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Department of Water Resources,
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सत्यमेव जयते

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


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# MATHEMATICAL MODEL STUDIES FOR TIDAL HYDRODYNAMICS & SILTATION FOR THE REVISED LAYOUT OF PHASE-I & MASTER PLAN FOR PORT AT VADHAVAN

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**A K Agrawal**
**Director**

## REPORT DOCUMENTATION SHEET

**Technical Report No:** 5968 **Date:** November 2021

**MATHEMATICAL MODEL STUDIES FOR TIDAL HYDRODYNAMICS & SILTATION FOR THE REVISED LAYOUT OF PHASE-I & MASTER PLAN FOR PORT AT VADHAVAN**

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**Synopsis:**

The development of a major Greenfield, all-weather port at Vadhavan at Lat. 19° 55.8′ N, Long. 72° 39.6′ E in Dahanu Taluka, Palghar district of Maharashtra state (at about 110 km north of Mumbai) has been proposed to be developed on the seaward side of headland at Vadhavan on the open coast facing the Arabian Sea. The area of proposed port is about 175 Sq. km and the layout of port studied at CWPRS was finalised and recommended vide TR No. 5583 of March 2018. This layout was further modified by JN Port to accommodate increase in the quay lengths by relocation of various berths as well as altering the shape of reclamation while keeping the layout of main breakwater as recommended earlier by CWPRS and entrusted studies to assess the suitability of layout along with optimisation of length of Current Deflecting Wall (CDW).

The initial part of this report describes the mathematical model studies carried out for tidal hydrodynamics and siltation for the Phase-I & master plan layouts along with optimisation of length of CDW. The tidal hydrodynamics & siltation studies carried out for the oceanographic data provided by JNP for non-monsoon (2017) & monsoon (2020) seasons reveals that model is reasonably well calibrated. In view of relocation of berths, the studies to assess possibility of optimization of length of CDW were carried out and it reveal that the length CDW of 1.4 km is the optimal length. The JN Port in order to minimize the transit time for containers from stack yard (reclamation on tidal flats) up to container berths has further revised the master plan layout by shifting the reclamation towards berths (deeper depths) and proposes to have a north breakwater keeping the layout of main breakwater same and was considered as preferred masterplan layout. The hydrodynamic & siltation studies carried out to assess suitability of preferred master plan layout with and without north breakwater reveal that, there is cross-flow at berths which are perpendicular to the reclamation face as well as the complex flow conditions are observed between harbour entrance and turning circle wherein there is significantly steep velocity gradient. Also, with north breakwater the quantum of likely rate of siltation is significantly higher (70%) than that observed without north breakwater. Hence, it is desirable to modify the preferred layout.

The preferred master plan layout was further revised to achieve suitable flow conditions at berth locations as well as to reduce the quantum of likely siltation in the proposed dredged area. The various alternatives of shape of reclamations along with relocation of multipurpose and Tug berths were studied and discussed with project Authority and their consultants. The modified revised layout is finalised as master plan layout from tidal/wave hydrodynamics and siltation considerations. The finalized master plan layout includes 10.3 km long breakwater (as recommended by CWPRS in TR. No. 5583), offshore reclamation of about 1262 Ha. (backup area for 9 km long container terminals, RO-RO & multipurpose berths), shore connected reclamation of about 222 Ha. and dredged area of about 1210 Ha with dredged depths of 22 m and 19.5 m below CD in approach channel & dredged area respectively. The quantum of likely siltation in the dredged area will be about 8.45 million cum per annum. Similarly, the studies were also carried out for Phase-I layout of proposed development. The reclamation area for Phase-I layout is about 970 Ha. while the dredged area for the same is about 981 Ha. The depths maintained in approach channel, dredged area will be 20 m and 17.5 m below CD respectively while in berth pockets, it is 19.5 m below CD. The quantum of likely siltation in the dredged area for Phase-I layout will be about 6.45 million cum per annum.

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

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## 1. INTRODUCTION

The Government of India (GOI) has a proposal to develop a major Greenfield, all-weather port at Vadhavan through a joint venture between Jawaharlal Nehru Port (JNP) working under Ministry of Surface Transport, GOI and Maharashtra Maritime Board (MMB) of Government of Maharashtra (GoM). The location of proposed port is at Lat. 19° 55.8′ N, Long. 72° 39.6′ E in Dahanu Taluka, Palghar district of Maharashtra state and is at about 110 km north of Mumbai. It has been proposed to develop this port offshore of headland at Vadhavan and the port limit extends up to 26 m depth below CD in the deeper part of the Arabian Sea. 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 area of proposed port is of about 175 Sq. km. and is shown in FIG.1.

The port is proposed to be developed on the seaward side of the headland at Vadhavan and stack-yard area will be formed by creating an artificial land in the foreshore area wherein reclamation of about 1428 Ha in the intertidal zone at Vadhavan point was under consideration. The port will have entrance through the navigational channel from the Arabian Sea, wherein waves are predominant from two quadrants namely North-West & South-West. The tides are of macro type with tidal range of about 6 m and are semi-diurnal in nature.

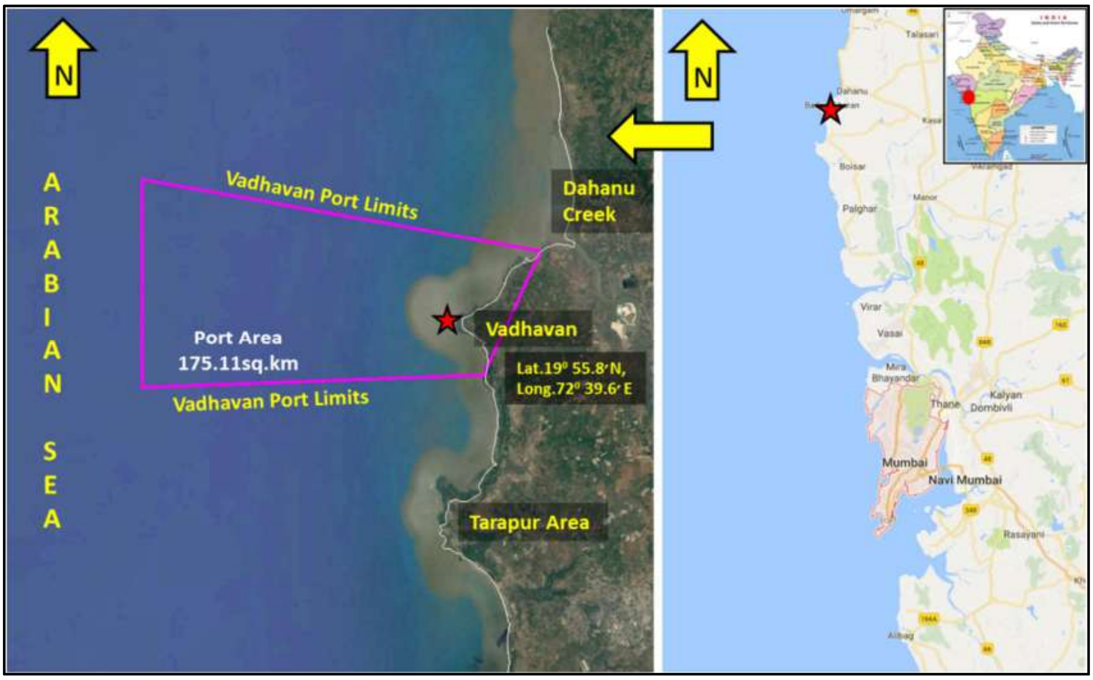



**FIG.1: Location Plan of Proposed Port at Vadhavan**

The JN Port has taken up the task of planning the configuration of port layout, positioning and alignment of components like breakwaters, berth structures, operational area, harbour basin, approach channel etc. and thus to finalize the conceptual layout for the development for the proposed port at Vadhavan.

The JN Port officials planned a meeting at JNP on 10th March 2017 between officials of CWPRS and JNP regarding various model studies which needs to be carried out for the proposed development of port at Vadhavan. Based on the discussions, The JN 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 TAPS through model studies. In response to this to decide the scope of various hydraulic model studies, a meeting was held at CWPRS on 22nd March 2017 and the preliminary layout plans were submitted by JN Port. The studies which were proposed to be carried out are divided in to two phases namely:

I) Studies to finalize the layout of proposed port at Vadhavan and

II) Assess the impact of proposed port at Vadhavan on TAPS.

In this context, the four studies were carried out as Part-I and technical reports for the same were submitted to JN Port in year 2018. The four studies carried out are as follows:

- Wave transformation and tranquility for assessing wave conditions at berths (CWPRS TR. No. 5558 of January 2018)
- Hydrodynamics and siltation to finalize layout of port and estimate the siltation (CWPRS TR. No. 5583 of March 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 hydrodynamics and wave tranquility studies is shown in FIG. 2.

