

Offshore Detached Breakwaters Alignment Changes Its Impact On Scour Deposition Pattern Using Numerical Model

P. Mohamed Rajab, K. Thiruvengataswamy, Indra Kumar Dev, Mohamed Hatha Abdulla and S. Shafeer Ahamed

Abstract— To protect scour around an offshore breakwater, prediction of scouring potential are desirable. In this study, scouring pattern by changing the alignment of an offshore breakwater has been investigated with subjected to uniform steady currents, using a 2-D numerical model such as DHI-MIKE21 module. Hydrodynamic analysis have been carried out for an offshore detached breakwater structure to simulate the flow field using Hydrodynamic (HD) model and sedimentation pattern using Sand Transport (ST) model. The calibrated model setup has been used for predicting the flow and scour conditions by changing alignment of an offshore detached breakwater for the following cases, viz., Case-I: an offshore breakwater oriented perpendicular to shoreline, Case-II: an offshore breakwater oriented parallel to shoreline, and Case-III: an offshore breakwater oriented 45° to shoreline. The simulated results show that by changing the orientation of an offshore breakwater with predominant current speed, the scouring can be minimized near the structure effectively. Moreover, it can be used as one of suitable shoreline protection methods to avoid shoreline erosion.

Key words— [Scour, Scour protection, Offshore detached breakwater, Alignment, Numerical model and MIKE21]

1 INTRODUCTION

A breakwater is a structure protecting an area from wave action. In the case of offshore breakwaters, it will be an area located offshore. The literature review shows that, there are scour holes existing up to 10m diameter, at the head of a breakwater [1]. Also, the failures of offshore breakwaters due to scour have been reported [2] and [3]. Several numerical model studies on scour around breakwaters have been carried out by various researchers [4], [5] and [6]. But, the numerical investigations on scour by changing the structural orientation subjected to uniform currents are not available in the published literature. To protect scour around offshore breakwater, prediction of scour potential are desirable. In this study, scour pattern by changing the alignment of an offshore breakwater has been investigated with subjected to uniform steady currents, using 2-dimensional numerical model such as DHI-MIKE21 module.

2 METHODOLOGY

2.1 Model Setup

Hydrodynamic analysis have been carried out for an offshore detached breakwater structure by changing alignments to simulate the flow field using Hydrodynamic (HD) model and sedimentation pattern using Sand Transport (ST) model for the same uniform current conditions. The dimensions of the rectangular grid are, spacing of 5m x 5m generated with dimension of 1000 m wide x 1000 m long and 5 m deep. The model setup is shown Fig. 1.

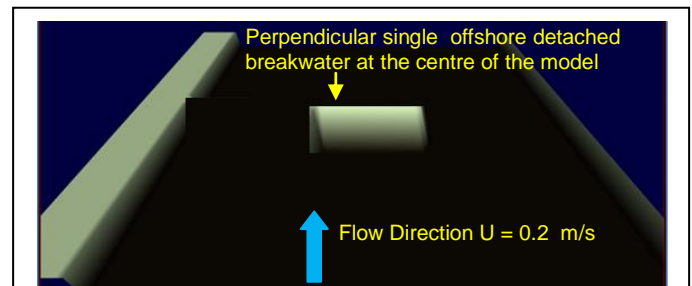


Fig. 1 Model Setup and animator view of Model domain – MIKE21

2.2 2-D Flow Model

The 2-D Flow model component of MIKE 21 is a general numerical modeling system for the simulation of tidal level, flow field in coastal areas. The main inputs to the model are bathymetry, bed resistance coefficients, and wind fields [7].

2.3 Governing Equations

The appropriate governing equations for studying water movement in coastal areas are the two dimensional shallow water equations with making simplified assumptions [7]. These are obtained by vertically integrating the three-dimensional Navier Stokes equations of motion given below [7],

Continuity Equation

$$\frac{\partial z}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} = 0 \quad (1)$$

Equation of Motion in X-direction

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial z}{\partial x} + \tau_{bx} - C_f v - E_c \nabla^2 u = 0 \quad (2)$$

Equation of Motion in Y-Direction

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$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial z}{\partial y} + \tau_{by} + C_f u - E_c \nabla^2 v = 0 \quad (3)$$

where, z - water surface elevation (m), h -total water depth ($z+d$) (m), u,v - Velocity components in x & y direction(m/s), C_f - Coriolis force (N), E_c - Eddy viscosity coefficient. The computational domain is discretized into number of grids and the equations are solved at every grid point. The governing equations are solved using Alternating Directions Implicit (ADI) finite difference technique based on Crank-Nicholson scheme. The equation matrices that result for each direction and each individual grid line are resolved by a Double Sweep (DS) algorithm [7].

