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Hydrodynamic Changes Due to Large Seabed Installations in Coastal Waters off West Coast of India

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Abstract

Offshore marine environment can very well be utilized for mass storage of liquids which are not harmful to that environment. Improper placement of large tanks on the seabed, to store large quantities of liquids, would adversely affect the hydrodynamics of adjoining environment. Thorough understanding on the hydrodynamics of the adjoining environment is thus required before and after placing such tanks so as to properly plan the placement of these large tanks. A two dimensional numerical hydrodynamic model is used to study influence of placing large number of tanks in a dynamic marine environment. Cylindrical tanks (5 m dia.) are arranged in three rows with 50 tanks placed in each row with their length (100 m) aligned perpendicular to the coast. These tanks cover an area of about 36000 m^2 and are placed on seabed in water depths about 15 m. Hydrodynamic simulations carried out with tidal forcing for cases of (a) before and (b) after placement of tanks showed that current speeds increase up to 65% in the region where the tanks are placed compared to currents without placement of tanks. However, up to 85% increase in current speeds is observed in regions beyond the tanks. In this manuscript results of the effects on the hydrodynamics of a region due to placing large number of tanks in shallow waters are presented.

Key words: 2D Hydrodynamic Modeling, Tidal Currents, Large Underwater Tanks, Current Analysis, MIKE21, TASK2000

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1. INTRODUCTION

Seabed storage is a preferred option for most offshore production activities. Generally fluid storage is more feasible due to ease in handling. Offshore oil and natural gas production platforms conveniently use sub-sea conditions for major storage of oil and gas through appropriate structures, whereas hydrogen storage for offshore thermal power generation and offshore waste disposal such as nuclear wastes comes under minor storage category. However, these kind of storage facilities are placed mostly in deeper waters and thus do not have direct effect on the coastal hydrodynamics which in turn has an impact on the adjoining coastal environment.

Introduction of numerous large structures into a stabilized shallow water environment leads to alteration of hydrodynamics in the region which in turn might adversely impact the adjoining coastal environment. In order to ascertain the effect of placement of such large underwater structures, it would be essential to understand the prevailing marine environment at first instance and further estimate or predict their influence on the environment. In the present context the physical environment is considered and termed in general as marine environment. Scaled physical models or numerical models are used both to understand the prevailing marine environment as well as to predict changes in environment due to perturbations in the prevailing conditions. Though both physical modeling and numerical modeling have proved to provide reliable and reasonable results, numerical models are being preferred due to the ease in setting up the models and advantages in terms of cost and time. In this manuscript, numerical model study has been carried out to understand the prevailing hydrodynamics of a region and also to study the effect of placement of large underwater storage tanks on the physical environment. The changes in the flow characteristics due to incorporation of the tanks would also be required for the stability aspects of the tanks as well as environmental impact due to post tank installation conditions.

Hydrodynamics in shallow waters are mainly influenced by tides, waves and winds. Tide induced currents are envisaged to be persistent and periodic and therefore are considered suitable to provide initial comparisons on the changes in hydrodynamics due to placement of large number of tanks in shallow waters. In order to be realistic in simulating the hydrodynamics, coastal region along the west coast of India is considered in this study. Though the tanks cover an area of 36000 m^2, a much larger domain is considered to generate the hydrodynamics of the region. An attempt is made in this manuscript to study the changes in the flow characteristics due to placement of numerous large underwater storage tanks over the seabed in water depths of *circa* 15 m.

2. STUDY REGION

In order to study the prevailing hydrodynamics of a region, devoid of large underwater tanks, and to validate the numerical model as well, a region between Karwar in the south and Vengurla in the north is considered (Fig. 1). Towards northern offshore boundary the domain is considered up to water depths of 60 m below Chart Datum (CD) and towards southern offshore boundary up to water depths of 210 m CD. The total area of the study region is about 14850 km^2. The coastal tract of the study region constitutes of a variety of features viz., wave cut platforms, headlands, open and protected sandy beaches, river inlets, etc. Seabed in this region has gentle slope of 1:650 and the surface sediment is of clayey silt in nature. The beach material comprises mostly sand and sea bed material varies with depth. Oceanographic climate in this region is highly influenced by southwest monsoon during June to September. Significant wave heights during southwest monsoon range between 0.8 m and 5.9 m whereas they are in the range between 0.2 and 3.3 m during rest of the year and wave periods range between 3 s and 8 s. Cyclones in this region are not common unlike on the east coast of India. Tides are semi-diurnal in nature with average spring tidal range of 1.69 m and average neap tidal range of 0.73 m at Mormugao Port, Goa.

