Government of India
Ministry of Jal Shakti
Department of Water Resources,
River Development and
Ganga Rejuvenation

सत्यमेव जयते

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास
और गंगा संरक्षण विभाग

Technical Report No:5970
November 2021

MATHEMATICAL MODEL STUDIES TO ASSESS THE IMPACT OF PROPOSED CAPITAL DREDGING ON TIDAL HYDRODYNAMICS OF NEARBY AREA OF PROPOSED PORT AT VADHAVAN

केन्द्रीय जल और विद्युत अनुसंधान शाला, पुणे
CENTRAL WATER AND POWER RESEARCH STATION, PUNE

A. K. AGRAWAL
Director

GOVERNMENT OF INDIA
CENTRAL WATER AND POWER RESEARCH STATION
PO: KHADAKWASLA RESEARCH STATION
PUNE-411 024, INDIA

COASTAL AND OFFSHORE ENGINEERING LABORATORY

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REPORT DOCUMENTATION SHEET

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Title: MATHEMATICAL MODEL STUDIES TO ASSESS THE IMPACT OF PROPOSED CAPITAL DREDGING ON TIDAL HYDRODYNAMICS OF NEARBY AREA OF PROPOSED PORT AT VADHAVAN

Officers Responsible for conducting the studies:

The studies were carried out by Shri. M. M. Vaidya Scientist-C with the assistance of Shri. K.R. Karambelkar, Research Assistant. Shri A. A. Purohit, Scientist-E was the in-charge of the group and the studies were completed under the overall Supervision of Dr. J.D. Agrawal, Scientist "E"

Name and address of the organization conducting the studies:

Coastal and Offshore Engineering Laboratory
CENTRAL WATER AND POWER RESEARCH STATION
PUNE-411 024, INDIA

Name and address of Sponsoring Authority:

The Chief Manager, (PPD)
Jawaharlal Nehru Port,
Sheva, NAVI MUMBAI- 400 707

Synopsis:

A major Greenfield, all-weather port at Vadhavan is proposed to be developed on the seaward side of headland at Vadhavan and is located at about 110 km north of Mumbai in Dahanu Taluka, Palghar district of Maharashtra state at Lat. 19° 55.8′ N, Long. 72° 39.6′ E. The port will be developed through a joint venture between Jawaharlal Nehru Port (JNP) and Maharashtra Maritime Board (MMB). The port limit extends up to 26 m depth below CD in the deeper part of the Arabian Sea with port area of about 175 Sq. km. The northern limit of the proposed Vadhavan Port is on the southern side of entrance to the Dahanu creek while the southern limit is about 3 km southward from Vadhavan Headland. The tides in this region are of macro semi-diurnal in nature with tidal range of about 6 m and waves are predominant from two quadrants namely North-West & South-West.

The mathematical model studies carried out to assess the impact of proposed capital dredging on tidal hydrodynamics of nearby area of proposed port at Vadhavan considers the oceanographic data collected near the proposed port site for non-monsoon (2017) & monsoon season (2020). The hydrodynamic model calibrated for the field data of both non-monsoon and monsoon seasons reveal that the model is reasonably well calibrated. The consultants to JN port has revised the layout recommended by CWPRS earlier in year 2018 by altering the shape of reclamation proposed on tidal flat and relocation of various berths viz. Multipurpose and RO-RO at north end of harbour without modifying the layout of 10.3 km long breakwater and CDW. The development of the port is also proposed in two phases with layouts as Phase-I & Master plan. The studies for the same were completed; however, these layouts were again revised by JN Port wherein it was proposed to shift the reclamation from intertidal region towards deeper depths in order to have improvement in operational efficiency/ turnaround time of transport of containers from stack-yard to the berths. Accordingly, tidal/wave hydrodynamics and siltation studies for various layouts were carried out and the master plan layout of the port has been finalized in consultation with JN Port based on the results of model studies. Based on the finalized master plan layout the Phase-I layout provided by JN Port was also studied from tidal hydrodynamic and siltation considerations.

The hydrodynamic studies carried out to assess the impact of capital dredging for finalised Phase-I & Master Plan layouts on the flow field (water level, currents) of nearby area of proposed port at Vadhavan reveal that the variation in current strength is less than 0.45 % during non-monsoon as well as monsoon seasons. The variation in water levels for Phase-I layout is less than 0.050 % for all locations considered along the shoreline, mouth and inside the Dahanu creek as well as in the harbour area for both non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths of 17.5 m below CD in dredge area, 19.5 m at berth pocket & 20 m in approach channel conditions. Similarly, for master plan layout wherein depth of 19.5 m below CD in dredge/berth pocket area & 22 m in approach channel were considered, the variation in water levels is less than 0.030 % during both seasons at all 15 locations. Thus, studies conducted reveal that there is practically no impact of proposed capital dredging in Phase-I & Master Plan layouts of port development on the tidal hydrodynamics of shoreline, Dahanu creek as well as in the harbour area of proposed port at Vadhavan.

Key Words: Dredging, Impact, Master Plan layout, Phase-I layout

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MATHEMATICAL MODEL STUDIES TO ASSESS THE IMPACT OF PROPOSED CAPITAL DREDGING ON TIDAL HYDRODYNAMICS OF NEARBY AREA OF PROPOSED PORT AT VADHAVAN

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1. INTRODUCTION

A major Greenfield, all-weather port at Vadhavan is proposed to be developed at the offshore of headland at Vadhavan in Dahanu Taluka, Palghar district of Maharashtra state at Lat. 19° 55.8′ N, Long. 72° 39.6′ E. This port is proposed to be located at about 110 km north of Mumbai and will be developed through a joint venture between Jawaharlal Nehru Port (JNP) and Maharashtra Maritime Board (MMB). The area of proposed port is of about 175 Sq. km. The northern limit of the proposed Vadhavan Port is on the southern side of entrance to the Dahanu creek while the southern limit is about 3 km southward from Vadhavan Headland with its port limit extends up to 26 m depth below CD in the deeper part of the Arabian Sea. The location plan of proposed port is shown in FIG.1.The important oceanographic phenomena such as tides in this region are of macro semi-diurnal in nature with tidal range of about 6 m and waves approaching to the port location are predominant from two quadrants namely North-West & South-West.

FIG.1: Location Plan of Proposed Port at Vadhavan

The JNP has taken up the task of planning the configuration of the entire port layout, its positioning and alignment of components like breakwaters, berth structures, operational area, harbour basin, approach channel etc. and to finalize the conceptual layout. The port is proposed to be developed on the seaward side of the headland at Vadhavan and stack yard area was proposed to be formed by reclaiming an area of about 1428 Ha in the intertidal zone near Vadhavan point. The entry to the port was proposed to be from the Arabian Sea through the navigational channel.

The port Authority with regard to the development of port requested CWPRS vide their letters JNP/PPD/Vadhavan/2017/422 and JNP/PPD/Vadhavan/2017/426 both dated 10th March

2017 to carry out the various hydraulic model studies to finalize the concept layout for the proposed port at Vadhavan and to assess the impact of proposed development on Tarapur Atomic Power Station (TAPS) through model studies.

The Central Water & Power Research Station (CWPRS) in this context, initially carried out four studies to finalise the layout of port and technical reports for the same were submitted to JN Port in year 2018.The four technical reports submitted are as follows:

- Hydrodynamics and siltation to finalize the layout of port and estimate the siltation (CWPRS TR. No. 5583 of March 2018)
- Wave transformation and tranquility for assessing wave conditions at berths (CWPRS TR. No. 5558 of January 2018)
- Shoreline changes and littoral drift (CWPRS TR. No. 5559 of March 2018)
- Design of breakwaters – Wave flume studies (CWPRS TR. No. 5648 of November 2018)

The layout finalized through tidal hydrodynamic and wave tranquility studies is shown in FIG.2

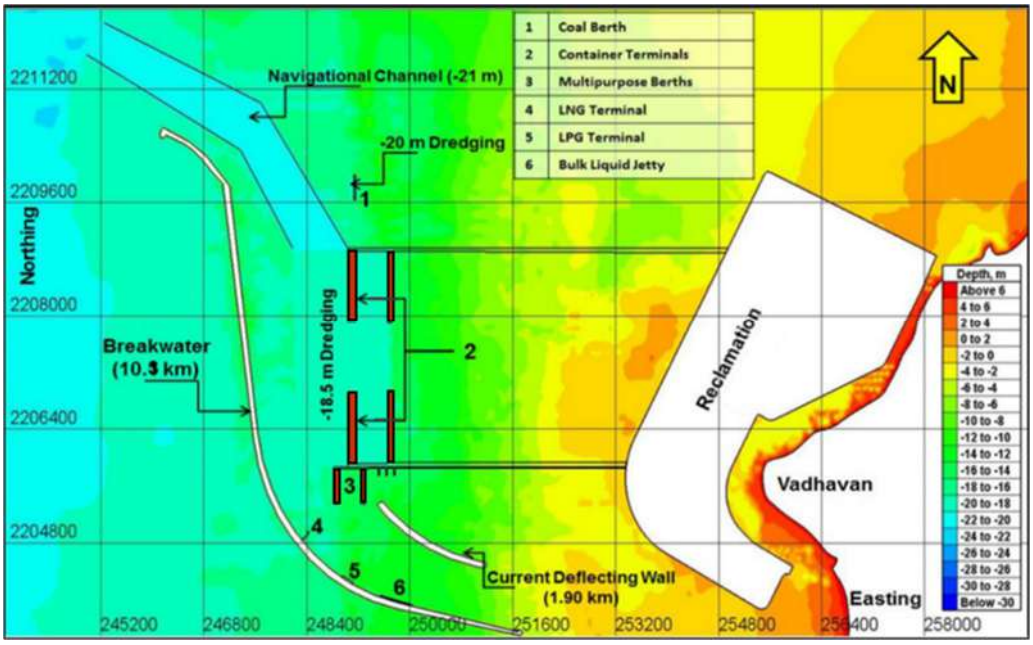


FIG.2: Recommended layout of Proposed Port at Vadhavan by CWPRS

The layout finalized in the year 2018 was considered to assess the impact of proposed port development on intake/outfall facilities of TAPS and technical reports for the same were submitted to JN Port in year 2018-19 and are as follows:

- Thermal model studies to assess the dispersion of hot water due to proposed port development (CWPRS TR. No. 5605 of July 2018)
- Field data collection at Tarapur for the proposed development of port at Vadhavan (CWPRS TR. No. 5615 of August 2018)
- Hydrodynamic and siltation studies to assess the impact of proposed port at Vadhavan on TAPS (CWPRS TR. No. 5667 of January 2019)

The JNP further to this submitted the proposal to Ministry of Environment Forest and Climate Change (MoEF&CC) for EIA clearance. The Expert Appraisal Committee (EAC) meeting was held by MoEF&CC, New Delhi on 26th August 2020 and recommended the project for the grant of TOR with conditions to carry out various additional studies. In this context to fulfil the TOR conditions, JNP hold a meeting between officials of JN Port, CWPRS, appointed Consultants and experts from other organizations on 9th September 2020 to discuss the requirements of additional studies and their scope. Based on this meeting, JN Port referred the additional studies vide their letter dated 11th September 2020 as mentioned below.

1) Assess the impact of proposed capital dredging on the flow field in the nearby area
2) Flooding and related impact on creek at Control area during the cyclonic storm

This report describes the studies carried out to assess the impact of proposed capital dredging on the flow field in the nearby area. A brief history of various layouts studied at CWPRS and the layout finalised and reported in CWPRS Technical Report No. 5968 of November 2021 is given in the following paragraphs.

The layout of port at Vadhavan recommended by CWPRS (CWPRS TR No. 5583 of March 2018) was modified by the newly appointed consultant to prepare a DPR for proposed port at Vadhavan. The consultant modified the layout by altering the shape of reclamation earlier proposed and relocation of various berths such as multipurpose berth, RO-RO berths on the northern end of harbour (FIG.3) which were proposed earlier immediately on the north side of Current Deflecting Wall as shown in FIG. 2. It is also proposed to develop the port in two phases viz. Phase-I & Master plan. The JN Port provided two layouts to CWPRS for carrying out studies vide e-mail dated 4th February 2021 and are shown in FIG. 3 & 4 respectively.

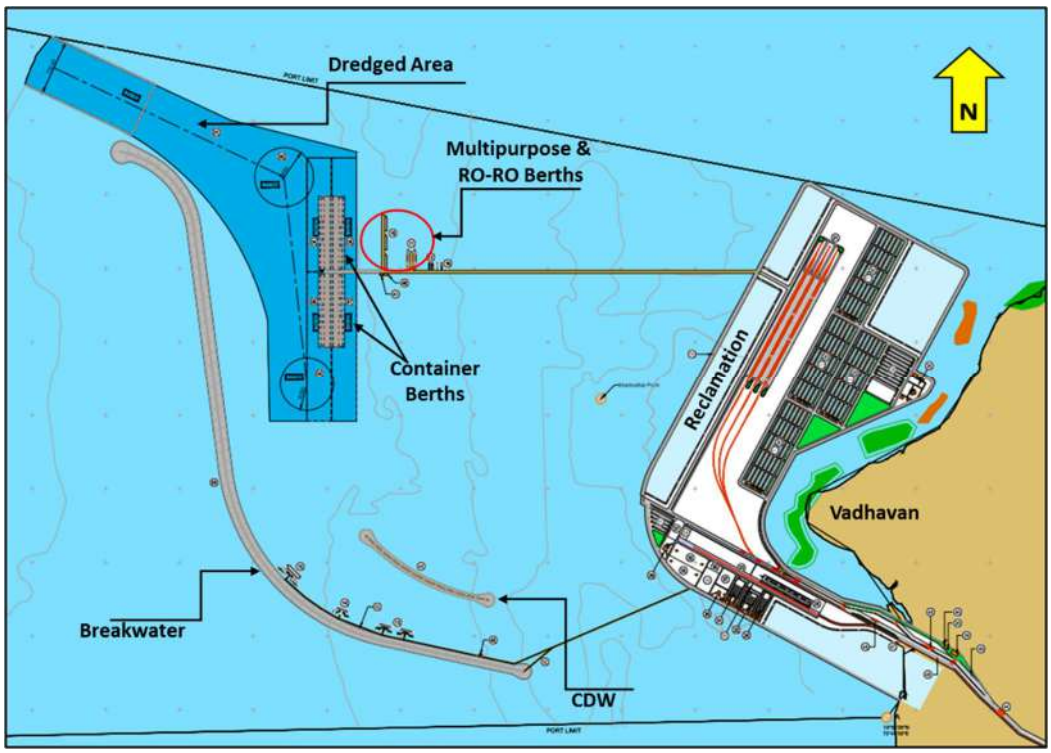


FIG.3 : Phase-I Layout of Proposed Port at Vadhavan

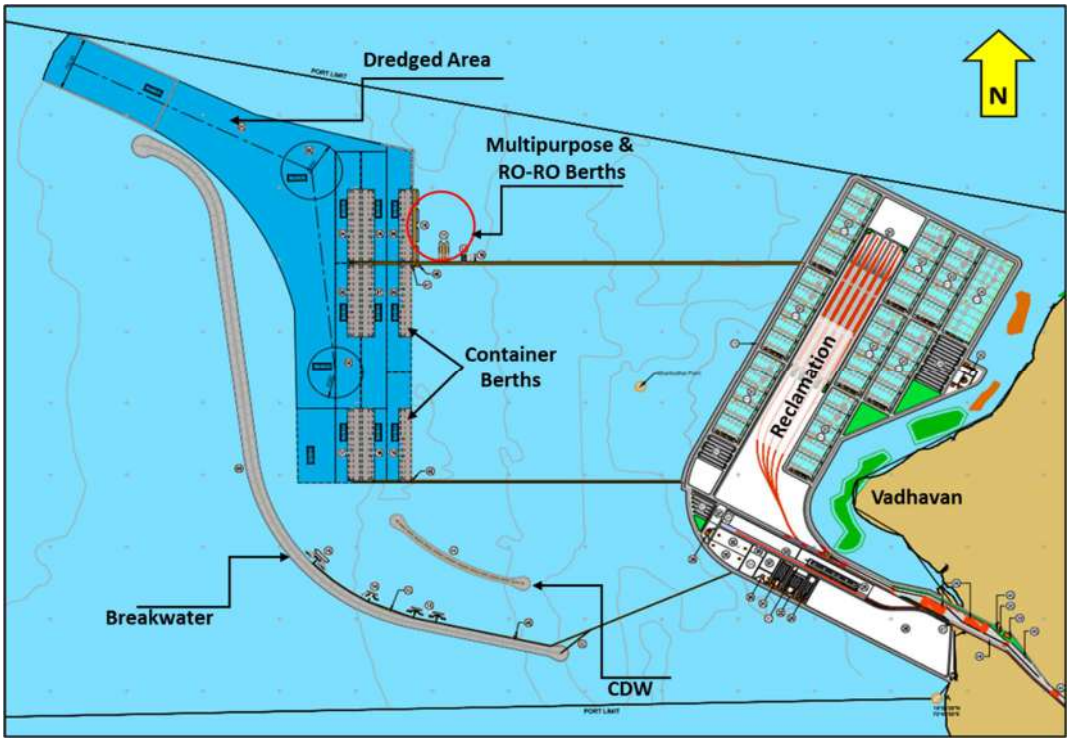
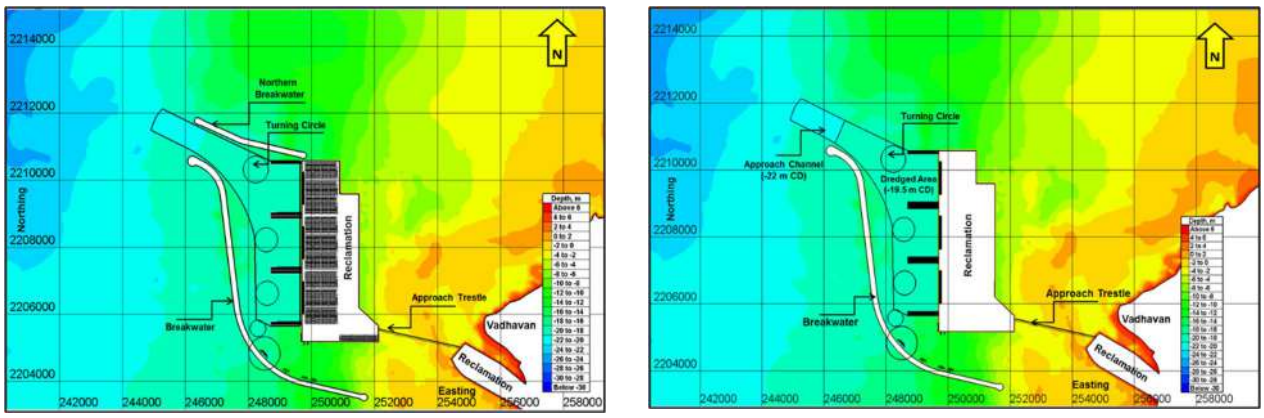


FIG.4 : Master Plan Layout of Proposed Port at Vadhavan

These layouts studied at CWPRS from tidal hydrodynamic and siltation considerations reveal that the flow conditions are suitable for berthing of container vessels along the berths under consideration with likely siltation in proposed dredged area for master plan is estimated as 8 million cum per annum and about 4.9 million cum per annum for Phase-I layout. However, the Port officials discussed the matter of improving the operational efficiency/turnaround time of transport of containers from stack yard proposed on intertidal zone and berths in deeper depths with their terminal operators. The port officials accordingly propose to modify the shape of reclamation and desires to relocate the same immediately on the leeward side of container berths in deeper depths. The studies were carried out for the layouts shown in FIG. 5.