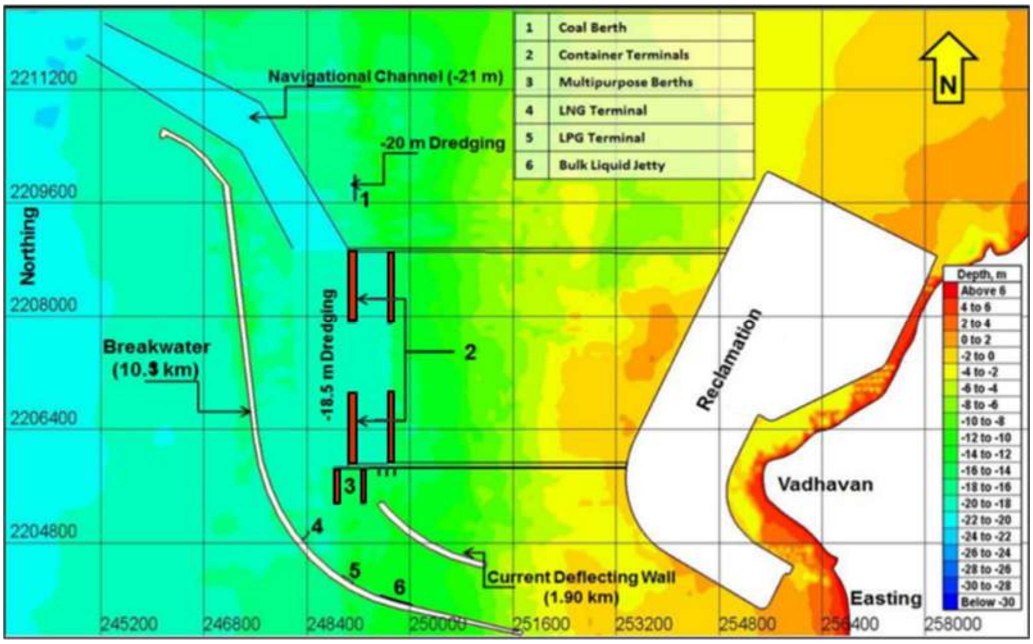



**FIG.2: Recommended layout of Proposed Port at Vadhavan by CWPRS**

The layout finalized was considered to assess the impact of proposed port development on intake/outfall facilities of TAPS as Part-II and technical reports of the same were submitted to JN Port in year 2018-2019.The studies carried out 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 part 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)

Further to this, the proposal was submitted by JN Port 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. Consequently, JNP held a meeting between officials of JN Port, CWPRS and 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 to assess the impact of proposed capital dredging on the flow field in the nearby area vide their letter dated 11th September 2020 and vide e-mail dated 25th September 2020 referred studies related to flooding during cyclonic storms. Accordingly, CWPRS vide letter No. TC/2020/632 dated 18th September 2020 & 9th November 2020 submitted the study proposals and the data on various oceanographic parameters viz. tides, current, waves as well as wind data etc. for monsoon season was requested.

The layout of port at Vadhavan recommended by CWPRS (CWPRS TR No. 5583 of March 2018) was further modified by the consultants to JN Port by altering the shape of reclamation and relocation of various berths. It is also proposed to develop the port in two phases viz. Phase-I & Master plan. Accordingly, JN Port provided two layouts to CWPRS vide e-mail dated 4th February 2021 and are shown in FIG. 3 & 4 respectively.

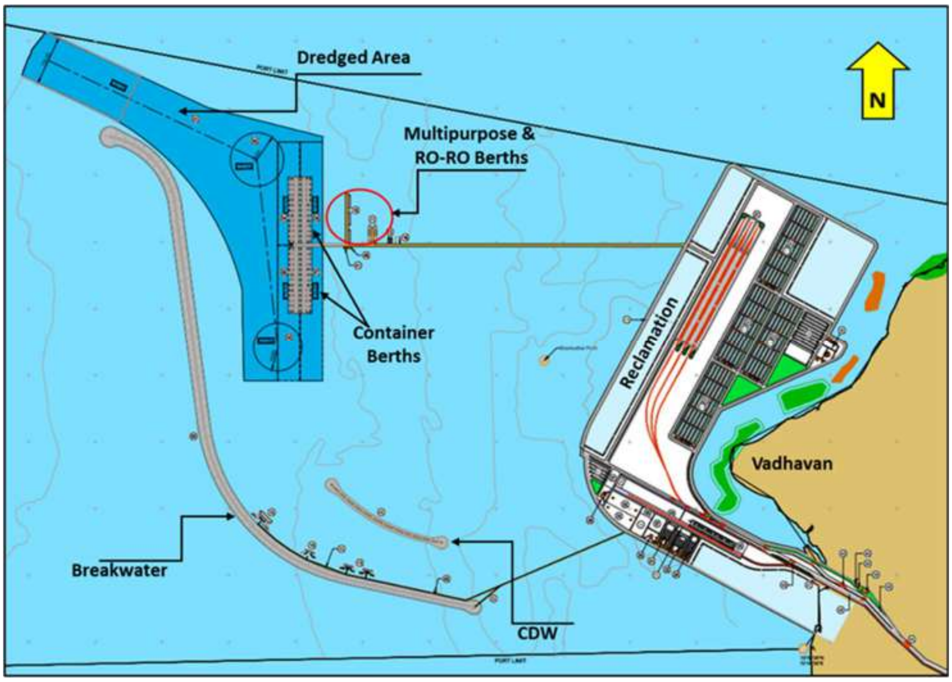



**FIG.3 : Phase-I Layout of Proposed Port at Vadhavan**

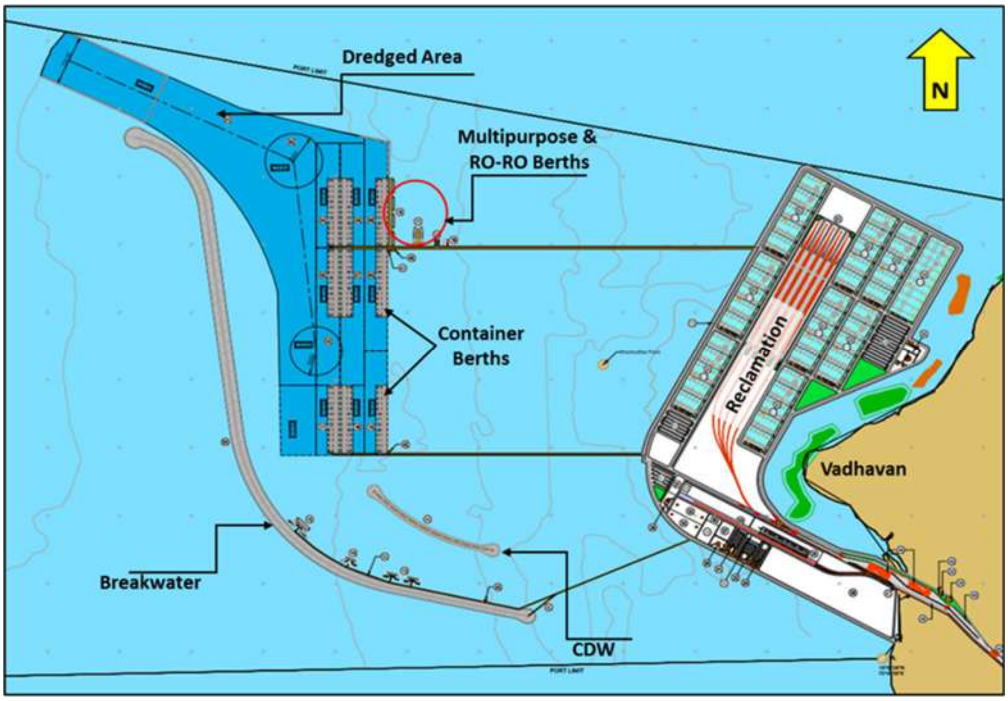



**FIG.4 : Master Plan Layout of Proposed Port at Vadhavan**

The Chairman, JN Port along with senior officials of JN Port and their consultants subsequently visited CWPRS on 12th February 2021 to discuss the various aspects related to development of port at Vadhavan. During discussions, in view of relocation of various berths (viz. Multipurpose berths, Ro-Ro- Berths etc.) from southern side near Current Deflecting Wall (CDW) to the northern end near navigational channel in revised layouts (Fig.3 & 4), JN Port officials requested CWPRS to assess the possibility of optimization of length of Current Deflecting Wall (CDW) recommended by CWPRS in earlier technical report vide JN Port letter dated 11th March 2021. The CWPRS study proposal was submitted on 31st March 2021 and accordingly, studies were taken up and were near completion.

Further to this, during the VC meetings held on 8th & 22nd June 2021 between Chairman and other officials of JN Port as well as their consultants and officials of CWPRS, discussions were held on various revised master plan layouts proposed by consultants wherein it has been proposed to shift the reclamation from intertidal zone to deeper depths (towards berth). Based on expert's comments during VC meetings on 8th & 22nd June 2021, the consultants to JN Port revised the master plan layouts and presented preferred master plan layout in VC meeting held on 29th June 2021. The JN port vide letter dated 30th June 2021 requested CWPRS to verify the suitability of preferred master plan layout by conducting mathematical model studies. Accordingly, the earlier scope of the studies was revised and CWPRS submitted revised estimate to JN port on 15th July 2021 for the mathematical model studies for tidal hydrodynamics and siltation for the preferred master plan & Phase-I layouts of proposed port at Vadhavan.

The mathematical model studies carried out for hydrodynamics and siltation for Master Plan and Phase-I (Reclamation on tidal flats and optimisation of CDW) as well as various layouts studied for preferred master plan & Phase-I (reclamation shifted towards berths in deeper depths) are described in this report.