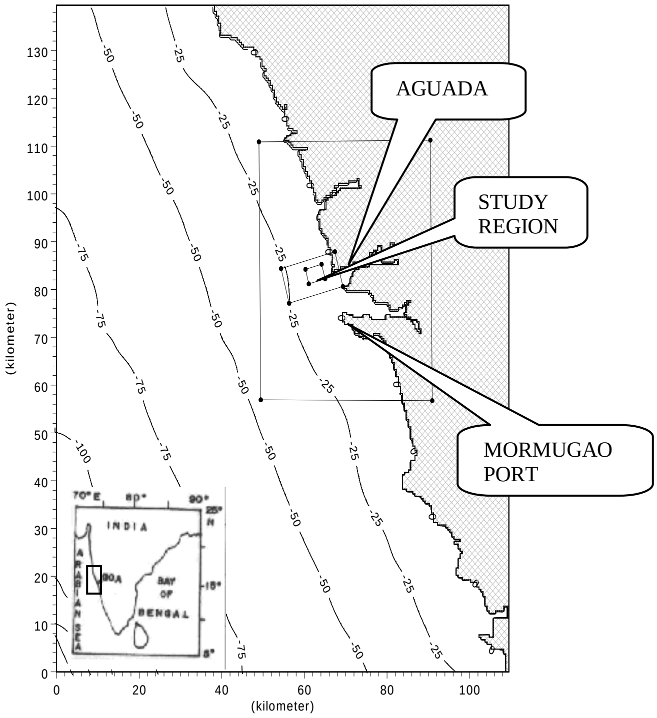

Fig.1 Location Map of study area

3. TANKS PLACEMENT

In present study, 150 tanks (100 m long and 5 m diameter) are considered in water depths of 15-16m, to store about 300,000 m^3 of liquid. These tanks are placed in three rows, 50 tanks in each row, with length-wise spacing of 30 m and width-wise spacing of 15 m. The tanks are aligned perpendicular to the coast as well as they are aligned perpendicular to the prevailing bathymetry. These tanks are considered to be fully loaded and are represented in the numerical model as perturbations in bathymetry.

4. METHODOLOGY

A depth averaged two-dimensional hydrodynamic model (MIKE21-HD) used for modelling hydrodynamics of coastal seas and lakes, developed by DHI-Water Health & Environment, Denmark, is made use of in this study (Anonymous, 2005). This numerical model has been used in the simulation of hydrodynamics, water quality, and related processes in estuaries, bays and coastal areas of India (Babu, et al, 2005, 2006; Chauhan et al, 2006; Chubarenko and Tchepikova, 2001; Vethamony, et al, 2007a, 2007b).

4.1 Model description

The depth averaged momentum equations in *x* and *y* directions and continuity equation used in the model are as follows:

X – momentum:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \varsigma}{\partial x}+\frac{g\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\frac{p}{h}}{C^2}-fVV_x-\frac{h}{\rho_w}\frac{\partial p_a}{\partial x}-\Omega q-E\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 q}{\partial y^2}\right)=S_{ix} \quad (1)$$

Y – momentum:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \varsigma}{\partial y}+\frac{g\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\frac{q}{h}}{C^2}-fVV_y-\frac{h}{\rho_w}\frac{\partial p_a}{\partial y}-\Omega p-E\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 q}{\partial y^2}\right)=S_{iy} \quad (2)$$

Continuity:

$$\frac{\partial \varsigma}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=S-e \quad (3)$$

where P and q are the flux in the x and y directions, respectively, h - water depth, t - time, P_a - atmospheric pressure, ρ_w - density of water, g - acceleration due to gravity, η - surface elevation, S - source magnitude, e - evaporation rate, C - Chezy's coefficient, f - wind friction factor, Ω - Coriolis force, S_{ix}, S_{iy} - source impulse in x and y directions and E - eddy viscosity coefficient. The eddy viscosity coefficient E is expressed as a time-varying function of the local gradient of the velocity, known as the Smagorinsky scheme given as:

$$E=C_s^2\Delta^2\left[\left(\frac{\partial u}{\partial x}\right)^2+\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2\right] \quad (4)$$

