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Performance Evaluation of Groynes for Protecting Coastlines - A Case Study of Alappad Coast

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***Abstract*—-The effectiveness of transition groynes for the protection of Alappad coast is numerically investigated using the software MIKE 21. The study area comprises of a coastal stretch of 3.5 km along shore and 6.5 km offshore. Results reveal predominant longshore transport which favours selection of groynes as a coastal protection measure. Parametric studies are conducted to reach a suitable configuration of transition groynes that drastically reduces the sediment transport rate especially during monsoon. Design of the proposed groyne field is also presented.**

Keywords—coastal protection, groyne, sediment transport

I. Introduction

Coastal erosion has become a serious threat which has a long term effect on the coastlines. Coastal properties and roads are ruined by erosion, particularly during the monsoon. Long lasting coastal protection methods are needed to solve the beach erosion problems. Groynes offer an attractive solution in reducing the long shore sediment transport and also in restoring the shoreline of the area. The coastal state of Kerala, lying in the western coast of India has a coastline of 588 km and experiences intense wave activity. The coastal properties and roads remain threatened by erosion, particularly during the south-west monsoon. A case study is undertaken at Alappad coast (9°2' N, 76°30' E to 9°4' N, 76°29' E) of Kerala. The precious mineral-rich soil of this region contains Ilmenite which is used for Titanium dioxide production. Groynes are expected to offer significant protection from coastal erosion especially during monsoon as they form a cross-shore barrier that traps sand that moves along-shore, thereby increasing the width of the beach on the upstream side. Wave-induced long-shore currents move sediments and cause it to accumulate along the groyne's up-drift side. The groyne also shelters a short reach of shoreline along its down-drift side from wave action. But when groynes are placed, it often results in erosion on the down-drift side of the structure. Down-drift erosion can be reduced by filling the groyne embayment and by the use of transitional groynes both up-drift and down-drift to allow changes in the beach. Thus transition groynes were considered in the study to reduce the negative effects of down- stream erosion in the study area.

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Studies point out to the fact that the effectiveness of various hard coastal protection measures is purely site-specific depending on the various parameters existing in the site such as predominant current direction, sediment characteristics etc. Studies conducted by Schoones *et al.* [3] found out that groynes acted as total traps to sediment transport and the accreted sand was only slightly coarser than that before the groynes were constructed. Joseph *et al.* [1] suggested that groyne system with two groynes which go up to 5 m water depth with spacing of twice the length was most effective for the coast of Paravoor located on the south-west coast of Kerala. Thus groynes function best on beaches with a predominant along-shore transport direction.

II. Analytical Investigation

The feasibility of transition groyne field in the study area is numerically investigated using the 2D free surface numerical model, MIKE 21- Near-shore Spectral Wave (NSW), Hydrodynamic (HD) and Sediment Transport (ST) modules. The net littoral transport and shoreline evolution due to the introduction of groynes are output in LITPACK. Bathymetry of the study area is generated in MIKE 21 from the water depth data, and is the input in NSW module. This module is used to calculate the refraction and shoaling of the incident waves. The output from NSW module is the significant wave heights and radiation stresses in the study area. These results are used as boundary conditions in order to generate flows due to waves in the module MIKE 21 HD. This module calculates the wave generated orbital currents x and y directions. The results of MIKE 21 HD are then used to generate the bed load sediment flows in the x and y directions in MIKE 21 ST module. The net annual littoral drift occurring in the area is calculated using LITDRIFT module in LITPACK over a selected cross-shore profile and the shoreline evolution occurring in the study area over a given period of time due to the introduction of groynes is obtained in the LITLINE module in LITPACK. In order to obtain the shoreline evolution due to the application of groynes, the wave climate data is to be given as input in the form of a time series whose accuracy is to be ensured by calibrating with the output obtained from the net annual sediment drift from LITDRIFT.

The seasons are described as 'pre-monsoon' for February-May, 'monsoon' for the south-west monsoon period of June-

September and 'post-monsoon' for September–December. Three cases each for the three seasons have been analyzed i.e., (1) without groynes (2) with nine transition groynes (L= 200 m, 158 m, 125 m) of spacing 2L and (3) with seven transition groynes (L= 200 m, 142 m) of spacing 2L, where L= length of individual groyne.

A. *Input Data*

The data required for the modeling are wind and wave data, tidal data, sounding data and sediment characteristics. Some of these data were collected from published literature and the others were obtained from Port Office at Neendakara and Danish Hydraulic Institute (DHI India). The wave data viz. significant wave heights, mean wave direction and mean wave period used for the study taken from Nair and Kurian [2] is tabulated in Table 1.