2.4 Sand Transport Model

The simulations on scour around an offshore breakwater have been carried out using sediment transport module MIKE-21(ST). The results of the hydrodynamic simulations are the basic inputs along with sediment data. MIKE 21 Sediment Transport (ST) is a module in the MIKE 21 application, suitable, for calculating non-cohesive sediment [sand] transport rates. With this module, one can calculate sand transport based on pure current information: Or, one can take waves into consideration too. In addition to sand transport rates, a simulation will give the initial rates of bed level changes which is sufficient to identify potential areas of erosion or deposition [8].

2.5 Validation of Model Results and Simulations

The validation of the model has been performed for an undisturbed current speed of 0.2 m/s with the presence of structure. It is observed that the results of the model studies are in good agreement with simulated undisturbed flow velocity. The calibrated model setup has been used for predicting the flow and scour conditions by changing alignment of an offshore breakwater for the following cases, viz., Case-I: an offshore breakwater oriented perpendicular to shoreline, Case-II: an offshore breakwater oriented parallel to shoreline, and Case-III: an offshore breakwater oriented 45° to shoreline.

2.6 Model Input

The following inputs are given in Hydrodynamic (HD) and Sand transport (ST) model. The model parameters are as follows,

- i. Model offshore breakwater length $L = 100\text{m}$
- ii. Width of the offshore breakwater $B = 10\text{m}$
- iii. Domain water depth = 5m
- iv. Constant depth averaged current = 0.2 m/s
- v. Mean sediment size = 0.2 mm

The relevant parameters of hydrodynamic and sand transport model used in simulation are given in Table 1.

TABLE 1
MODEL INPUT PARAMETERS ARE USED IN SIMULATIONS

Vari able	Description	Unit	Default and references
kn	Nikuradse roughness parameter	m	0.002 [8]
γ_1	Wave breaking parameter- α controls the steepness condition	-	1 [9]
γ_2	Wave breaking parameter- α_2 controls the limiting water depth condition	-	0.8 [9]
α	Wave breaking parameter	-	1 [9]
M	Manning number (Calibration factor)	$M^{1/3} s^{-1}$	32 [10]
cs	Smogrinsky coefficient (Calibration factor)	-	0.5 [10]
S	Relative density of the bed material	-	2.6
n	Porosity of the bed	-	0.4 [11]
d50	Median diameter of sediment	m	0.20 field study [10]
T	Water temperature	C0	25 field study [10]
θ_c	The critical value of the shield parameter -	-	0.045 [11]

3 RESULTS AND DISCUSSION

The simulated results of flow field and scour-deposition for an offshore breakwater with different orientations are given below.

- a) Case I – an offshore breakwater oriented perpendicular to shoreline:

The simulated flow field around an offshore detached breakwater aligned perpendicular to shore using numerical model is shown in Fig. 2. The simulated results indicate that in case I, the flow is constricted and reversed near both the corners of the offshore breakwater. The current speeds get amplified by a factor of 2 upto 0.4 m/s near the tip of the breakwater. These increased current speeds induce the scour, near the tip of the offshore breakwater. It could be seen that the flow is streamlined away from the breakwater and there are observed circulations near the corners of the offshore breakwater. The flow velocities, on leeward side of the offshore breakwater are low, of the order of 0.05 m/s.

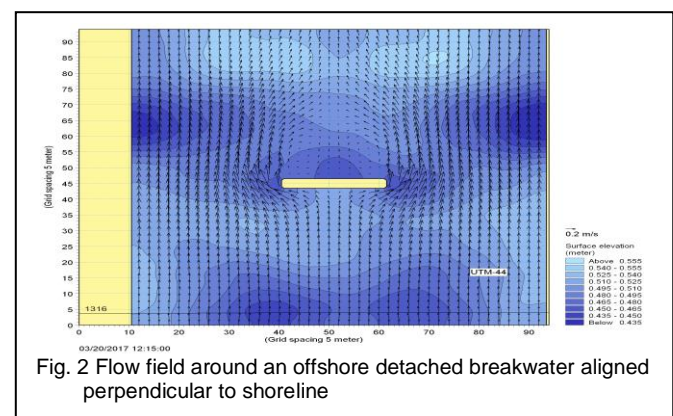


Fig. 2 Flow field around an offshore detached breakwater aligned perpendicular to shoreline

