Hydrodynamic Modelling On Seabed Scour In Front Of The Seawall – A Case Study

P. Mohamed Rajab, J.Abjit and S.Shafeer Ahamed

Abstract : Seawalls are constructed along the shoreline to prevent coastal erosion due to wave action. Scour at seawall toe is an important aspect leading to the failure of many seawalls and it can cause structural instability. In this study, the investigations on seabed scour in front of the seawall existing along the Puducherry coast have been carried using one dimensional, DHI-LITPACK-LITPROF module for three monsoon seasons viz., i) Fairweather, (ii) South west monsoon season and (iii) Northeast monsoon season. The numerical result indicates that the maximum scour hole formation in front of the seawall after completion of one year simulation i.e. at the end of the northeast monsoon season is around 4.5m with covering 100m wide area and 110 m away from the seawall. In front of the seawall an alternative scour and deposition has been observed in seawall parallel.

Key words: Sea wall, Scour, Seabed, one dimensional model, DHI-LITPACK, LITPROF module and Puducherry]

1 INTRODUCTION

Scour at seawall toe is an important factor leading to the failure of many seawalls and it can cause structural instability. Scour will occur away from the toe of the structure in the case of inclined seawall. It is accounted about 12% of the failure case studies in history [1] and for an additional 5% of cases in some way liable which includes fill material washing out, breaking up / breaching of seawalls. Incidents of failure of seawall construction due to scour have been reported worldwide [2], [3] and [4]. The two breakwaters is constructed at Ariyankuppam river mouth along the Puducherry coast which is the primary cause of coastal erosion, South India and barricade the natural drift of sand from south to north during the monsoons. There is a localized adjustment of shoreline geometry, with accretion on the south of river mouth and erosion on the northern side of the breakwater. To put off beach erosion, 8.55 km length of seawall has been built by the Government of Puducherry with boulders varying size of 1.5 tons to 0.5 tons. It is being eroded due to forceful wave action and ground settlement in many places. Sliding of the armor layer of existing seawall along the Puducherry coast is shown in Fig. 1. In the present analysis, the bed level changes due to scour in front of the seawall existing along the Puducherry coast have been carried using DHI-LITPACK-LITPROF module for three monsoon seasons viz., i) Fairweather, (ii) Southwest monsoon season and (iii) Northeast monsoon season. The objectives of the present investigations are to assess the scour potential and to predict scour depth is essential in order to propose suitable design methods.

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The baseline data on geomorphology, bathymetry, sediment properties, water properties, tides, currents, wind, waves, and storms over the coastal region of Puducherry were compiled from available reports and data records to understand the nearshore sediment process and to predict the scour depth in front of the seawall for three monsoon season. The measured waves at 15m water depth off Puducherry coast have been used in this study to assess the scour depth near seawall front for different season.

Fig. 1 Sliding of armor layer of seawall existing along the Puducherry

1.1 Seabed Scour in front of the Seawall – Theoretical Background

The 2-dimensional seabed scour in front of the seawall, the approaching waves at right angles to the coast may involve the following flow process, viz., i) it may break on the seawall itself, ii) it may break before they reach the seawall, iii) during storm surges, the waves may reach the seawall without breaking and are reflected and iv) the waves may overtop the seawall. The strong downward directed flow is created while wave breaking which is erode the bed [5]. For plunging wave breaker, the plunging breaker will go through down to the bed and drift the sediments at the seawall toe area. These processes will most probably lead to scour at vertical wall breakwaters. The maximum scour depth will be developed during wave plunging at the wall; the reduction of reflection reduces the scour and the current will increase the reflection. Fowler's studied the scour at vertical wall and proposed the following empirical equation [6],

$$\frac{S_m}{(H_{mo})_o} = \sqrt{22.72\frac{h}{(L_p)_o} + 0.25} \qquad (1)$$

Where, S_m = Maximum scour depth from bed level (m), (Hmo)o = Deep water significant wave height (m), h = pre scour water depth at breakwater (m), (Lp)o = Deepwater wave length (m) associated with Tp. Tp= peak wave period (s). This equation is valid for the following condition,

$$0.11 < \frac{h}{L} < 0.045 \quad and \quad 0.015 < \frac{(H_{mo})_o}{(L_p)_o} < 0.04$$

The similar equation given by Hughes (1997) for the maximum scour is given as $S_m = H_{max}$ or $S_m = h$, where, S_m= maximum scour depth in front of the vertical wall breakwater (m), H_{max} = maximum wave height (m), h = water depth (m). For estimating maximum scour depth and other characteristics of the scour process in the case of sloping seawalls, no generally acceptable method is available and thumb rules are given in manaul [5]. Hence, a conventional scour estimate is adopted. At the toe of a sloping structure The maximum scour is expected to be somewhat smaller than that calculated for a vertical seawall at the same location and under the same wave conditions.