TABLE I. OFFSHORE WAVE DATA OF ALAPPAD AREA

Season	Mean sig. wave ht.	Mean wave direction	Mean wave periods
Pre monsoon	0.4 m	240-2700	5.6 – 7.2 s
Monsoon	2 to 2.2 m	250-2720	8 – 8.8s
Post monsoon	1.6 to 1.8m	270-2850	7 – 8 s

B. *Bathymetry*

The bathymetry of the study area modelled is depicted in Fig.1 for the three cases; viz. Case 1-without groynes, Case 2-with transition groynes of spacing 2L, Case 3- with transition groynes of spacing 2.75L.

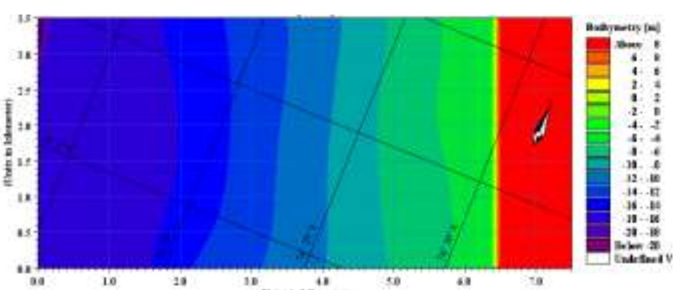

Fig. 1 (a) Case 1

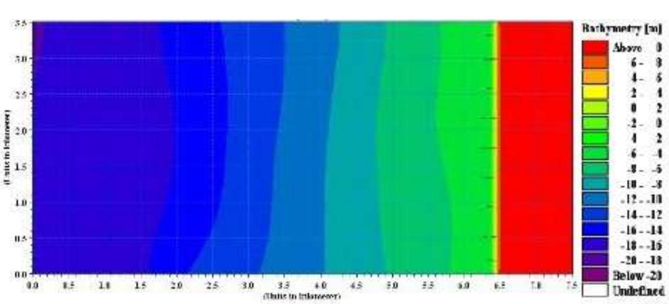

Fig. 1 (b) Case 2

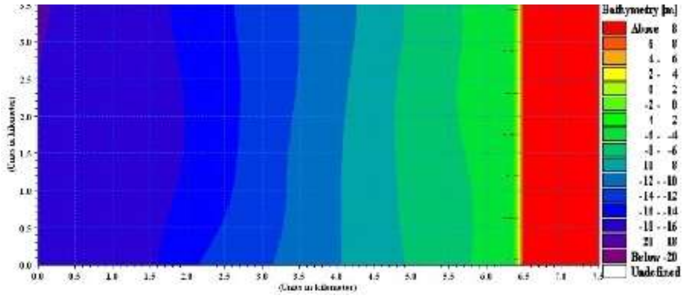

Fig. 1 (c) Case 3

Fig. 1 Bathymetry of the Study Area Derived using MIKE 21

III. Results and Discussion

A. *Wave Parameters*

The significant wave height (Hm_0) at the study area for the cases investigated, during monsoon season as obtained from MIKE 21 NSW simulation is shown in Fig.2. It is evident that when groynes are used, reduction in wave height is observed only in the immediate vicinity of the structure.