## 2. SCOPE OF THE STUDIES

The mathematical model studies for the tidal hydrodynamics and siltation for proposed port at Vadhavan is 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) Optimize the length of Current Deflecting Wall (CDW) by incorporating the master plan layout (submitted by JN Port on 4$^{th}$ February 2021) in the calibrated model.

iv) Study the flow field in the harbour area of proposed port at Vadhavan for Master Plan & Phase-I layouts (reclamation on tidal flats) for optimized CDW condition.

v) Estimate the likely rate of siltation per annum in the approach channel and proposed dredged area for Master Plan & Phase-I layouts (reclamation on tidal flats) for optimized CDW condition.

vi) Study the flow field in the harbour area of proposed port at Vadhavan along with estimation of siltation for preferred Master Plan layout (reclamation near berths in deeper depths) and finalise the layout of Master Plan and estimate the siltation.

vii) Carry out hydrodynamics and siltation studies for the Phase-I layout of finalised port layout.

## 3. FIELD DATA FOR MODEL STUDIES

The field data viz. bathymetry, topography, oceanographic parameters such as tides, current, waves, suspended sediment concentration, bed samples 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 submitted to CWPRS is as follows:

1. Bathymetry survey of proposed port site w.r.t. CD of Dahanu (Ref.12 & 13)
2. Topography of Dahanu creek and nearby region within Control Area up to +10m contour w.r.t. CD of Dahanu (Ref. 16)
3. Tide data collected at Dahanu Creek Bridge at the entrance of Dahanu creek for non-monsoon and monsoon seasons (Ref. 11 & 15)
4. Tidal current data at ADCP location inside the port for non-monsoon and monsoon seasons (Ref. 11 & 15)

5. Suspended Sediment Concentration data at one location for non-monsoon and monsoon seasons (Ref. 11 & 17)
6. Grain size analysis of bed samples collected for non-monsoon and monsoon seasons (Ref. 11 & 15)
7. Wave data at one location in the port limit for non-monsoon and monsoon seasons (Ref. 11 & 14)
8. Meteorological data viz. wind speed, direction etc. at one location (Ref. 11 & 14)

The locations of oceanographic field data collected are shown in FIG. 5.

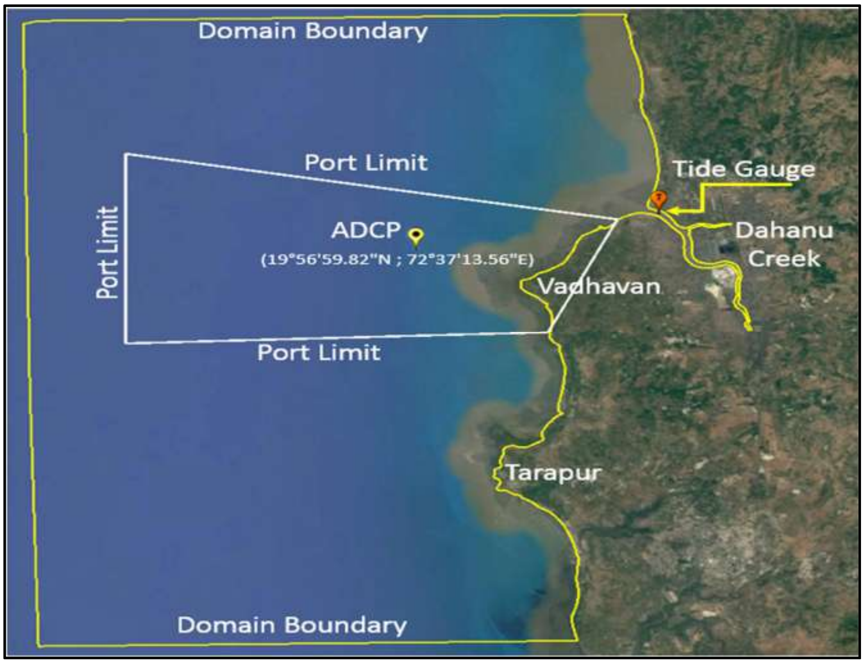



**FIG.5: Locations of Field Data Measurements for Proposed Port at Vadhavan**

### 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.6.

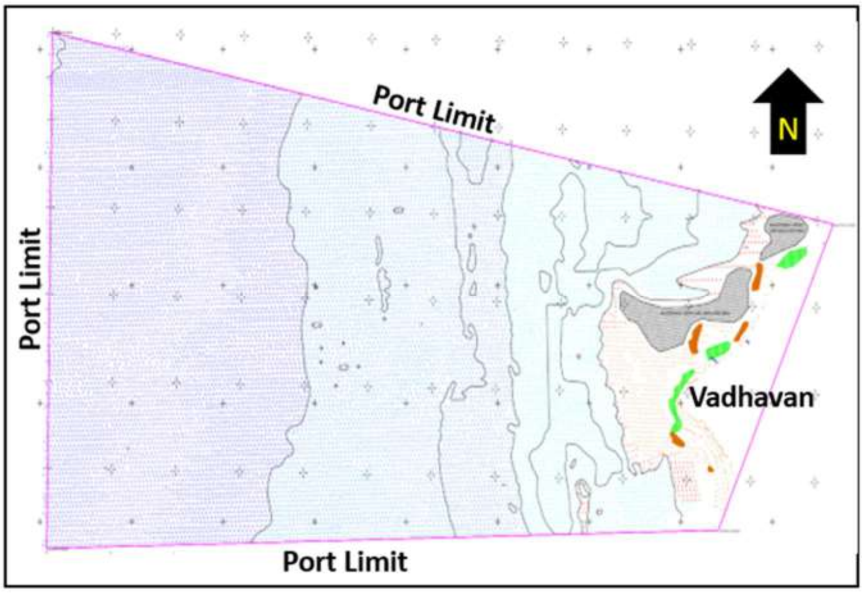



**FIG.6: Bathymetry Data for Proposed Port at Vadhavan**

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 +10 m contour has been carried out by Drone survey 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.7 as blue portion. The data provided is w.r.t. MSL and is correlated to CD based on the relation between MSL and CD provided by JN Port.