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2 METHODOLOGY - NUMERICAL MODEL APPROACH

Several researchers have examined the scour pattern near the seawall using numerical model such as SBEACH, DHI-LITPACK module [7], [8] and [9]. The model results have been compared with the results of a large scale physical model study. This numerical model comprises of two elements; (i) nearshore wave-transformation model and sediment transport algorithm. The wave model includes refraction, shoaling, breaking and reflection phenomena from the seawall. The sediment transport is used to predict the beach profile. In the present study, the bed level changes due to scour in front of the seawall existing along the Puducherry coast have been carried out using DHI-LITPACK-LITPROF module for three monsoon seasons viz., i) Fair-Weather, (ii) South-West and (iii) North-East monsoon seasons. DHI- LITPACK-LITPROF is a suitable and verified tool for analyzing the beach profile changes caused mainly by wave action. It can be applied to a different variety of situations involving almost arbitrary numbers and combinations of groins, jetties, detached breakwaters, seawalls, and beach fills [10].

2.1 DHI-LITPACK-LITPROF Model Description

The DHI-LITPACK-LITPROF is used to identify the cross-shore profile changes with or without the presence of structure for different wave and storm condition. A short description about the applications, basic equations and solution techniques for LITPROF module is presented [10]. LITPROF module can be applied to examine storm profile progress and the shoreline behaviour for beach nourishment and storm conditions. Furthermore, a profile envelope for various wave conditions may be obtained forming the basis for estimating burial depths for pipelines. LITPROF module describes the variations of cross-shore profile by solving the sediment bottom continuity equation by STP calculation of sediment transport rates. LITPROF module is being a time-domain model includes the wave induced beach morphology and transport regime. It enables a simulation of profile progress for time-varying wave field incident. LITPROF module involves the following efforts,

- ✓ Wave shoaling
- ✓ Wave breaking
- ✓ Sediment transport, including the effects of undertow, streaming, Lagrangian drift and bed slope.
- ✓ Structures (submerged breakwater and/or revetment).

The following basic input is required in LITPROF module,

- ✓ Cross-shore profile bathymetry
- ✓ wave heights and water levels in Time-series
- ✓ Sediment data

The main outputs from LITPROF module are as follows,

- ✓ Beach Profile response under various conditions
- ✓ Effect of nourished material
- ✓ Profile response to structures
- ✓ Profile envelope

2.2 Model Equation

Sediment transport tables based on STP calculation are used, as the basis for the morphology module describing the development of the coastal profile. The bed level change is described by the sediment transport rate continuity equation as

$$\frac{\partial h}{\partial t} = -\frac{1}{(1-n)}\frac{\partial q_s}{\partial x} \qquad (3)$$

where, h – water depth in metre, t- time in seconds, qs – volume of sediment transport rate (m3/yr), x-beach width (m). The boundary condition is that the sediment transport rate is zero at the coastline. The morphological model cannot be based directly on the sediment transport rates calculated from the local wave parameters, because it is not physically correct to expect an immediate, local response of the sediment transport for varying hydrodynamic conditions. Today no theory exists that can describe the actual cross shore variation of the sediment transport and a heuristic transformation of the sediment transport calculated from the local conditions has been applied. The transformation reflects that the circulation current dose not adjust immediately to the driving forces, but develops gradually. The peak of sediment transport is therefore shifted shore wards relative to the maximum of the driving forces. The transformation, giving the sediment transport, qsl used for profile modeling, is expressed as a response function:

$$\frac{\partial q_{sl}}{\partial x} = \frac{q_s - q_{sl}}{L} \qquad (4)$$

Where, L – profile length (m), qs – volume of sediment transport rate (m3/yr), qsl – volume of sediment transport rate over profile length (m3/yr), x-beach width (m). The above equations are solved with variables defined on a space staggered equidistant horizontal grid using finite difference techniques [10].