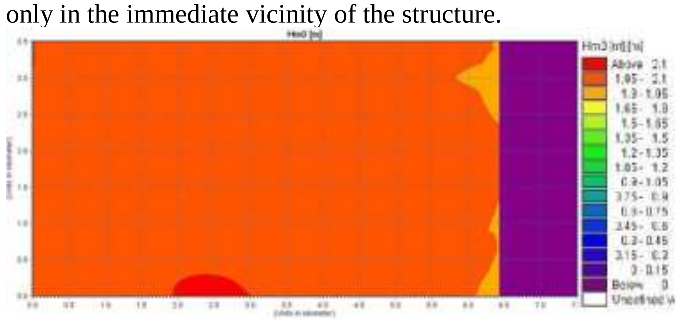

Fig. 2 (a) Case 1

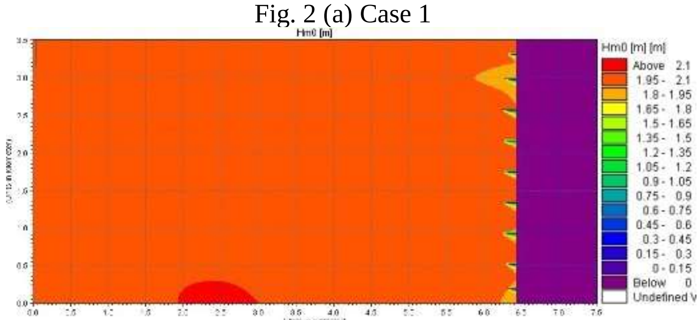

Fig. 2 (b) Case 2

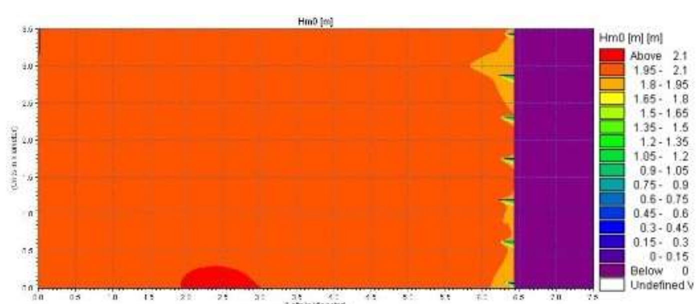

Fig. 2 (c) Case 3

Fig. 2 Significant Wave Heights during Monsoon (July)

This result is expected, as wave height reduction is not a function of groynes.

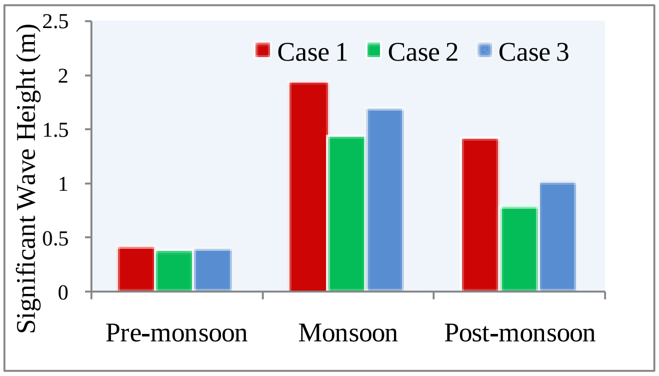

Fig. 3 Wave Heights for the Various Cases during the Three Seasons

The significant wave heights obtained for all the cases and seasons considered are compared in Fig. 3. The wave height reduction obtained by Case 2 where the spacing of the groynes is twice the length is more when compared to Case 3 where the spacing of the groynes is 2.75 L.

B. Current Speed and Direction

The simulation results obtained from HD module for monsoon season for the three cases are presented in Fig. 4. It could be observed that northerly current is dominant during all the three seasons. The current velocity for the area under study is observed to be between 0.5 m/s to 1 m/s.

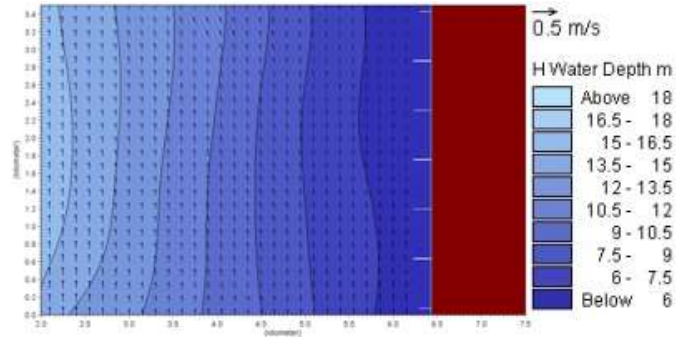

Fig. 4 (c) Case 3

Fig. 4 Typical Current Circulation during Monsoon (July)

Thus use of groynes would be a suitable shore protection measure from the perspective of reducing the currents, as it could offer a suitable barrier to the northerly currents which is dominant for all the three seasons considered.

C. Sediment Transport Rates

Potential areas of erosion or deposition of the coastal area can be identified with the help of the results obtained from the simulation in MIKE 21 ST module. A positive value in the cross-shore sediment transport indicates accretion in the coastline due to the transport of sediment towards the shore. The cross shore and long shore sediment transport as obtained from the simulation is shown in Fig. 5 and Fig. 6 respectively.