(A) Layout with North Breakwater

(B) Layout without North Breakwater

FIG.5: Vadhavan Port Layout with Stack-yard Reclamation on leeside of Berths (Preferred layout)

These layouts studied reveal that the rate of siltation with north breakwater (about 11 million cum per annum) is significantly higher than for without north breakwater (about 6.5 million

cum per annum). Moreover, due to very steep velocity gradient at harbour entrance, layout with north breakwater is not desirable. Also, flow in the berthing area being perpendicular to the orientations of those berths which are at right angle to the reclamation face and its magnitude is more than 0.1 m/s and it exceeds the PIANC guidelines recommended for transverse current of 0.1 m/s during berthing/de-berthing operations and hence it was not considered as suitable layout unanimously by experts, consultant & officials of JNP.

The consultant further to this, to achieve flow conditions suitable for berthing/ de-berthing at berth faces the layout of reclamation was modified and the same was submitted by JN Port vide letter dated 30th June 2021 to CWPRS for assessing its suitability from hydrodynamic consideration. The proposed port layout consists of an offshore reclamation of about 963 Ha while utility area of about 222 Ha. which will be created in the intertidal zone near Vadhavan point along-with the breakwater proposed by CWPRS earlier (CWPRS TR No. 5583 of March 2018). The studies were carried out and the modifications were suggested by CWPRS in this revised master plan layout after studying various changes in the reclamation layout at southern end. The layout finalized as master plan layout of the port includes 10.3 km long breakwater, offshore reclamation of about 1262 Ha. with its westward face located at about 6.5 km from headland at Vadhavan and shore connected reclamation of about 222 Ha. on tidal flats near the headland at Vadhavan and is shown in FIG.6. The Phase-I development includes 10.3 km long breakwater, offshore reclamation of about 970 Ha. with its westward face located at about 6.5 km from headland at Vadhavan and shore connected reclamation of about 222 Ha. on tidal flats near the headland at Vadhavan and is shown in FIG.7.

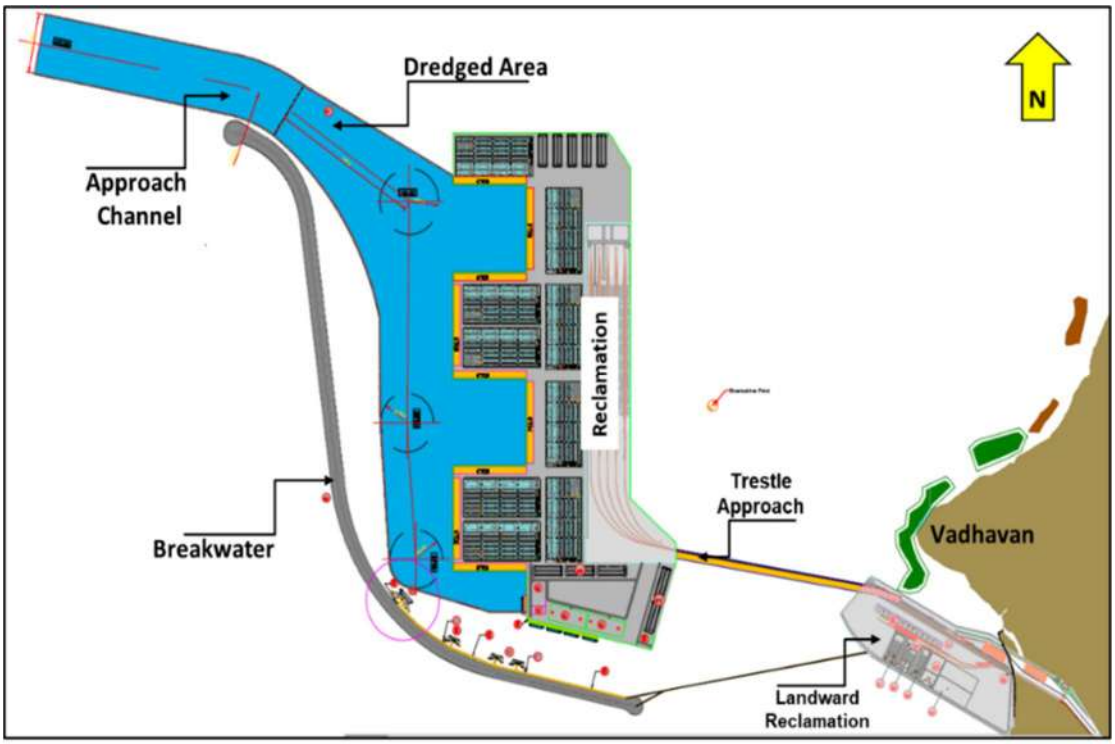


FIG.6 : Finalised Master Plan Layout of Proposed Port at Vadhavan

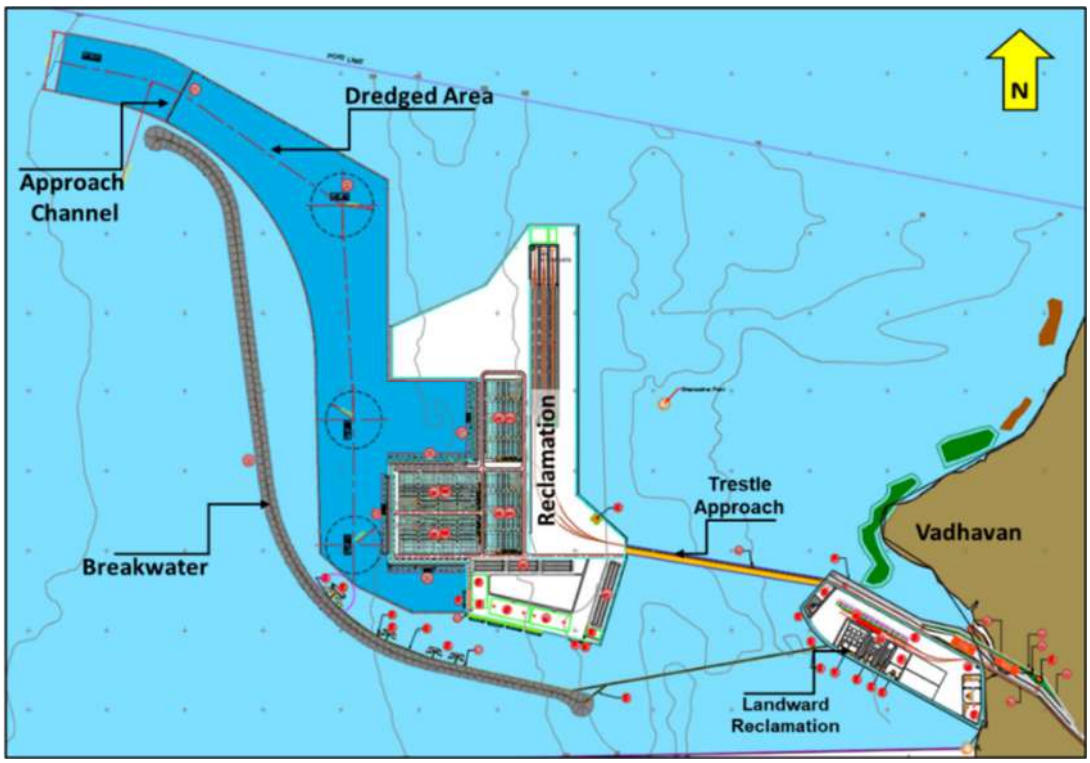


FIG.7 : Finalised Phase-I Layout of Proposed Port at Vadhavan

The layouts shown in FIG. 6 & 7 are considered as final layouts of master plan & Phase-I layout respectively (CWPRS TR. NO 5968 of November 2021) to assess the impact of proposed capital dredging on tidal hydrodynamics of nearby area of proposed port at Vadhavan. The mathematical model studies carried out are described in this report.

2. SCOPE OF THE STUDIES

The mathematical model studies to assess the impact of proposed capital dredging are proposed to be carried out by simulating prevailing hydrodynamic flow field. The scope of studies is as follows:

i) Develop a mathematical model covering the area of proposed port at Vadhavan, Dahanu creek, part of Arabian sea along with shoreline within control area (within 10km radius from Vadhavan point).

ii) Simulate the hydrodynamic conditions prevailing in Vadhavan area by calibrating the model for monsoon and non-monsoon seasons based on the oceanographic data provided by JN Port.

iii) Study the flow field in the nearby area of proposed port at Vadhavan for existing bathymetry and design dredged depths conditions in area proposed to be dredged considering Phase-I & Master Plan layouts.

iv) Comparison of various flow parameters viz. water levels, tidal current strength is to be carried out in harbour and nearby area for models with the existing bathymetry and design dredged depths conditions in Phase-I & Master Plan layouts to assess the impact of dredging on flow field.

3. FIELD DATA FOR MODEL STUDIES

The field data viz. bathymetry, topography, oceanographic parameters such as tides, current, waves etc. as well as wind data was collected and provided by JN Port to simulate the prevailing tidal hydrodynamic flow conditions for both monsoon and non-monsoon seasons. The non-monsoon field data was collected in January-February 2017, while monsoon field data was collected in September-October 2020. The field data was submitted by JNP to CWPRS and is as follows:

1. Bathymetry survey of proposed port site (Ref. 4)
2. Topography of Dahanu creek and nearby region within Control Area up to +10 m contour (Ref. 8)
3. Tide data collected at Dahanu Creek Bridge at the entrance of Dahanu creek for non-monsoon and monsoon seasons (Ref. 3 & 7)
4. The current data at ADCP location in the port limit for non-monsoon and monsoon seasons (Ref. 3 & 7)
5. Wave data at one location in the port limit for non-monsoon and monsoon seasons (Ref. 3 & 6)
6. Meteorological data viz. wind speed, direction etc. at one location (Ref. 3 & 6)

The locations of oceanographic field data collected are shown in FIG. 8.

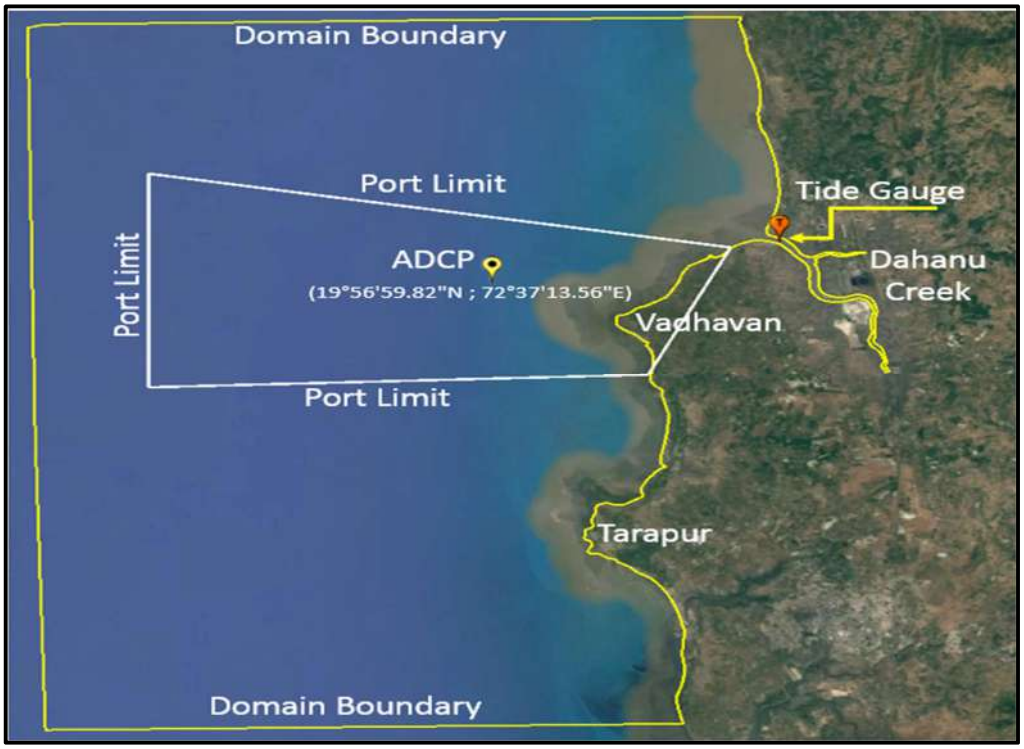


FIG.8: Locations of Oceanographic Field Data Measurements for Proposed Port at Vadhavan

3.1 Bathymetry Survey for Proposed Port Site

The hydrographic survey for the proposed port area within its limit is carried out by project authorities during December 2016 to March 2017 and the same is shown in FIG.9.

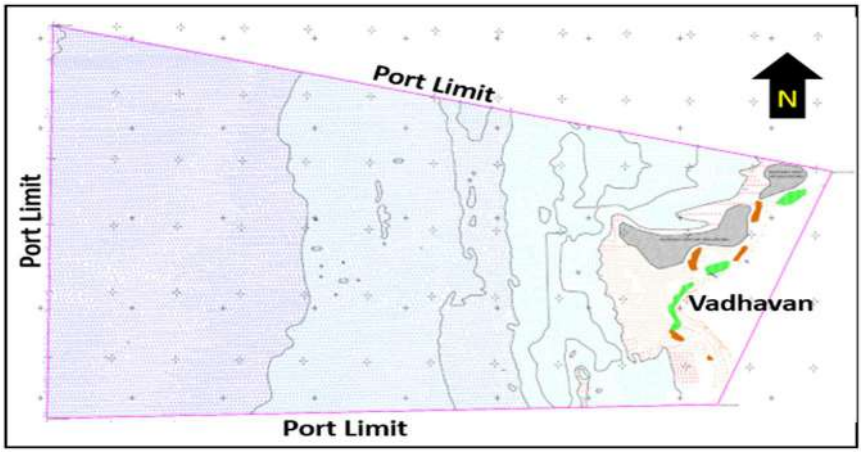


FIG.9: Bathymetry Data for Proposed Port at Vadhavan

The depths within the port limit vary between -26 m and +2 m w.r.t. CD of Vadhavan area. The data shows some patches of rocky outcrops and areas of mangrove coverage near shoreline. The bathymetry in the areas like Dahanu creek, Vadhavan, Tarapur area was provided by JNP and part of this data is based on the hydrographic charts prepared by MMB in year 2003 for Tarapur site and Vadhavan headland area, while for Dahanu creek in year 2020.

3.2 Topography of Dahanu Creek and nearby region within Control Area

The topography survey of the Dahanu creek and nearby region within Control area from HTL up to +10m contour has been carried out by Drone survey and was provided by JN Port. This data is used to reproduce the topographical details of Control area. The area over which topographic survey carried out is shown in FIG.10 as blue portion. The data provided is w.r.t. MSL and is correlated to CD of Vadhavan area based on the relation between MSL and CD provided by JN Port.

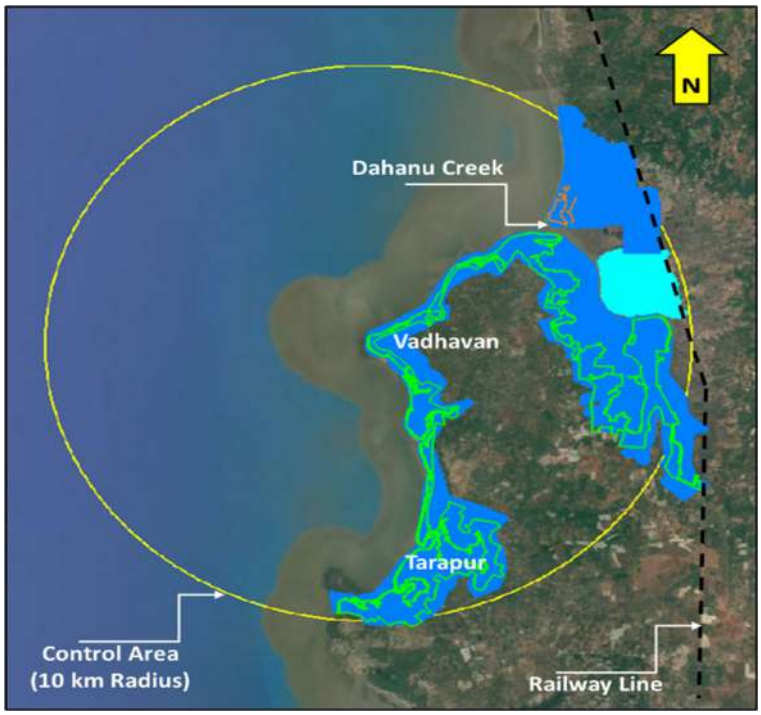


FIG.10: Topography Data in Control area for Proposed Port at Vadhavan

3.3 Tide Data

The tidal data was collected at 3rd pier of Bridge on Dahanu Creek for the duration of one month from 10/01/2017 to 10/02/2017 for non-monsoon season, while for monsoon season it was collected from 11/10/2020 to 27/10/2020. The data was correlated with CD of Vadhavan area and the CD was correlated w.r.t. Benchmark established on the Light House at Dahanu. The plots of tide data collected for non-monsoon & monsoon seasons are shown in FIG. 11(A) & 11(B).