3 MODEL INPUT DETAILS

3.1 Sediment Grain Size

The seabed sediment of the coastal region of Puducherry is predominantly composed of medium sand to coarse sand [11].

The mean grain diameter of the sand is 0.2mm. The median size of d_{50} = 0.2 mm with gradation of 1.1 has been given as input to the LITPROF model [12].

3.2 Cross-Shore Beach Profile

The measured cross-shore beach profile data is compiled from the bathymetry survey [13]. This survey area is covering 20 km along the Puducherry coast and up to 20m water depth across the shore. The variation of water depth with distance from the shore is is given as input to the LITPROF module shown in Fig. 2.

3.3 Measured Wave Data at 15m Water Depth

The measured wave data at 15m water depth, southeast of Ariyankuppam village, Puducherry (latitude: 11.87^{o} N and longitude: 79.84^{o} E), at 3 hourly interval for a period of one year by Indian National Centre for Ocean Information Services (INCOIS), Hyderabad have been compiled and analyzed. This data set contains of information on significant wave heights, zero crossing wave periods and directions of waves corresponding to peak energy. In the present study, the measured waves at 15 m water depth off Puducherry coast at the interval of 3 hours from January 2008 to December 2008 is used to predict the scour depth in front of the seawall. The wave climate has a data of 2928 [12].

3.4 Model Setup and Validation of Module Results

The DHI-LITPACK module setup is shown in Fig. 3. The profile orientation is 105° N (shore normal off Puducherry coast). The grid spacing is selected as 10m which is on the basis of the profile length. The predicted beach profile changes using DHI-LITPROF module is validated with measured beach profile on 23.2.2017 along the Puducherry coast The predicted shoreline changes have qualitative agreement with measured beach profile.

4 RESULTS AND DISCUSSION

4.1 Scour and Deposition Pattern in front of the Seawall

The simulation of scour and deposition pattern in front of the existing seawall is performed using DHI-LITPACK-LITPROF. module. The simulated results for three seasons are discussed as below. Fair-weather Season: The scour and deposition in front of the seawall after completion of fair-weather season period is shown in Fig. 4. The measured waves at 15m water depth representing fair-weather season, i.e. from 15th February 2008 to 30th April 2008 is given as wave input to the module. The simulated results clearly show that the seawall has impact on beach profile. In front of the seawall an alternative scour and deposition have been observed in seawall parallel and matches with previously published results [11] and [13]. The maximum scour hole formation in front of the seawall during Fairweather season is around 0.5m in depth and 25m width at -1.5m water depth and 50 m away from the seawall.

Southwest monsoon season: The scour and deposition in front of the seawall after the completion of southwest monsoon season period is shown in Fig. 5. The measured waves at 15 m water depth representing south west monsoon season, i.e. from 15th May 2008 to 15th October 2008 have been given as wave input to the module. The simulated results clearly indicate that the seawall has impact on beach profile. In front of the seawall an alternative scour and deposition have been observed in seawall parallel. The maximum scour hole formation in front of the seawall during southwest monsoon season is around 2.0m in depth loss and 80m width at -4.0 m water depth and 200m away from the seawall. The sand bar formed with height of 4 m at -6 m water depth is observed.

Northeast monsoon season: The scour and deposition in front of the seawall after the completion of northeast monsoon season period is shown in Fig. 6. The measured waves at 15m water depth representing north east monsoon season, i.e. from 1st November 2008 to 31st January 2009 has been given as wave input to the module. The simulated results clearly indicate that the seawall has impact on beach profile. In front of the seawall an alternative scour and deposition have been observed in seawall parallel. The maximum scour hole formation in front of the seawall during northeast monsoon season is around 4.5 m in depth loss and 100 m width at -2.0 m water depth and 110 m away from the seawall.