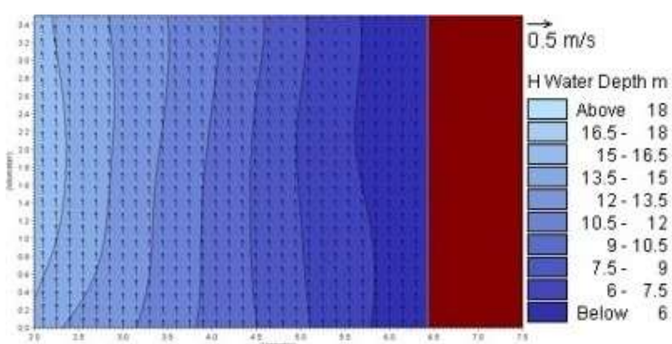

Fig. 4 (a) Case 1

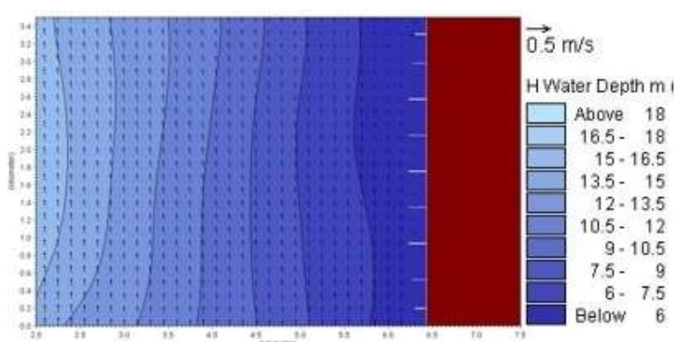

Fig. 4 (b) Case 2

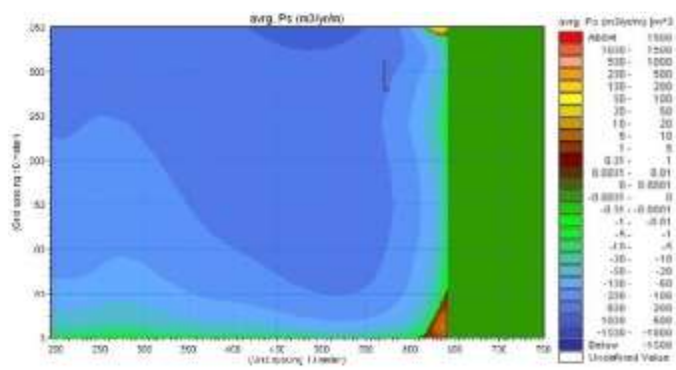

Fig. 5 (a) Case 1

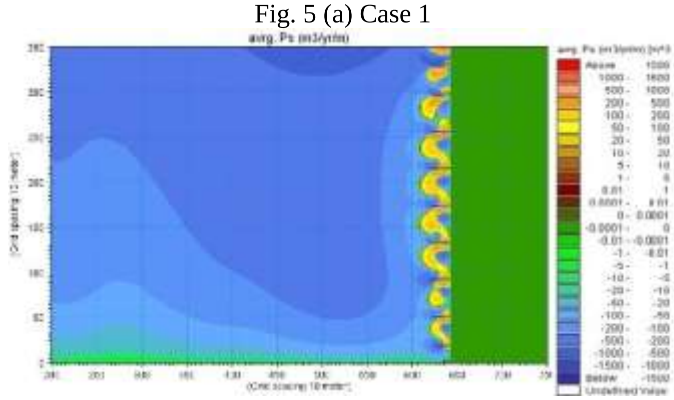

Fig. 5 (b) Case 2

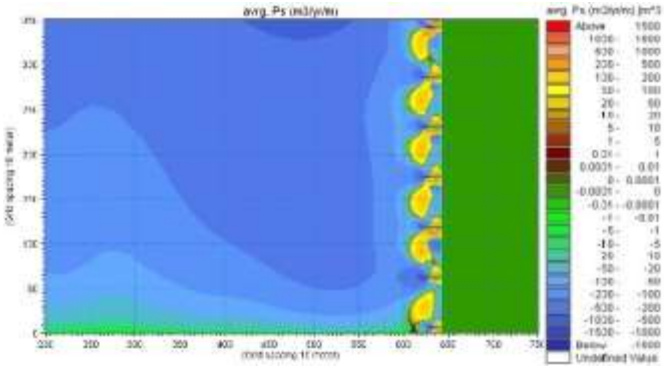

Fig. 5 (c) Case 3

Fig. 5 Cross-Shore Sediment Transport during Monsoon (July)

In the Fig. 5 (a), the blue patch indicates a negative value which implies that the sediment transport is in the offshore direction when no groynes are present. In Fig. 5 (b) and Fig. 5 (c), the yellow portion in the vicinity of the groynes indicates a positive value of sediment transport, which means that there is accretion of sediment towards the shoreline.