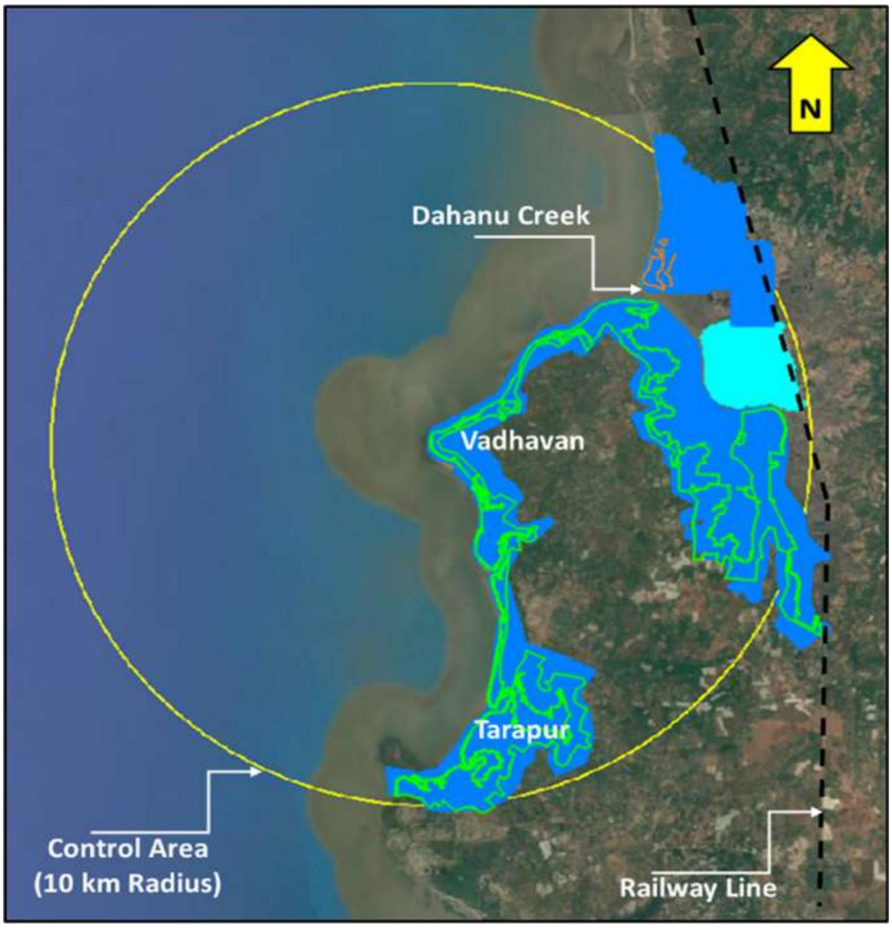



**FIG.7: Topography Data in Control area for Proposed Port at Vadhavan**

### 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. 8(A) & (B).

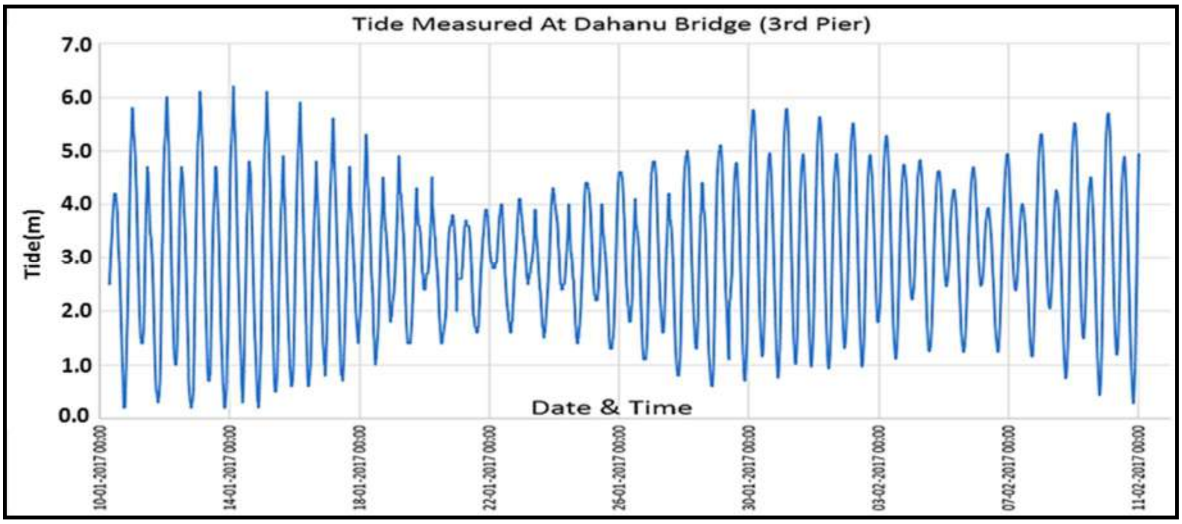



**FIG.8(A) : Measured Tide Data at Dahanu Bridge Location (Non-monsoon Season)**

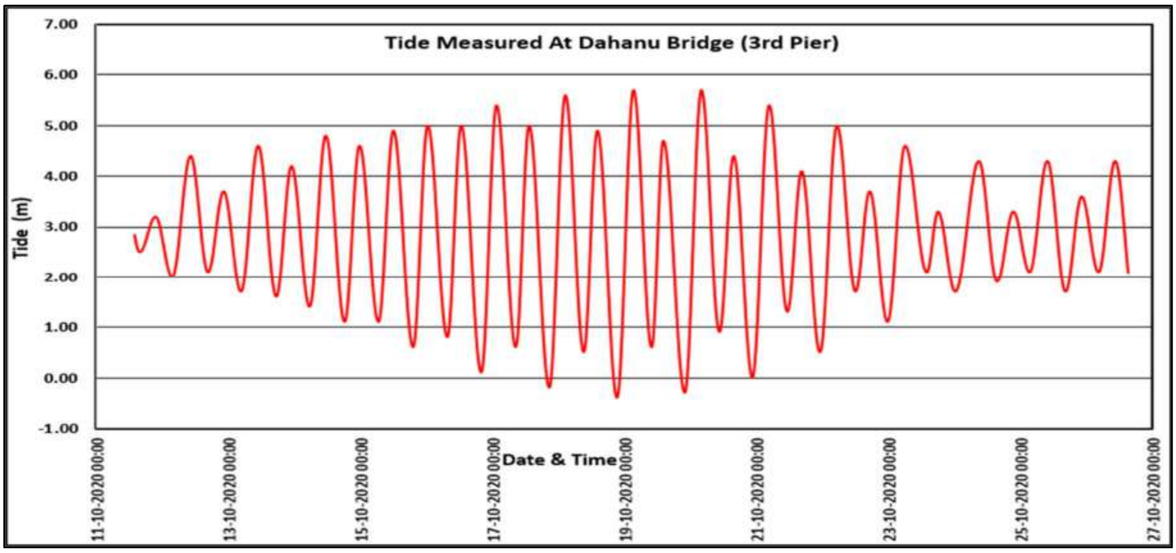
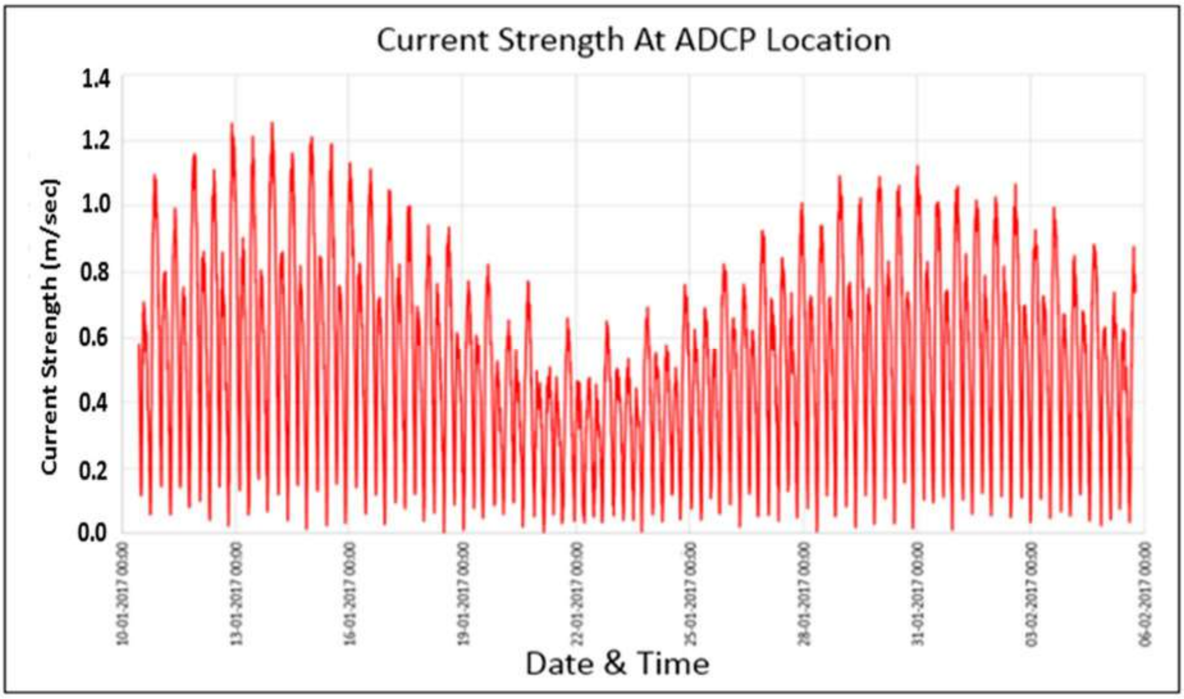



**FIG.8(B) : Measured Tide Data at Dahanu Bridge Location (Monsoon Season)**

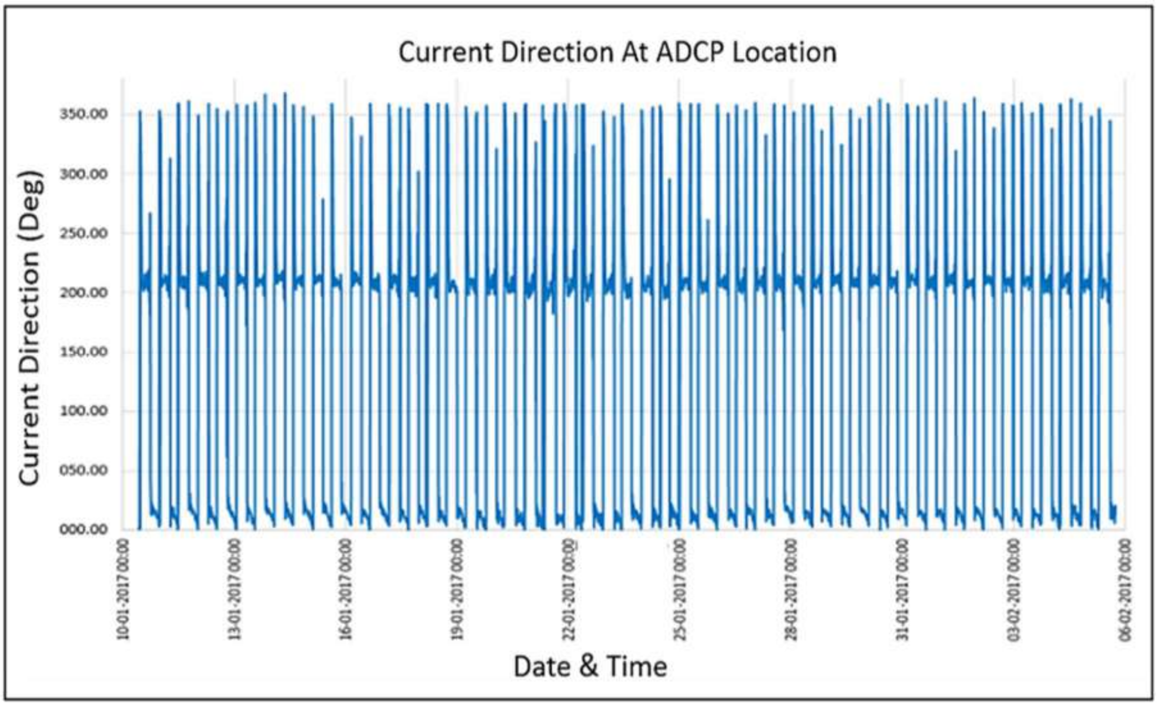
The analysis of measured tidal data was carried out and it reveal that the tides are semi-diurnal in nature with diurnal inequality for both non-monsoon and monsoon seasons. During non-monsoon season, the maximum tidal variation is about 5.87 m, while minimum tidal variation is about 2.10 m. Similarly, during monsoon season, the maximum tidal variation is about 6.0 m, while minimum tidal variation 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. 9 and FIG.10 respectively.