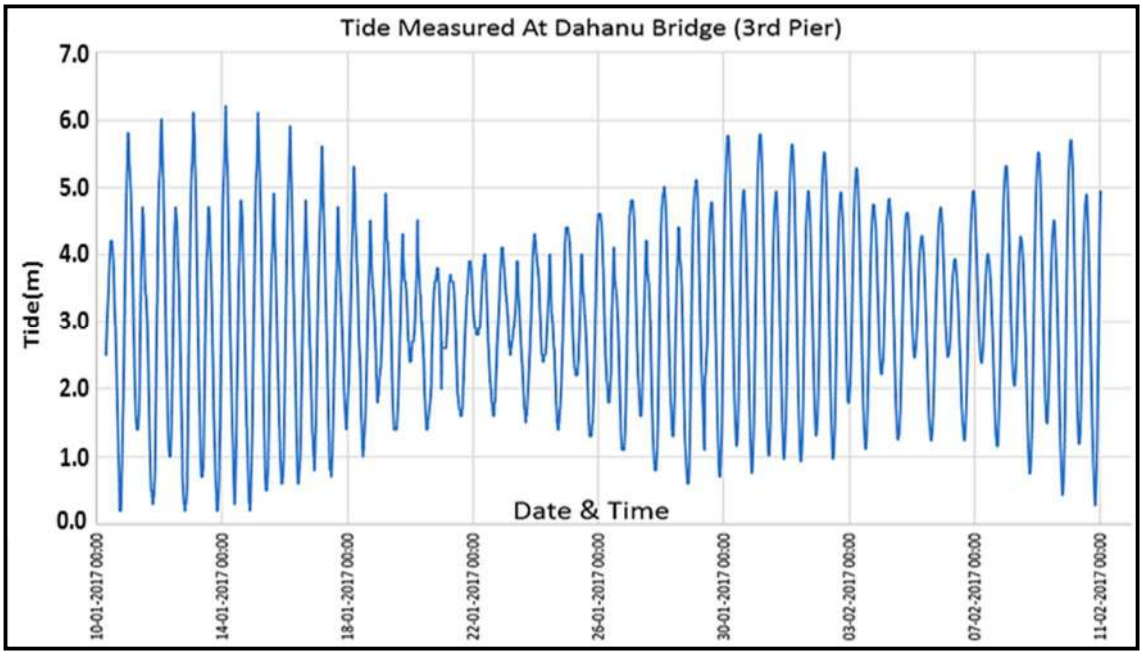


FIG.11(A) : Measured Tide Data at Dahanu Bridge Location (Non-monsoon Season)

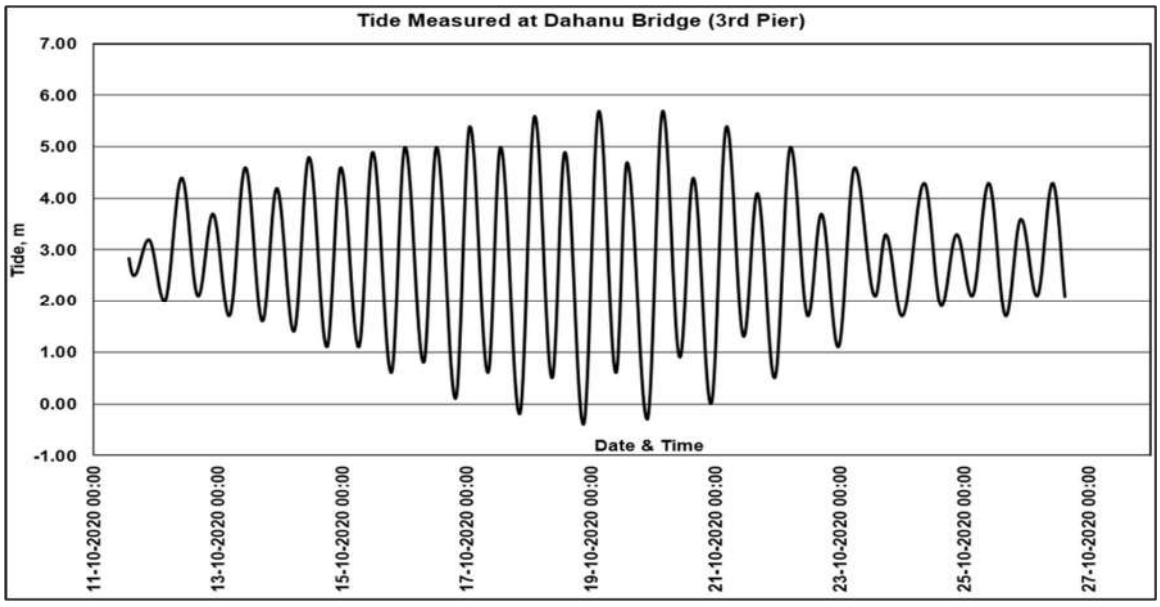


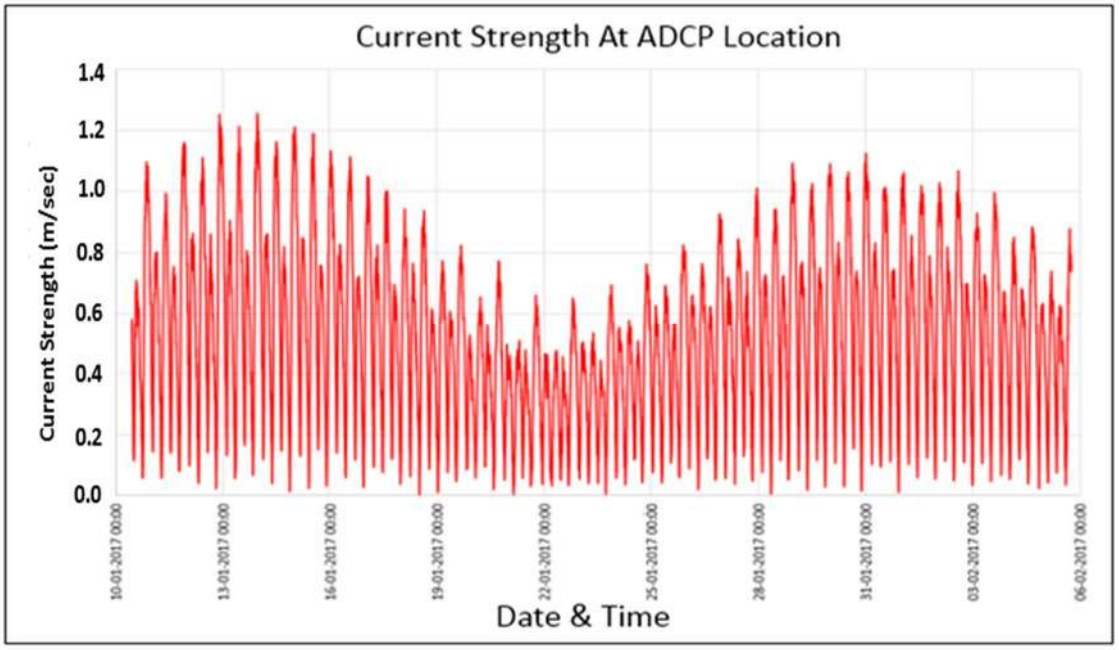
FIG.11(B) : Measured Tide Data at Dahanu Bridge Location (Monsoon Season)

The analysis of measured tidal data was carried out and it reveal that the tides are semi-diurnal in nature with diurnal inequality for both non-monsoon and monsoon seasons. During

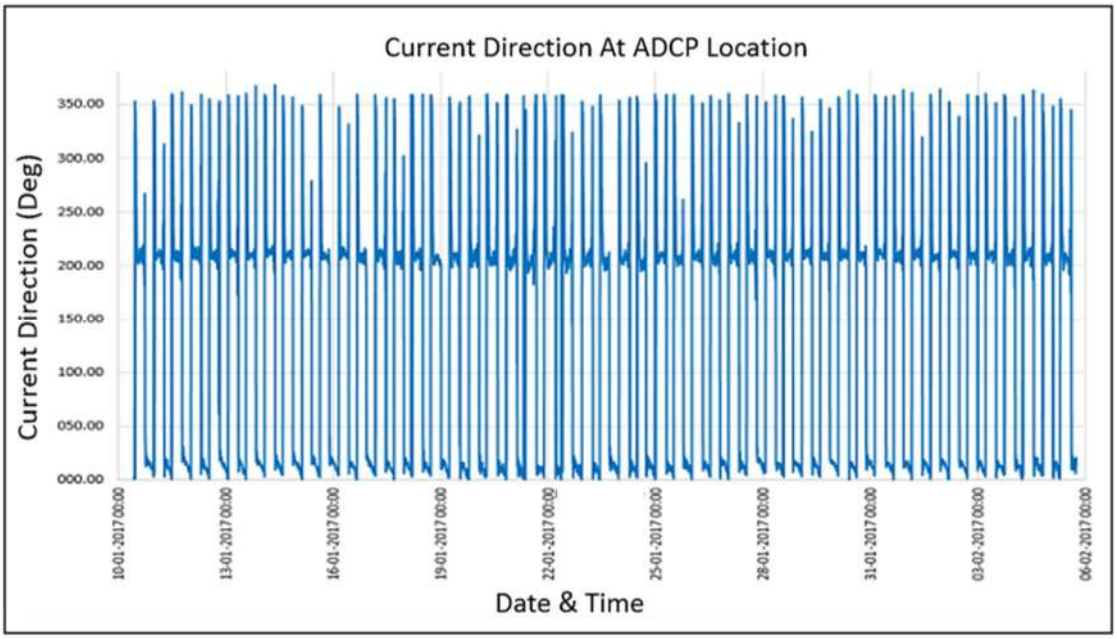
non-monsoon season, the maximum tidal range is about 5.87 m, while minimum tidal range is about 2.10 m. Similarly, during monsoon season, the maximum tidal range is about 6.0 m, while minimum tidal range is about 1.14 m.

3.4 Current Data

The ADCP was deployed at Lat.19°56'59.82" N, Long. 72°37'13.56" E for the measurement of current (strength & direction) in the port limit both for non-monsoon and monsoon seasons. The plots of measured current data (strength & direction) at mid depth for non-monsoon and monsoon seasons are shown in FIG. 12 and FIG.13 respectively.



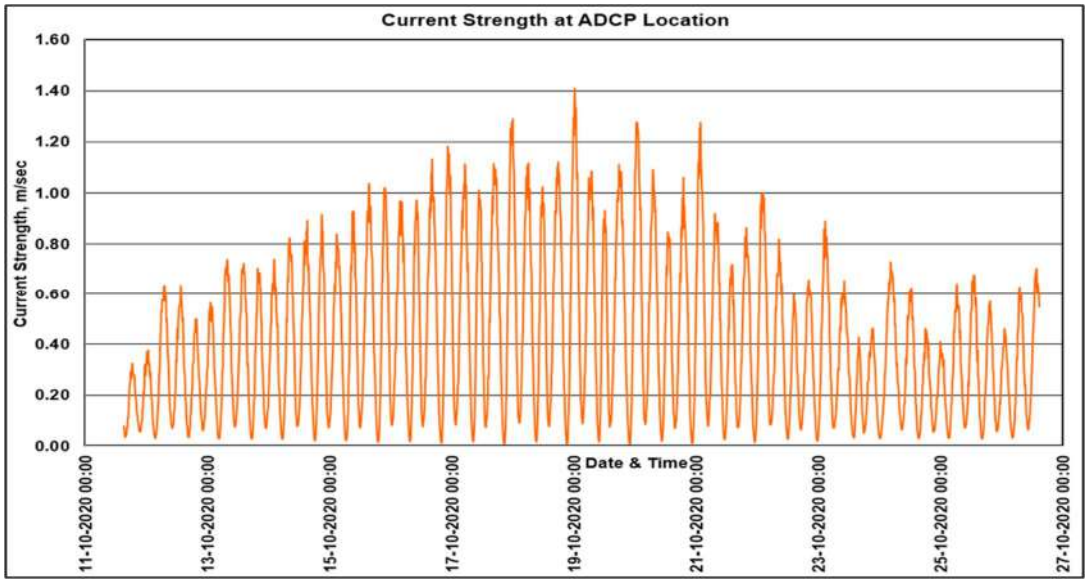
(A) Current strength at Mid depth



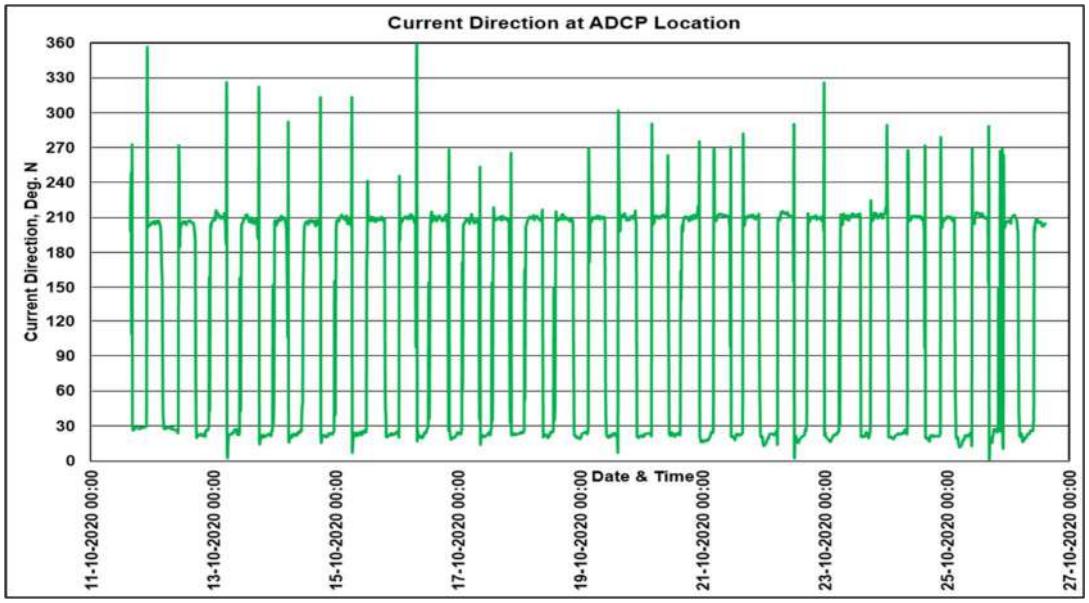
(B) Current Direction at Mid depth

FIG.12 : Measured Current at ADCP Location (Non-monsoon Season)

The analysis of current data for Non-monsoon season reveals that maximum current strength observed is 1.25 m/s during spring tide, while it is 0.66 m/s during neap tide. The current direction w.r.t. north varies between 3° and 23° during flood tide, while it is between 204° and 215° during ebb tide.



(A) Current strength at Mid depth



(B) Current Direction at Mid depth

FIG.13 : Measured Current at ADCP Location (Monsoon Season)

The analysis of current data for monsoon reveals that maximum current strength observed is 1.40 m/s during spring tide, while it is 0.40 m/s during neap tide. The current direction w.r.t. north varies between 16° and 23° during flood tide, while it is between 203° and 210° during ebb tide.

3.5 Wave Data

The wave data (height & direction) was also made available by JN Port at ADCP location for Non-monsoon as well as monsoon seasons. The plot of significant wave height, peak

direction and its wave rose diagram for Non-monsoon season are presented in FIG.14 (A) & (B) respectively.

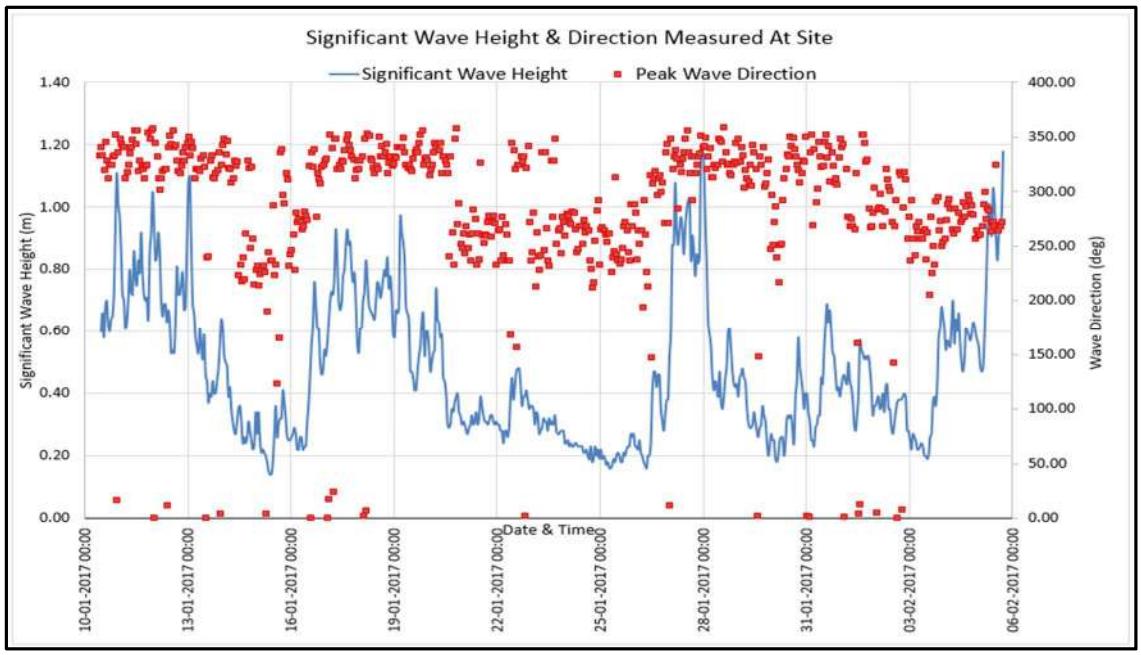


FIG.14(A) : Wave Data at ADCP Location (Non-monsoon)

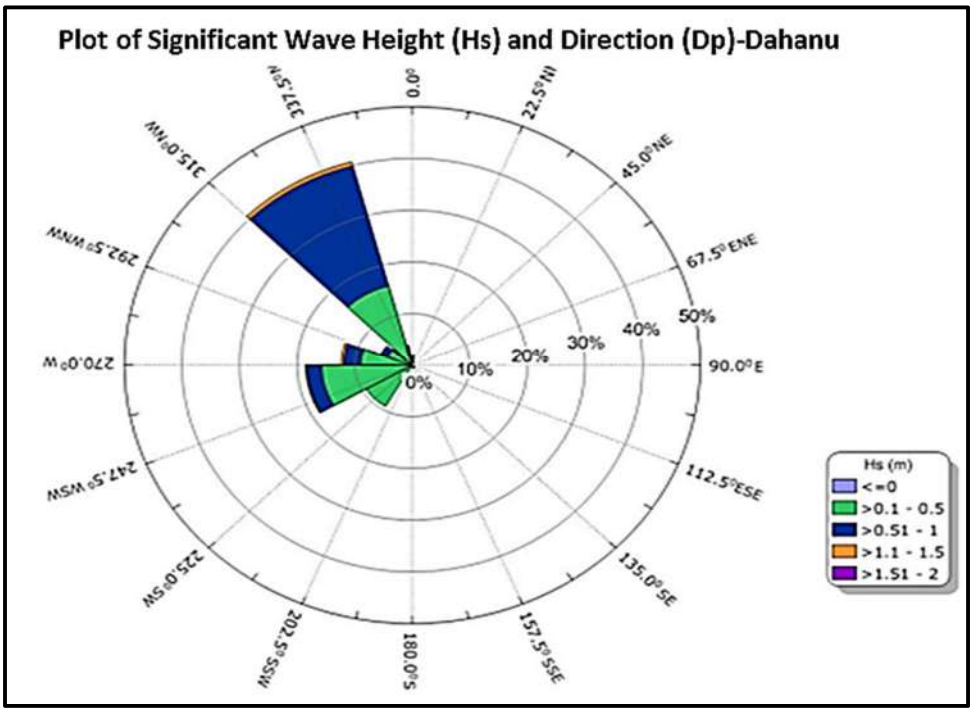


FIG.14(B): Wave Rose Diagram For Wave Data at ADCP Location (Non-monsoon)

The plot shows maximum significant wave height observed during the period as 1.19 m while minimum significant wave height observed is 0.14 m with corresponding peak wave directions as 351° N and 244° N respectively. Thus, the majority of waves during the period of observation (non-monsoon period) are approaching from North-West quadrant (FIG.14 (B)).

The plot of significant wave height, peak direction and its wave rose diagram for monsoon season are presented in FIG.15(A) & 15(B) respectively. This data was obtained by JN port from INCOIS, India and was provided to CWPRS.