where, u and v are depth-averaged velocity components in x and y directions, respectively. In the present study, the velocity-based Smagorinsky scheme with a constant value of C_s = 0.5 has been applied for all simulations and grid spacing criteria used for Eddy viscosity is:

$$\frac{E.\Delta t}{\Delta x^2}\leq\frac{1}{2} \quad (5)$$

The bed resistance F is expressed as $F=\frac{g.u.|u|}{C^2}$ (6)

where, C is the Chezy number and M is Manning number which is expressed as

$$C=M.h^{\frac{1}{6}} \quad (7)$$

The dynamic stability C_R of the model is defined using the Courant–Friedrichs–Lewy (CFL) stability criterion:

$$C_R=c\frac{\Delta t}{\Delta x} \quad (8)$$

Where, wave celerity, $c=\sqrt{gh}$ (9)

4.2 Simulations

The flow is simulated with appropriate tidal forcing along the boundaries for studying the hydrodynamic characteristics of the region both before and after placement of tanks. Along the northern boundary tide at Vengurla is given and along the southern boundary, tide at Karwar is given. Along the offshore boundary, linearly interpolated tide between Karwar and Vengurla is provided. The existing flow conditions of the selected region are studied in the first instance and the results were compared with available field measured data for ascertaining the reliability of the model to the selected region. For this purpose, a model domain of 110 km x 116 km with 200 m square grid (Fig. 2) is considered to simulate the tidal flow conditions over the selected region. The measured currents over the region are analysed using TASK2000 software (Bell et al, 1998) to obtain tidal current components so as to compare with the results of numerical model simulations.

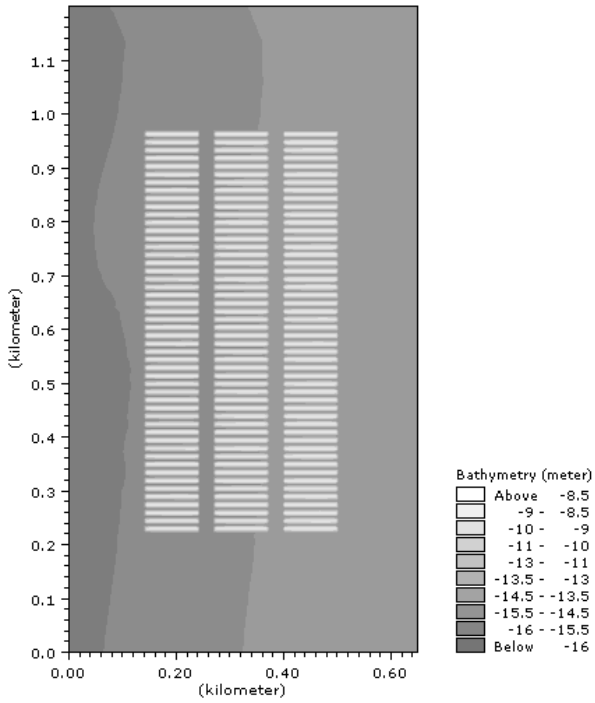

Fig.2 Bathymetry map with tanks of smaller domain of grid size 5mx1m

On validating the numerical model for the selected region, various domains with varying grid dimensions are considered, within the validated domain, so that the flow conditions in the smaller region comprising the 150 tanks are simulated well. The domains considered with different square grid sizes are 150 m, 50 m, and 15 m (Fig. 1). The input data for 15 m domain is taken from the output of 50 m grid domain. And the input for 50 m grid domain is considered from 150 m grid domain. Similarly, input for 150 m grid domain is taken from 200 m domain for which the results are validated with measured current data. The finest grid size used in the study was 5 m x 1 m wherein the bathymetry is considered for two cases viz., (i) without tanks and (ii) with tanks placed in the domain. The region for the finest grid bathymetry covers an area of 1220 m x 650 m (Fig. 2). The input conditions for these two model domains are same and are taken from the 15 m grid size model simulations. Simulations on the smaller grid model with and without incorporating the tanks, representing the pre-tank and post-tank conditions respectively, and the changes in the flow characteristics due to incorporation of the tanks are studied by comparing the currents obtained from these two simulations at various locations inside the model domain. Thus the impact of the tanks on the flow conditions is observed.