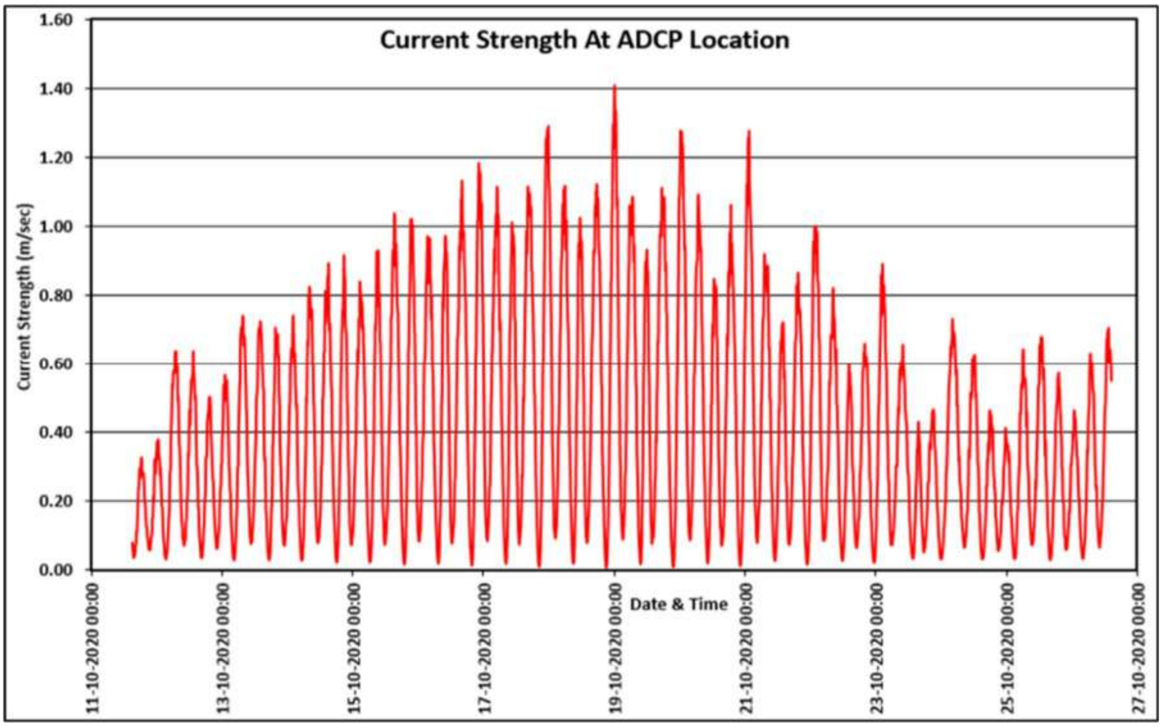

(A) Current strength at Mid depth



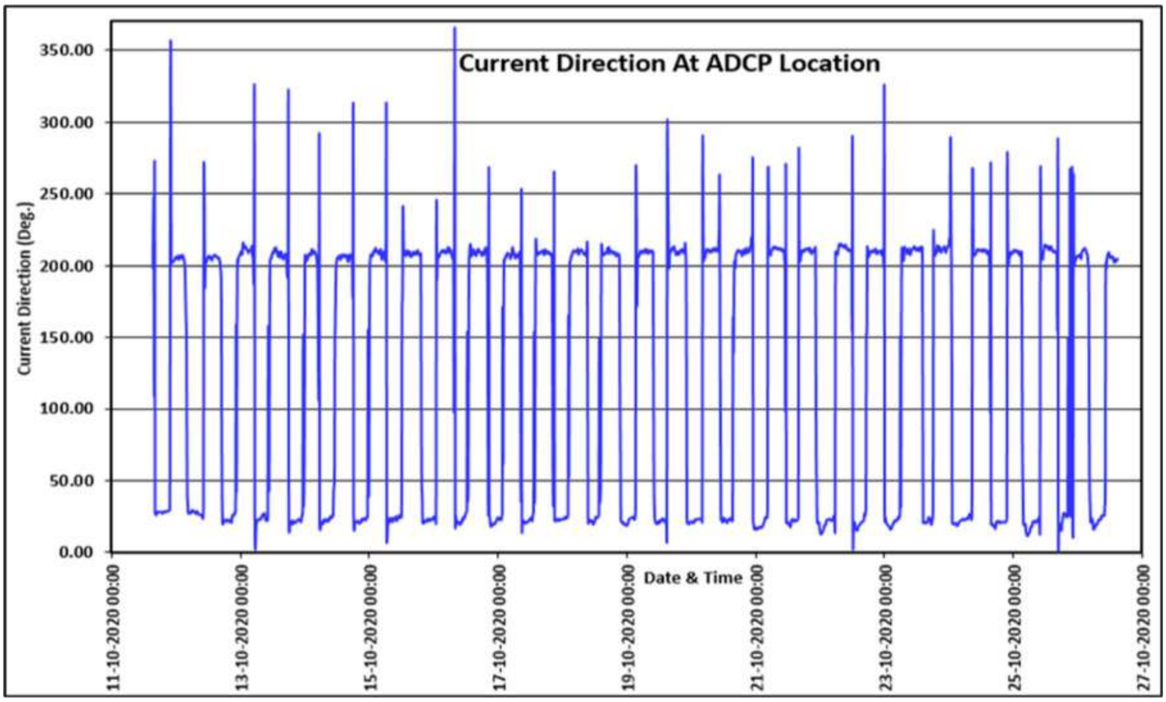

**(B)** Current Direction at Mid depth

**FIG.9 : 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 0.50 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.10 : 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 Suspended Sediment Concentration (SSC)

The data on SSC collected for non-monsoon season for the period from 07th January 2018; 07:30 Hrs to 08th January 2018; 06:30 Hrs at mid depth for one-hour interval was provided by JN Port vide letter dated 23.01.2018. The location (Lat. $19^0$ 54' 57" N, Long. $72^0$ 36' 37" E) where the data was collected is shown in FIG.11.

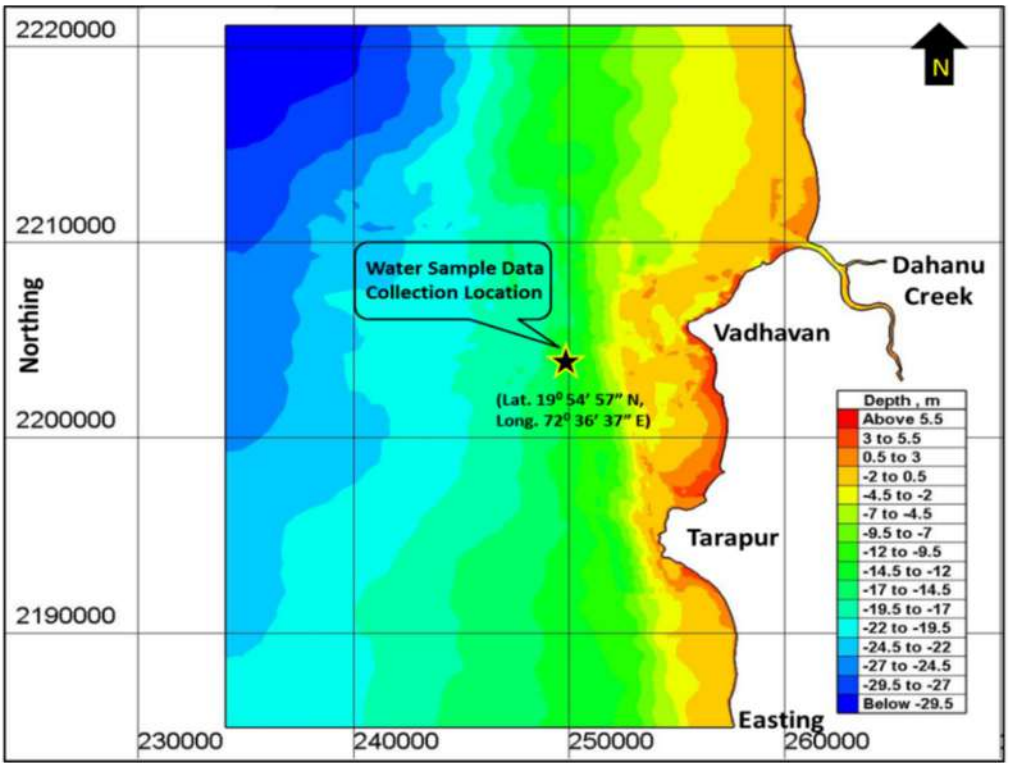



**FIG.11: Location Plan of Water Sample Data Collection at Site**

The data indicate that SSC for non-monsoon season varies from 380 mg/lit to 170 mg/lit. It is also observed that the concentration is higher during mid-tide level, while it reduces as the flow reaches to high water during flood tide and low waters during ebb tide. The grain size analysis of suspended sediments carried out reveal that the suspended sediments contain 68% of silt and 26% of clay and as such the sediment is classified as clayey silt having grain size $D_{50}$ as 0.008 mm.