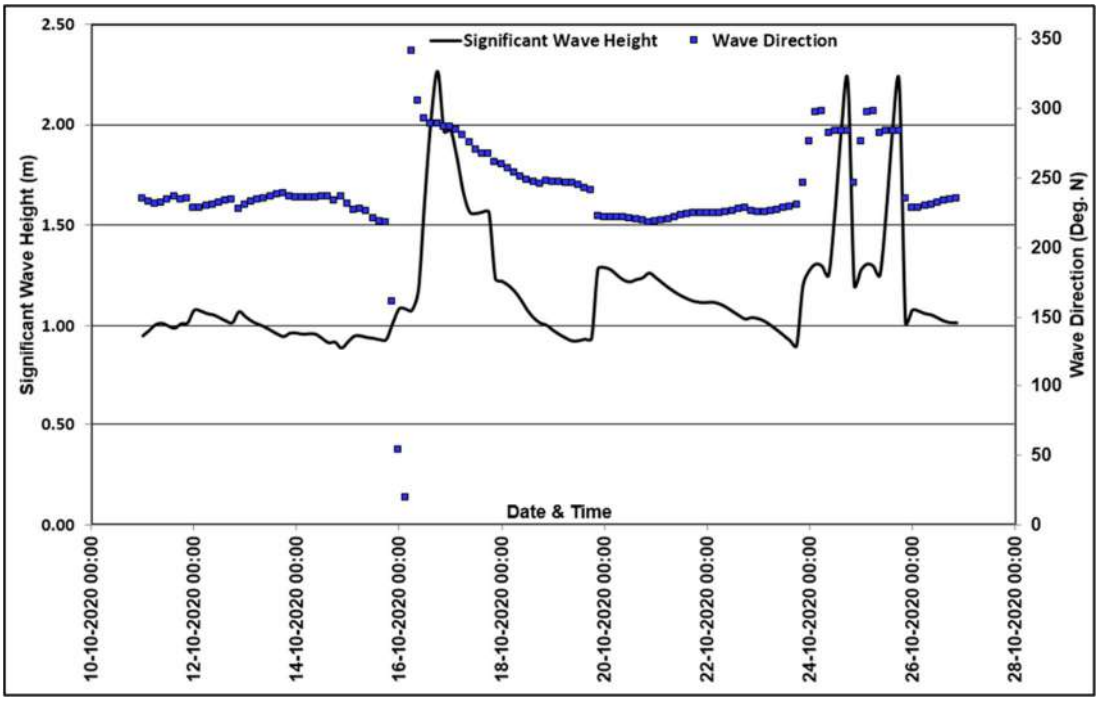


FIG.15(A) : Wave Data at ADCP Location (Monsoon)

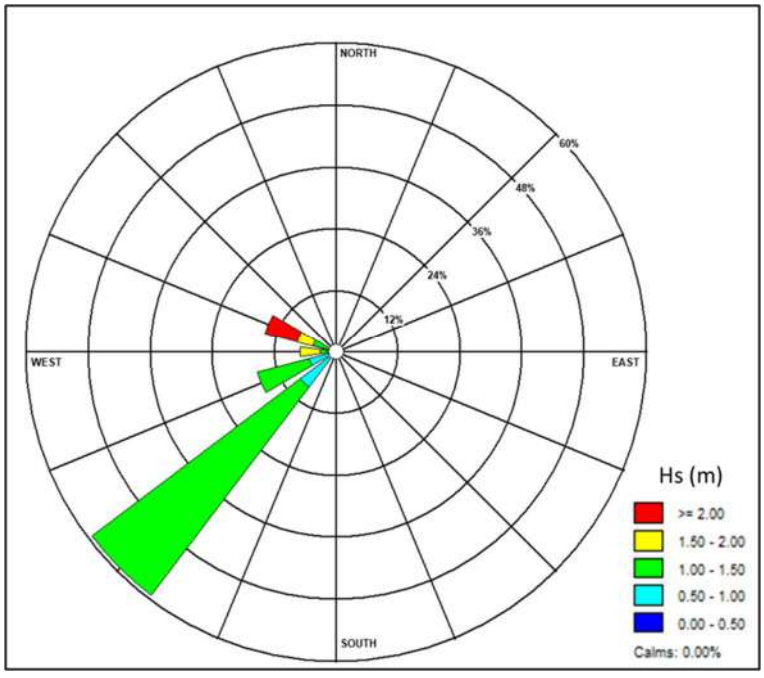


FIG.15(B): Wave Rose Diagram For Wave Data at ADCP Location (Monsoon)

The plot shows maximum significant wave height observed during the period as 2.3 m while minimum significant wave height observed is 0.9 m with corresponding wave directions as 233° N and 288° N respectively. Thus, the majority of waves during the period of observation (monsoon period) are approaching from SW-WNW quadrant (FIG.15 (B)).

3.6 Wind Data

The wind data was measured at Dahanu for the period of one month (10/01/2017 to 10/02/2017). Wind speed and direction are plotted in FIG.16 (A) & 16 (B) respectively.

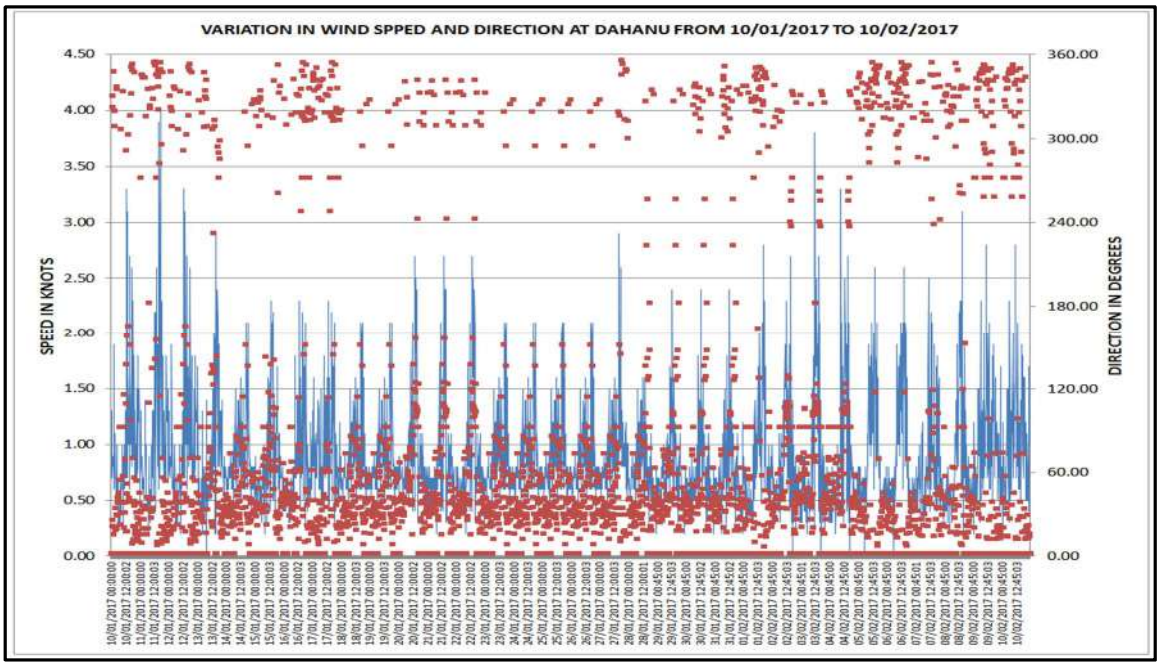


FIG.16(A) : Measured Wind Data at Dahanu (Non-monsoon)

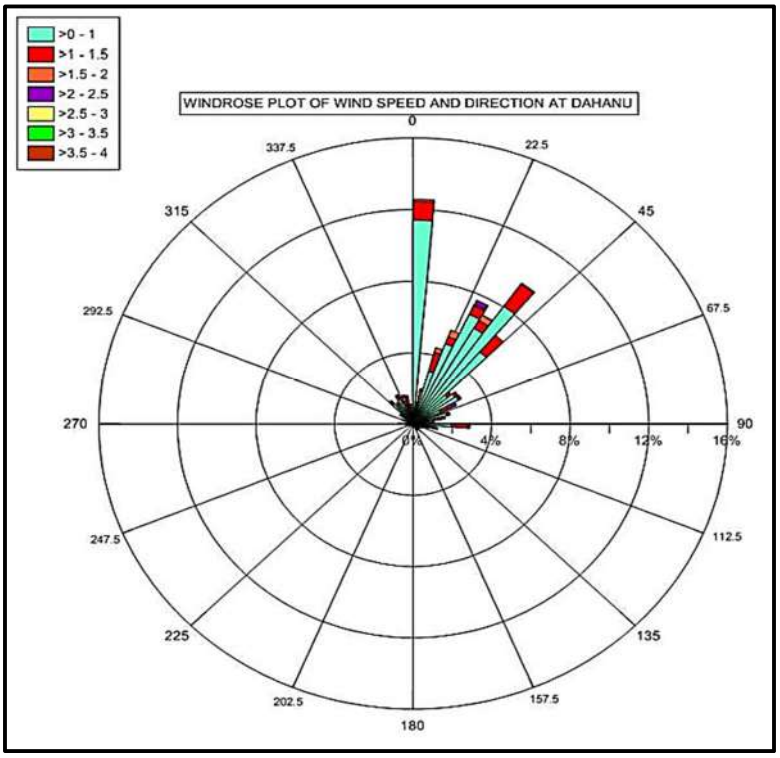


FIG.16(B):Rose Diagram for Measured Wind Data at Dahanu (Non-monsoon)

The wind speeds measured during the period varies from 0.20 knots to 4.00 knots with the majority of wind blows from 0°- 45° N.

Similarly, wind data at Dahanu for the period 11/10/2020 to 26/10/2020 is shown as wind speed and direction in FIG.17 (A) & 17 (B) respectively.

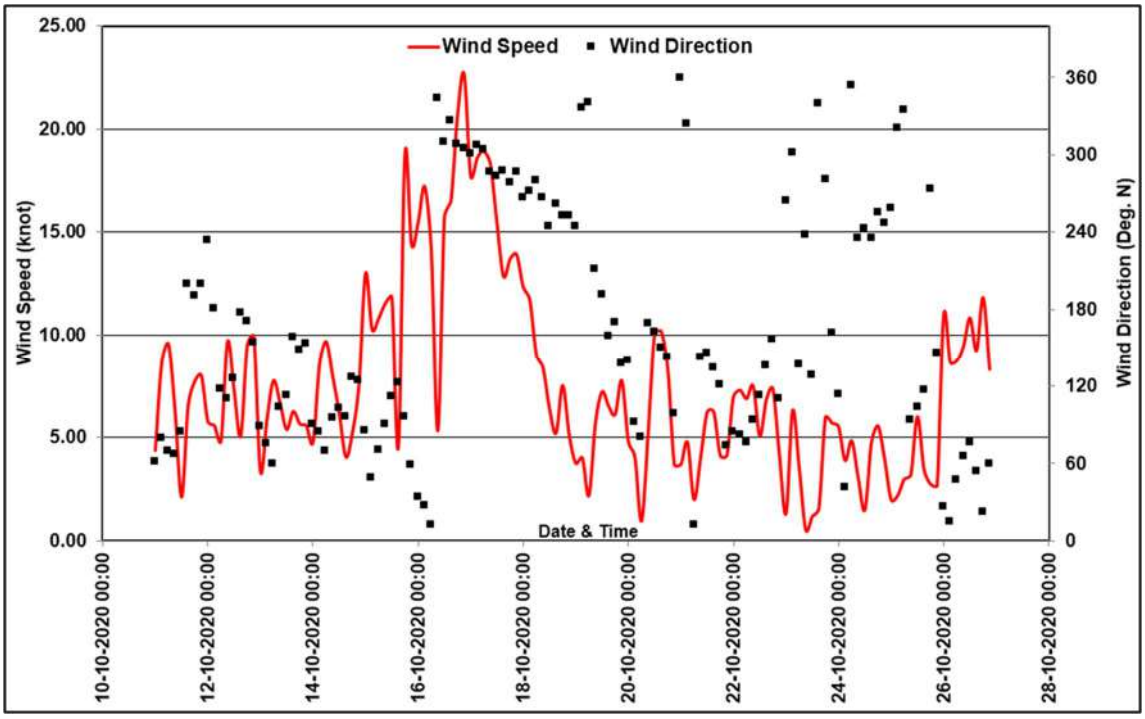


FIG.17(A) : Wind Data at Dahanu (Monsoon)

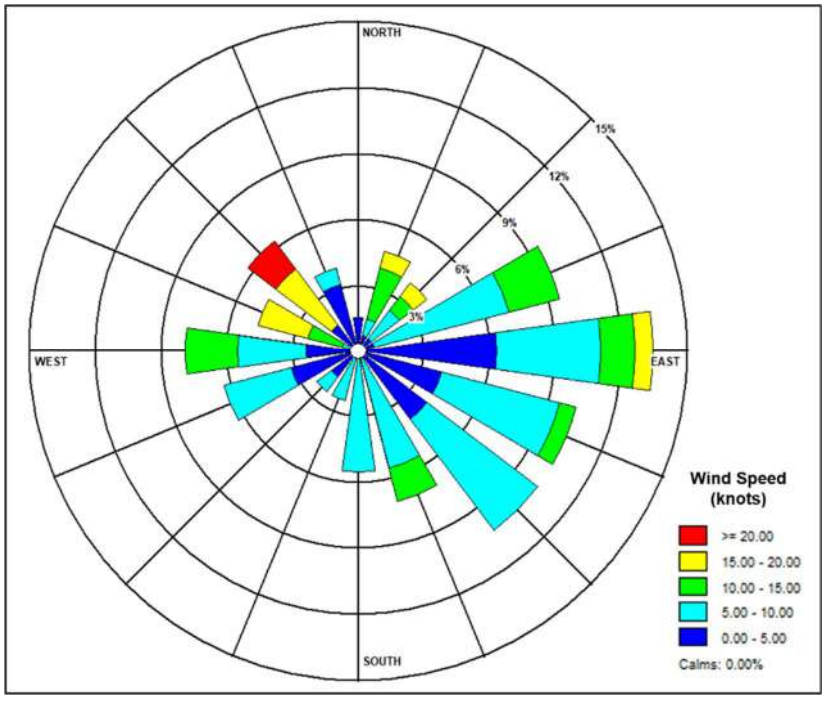


FIG.17(B): Rose Diagram for Wind Data at Dahanu (Monsoon)

The wind speeds measured during the period varies from 0.50 knots to 22.6 knots with the wind blows from all directions.

The data on sea water temperature, density and salinity were also measured at site and the average sea water temperature is 23.5°C, average sea water density is 1024 kg/cum and average salinity is 35.5 PSU. The bed samples were also collected and grain size analysis of the bed samples indicate that the material is Clayey Silt with D_{50} varies between 0.005 mm and 0.015 mm.

4. MATHEMATICAL MODEL STUDIES

The mathematical model study provides the information on simulation of tidal hydrodynamics for the area in the vicinity of proposed port at Vadhavan in the Arabian Sea. The studies were carried out by using TELEMAC-2D software available at Central Water & Power Research Station (CWPRS), Pune. The TELEMAC-2D is finite element software, which considers solution of hydrodynamic equations of Saint Venant's. The model considers depth-averaged velocities. The equations are solved by solving matrices element by element at number of nodes of finite element, which is an unstructured triangular mesh.

The TELEMAC-2D code solves the following three hydrodynamic equations simultaneously

$$\frac{\partial h}{\partial t} + \vec{u}.\vec{\nabla}(h) + h div(\vec{u}) = S_h \quad \text{----------} \quad \text{Continuity}$$

$$\frac{\partial u}{\partial t} + \vec{u}.\vec{\nabla}(u) = -g\frac{\partial Z}{\partial x} + S_x + \frac{1}{h} div(h\nu_t \vec{\nabla} u) \quad \text{----------} \quad \text{Momentum along x}$$

$$\frac{\partial v}{\partial t} + \vec{u}.\vec{\nabla}(v) = -g\frac{\partial Z}{\partial y} + S_y + \frac{1}{h} div(h\nu_t \vec{\nabla} v) \quad \text{----------} \quad \text{Momentum along y}$$

in which,

h	(m)	----------	depth of water
u, v	(m/s)	----------	velocity components
g	(m/s^2)	----------	gravity acceleration
ν_t	(m^2/s)	----------	momentum diffusion coefficient
Z	(m)	----------	free surface elevation
t	(s)	----------	time
x, y	(m)	----------	horizontal space coordinates
S_h	(m/s)	----------	source or sink of fluid
S_x, S_y	(m/s^2)	----------	source and sink terms in dynamic equations

u, v are the unknowns

The equations are given in Cartesian Co-ordinates. They can also be processed using spherical co-ordinates.

S_x and S_y are source terms representing the wind, Coriolis force, bottom friction, a source or sink of momentum within the domain. The different terms of these equations are processed in one or more steps (in case of advection by method of characteristics).

1. Advection of h, u and v
2. Propagation, diffusion and source terms of the dynamic equation

4.1 Discretisation of the Domain Area

The model domain covers areas like harbour area of proposed port, coastlines of Vadhavan and Tarapur as well as Dahanu Creek. The model is extended up to Gholvad on north side as well as up to Nandgaon on the south side and up to about 30 m depth below CD in deeper part of Arabian Sea on the west-side. The Dahanu creek along with topography up to +10m contour in the control area is also considered in the model. The model domain is discretized using finite elements (FE) and is developed for the existing bathymetry condition. The total domain area considered is about 940 sq. km. The mesh generated for the domain is shown in FIG. 18(A). The triangular finite elements with fine resolution near shoreline, in the creek-lets of Dahanu creek

area etc. were adopted for true simulation of all water areas, steep slopes, rocky outcrops and coarser resolution in deeper depths to optimize the number of elements for minimizing the simulation time. Thus, mesh generated can effectively reproduce hydrodynamic conditions without compromising on the quality of results. The variable element sizes in proportion to bathymetry were also adopted to schematize the navigational channels, deeper depths and land boundaries. The bathymetry data supplied by JNP for proposed port area, C-map data (DHI) for deeper part of the sea and charts prepared by MMB for Dahanu Creek (Year 2020), Tarapur and Vadhavan (Year 2003) were used for reproducing the bathymetry in the domain area under consideration. The topography data from HTL up to +10m contour is also considered to represent the detailed topography of the Dahanu creek area. The bathymetry of the Vadhavan area along with the tide/current data measurement locations is shown in FIG. 18(B). The interpolated depths were assigned at nodal points of the finite elements to represent the depths in model and hydrodynamic equations in terms of water depth and velocity are solved. Thus, mesh generated can effectively reproduce hydrodynamic conditions prevailing at site.