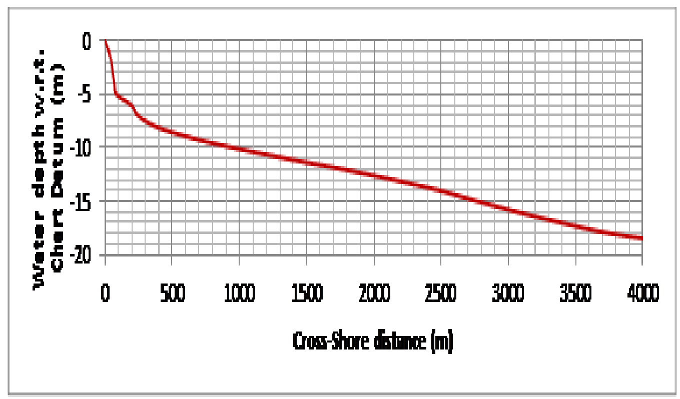

Fig. 2. Measured Cross-shore beach profile–Puducherry coast

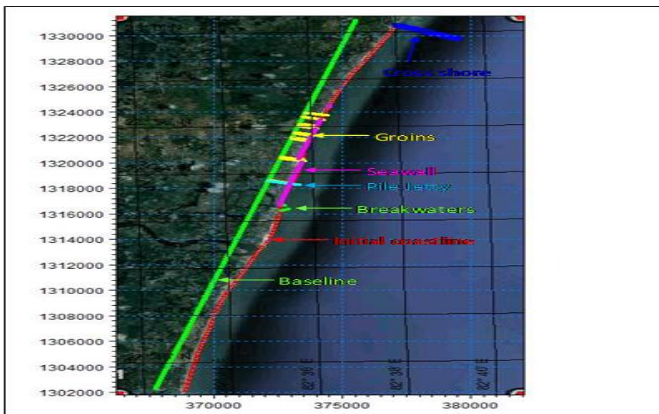

Fig 3. Model setup – DHI-LITPACK-LITPROF module

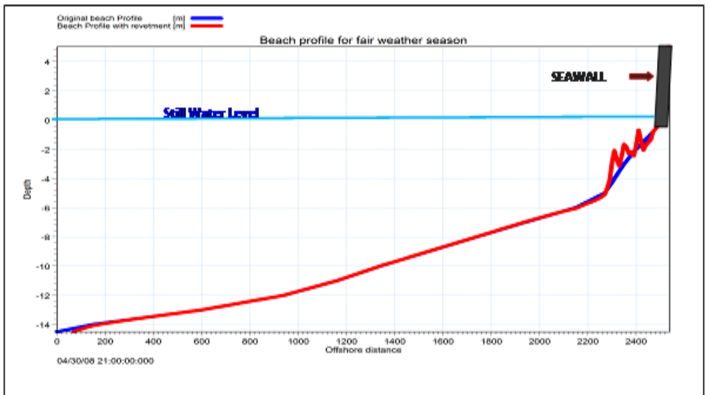

Fig. 4. Scour and deposition pattern afterFair-weather season

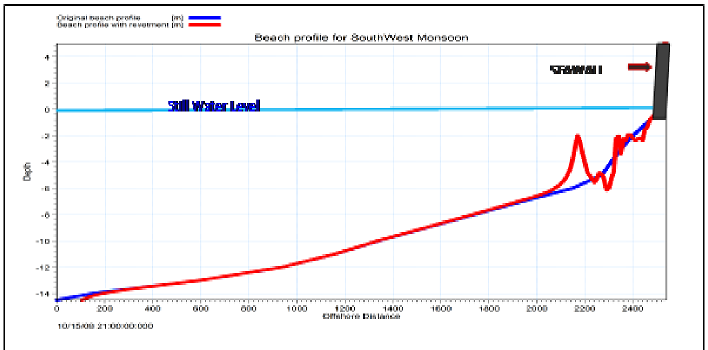

Fig. 5. Scour and deposition pattern afterSouthwest monsoon season

5 CONCLUSIONS

The simulations of seabed scour in front of the seawall existing along the Puducherry coast have been carried out using DHI-LITPACK-LITPROF module. The numerical results indicate that the seawall has impact on beach profile. In front of the seawall an alternative scour and deposition have been observed in seawall parallel. The maximum scour hole formation in front of the seawall after completion of three monsoon season i.e. at the end of the northeast monsoon season is around 4.5 m in depth loss and 100 m width at -2.0 m water depth and 110 m away from the seawall. The present study shows one-line model can be used for the prediction of scour depth at the toe of the seawall and it recommends further research for the scour protection along the Puducherry coast around seawall with implementation of sand bypassing system [11] or construction of offshore submerged breakwater.

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