Similarly, the data on SSC collected (location Lat. $19^0$ 54' 40" N, Long. $72^0$ 36' 37" E) for monsoon season for the period from 01st June 2021; 00:20 Hrs to 01st June 2021; 23:20 Hrs at mid depth for one-hour interval was provided by M/s JNP vide letter dated 24.06.2021. The data on SSC for monsoon season indicate that SSC varies from 473 mg/lit to 105 mg/lit. It is also observed that the concentration is higher during mid-tide level, while it reduces as the flow reaches to high water during flood tide and low waters during ebb tide.

### 3.6 Grain Size Analysis of Bed Samples

The bed samples were collected at eight (8) locations in the vicinity of proposed port area during non-monsoon season and its grain size analysis carried out is presented in Table-I.

**Table-I**

**Grain Size Analysis of Bed Samples (Non-monsoon)**

| Sr. No. | Description | Location | | Sample retained on 75 Micron % | % Fines | | $D_{50}$ |
|---|---|---|---|---|---|---|---|
| | | Easting | Northing | | Silt % | Clay % | |
| 1 | Dandepada (A1) | 252850.51 m E | 2202778.18 m N | 7.98 | 59.66 | 32.36 | 0.0100 |
| 2 | Dandepada (A2) | 252615.50 m E | 2202745.80 m N | 8.65 | 57.53 | 33.82 | 0.0115 |
| 3 | Dandepada (A3) | 252473.37 m E | 2202714.44 m N | 7.22 | 53.15 | 39.63 | 0.0050 |
| 4 | Dandepada (A4) | 252389.46 m E | 2202644.83 m N | 10.69 | 59.15 | 29.80 | 0.0076 |
| 5 | Chinchani (B1) | 254175.56 m E | 2200735.42 m N | 10.41 | 59.64 | 29.95 | 0.0150 |
| 6 | Chinchani (B2) | 252921.99 m E | 2201004.30 m N | 10.02 | 60.78 | 29.20 | 0.0114 |
| 7 | Chinchani (B3) | 252698.02 m E | 2200930.75 m N | 9.87 | 59.38 | 30.75 | 0.0113 |
| 8 | Chinchani (B4) | 252496.19 m E | 2200560.39 m N | 12.02 | 58.53 | 29.45 | 0.0138 |

The analysis reveal that the bed material is also clayey silt with $D_{50}$ varies between 0.005 mm and 0.015 mm. A typical grain size analysis curve plotted to determine $D_{50}$ of bed material is shown in FIG.12.

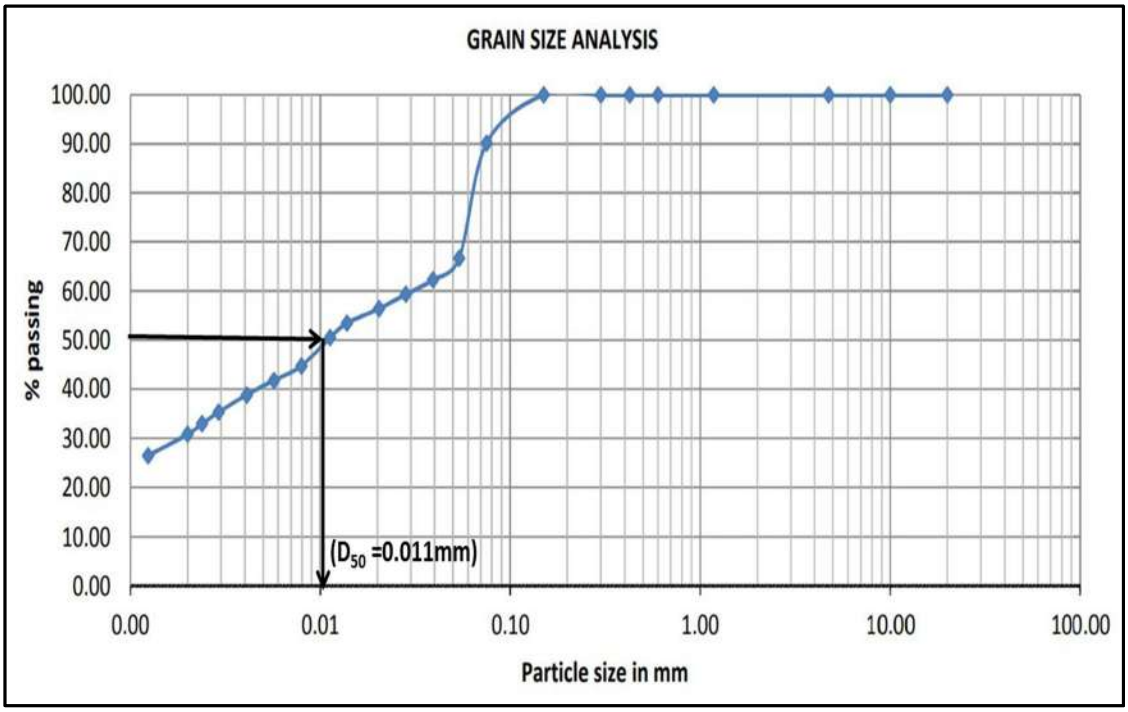



**FIG.12: Typical Plot of Sieve Analysis indicating $D_{50}$ size of Bed Sample (Non-monsoon)**

Similarly, bed samples were collected at nine (9) locations in the vicinity of proposed port area as well as in Dahanu creek area during monsoon season. The locations and its grain size analysis carried out is presented in Table. II.

**Table-II**

**Grain Size Analysis of Bed Samples (Monsoon)**

| Sr. No. | Description | Location | | Sample retained on 75 Micron % | % Fines | | $D_{50}$ |
|---|---|---|---|---|---|---|---|
| | | Easting | Northhing | | Silt % | Clay % | |
| 1 | Sea Bed Sample 1 | 260058.67 m E | 2210556.01 m N | 31.86 | 39.07 | 29.08 | 0.0193 |
| 2 | Sea Bed Sample 2 | 260506.45 m E | 2210118.04 m N | 31.71 | 38.18 | 30.11 | 0.0250 |
| 3 | Sea Bed Sample 3 | 260886.37 m E | 2209899.71 m N | 11.76 | 49.05 | 39.19 | 0.0050 |
| 4 | Sea Bed Sample 4 | 261362.28 m E | 2209702.34 m N | 14.46 | 46.04 | 39.50 | 0.0060 |
| 5 | Sea Bed Sample 5 | 261785.79 m E | 2209410.27 m N | 9.25 | 48.93 | 41.83 | 0.0043 |
| 6 | Sea Bed Sample 6 | 262231.29 m E | 2209010.97 m N | 20.62 | 45.78 | 33.61 | 0.0107 |
| 7 | Sea Bed Sample 7 | 262605.67 m E | 2208663.69 m N | 14.53 | 47.01 | 38.46 | 0.0065 |
| 8 | Sea Bed Sample 8 | 262714.88 m E | 2208258.59 m N | 5.57 | 54.05 | 40.38 | 0.0050 |
| 9 | Sea Bed Sample 9 | 262756.84 m E | 2207799.91 m N | 24.29 | 45.17 | 30.54 | 0.0150 |

The analysis reveal that the bed material is also clayey silt with $D_{50}$ varies between 0.005 mm and 0.0250 mm. A typical grain size analysis curve plotted to determine $D_{50}$ of bed material is shown in FIG.13.

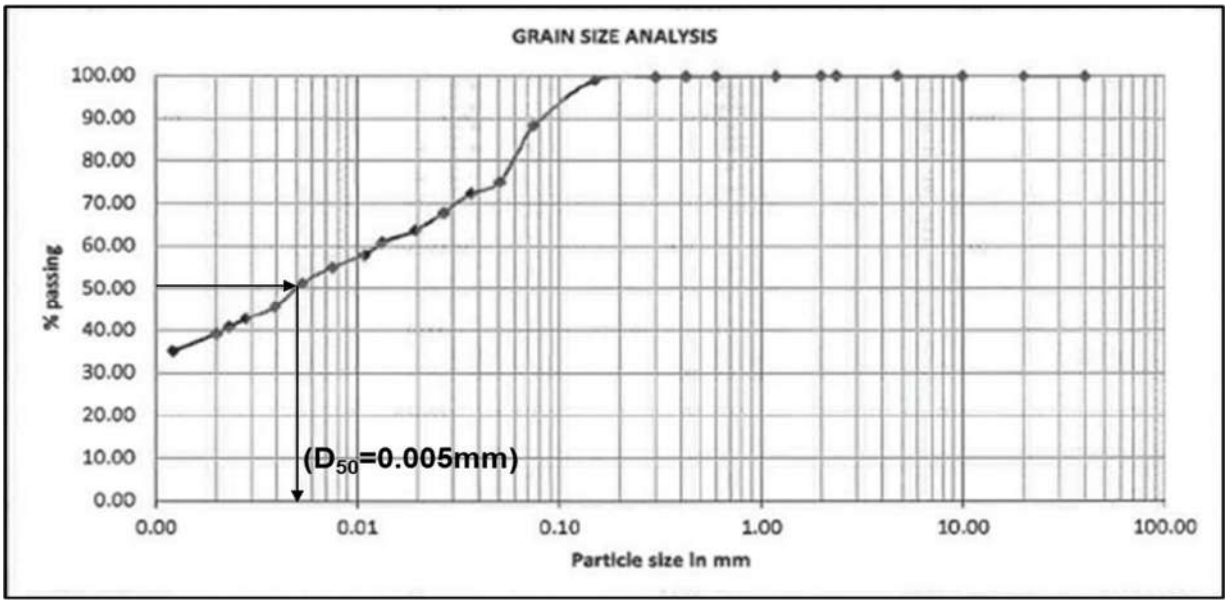



**FIG.13: Typical Plot of Sieve Analysis indicating $D_{50}$ size of Bed Sample (Monsoon)**

The material in suspension and that at bed is having similar characteristics i.e. material is of cohesive nature and it can also be inferred that the deposition of the material at bed is due to settlement of the material in suspension. This information is of significance to decide the type of sediment transport formulation to be used to estimate the likely rate of deposition/siltation in the harbour area.