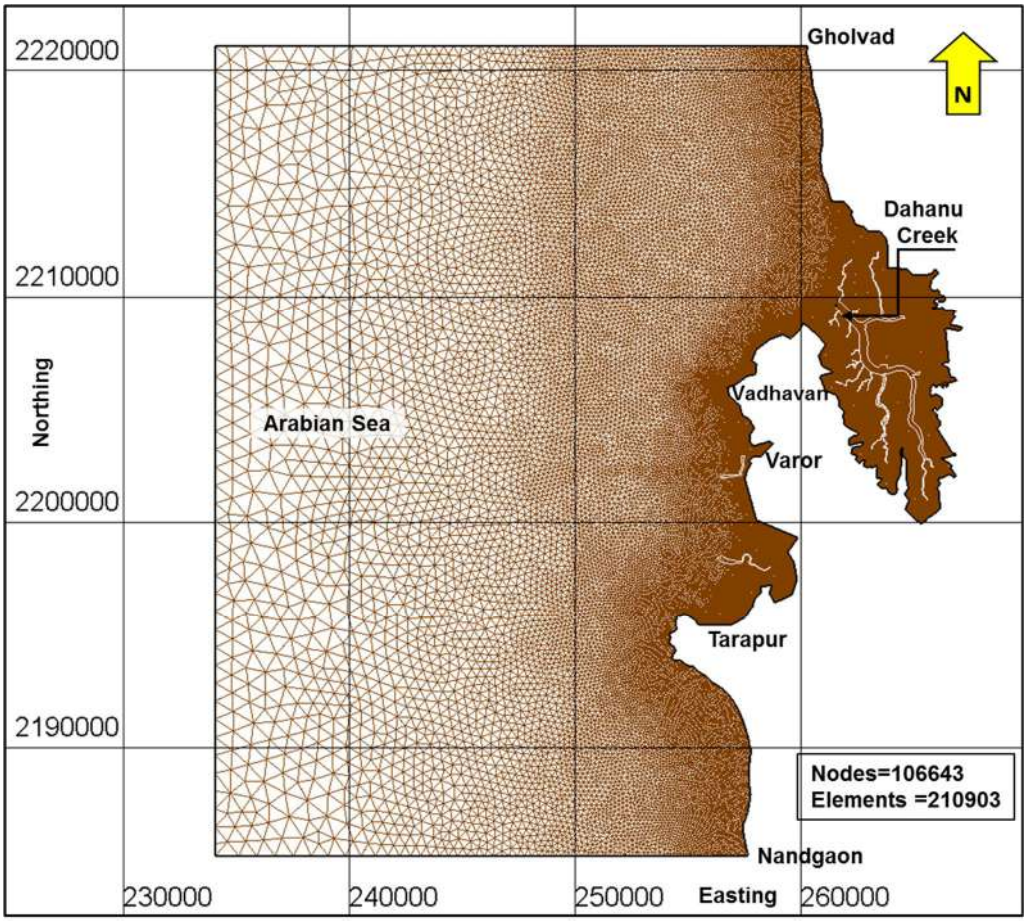


FIG.18(A):Finite Element Mesh for Vadhavan Model

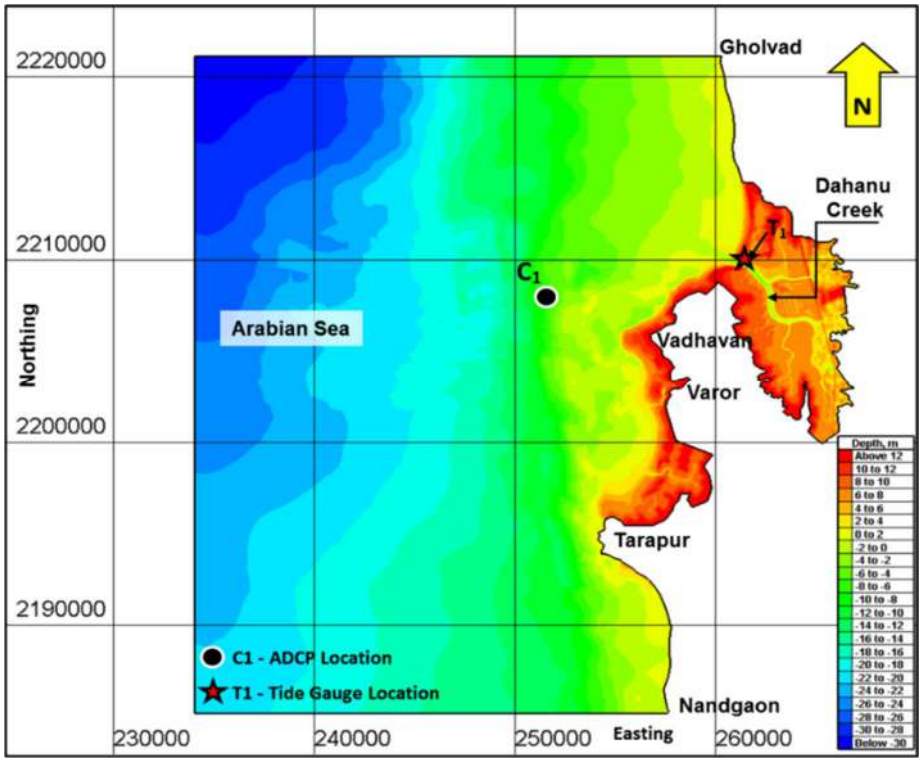


FIG.18(B):Bathymetry of Vadhavan Area

4.2 Simulation and Calibration of Model for Tidal Hydrodynamics

The observed tidal data for non-monsoon season is used as northern boundary condition and tidal data with lag is adopted as southern boundary condition for existing bathymetry to simulate the hydrodynamics prevailing in the domain area by mathematical model. Information on grain size for bed samples provided by JNP is used to consider the appropriate bed friction and the simulation of flow in the model is carried out. The current data and water level data in model were obtained at locations wherein field data for current at ADCP location & tide data at Dahanu bridge site. The comparison of water levels and current (strength & direction) observed in mathematical model and that prevailing at site based on field data for non-monsoon season is shown in FIG.19(A), 19(B) & 19(C) respectively.

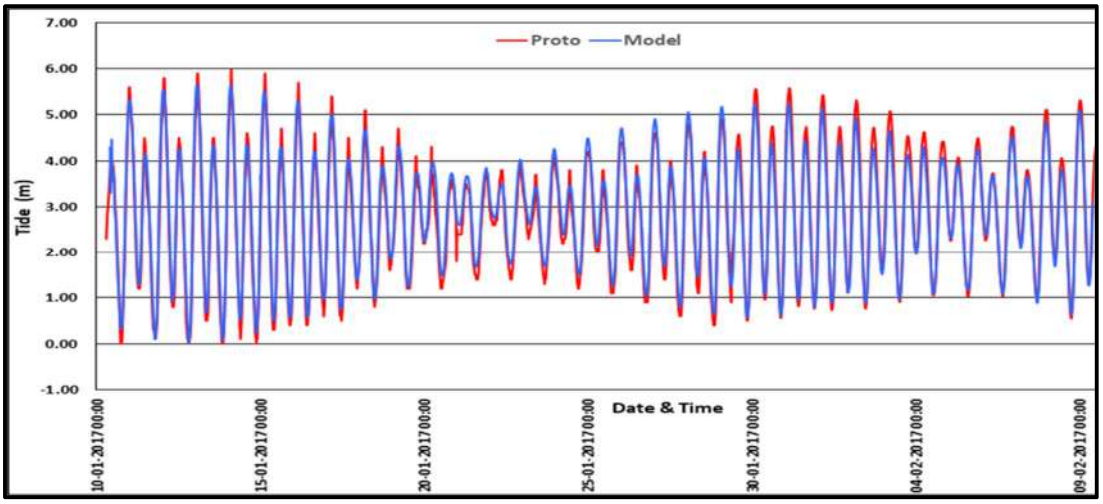


FIG.19(A): Comparison of Proto and Model Tide at T1 Location (Non-monsoon)

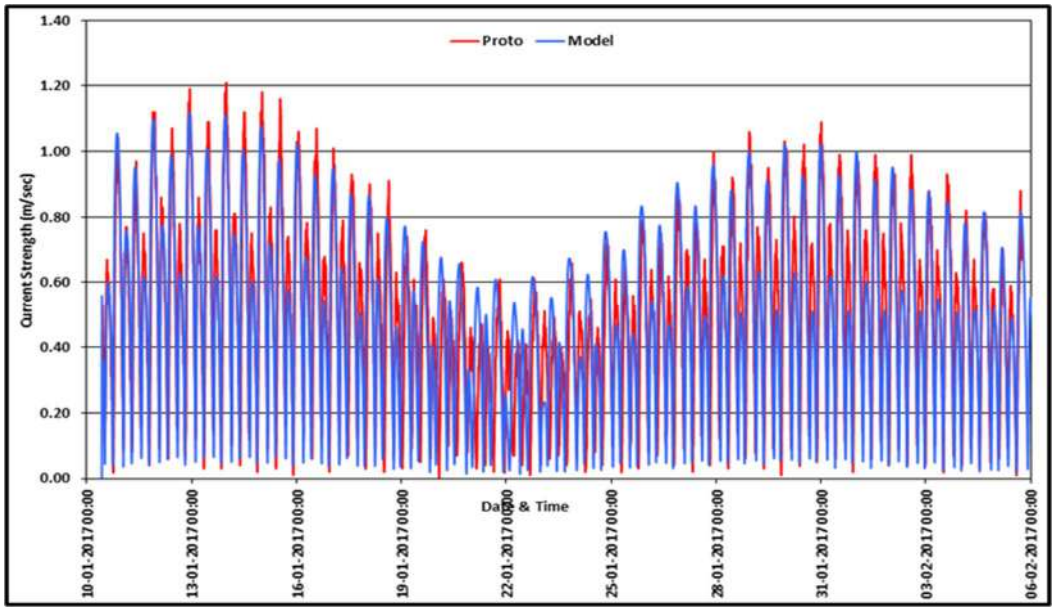


FIG.19(B): Comparison of Proto and Model Current Strength at C1 (Non-monsoon)

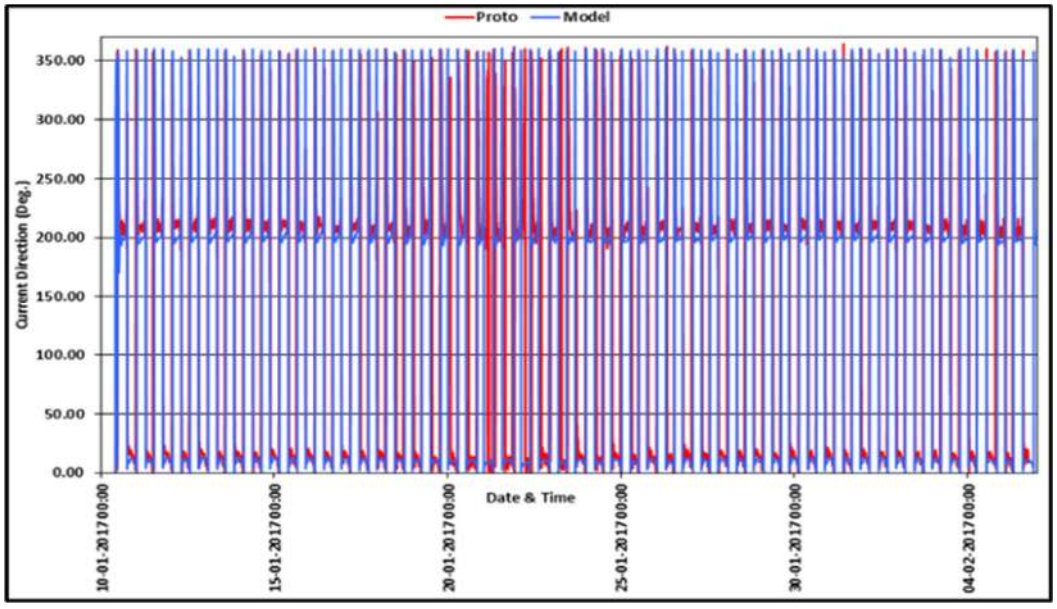


FIG.19(C): Comparison of Proto and Model Current Direction at C1 (Non-monsoon)

Similarly, the tidal hydrodynamic simulation for existing bathymetry condition for monsoon season is also carried out. The current data and water level data in model were obtained at locations wherein field data for current & tide is available. The comparison of water levels and current (strength & direction) observed in mathematical model and that prevailing at site based on field data for monsoon season is shown in FIG.20(A), 20(B) & 20(C) respectively.

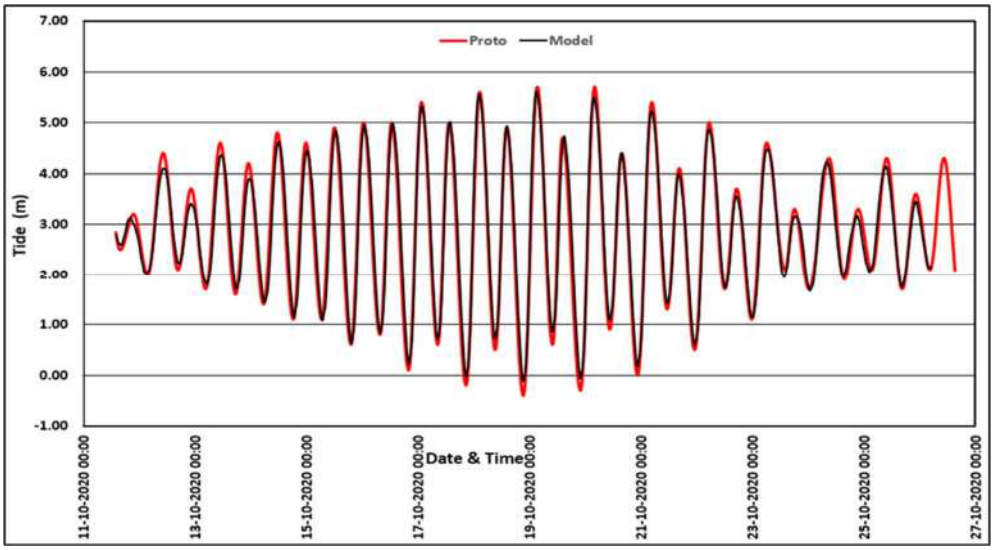


FIG.20(A): Comparison of Proto and Model Tide at T1 Location (Monsoon)

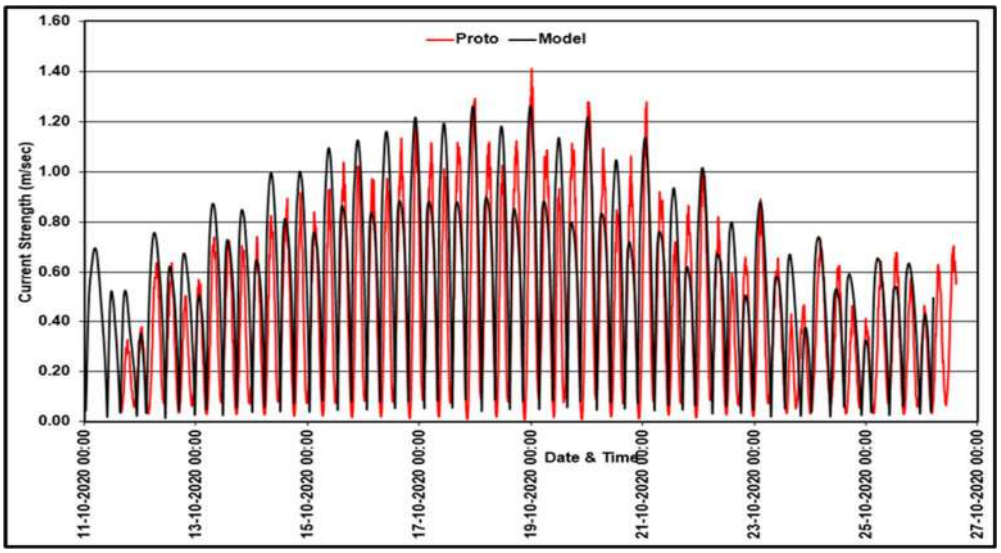


FIG.20(B): Comparison of Proto and Model Current Strength at C1 (Monsoon)

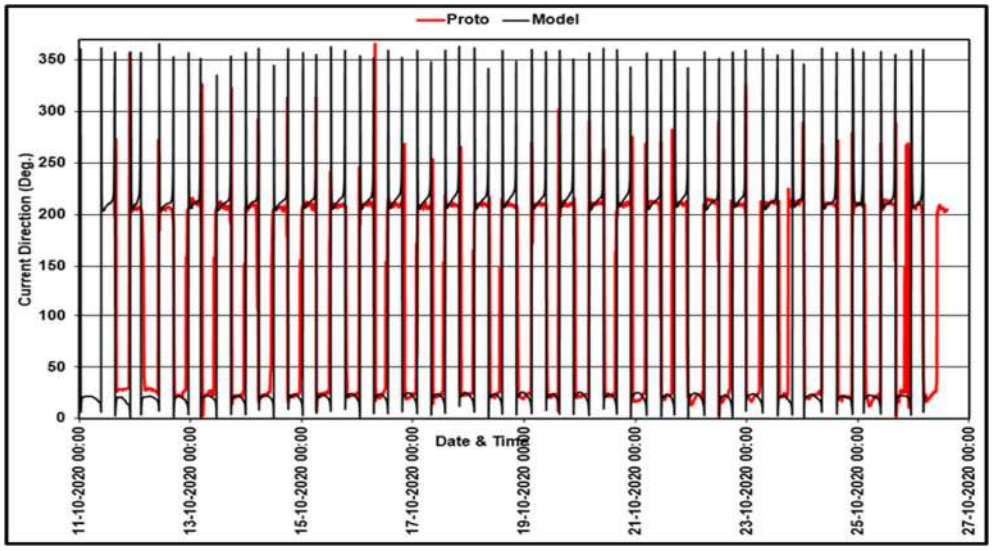
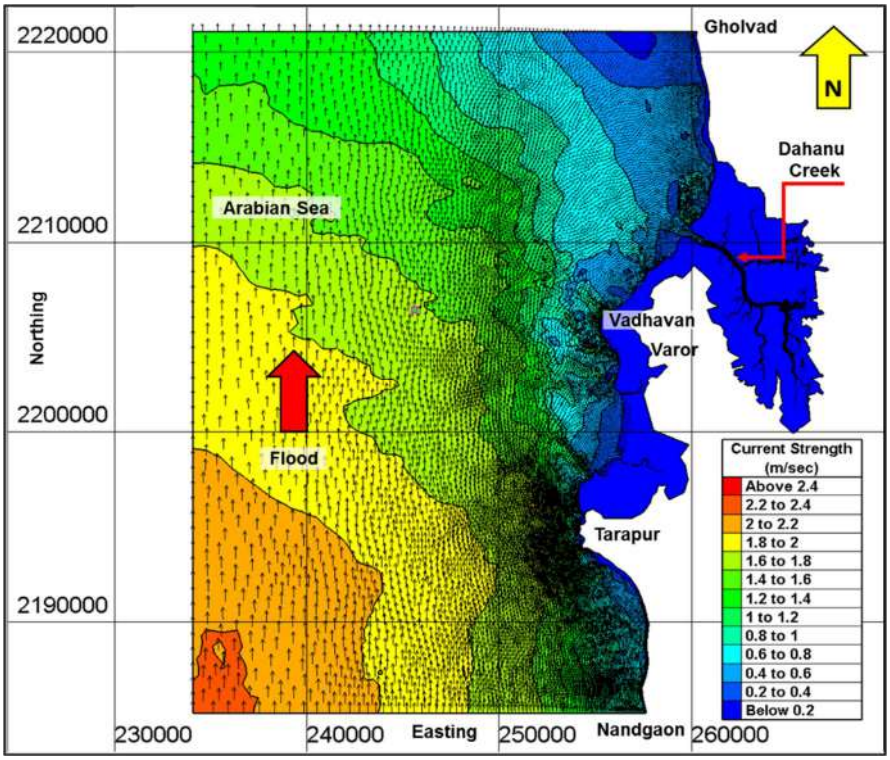
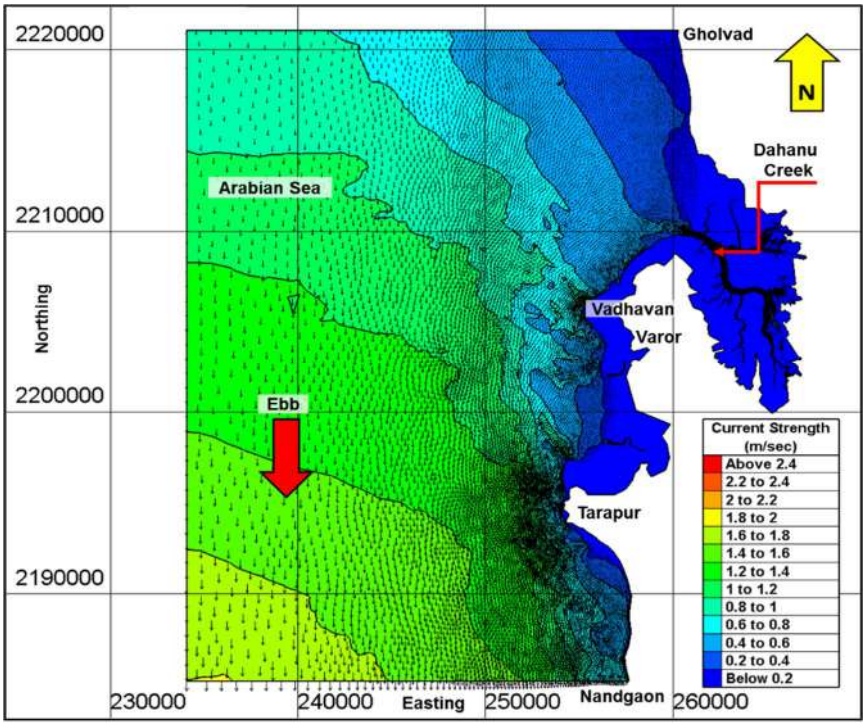


FIG.20(C): Comparison of Proto and Model Current Direction at C1 (Monsoon)

It can be seen from the above figures that measured and computed water levels as well as current at corresponding locations compares well for both non-monsoon & monsoon seasons. Hence, it can be inferred that mathematical model is reasonably well calibrated with respect to water level and current in the area under consideration. The flow patterns observed in model during flood & ebb are shown in FIG.21.



