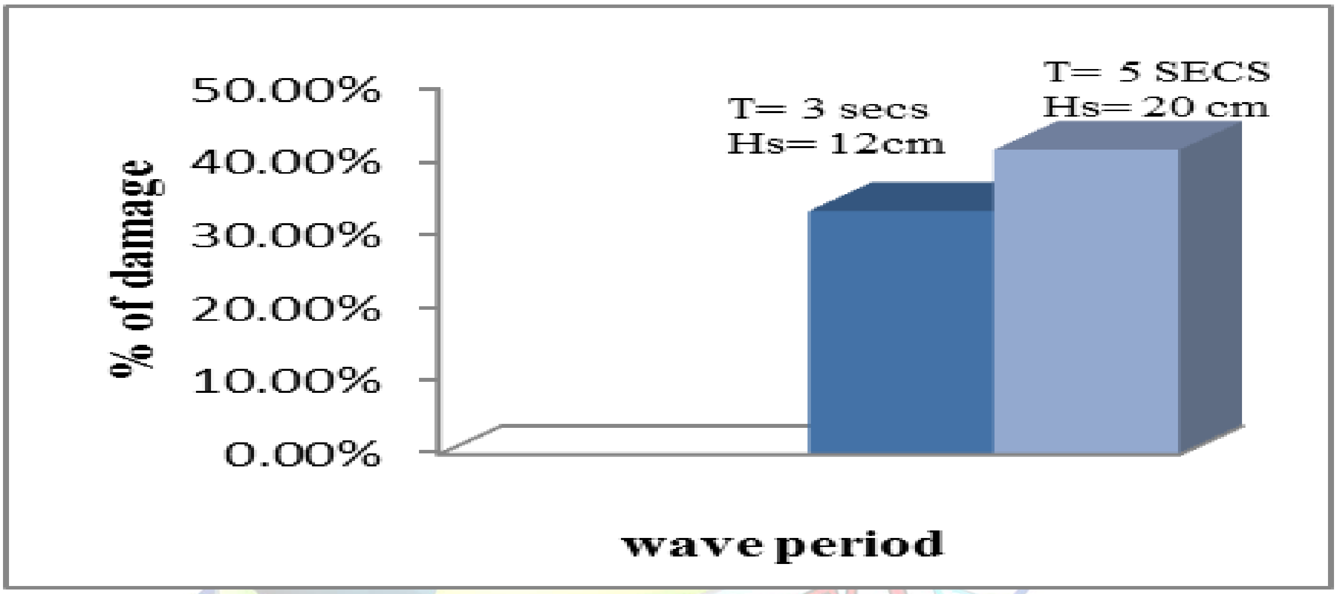

Fig.5. Percentage of damage of Quarry stones for significant wave height and wave period

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Fig.6. Quarry stones subjected to waves

XI.TEST ON TETRAPOD

Same wave conditions as that of quarry stones was used for testing of Tetrapods.

TABLE VIII. Testing schedule for the Tetrapod

(N=50 Tetrapod D=0.*65h,* Number of waves =200)

Wave direction (degree)	**Wave height (cm)**	**Wave Period (sec)**
85	12	3
90	20	5

A) *TRAIL 1*

Same procedure followed for quarry stones is observed in the Tetrapod. The damage efficiency of Tetrapod is tabulated below.

Total number of Tetrapod per m length=50

No of Tetrapod displaced = 1

For the test with a wave period of 3secs, and significant wave height of 12cm , the maximum damage to the structure is found to be 2%

No overtopping of the crest was observed in this case of Tetrapod

B) *TRAIL 2*

Total number of Tetrapod per m length=50

No of Tetrapod displaced = 1

For the test with a wave period of 5secs, and significant wave height of 20cm, the maximum damage to the structure is found to be 2%.

Spilling over the crest was not observed when continuously exposed to about 200 waves or more.

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TABLE XI. Damage efficiency of Tetrapod

Wave height (cm)	**Wave period (sec)**	**Damage efficiency (%)**
12	3	2%
20	5	2%

Percentage of damage limits **(i.e.) 5%.** Hence it is acceptable to use the Tetrapod as armour unit in Puducherry coast .