### 3.7 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.

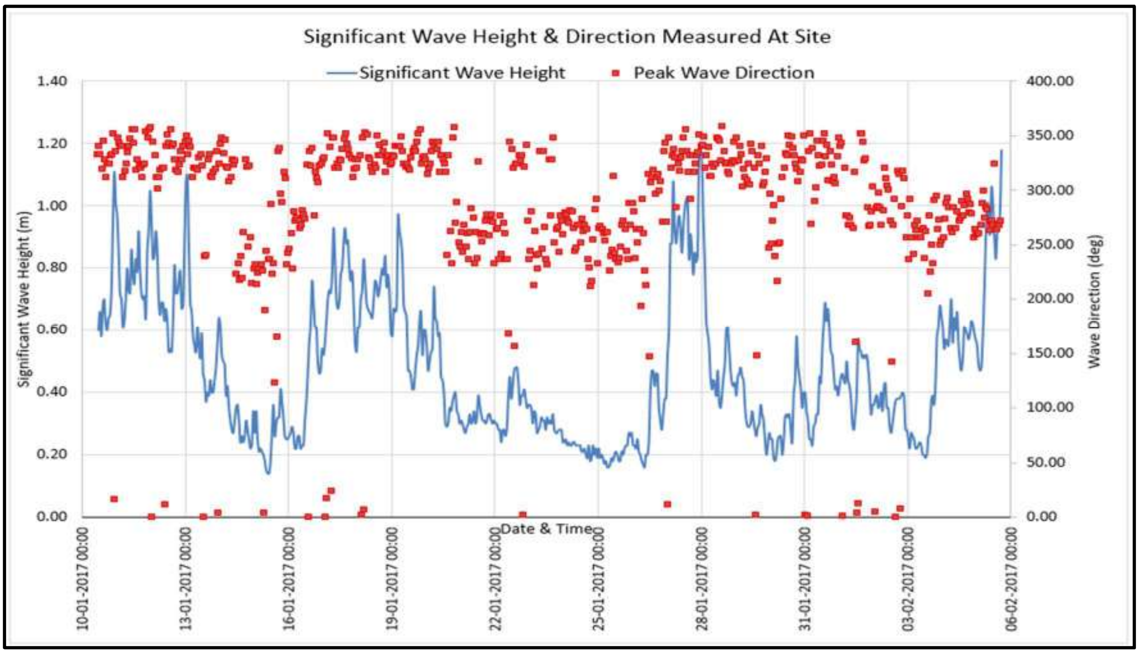



**FIG.14(A) : Wave Data at ADCP Location (Non-monsoon)**

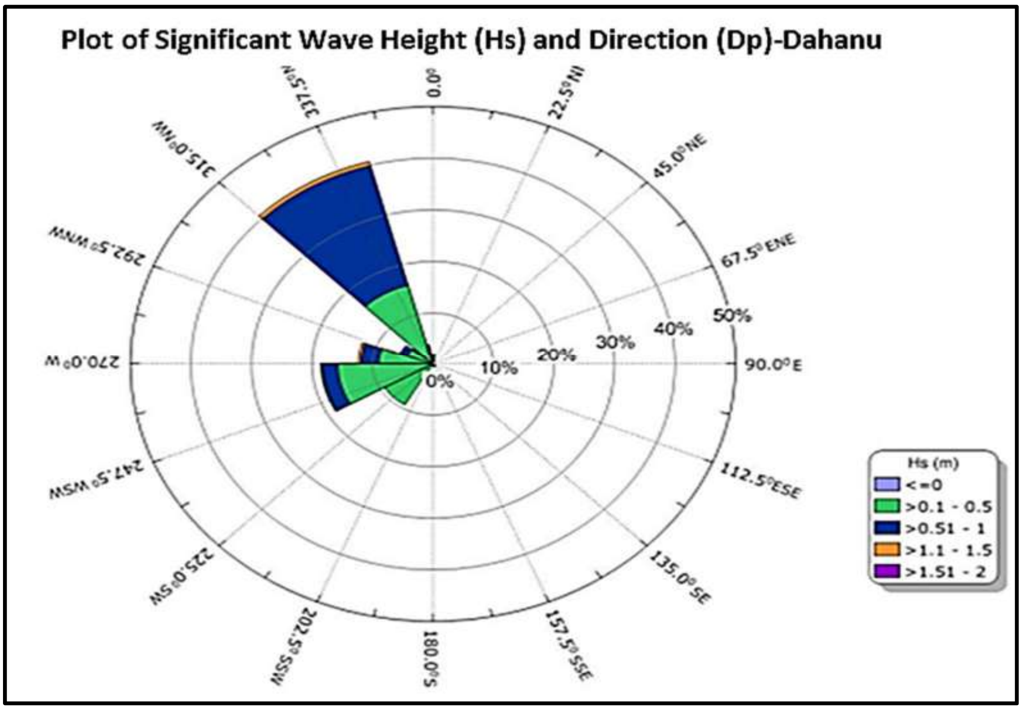



**FIG.14(B): Wave Rose Diagram For Wave Data at ADCP Location (Non-monsoon)**

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) & (B) respectively.