Flood Flow



Ebb Flow

FIG.21: Flow Patterns observed during Flood & Ebb for Existing Bathymetry Condition

5. MODEL STUDIES TO ASSESS IMPACT OF DREDGING

The studies were carried out to assess the impact of proposed capital dredging on the flow field (water levels, tidal currents) in the harbour and nearby area. The studies were carried out for existing bathymetry and design dredged depths conditions proposed for Master Plan as well as Phase-I layouts and are described as follows.

5.1 Model Studies for Impact of Dredging for Master Plan layout

The modification in the bathymetry of calibrated hydrodynamic model is carried out by incorporating various port structures viz. 10.3 km long breakwater, offshore reclamation of about 1262 Ha. and shore connected reclamation of about 222 Ha. on tidal flats near the headland at Vadhavan (CWPRS TR. NO 5968 of November 2021) along with bathymetry existing at site in the proposed area to be dredged for Master Plan layout. The finite element mesh and zoomed portion of bathymetry of the model for Master Plan layout is shown in FIG.22(A) & 22(B) respectively.

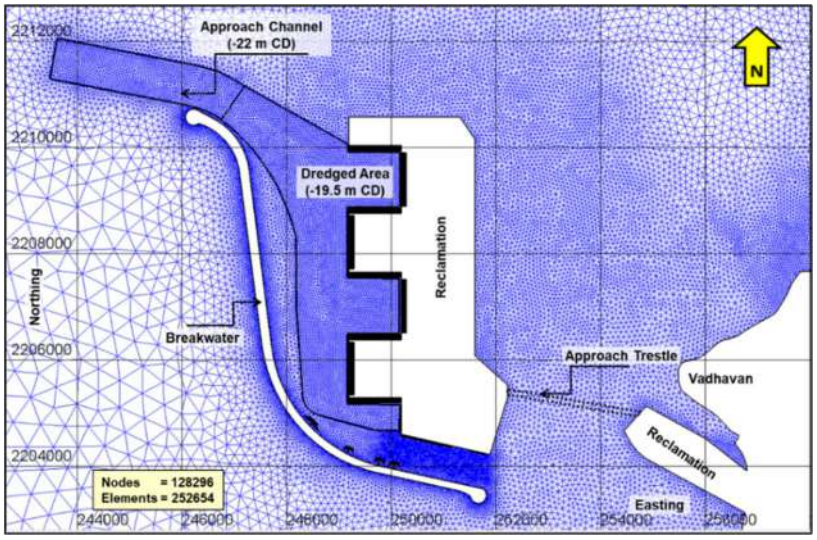


FIG.22(A):Finite Element Mesh for Master Plan Layout for Port at Vadhavan

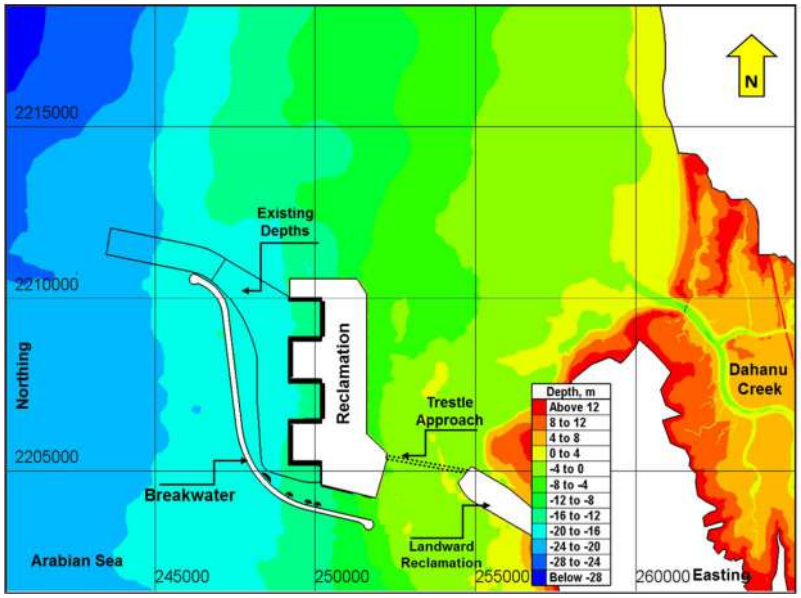


FIG.22(B): Zoomed Portion of Bathymetry for Master Plan Layout with Existing Bathymetry

The proposed capital dredging will be carried out over the area of about 1210 Ha. located at about 6.5 km westward of headland at Vadhavan with depths of 19.5 m below CD in the dredged area viz. manoeuvring and turning circle area, berth pocket and 22 m in approach channel. In order to assess the impact of proposed capital dredging on the flow field in harbour and nearby area, the existing bathymetry of the model is modified to above dredged depths. The zoomed portion of bathymetry of the model for master plan layout with proposed dredged depths in the harbour area is shown in FIG.23.

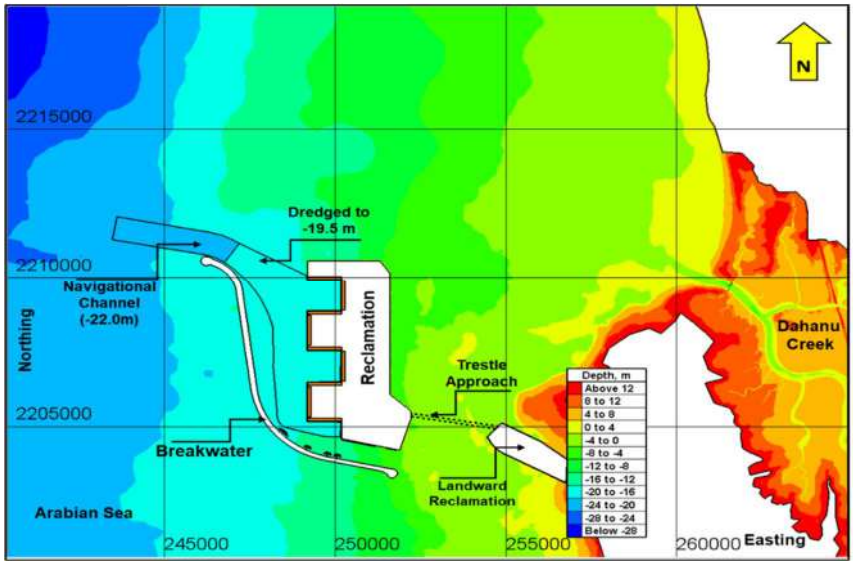


FIG.23: Zoomed Portion of Bathymetry for Master Plan Layout

The models developed for existing bathymetry and design dredged depths conditions in Master Plan layout were used to study flow conditions in the harbour and nearby area by applying the hydrodynamic boundary conditions which were considered for calibrating the model for non-monsoon and monsoon seasons. The typical flow field observed in the model during flood & ebb tide (monsoon season) for proposed deepened condition is shown in FIG.24 (A) & 24 (B) respectively.

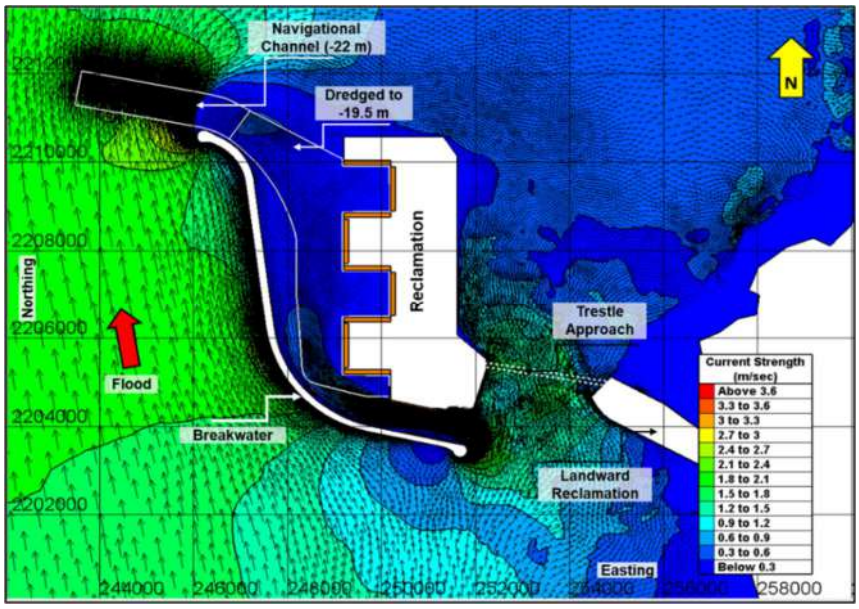


FIG.24(A): Zoomed Portion of Flow Field during Flood Tide – Master Plan

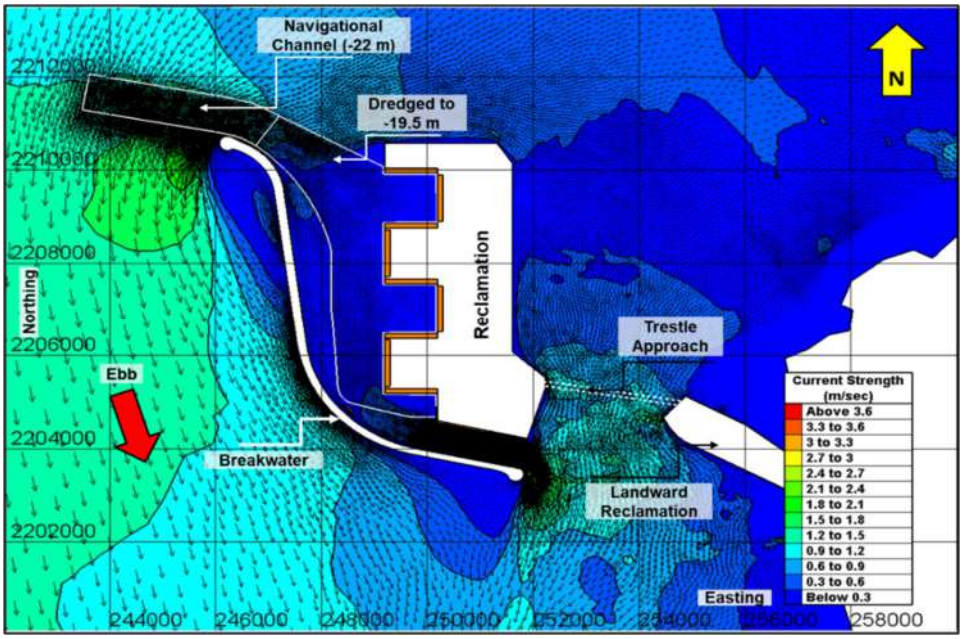


FIG.24(B): Zoomed Portion of Flow Field during Ebb Tide – Master Plan

The hydrodynamic parameters like currents, water levels were extracted from the models at various locations (15 locations) and they are decided in such a way that the magnitudes of these parameters are measurable and will be also in the vicinity of various villages located near the shoreline, at the mouth and inside the Dahanu Creek as well as in the harbour area. These locations for extraction of hydrodynamic parameters are shown in FIG. 25.

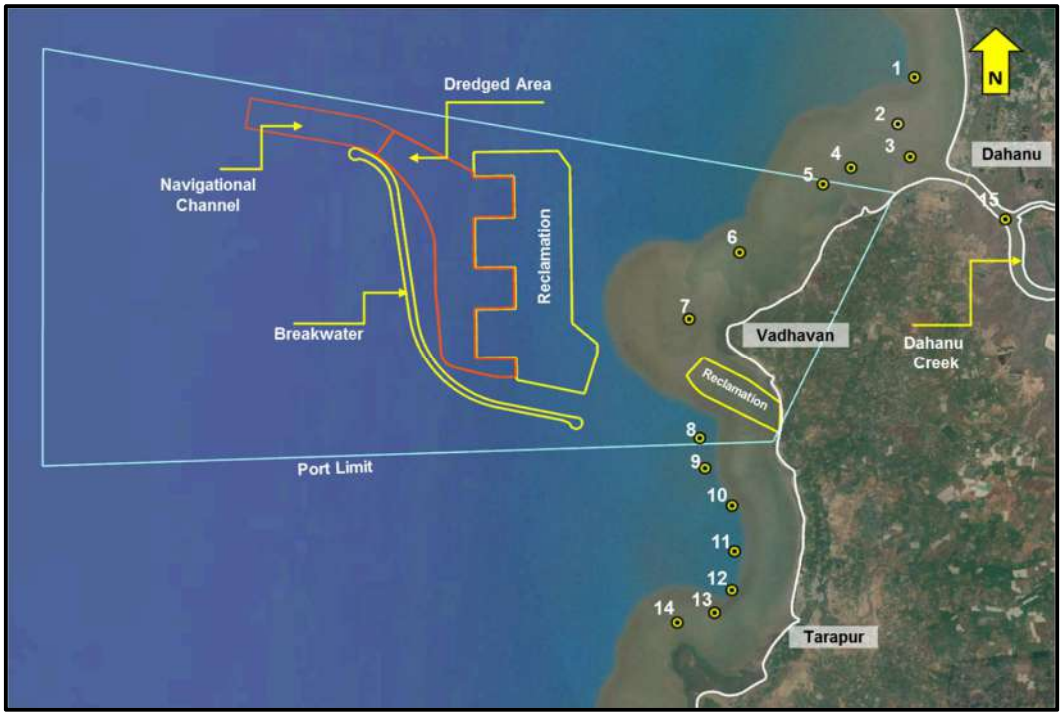


FIG.25: Plan Showing Data Extraction Locations – Master Plan

The maximum current strengths observed at all 15 locations for existing bathymetry and proposed dredged depths condition in area to be dredged for non-monsoon & monsoon season are given in Table-I & Table-II respectively.

Table-I
Maximum Current Strengths Observed During Non-Monsoon Season (Master Plan Layout)

Maximum Current Strength, m/sec		
Location	**Existing Bathymetry**	**With Dredged Depth**
1	0.616	0.615
2	0.918	0.918
3	1.151	1.151
4	0.501	0.499
5	0.639	0.637
6	0.327	0.327
7	0.586	0.585
8	0.812	0.812
9	0.560	0.559
10	0.419	0.418
11	0.358	0.358
12	0.373	0.373
13	0.402	0.402
14	1.015	1.016
15	0.944	0.943
16	0.467	0.474

Table-II
Maximum Current Strengths Observed During Monsoon Season (Master Plan Layout)

Maximum Current Strength, m/sec		
Location	**Existing Bathymetry**	**With Dredged Depth**
1	0.664	0.664
2	0.983	0.984
3	1.210	1.210
4	0.541	0.541
5	0.706	0.707
6	0.368	0.368
7	0.694	0.692
8	0.919	0.919
9	0.636	0.635
10	0.470	0.470
11	0.399	0.398
12	0.415	0.415
13	0.444	0.444
14	1.114	1.114
15	1.007	1.006
16	0.525	0.534

The comparison of current strengths at various locations for Master Plan layout with existing bathymetry and design dredged depths conditions over the complete tidal cycle was carried out. The plots showing percentage variation in current strength at 15 locations for non-monsoon and monsoon seasons are presented in FIG.26(A) & 26(B) respectively.