5. RESULTS AND DISCUSSIONS

Measured currents in the region were decomposed into alongshore component (u-component) and cross-shore component (v-component) and each component was analysed using TASK2000 to obtain the corresponding current components due to tidal forcing alone (measured tidal current). These measured maximum tidal current components were of the order of 0.08 to 0.12 m/s. Comparison of model derived current components and measured tidal current components showed that the model derived currents compare well with the measured tidal currents (Fig. 3). Thus it can be considered that the numerical model set up for the selected region reliably estimates the prevailing tidal current conditions in the region. Therefore, the model derived results are considered suitable for reliably studying the effects of placing the tanks on the flow conditions.

tank region which is due to reduced water depth in that region (Fig. 6b). Similarly for the ebb phase, maximum currents were seen almost in the same region as that observed during flood tide phase (Fig. 7b). From the difference between the maximum currents with and without tanks show for the flood tide phase, an increase in currents is seen at the top-right corner of the tank region (Fig. 8a) as well as the bottom-right corner. The increased current along the eastern boundary (bottom-right side) is due to shallower depths and therefore are not given importance in this discussion. For the ebb tide phase maximum increase in current speed is seen at the bottom-left corner of the tank region (Fig. 8b). From these observations, it is seen that the corners of the tank region that are in shallower depths are bound to experience higher currents than the tanks in the deeper regions as well as the sheltered ones in the middle of the region.