The simulated scour and deposition pattern around an offshore detached breakwater oriented perpendicular to the shore is shown in Fig. 3. The simulated scour pattern indicates that the maximum bed level change i.e. scour depth near the tip of the groin is around 0.1m in both corners of the offshore breakwater. The scour depth is 0.05m along the truncated side of the breakwater. The average sediment transport flux is 25 m³/year/meter widths near the tip of the offshore breakwater. It is seen that for most of the time, sediments are bypassing on both the corners of the offshore breakwater

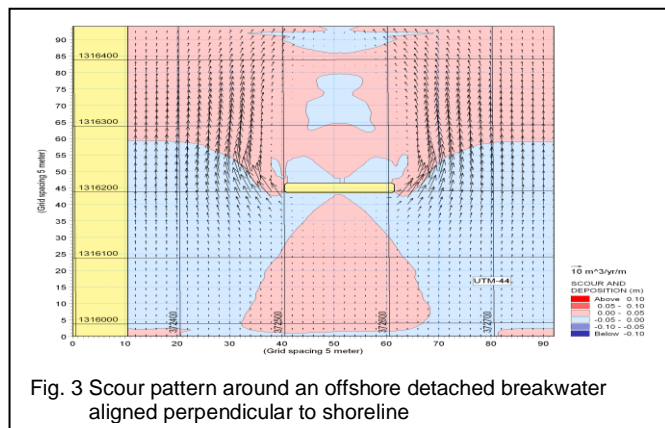


Fig. 3 Scour pattern around an offshore detached breakwater aligned perpendicular to shoreline

b) Case II - an offshore breakwater oriented to shore parallel: The simulated flow field around an offshore detached breakwater aligned parallel to shore is shown in Fig. 4. The simulated results indicate that in case II, the flow is streamlined and aligned parallel to the structure. The current speed is less amplified a factor of 1.25 with 0.25 m /s near the tip of the breakwater. This small amplification of current speeds induces the scour in both corners of the offshore breakwater.

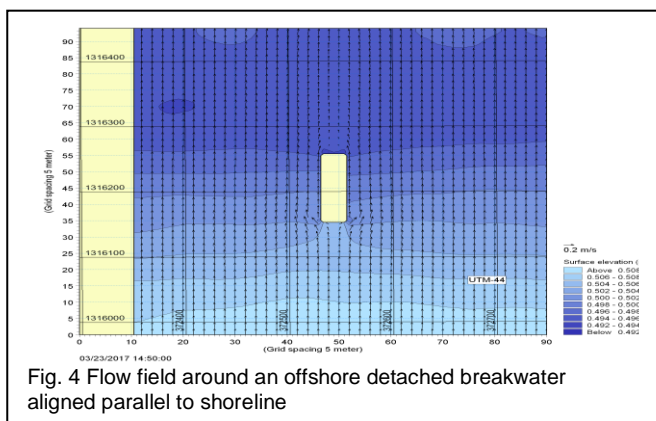


Fig. 4 Flow field around an offshore detached breakwater aligned parallel to shoreline

The simulation on scour and deposition pattern around an offshore detached breakwater oriented to shore parallel is shown in Fig. 5. The simulated scour pattern indicates that the maximum bed level change is 0.01m in both corners of the offshore breakwater. The average sediment transport flux is around 5 m³/year/meter width near both corners of the breakwaters. The maximum bed level change (i.e. scour depth) is less than 0.005 m along the truncated section of the offshore

breakwater. Further it is observed that when the offshore breakwater is oriented 180° with respect to predominant current direction, the scouring is reduced significantly 10 times lesser than that of the scouring observed in the case of shore perpendicular structures.