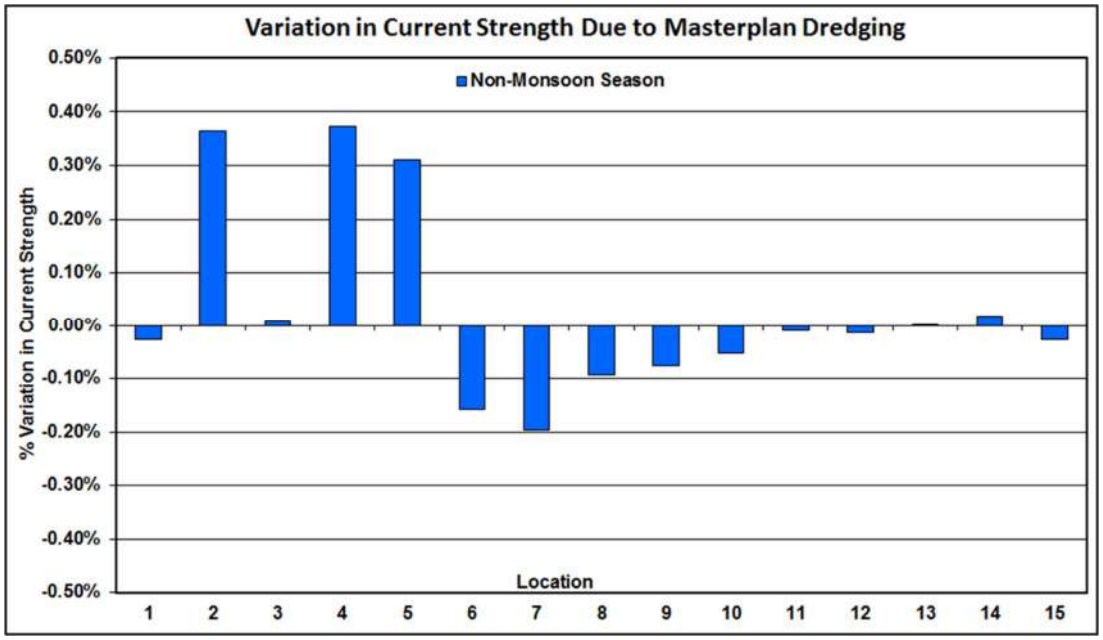


FIG.26 (A): Plot showing % variation in current strength for Master Plan (Non-monsoon)

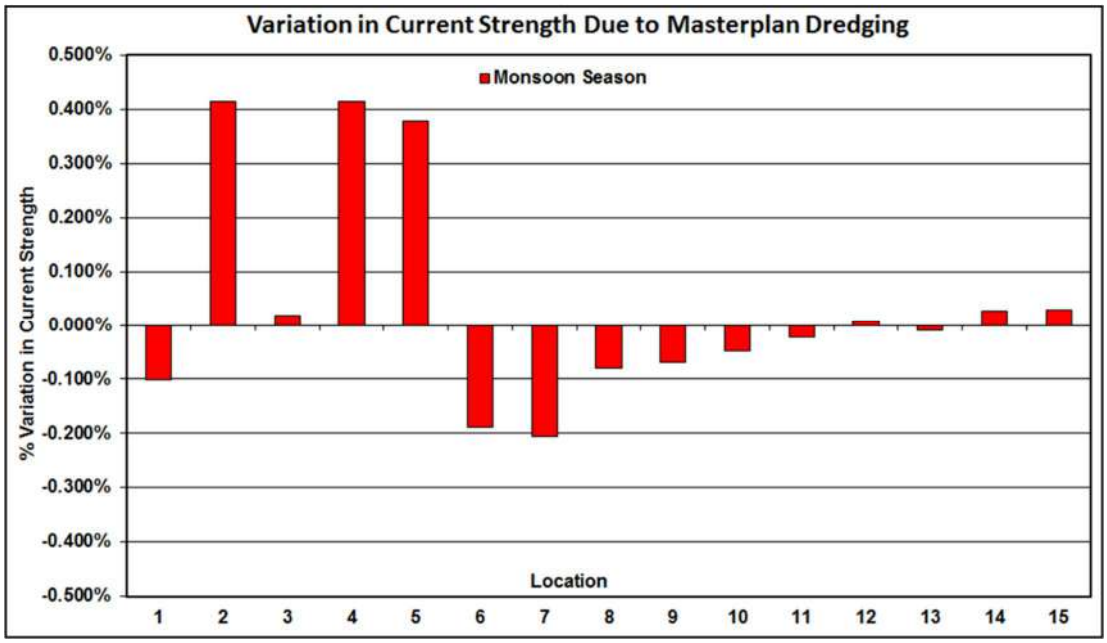


FIG.26(B): Plot showing % variation in current strength for Master Plan (Monsoon)

The above plots indicate that the variation in current strength is less than 0.40 % during non-monsoon season while during monsoon season, it is less than 0.45 % i.e. there is insignificant variation in the current strengths for all fifteen (15) locations for non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths conditions for Master Plan layout.

Similarly, the comparison of water level at 15 locations for Master Plan layout with existing bathymetry and design dredged depths conditions over the complete tidal cycle was carried out and the plots showing percentage variation of water levels for non-monsoon and monsoon seasons are presented in FIG.26(C) & 26(D) respectively.

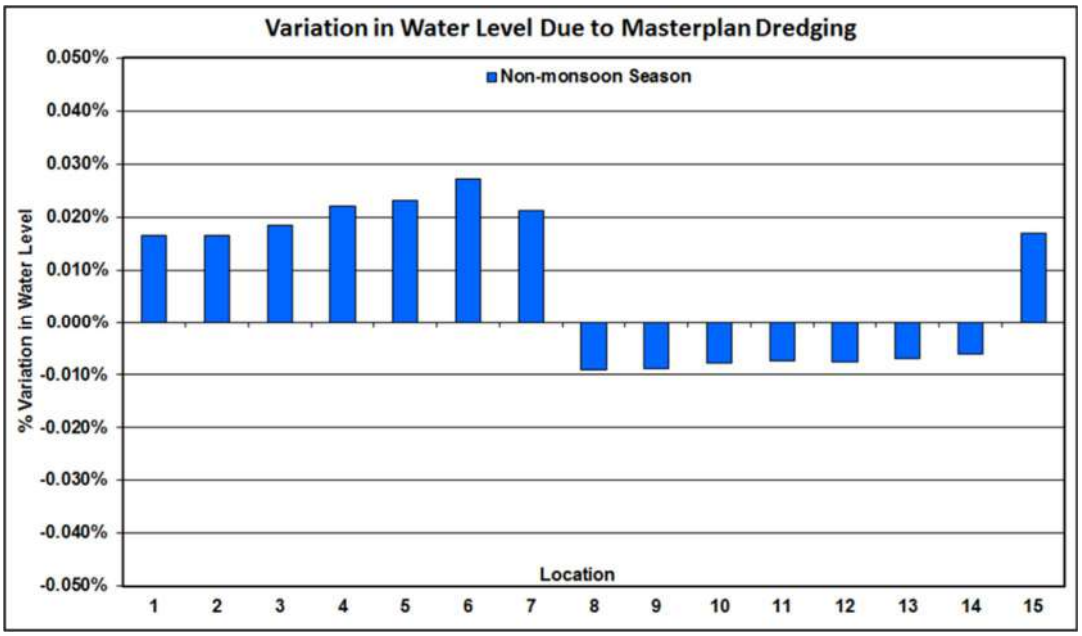


FIG.26 (C): Plot showing % variation in water level for Master Plan (Non-monsoon)

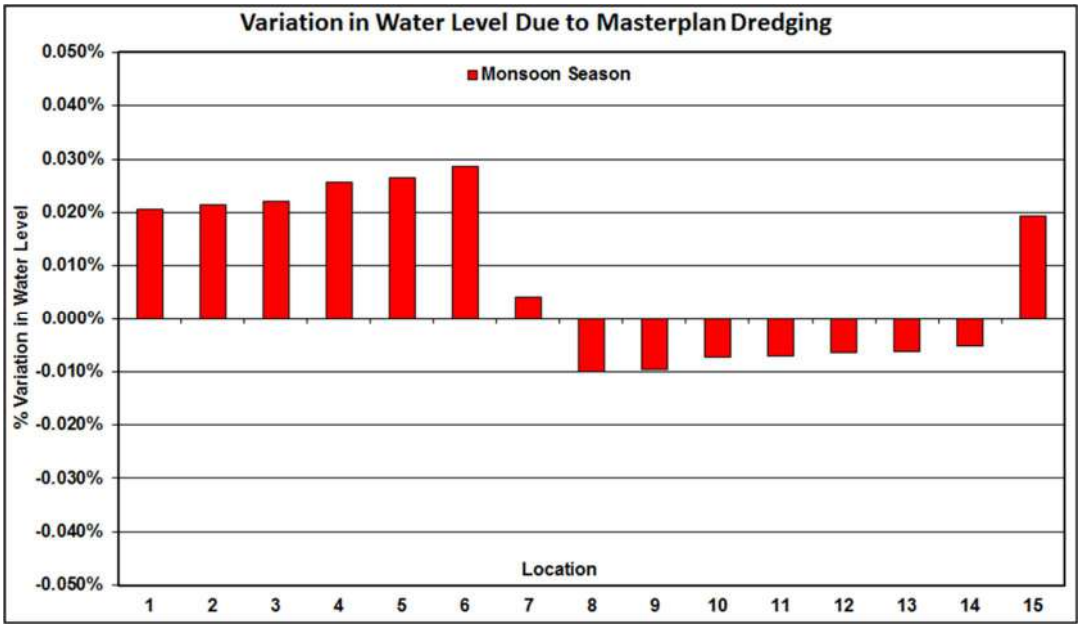


FIG.26 (D): Plot showing % variation in water level for Master Plan (Monsoon)

The above plots indicate that the variation in water levels is insignificant i.e. less than 0.03 % for all fifteen (15) locations for non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths conditions for Master Plan layout. Thus, it can be concluded that there is practically no impact of capital dredging carried out during Master Plan of port development on tidal hydrodynamics of shoreline, Dahanu creek as well as in the harbour area of proposed port at Vadhavan.

5.2 Model Studies for Impact of Dredging for Phase-I layout

The modification in the calibrated hydrodynamic model is carried out by incorporating various port structures viz. 10.3 km long breakwater, offshore reclamation of about 970 Ha. and shore connected reclamation of about 222 Ha. on tidal flats near the headland at Vadhavan along with bathymetry existing at site in the proposed area to be dredged for Phase-I layout. The finite element mesh and zoomed portion of bathymetry of the model for Phase-I layout is shown in FIG.27 (A) & 27(B) respectively.

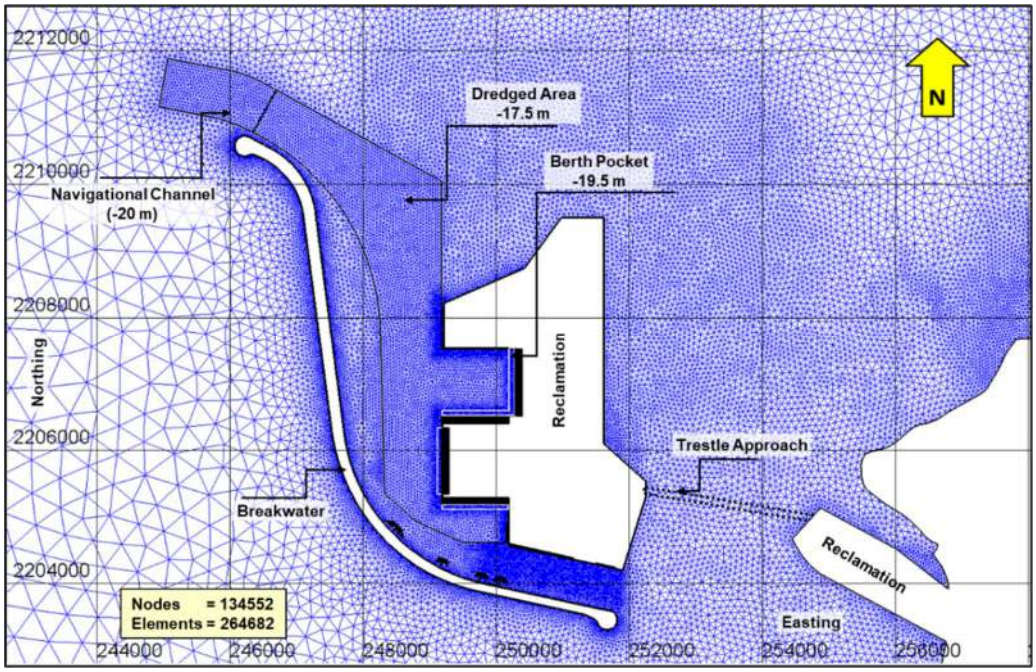


FIG.27(A):Finite Element Mesh for Phase-I Layout for Port at Vadhavan

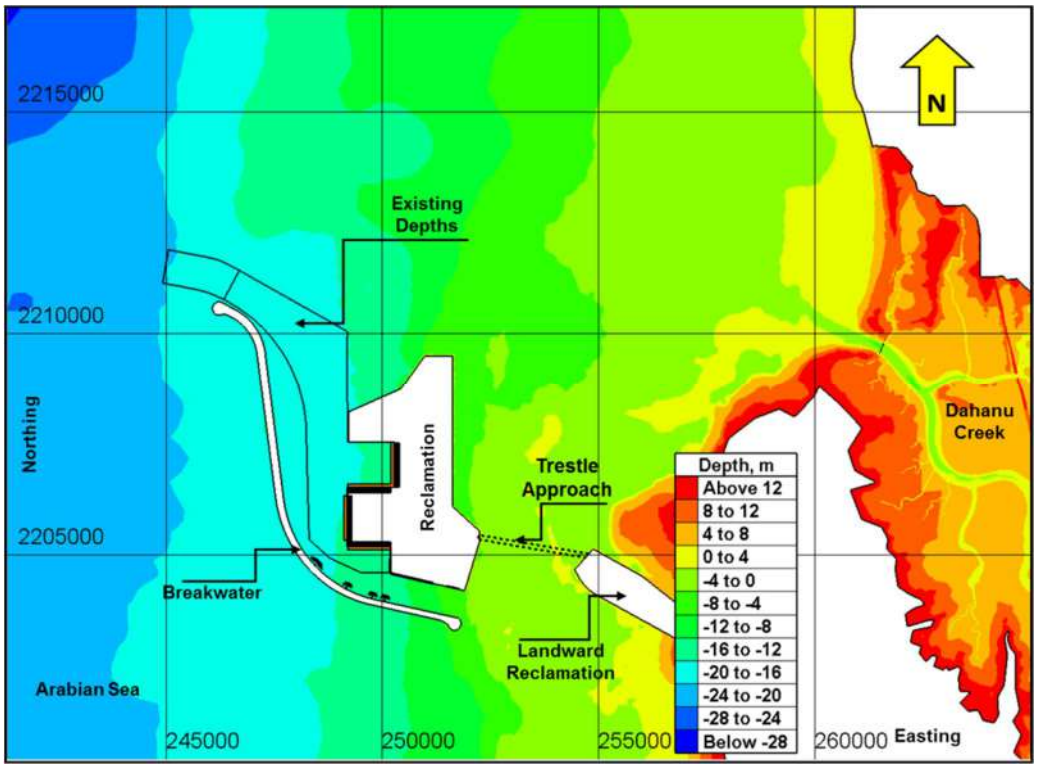


FIG.27(B): Zoomed Portion of Bathymetry for Phase-I Layout with Existing Bathymetry

The proposed capital dredging for Phase-I layout will be carried out over the area of about 981 Ha. located at about 6.5 km westward of headland at Vadhavan with depths of 17.5 m below CD in the dredged area viz. manoeuvring and turning circle area, while that in the berth pocket will be 19.5 m and 20 m below CD in approach channel. In order to assess the impact of proposed capital dredging on the flow field in harbour and nearby area, the existing bathymetry of the model is modified to above dredged depths. The zoomed portion of bathymetry of the model for Phase-I layout with proposed dredged depths in the harbour area is shown in FIG.28.

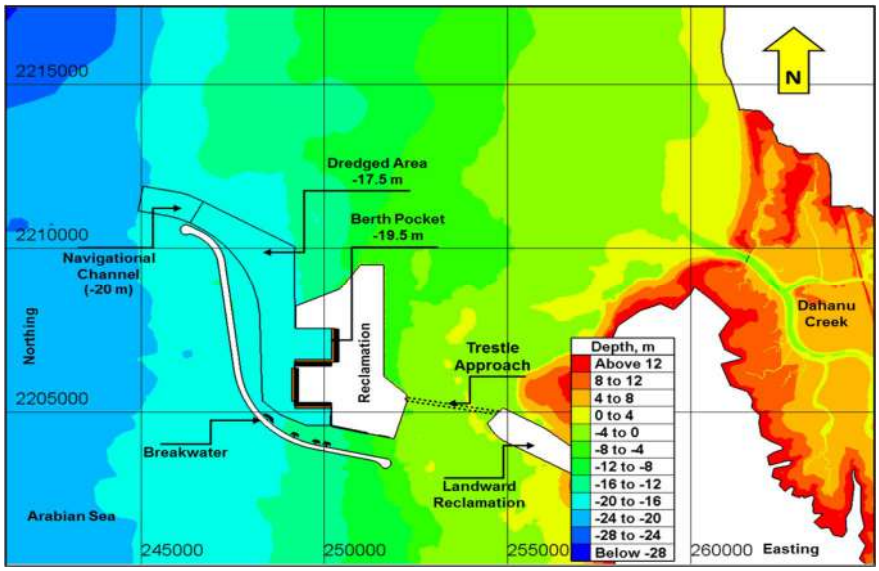


FIG.28: Zoomed Portion of Bathymetry for Phase-I Layout

The models developed for existing bathymetry and design dredged depths conditions in Phase-I layout were used to study flow conditions in harbour and nearby area by applying the hydrodynamic boundary conditions which were considered for calibrating the model for non-monsoon and monsoon seasons. The typical flow field observed in the model during flood & ebb tide (monsoon season) for proposed deepened condition is shown in FIG.29 (A) & 29 (B) respectively.

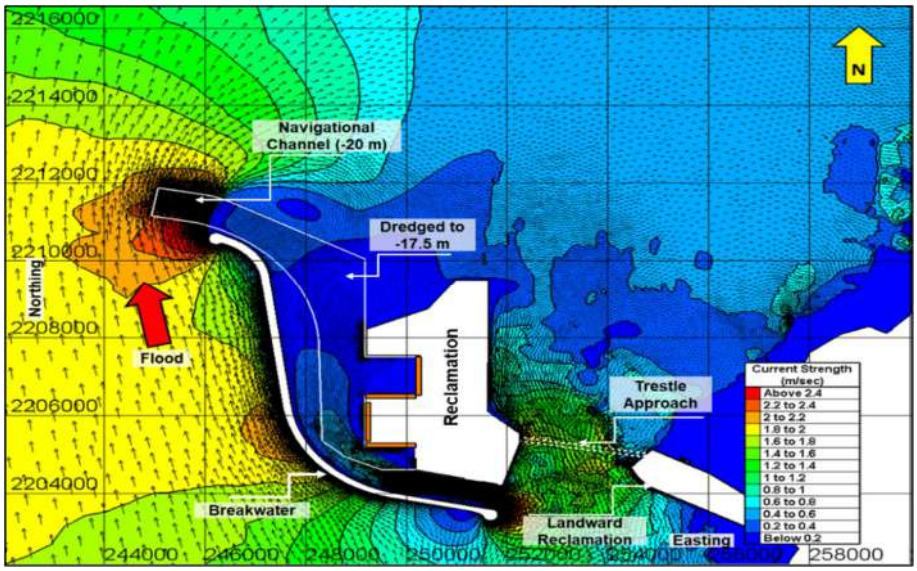


FIG.29(A): Zoomed Portion of Flow Field during Flood Tide – Phase-I

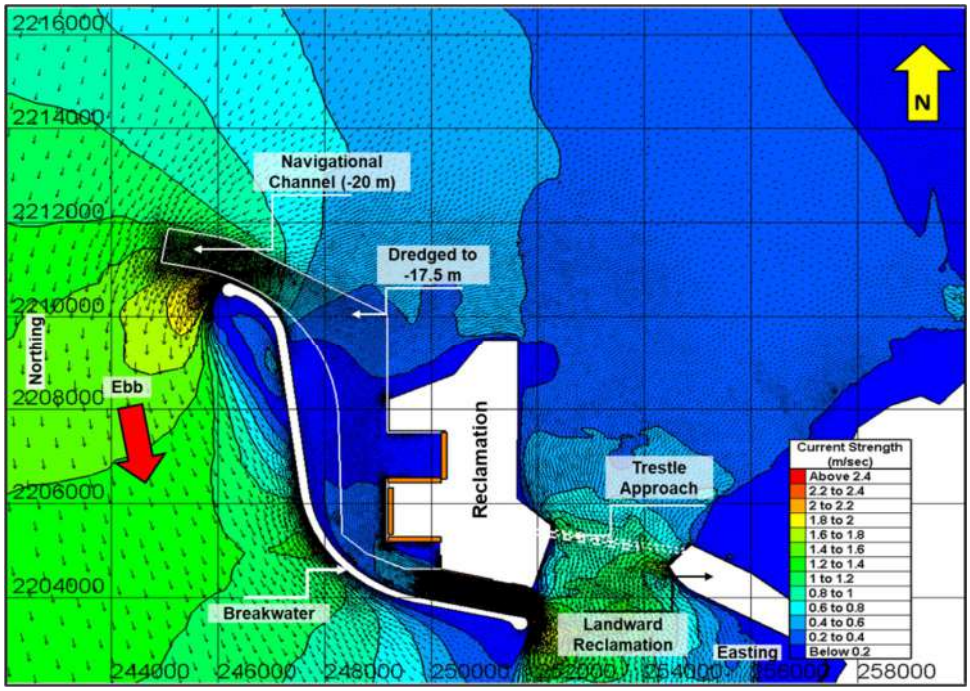


FIG.29(B): Zoomed Portion of Flow Field during Ebb Tide – Phase-I

The hydrodynamic parameters like currents, water levels were extracted from the models at various locations (15 locations) which will be in the vicinity of various villages located near the shoreline, at the mouth and inside the Dahanu Creek as well as in the harbour area. These locations for extraction of hydrodynamic parameters are shown in FIG. 30.