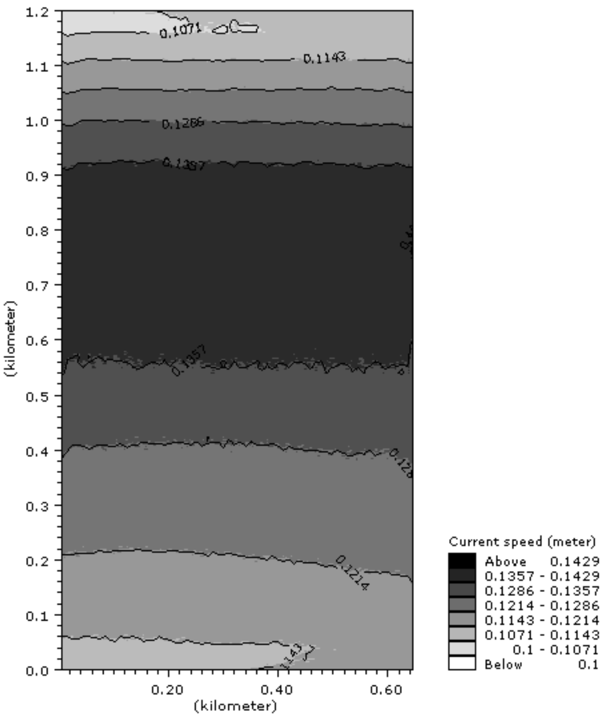

Fig.6a Maximum currents of pre-tanks condition for flood tide phase

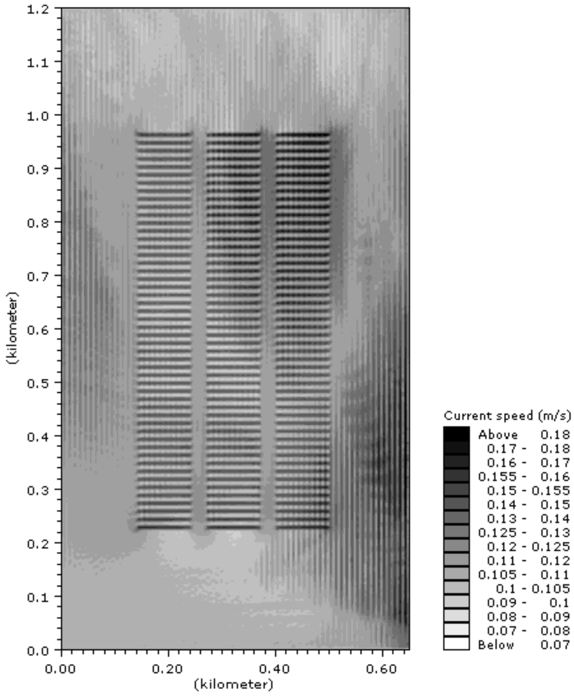

Fig.6b Maximum currents of post-tanks condition for flood tide phase

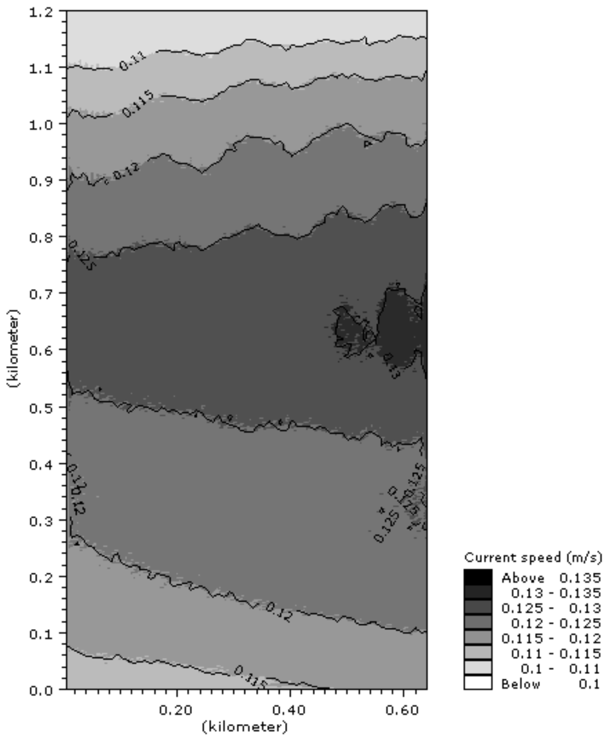

Fig.7a Maximum currents of pre-tanks condition for ebb tide phase

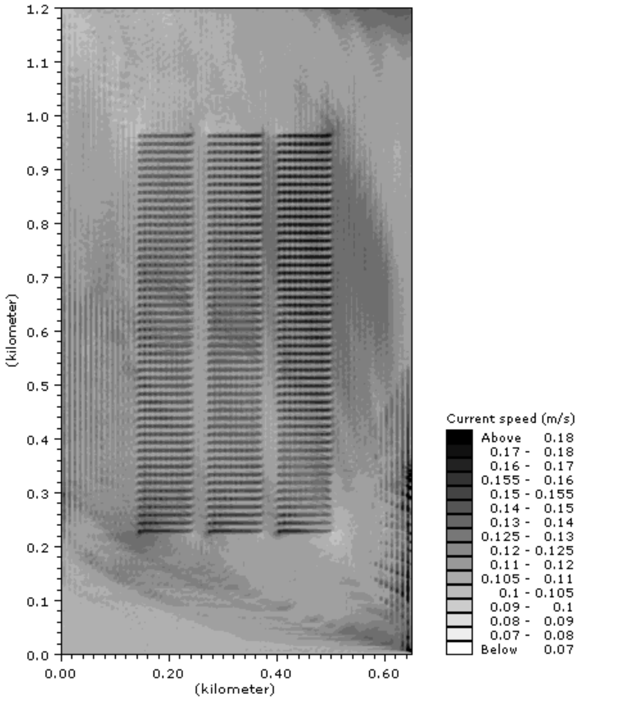

Fig.7b Maximum currents of post-tanks condition for ebb tide phase

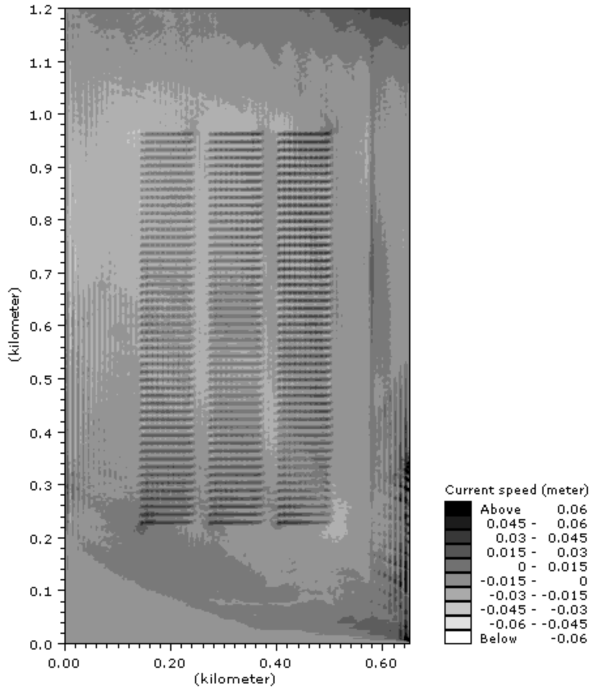

Fig.8b Difference in maximum currents of post-tanks condition with currents of pre-tanks condition for ebb tide phase