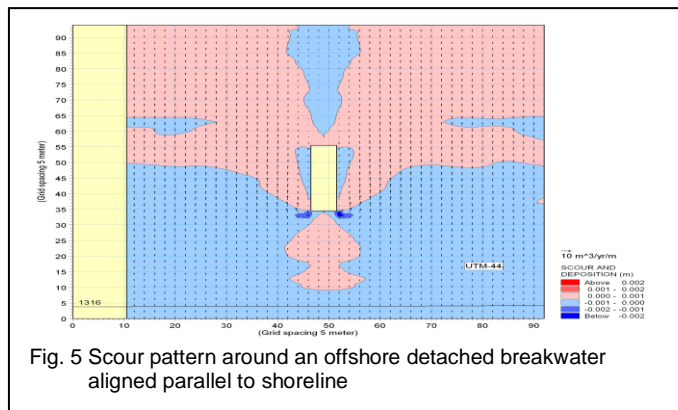


Fig. 5 Scour pattern around an offshore detached breakwater aligned parallel to shoreline

c) Case III - an offshore breakwater with 45° orientation: The simulated flow field around an offshore detached breakwater with 45° orientation is shown in Fig. 6. The simulated results indicate that in case III, the flow is constricted and reversed near the tip of the offshore breakwater. The current speed is amplified by a factor of 2 upto 0.4 m/s, near the tip of the breakwater. This amplified current speed induces the scouring near the tip of the offshore breakwater. It is observed that the flow is streamlined away from the breakwater. Circulations have been observed near the corners of the offshore breakwater. The flow velocities, on the leeward side of the offshore breakwater are low, of the order of 0.05 m/s.

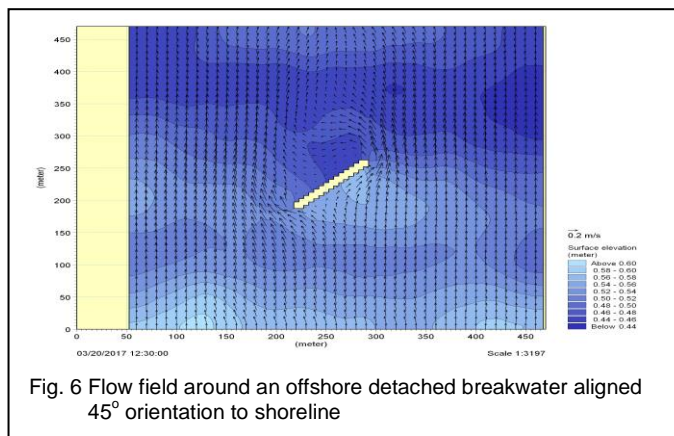


Fig. 6 Flow field around an offshore detached breakwater aligned 45° orientation to shoreline

The simulated scour and deposition pattern in the presence an offshore breakwater with orientation of 45° to shore normal is shown in Fig. 7. The simulated scour pattern indicates that the maximum bed level change is around 0.1m at both corners of the offshore breakwater. The average sediment transport flux is 25 m³/year/meter width near the tip of the breakwaters head. The maximum bed level change (i.e. scour depth) is less than 0.01m along the trunk section of the offshore breakwater. The scour hole is 0.05m at the tip of the breakwater, which is nearly 5 times lesser than the observed scour depth in the case

of shore perpendicular structures. It is seen that for the most of the time, sediments are bypassing near the tip of the offshore breakwater.

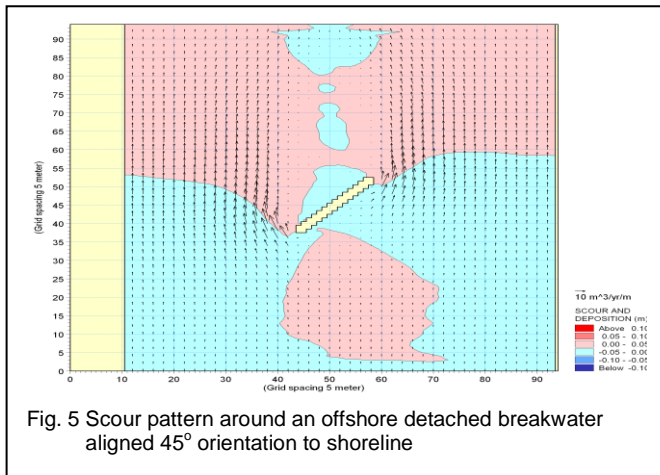


Fig. 5 Scour pattern around an offshore detached breakwater aligned 45° orientation to shoreline

4 CONCLUSIONS

The simulation results of flow field and scour around an offshore breakwater for different orientation indicates that So, the scour around an offshore breakwater can be reduced significantly by changing the orientation of coastal structures with respect to shoreline and the predominant current direction. Moreover, it can be used as one of suitable shoreline protection method to avoid shoreline erosion [10]. Further, it may be noted that the sedimentation estimation is only indicative as the studies are based on limited data [10] and [12]. Actual conditions at site are highly dynamic and vary continuously with time and space.

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