In long-shore sediment transport, negative sign indicates sediment transport towards south and positive sign indicates towards north. Thus from Fig. 6, the intensity of long-shore sediment transport also reduces when compared to the condition where no groynes are used. A change in the direction of sediment transport could also be observed near the groynes during the three seasons.

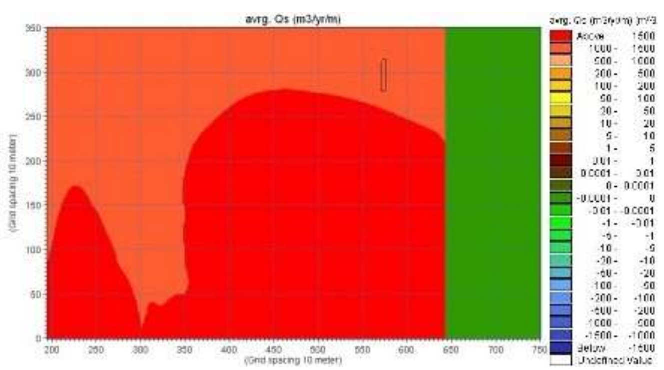

Fig. 6 (a) Case 1

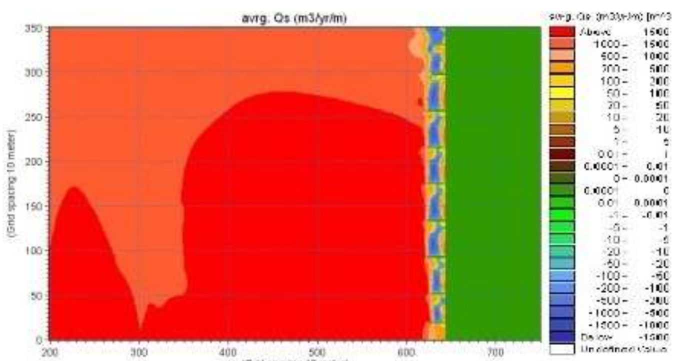

Fig. 6 (b) Case 2

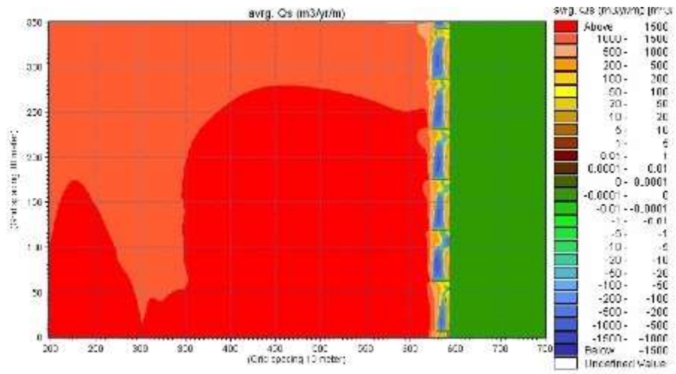

Fig. 6 (c) Case 3

Fig. 6 Long-Shore Sediment Transport during Monsoon (July)

D. *Littoral Drift*

LITLINE in LITPACK module is used for the determination of shore line evolution occurring over a given period of time. The net annual littoral drift occurring in the study area when no protective structures are present is about 0.8875×106 m^3/year over a selected cross-shore profile. Fig. 7 shows the expected beach evolution after one year and Fig.8 shows the expected beach evolution after three years due to the introduction of transition groynes.