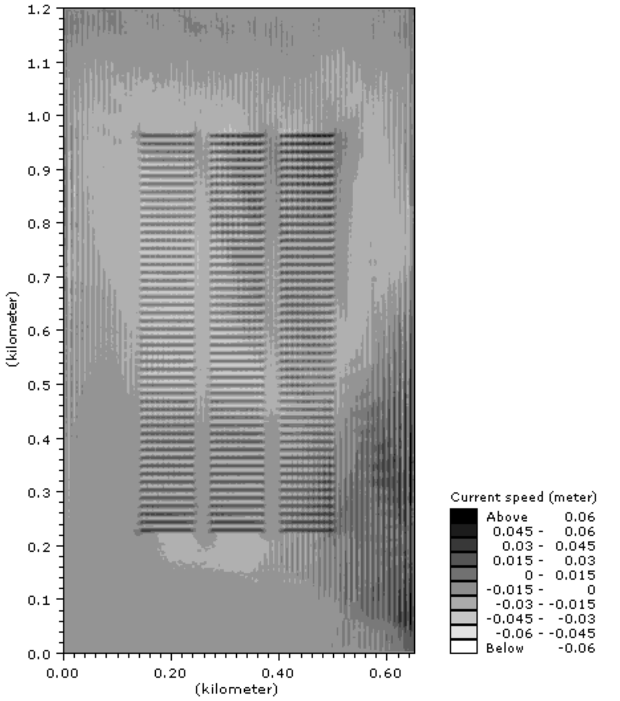

Fig.8a Difference in maximum currents of post-tanks condition with currents of pre-tanks condition for flood tide phase

The maximum currents, over for each of the tidal phase, with tanks in place, were individually picked up and compared with the corresponding currents from results of simulations without tanks to obtain the increase in current speeds quantitatively. The increase in current speeds due to placement of tanks range between 65% and 85% (Fig. 9).

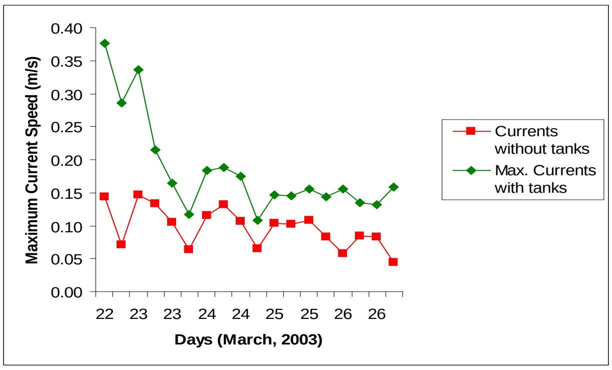

Fig.9 Comparison of maximum currents of post-tanks condition with currents of pre-tanks condition at select location for ebb tide

From the flow simulations, with the tanks in place, it is observed that there is an alternating increase and decrease in current speeds in front of the tanks due to changing tidal phase, which over a period of time would result in net erosion or accretion of the seabed due to these changes in currents. From these results on the flow changes due to placement of tanks, it can be seen that there is a net resultant increase in current speeds at the corners of the tank region in shallower depths which result in scouring of material from the adjoining seabed thus causing an engineering concern in terms of scouring and stability for the tanks. Though, it is certain that the hydrodynamics of the region gets affected due to placement of such large installations in shallow waters, as an initial step, effect of tide induced currents is studied to quantify the effect of placement of large tanks. However the wind and wave induced currents also need to be considered so as to completely study the overall effect of the placement of tanks on the hydrodynamics. Orientating the tanks in a manner so as to reduce the effects on the prevailing hydrodynamics would further reduce the impact on the adjoining environment.

6. CONCLUSIONS

Numerical modeling is carried out to study quantitatively the effect of placement of large underwater tanks on the prevailing hydrodynamics of a region. Model results were compared with measured currents to ascertain the validity of using the numerical model and found that the model used adequately simulates the prevailing tide induced hydrodynamics of a region. Simulations were carried out over domains with and without placing the tanks and the results were analysed to obtain the changes in the current speeds due to placement of tanks. Tanks along the corners in shallower regions were found to be subjected to higher currents and therefore require additional protection from scour due to increased currents. An increase in currents between 65% and 85% is observed due to tidal currents alone. To study the overall effect on the adjoining environment further studies on the wind and wave induced currents are required as well as the orientation of the tanks need to be finalized to minimise the impacts.

7. ACKNOWLEDGEMENTS

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