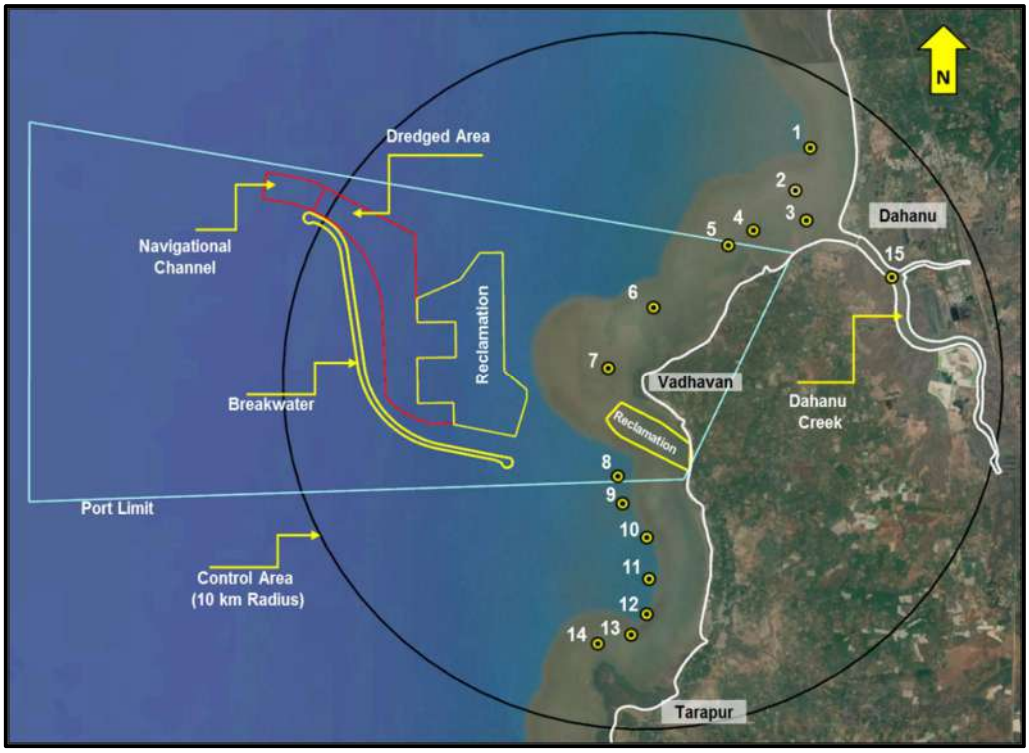


FIG.30: Plan Showing Data Extraction Locations – Phase-I

The maximum current strengths observed at all 15 locations for existing bathymetry and proposed dredged depths condition in area to be dredged for non-monsoon & monsoon season are given in Table-III & Table-IV respectively.

Table-III
Maximum Current Strengths Observed During Non-Monsoon Season (Phase-I Layout)

Maximum Current Strength, m/sec		
Location	**Existing Bathymetry**	**With Dredged Depth**
1	0.616	0.616
2	0.919	0.919
3	1.149	1.149
4	0.500	0.500
5	0.641	0.640
6	0.328	0.328
7	0.597	0.596
8	0.807	0.807
9	0.560	0.561
10	0.420	0.420
11	0.359	0.359
12	0.374	0.374
13	0.403	0.403
14	1.012	1.013
15	0.939	0.939
16	0.398	0.398

Table-IV
Maximum Current Strengths Observed During Monsoon Season (Phase-I Layout)

Maximum Current Strength, m/sec		
Location	**Existing Bathymetry**	**With Dredged Depth**
1	0.662	0.662
2	0.982	0.982
3	1.212	1.212
4	0.542	0.542
5	0.708	0.707
6	0.370	0.369
7	0.705	0.704
8	0.914	0.913
9	0.638	0.638
10	0.472	0.472
11	0.400	0.400
12	0.416	0.416
13	0.445	0.445
14	1.111	1.111
15	1.006	1.006
16	0.448	0.448

The comparison of current strength at various locations for Phase-I layout with existing bathymetry and design dredged depths conditions over the complete tidal cycle was carried out. The plots showing percentage variation of current strength at 15 locations for non-monsoon and monsoon seasons are presented in FIG.31(A) & 31(B) respectively.

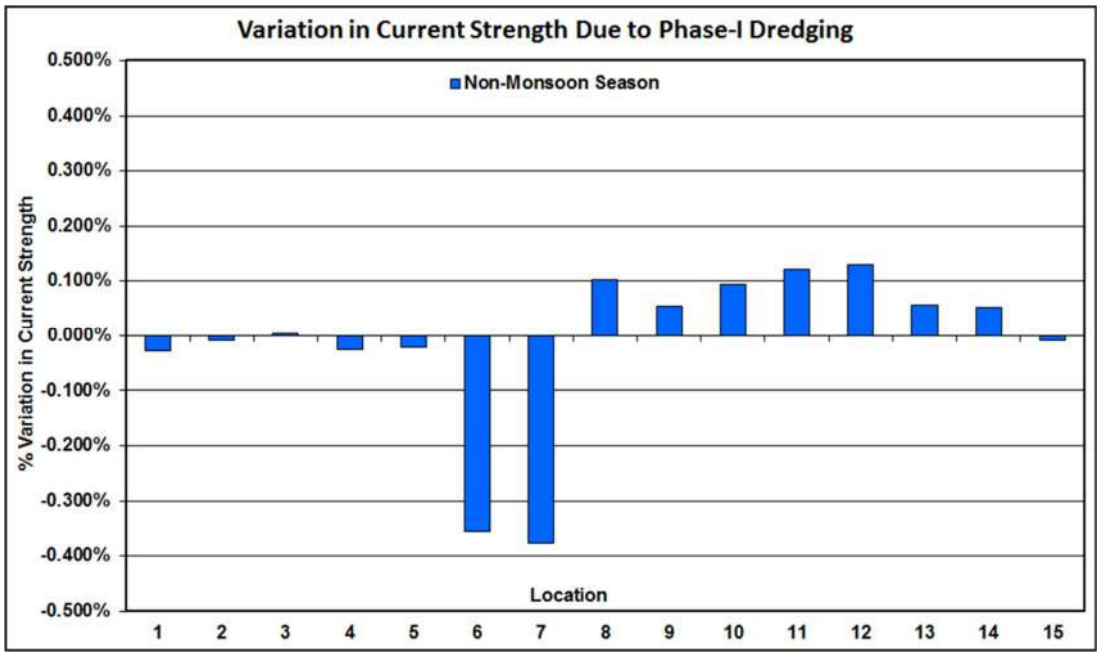


FIG.31(A): Plot showing % variation in current strength for Phase-I Layout (Non-monsoon)

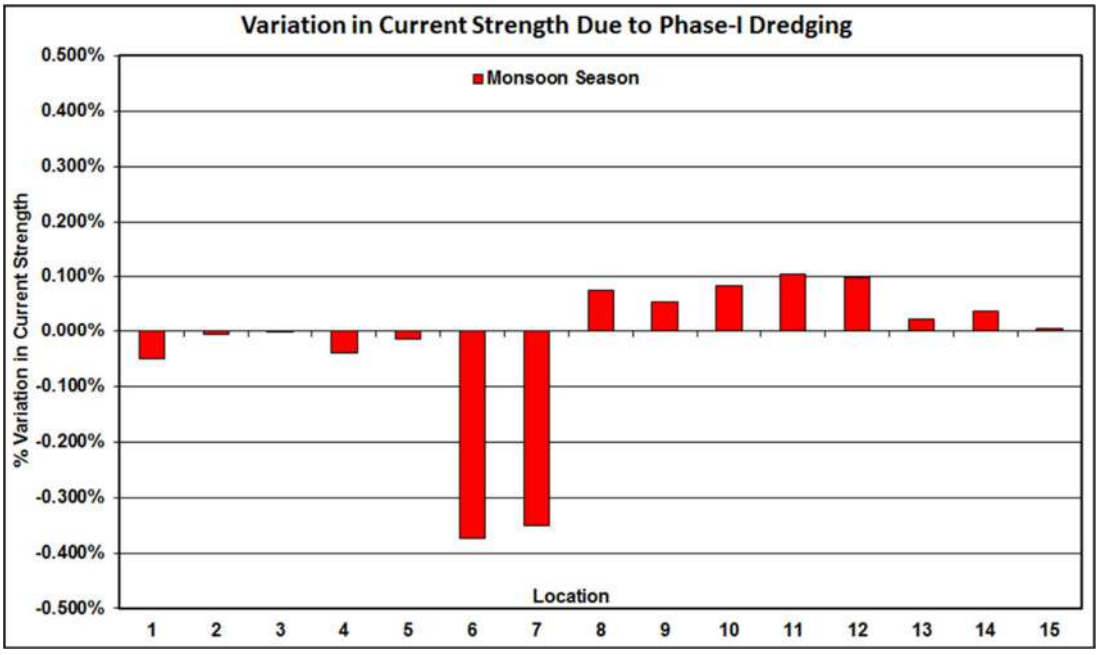


FIG.31(B): Plot showing % variation in current strength for Phase-I Layout (Monsoon)

The above plots indicate that the variation in current strength is less than 0.40 % during non-monsoon season while during monsoon season also it is less than 0.40% i.e. there is insignificant variation in the current strengths for all Fifteen (15) locations for non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths conditions for Phase-I layout.

Similarly, the comparison of water level at 15 locations for Phase-I layout with existing bathymetry and design dredged depths conditions over the complete tidal cycle was also carried out and the plots showing percentage variation of water levels for non-monsoon and monsoon seasons are presented in FIG.31(C) & 31(D) respectively.

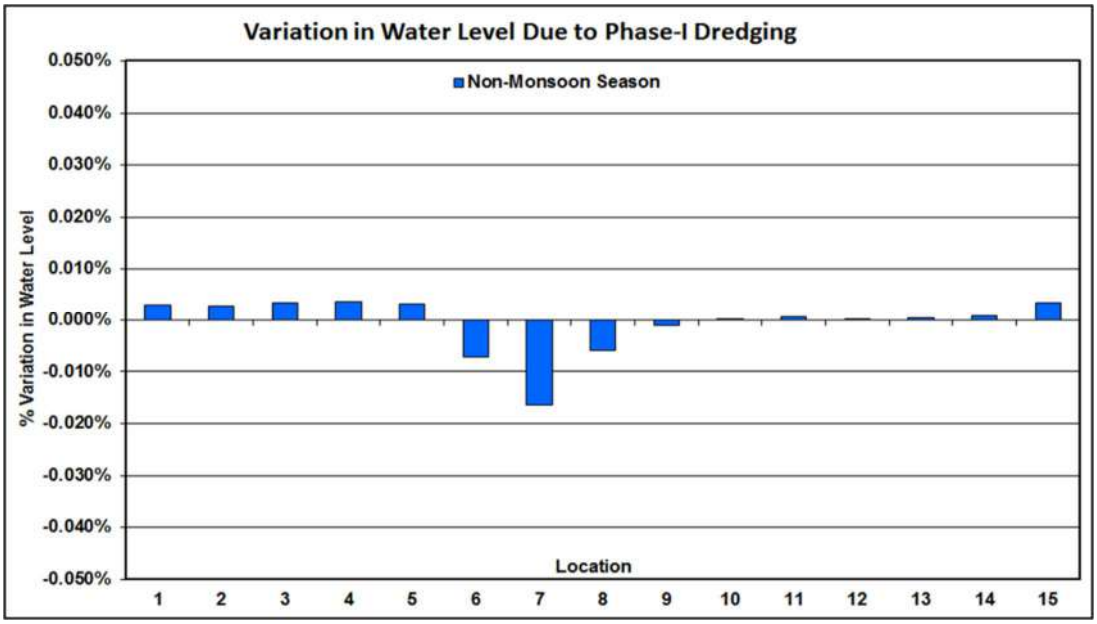


FIG.31(C): Plot showing % variation in water level for Phase-I Layout (Non-monsoon)

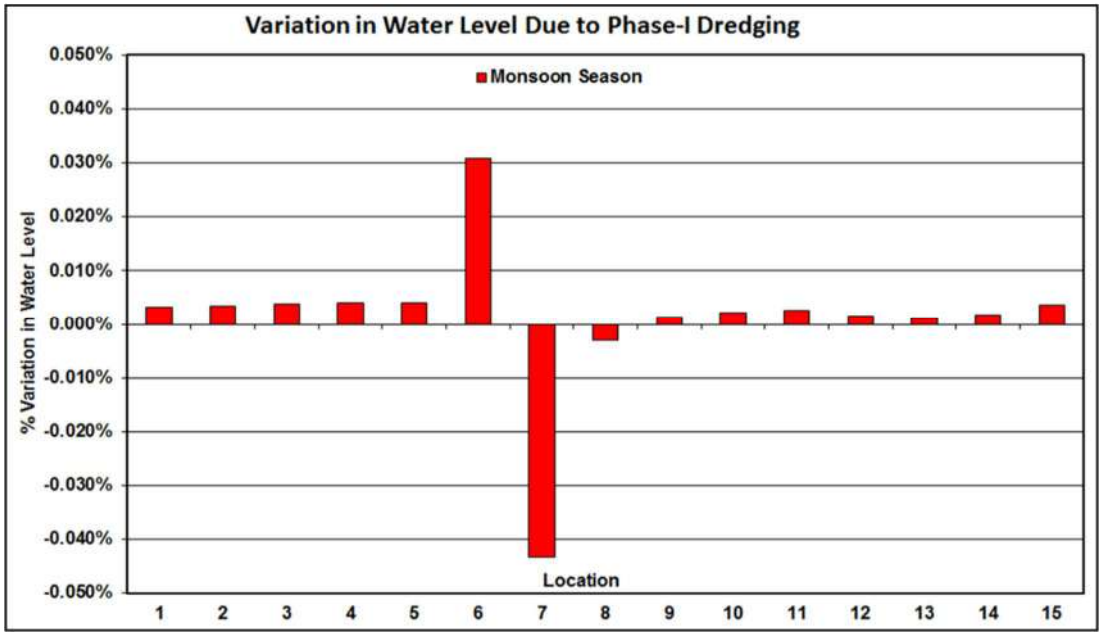


FIG.31(D): Plot showing % variation in water level for Phase-I Layout (Monsoon)

The above plots indicate that the variation in water levels is insignificant variation in the water level i.e. less than 0.05 % for all fifteen (15) locations for non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths conditions for Phase-I layout. Thus, it can be concluded that there is practically no impact of capital dredging carried out during Phase-I of port development on shoreline, Dahanu creek as well as in the harbour area of proposed port at Vadhavan.

6. CONCLUSIONS

1. The oceanographic data collected during January-February 2017 (non-monsoon) as well as September –October 2020 (monsoon) at the proposed port location at Vadhavan on various parameters such as tide, current, waves, bed samples etc. was analysed. The analysis indicate that the tides are semi-diurnal in nature with diurnal inequality and the maximum tidal range is about 5.87 m during spring tide while it is 2.1 m during neap tide during non-monsoon season and about 6.0 m during spring tide and 1.14 m during neap tide during monsoon season. As such the proposed project is in macro tidal region. The information on current strength measured at mid-depth during non-monsoon season indicate that the maximum strength of the current is about 1.25 m/s during spring tide while it is about 0.66 m/s during neap tide. The current direction w.r.t. north varies between 3° – 23° during flood tide, while it is about 204° – 215° during ebb tide. Similarly, during monsoon season, the maximum strength of the current is about 1.4 m/s during spring tide while it is about 0.4 m/s during neap tide. The current direction w.r.t. north varies between 16° – 23° during flood tide, while it is about 203° – 210° during ebb tide. The wave data provided by JN Port indicate that the maximum significant wave height (H_s) is 1.19 m and the waves approaches from N-W quadrant during non-monsoon season while for monsoon season the maximum significant wave height (H_s) is 2.3 m and the waves approaches from SW-WNW quadrant. The analysis of the bed sample indicate that the material is Clayey Silt with average D_{50} = 0.011 mm.
2. The mathematical model developed for Vadhavan area indicates that for the existing bathymetry condition prevailing in the proposed area, tide measured at the mouth of Dahanu creek and observed in model compares well and is in good agreement. Similarly, current strength & direction are also in good agreement with that observed at site both for non-monsoon as well as monsoon season. Thus mathematical model is reasonably well calibrated for the prevailing hydrodynamic flow conditions at the proposed port location for the tide and current data provided by JNP for non-monsoon and monsoon seasons.
3. The master plan layout finalized through tidal hydrodynamics and siltation studies along with its Phase-I development (CWPRS TR. No. 5968 of November 2021) was considered to assess the impact of proposed capital dredging on nearby area.
4. The hydrodynamic studies were carried out to assess the impact of capital dredging for Master Plan layout and it reveal that the variation in current strength is less than 0.40 % for non-monsoon while it is less than 0.45 % for monsoon season under non-cyclonic condition. The variation in water levels is less than 0.030 % at all fifteen (15) locations along the shoreline, mouth and inside the Dahanu creek as well as in the harbour area for both non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths conditions for Master Plan layout.

5. The hydrodynamic studies carried out to assess the impact of capital dredging for Phase-I layout reveal that the variation in current strength is less than 0.40 % both during non-monsoon season and monsoon seasons under non-cyclonic condition. The variation in water levels is less than 0.050 % at all fifteen (15) locations along the shoreline, mouth and inside the Dahanu creek as well as in the harbour area for both non-monsoon as well as monsoon seasons for existing bathymetry and design dredged depths scenario for Phase-I layout.
6. The dredged area wherein capital dredging is proposed for master plan and Phase-I layouts is located at about 6.5 km from the headland at Vadhavan on the seaward side. The studies carried out for Master Plan & Phase-I layouts to assess the impact of proposed capital dredging on flow characteristics from tidal hydrodynamics consideration reveal that there is practically no impact of proposed capital dredging on the flow field near shoreline, Dahanu creek as well as in the harbour area of proposed port at Vadhavan.

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The Director,

Central Water and Power Research Station

Khadakwasala, Sinhgad Road, Pune 411 024. Maharashtra

Telephone : +91-20-24103200/ 24381801

Fax : +91-20-24381004

Web : www.cwprs.gov.in