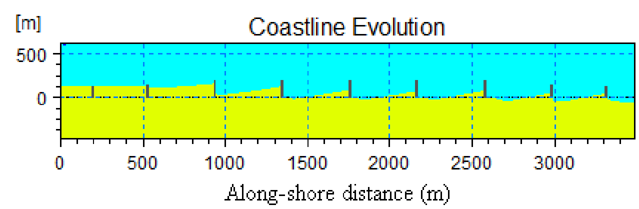

Fig. 7 (a) Case 2

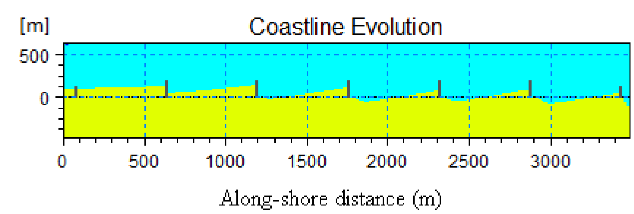

Fig. 7 (b) Case 3

Fig. 7 Plan of Coastline Evolution after One Year

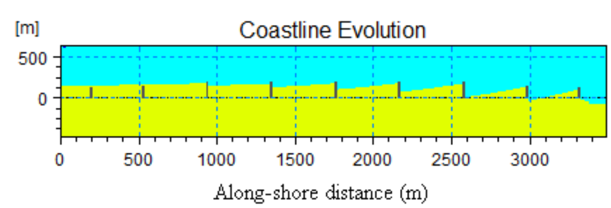

Fig. 8 (a) Case 2

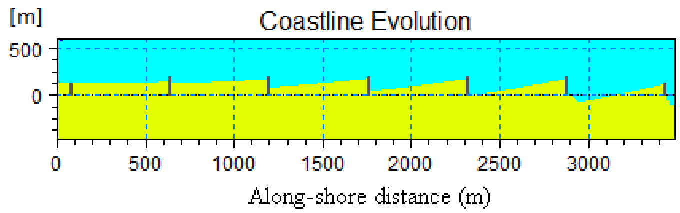

Fig. 8 (b) Case 3

Fig. 8 Plan of Coastline Evolution after Three Years

In Fig. 7 and Fig. 8, the blue portion indicates water, yellow portion indicates beach material and 0 m in the offshore direction indicates the initial beach position. After three years, Case 2 trapped maximum sediment in the up-drift side when compared to Case 3. From Fig. 7 and Fig. 8, it is clear that increased spacing between the groynes resulted in poor retention and scour within the groyne field. It can also be observed that Case 2 and Case 3 suffered down-drift erosion whose intensity may be reduced by artificial beach nourishment or sea-wall protection in the down-drift side. Results point out to the fact that Case 2 where transition groynes are with a spacing of twice the length is a better solution compared to Case 1 where no groynes were provided and Case 3 where transition groynes are placed at a spacing of 2.75 L.

E. ***Design of Transition Groynes***

The cross section of the proposed groyne system is designed using the guidelines given in Shore Protection Manual [4]. Groynes consist of interior graded layers of stone and an outer armor layer of stone or specially shaped concrete units such as tetrapods. Armor units must be of sufficient size to resist wave attack. However, if an entire structure is to consist of units of this size, the structure would allow high levels of wave energy transmission and finer material in the foundation or embankment below the structure could easily be removed. Thus, the structure unit sizes are graded in layers, from the large exterior armor units to small quarry-run sizes and finer stone at the core and at the interface with the native soil bed. The designed cross-section of the groynes with tetrapod armour layer is presented in Fig. 9. Tetrapods are used for reducing the cost and improving the stability of the structure.

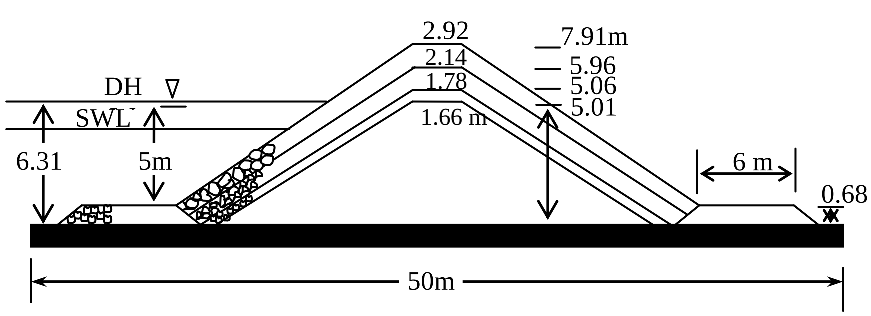

Fig. 9 Designed Cross Section of Groyne

IV. Conclusions

Based on the numerical model studies, it was observed that the effectiveness of transition groynes in wave height reduction is limited to its immediate down-drift side. In the Alappad coast, northerly currents are prevalent for all the three seasons in the near-shore region thereby making long-shore sediment transport dominant than cross-shore sediment transport which is suitable for the introduction of groynes as a shore protection measure. It was also found that spacing between groynes equal to 2 times the length is a better option compared to spacing of 2.75 times the length with respect to sediment trapping efficiency as well as shoreline development. Both configurations of the groynes exhibited down-drift erosion which might require artificial beach nourishment or seawall protection in the area immediately down-drift of the groynes. The groyne field can also be extended to the southern breakwater of the Kayamkulam harbor, which will make the entrance channel of the harbor coincide with the down drift erosion area which in turn will prevent the sedimentation of the entrance channel.

Acknowledgement

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