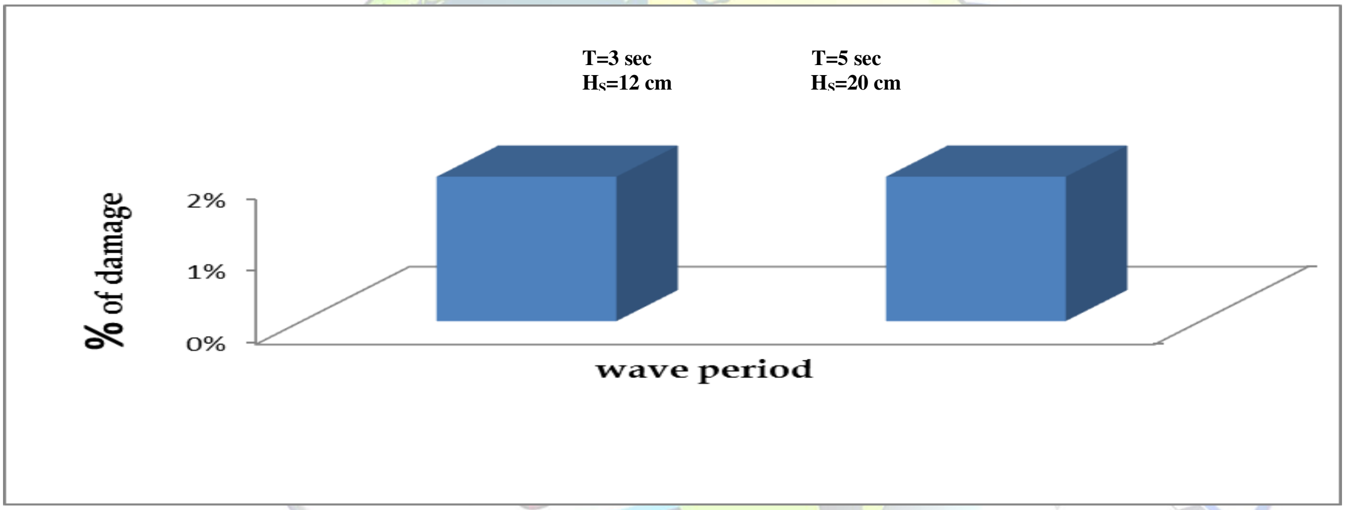

Fig.7. Percentage of damage of Tetrapod for significant wave height and wave period

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Fig.8. Tetrapod subjected to waves

X. WAVE ENERGY DISSIPATION BY TETRAPOD

The Tetrapod were placed in front on the seawall slope with a interlocking pattern in the form of a mound and the setup was subjected to regular wave pattern. The units were continuously monitored for determining the damage.

After passing a standard number of 100 waves onto the structure the wave height was measured using a scale both on leeward and seaward side of the armour unit mound. Pressure sensor was also used for determining the amount of energy dissipated. At specified Scale,

Wave height on the seaward side of Tetrapod = 2cm

Wave height on the leeward side of Tetrapod = 0.9cm

$$\frac{{H_t}^2}{{H_i}^2} = \frac{E_t}{E_i}$$

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From the above equation amount of energy transmitted was found and the percentage decrease in the wave energy due to placement of Tetrapod for the Puducherry coast condition was found to be **79.75%.**

Fig.9. Measurement of dissipation

XI. CONCLUSION AND RECOMMENDATIONS

Physical model studies were conducted to determine the efficacy of quarry stones and Tetrapod as a armour layer to prevent subsidence of Quarry stones into sea and to prevent the erosion in the Northern side of the coast. Of the two types tested the Quarry stones (33.33%, 41.67%) has higher damage efficiency than the Tetrapod (ie.2%). The maximum energy dissipation by the Tetrapod is 79.75%. By analysing the force on the structure (seawall with boulders) with the placement of armour unit it is found to be reduced by 38 %. For 1:1.5 slope, stability coefficient is 19.66 for random wave condition in the Puducherry coast.

To protect the northern coast from erosion, rubble mound seawalls where built by the government. Taking into account economic optimisation it is concluded that placement of Tetrapod as armour layer on the slope and as well as on the toe of the existing seawall proves to be the suitable mitigation step. This will also support the beach nourishment activities proposed for the coast and reduce the transient erosion.

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We conclude that placing Tetrapod on the existing seawall slope and toe, is a step forward in reduction of wave energy hitting the coast. Furthermore, a series of submerged wave energy dissipating structures could be studied for the existing coastal condition which would further reduce the incoming wave energy. This would improve the hydraulic stability and durability of proposed Tetrapod and boulders. Also the armours can be placed in the virgin beach stretch of Puducherry, Karaikal to prevent the beautiful sandy beach from getting eroded due to aggressive coastal environment. In addition to this, artificial beach nourishment can also be carried out in the coast and the combination of mitigation steps is sincerely hoped to work effectively and win back the beach.

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