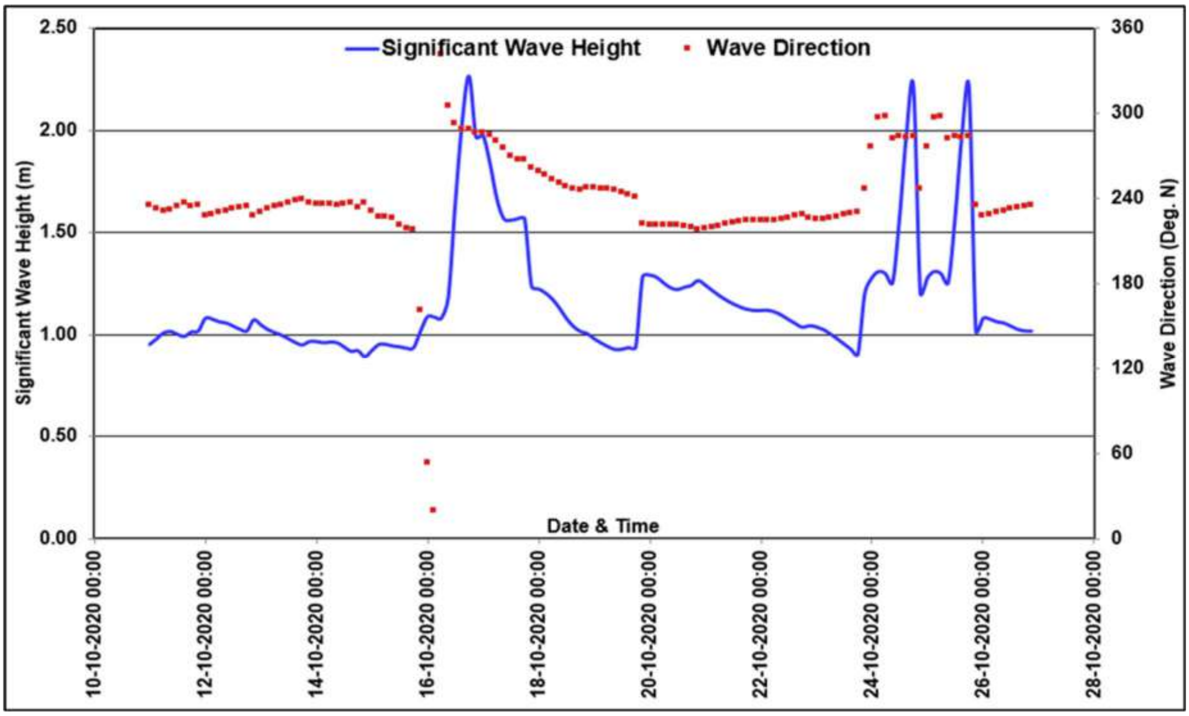



**FIG.15(A) : Wave Data at ADCP Location (Monsoon)**

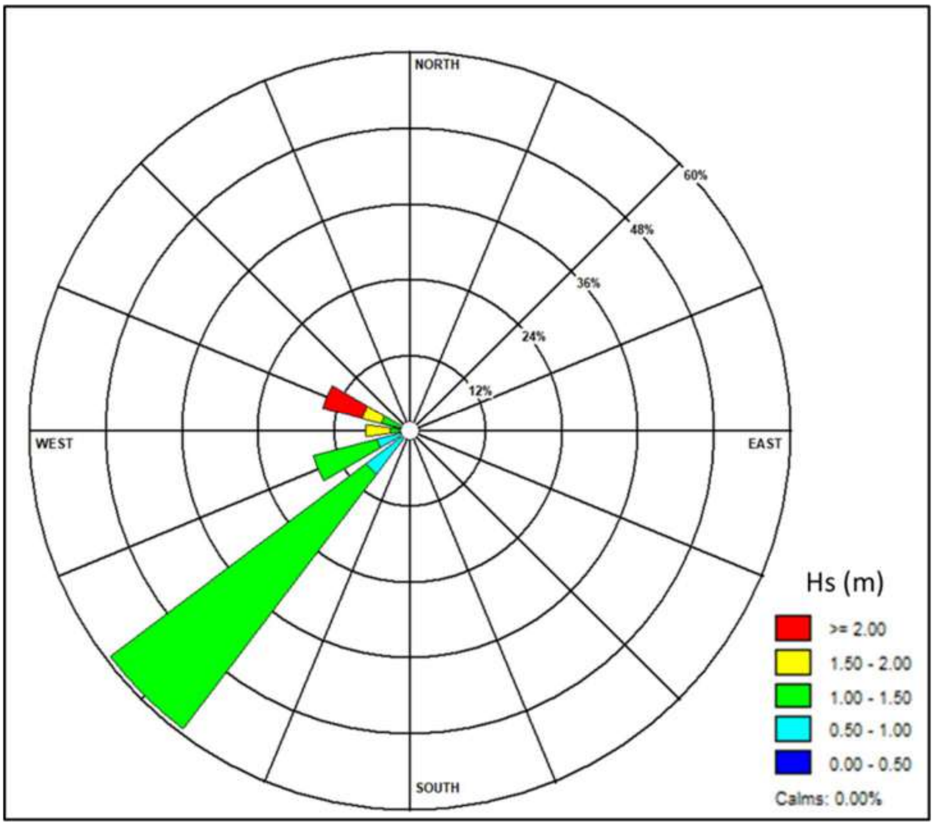



**FIG.15(B): Wave Rose Diagram For Wave Data at ADCP Location (Monsoon)**

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)).

### 3.8 Wind Data

The wind data 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.

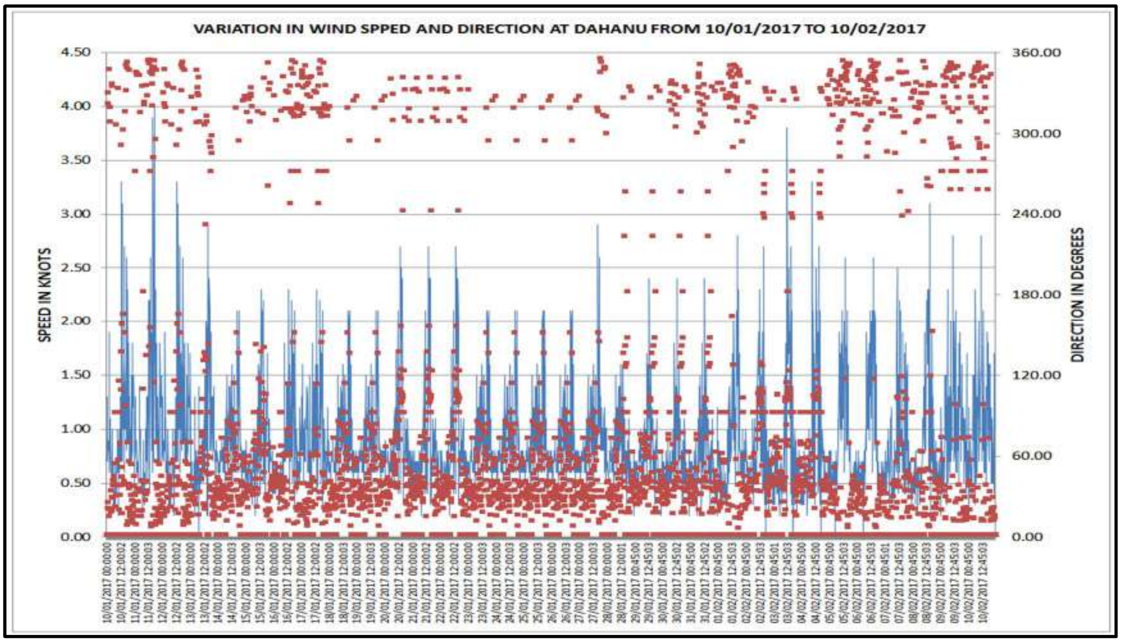



**FIG.16(A) : Wind Data at Dahanu (Non-monsoon)**

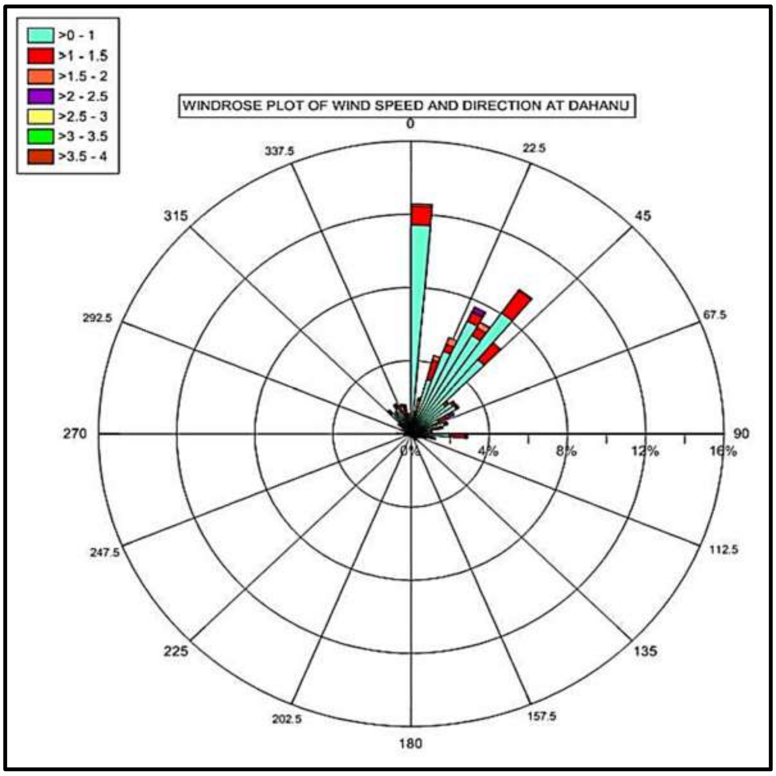



**FIG.16(B):Rose Diagram for Wind Data at Dahanu (Non-monsoon)**

The wind speeds during this 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.

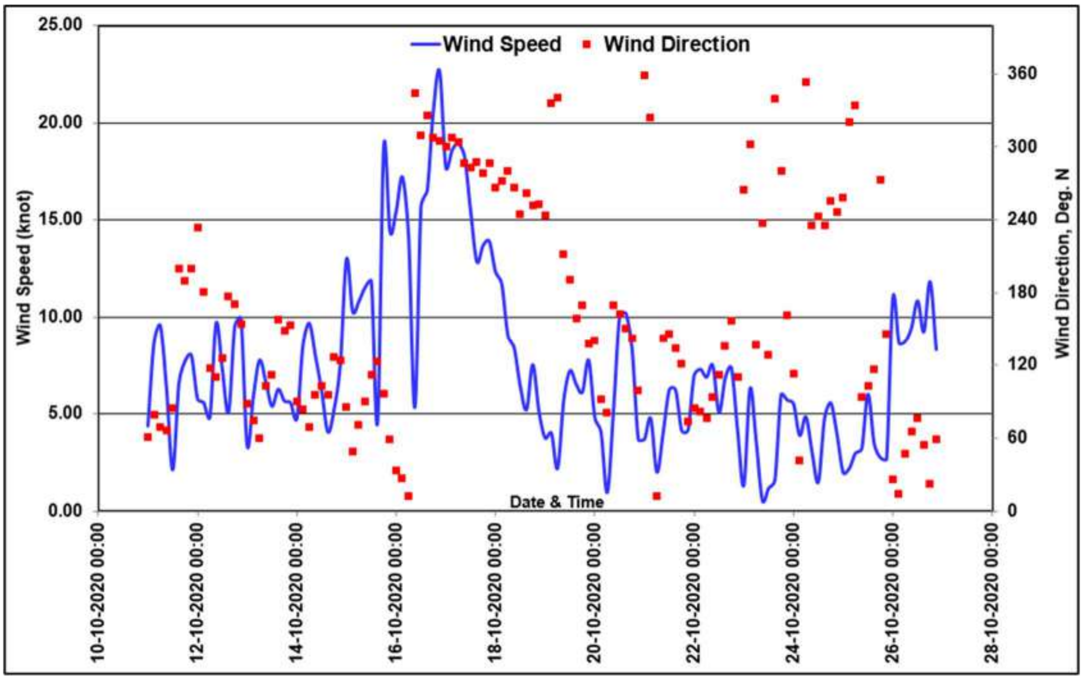



**FIG.17(A) : Wind Data at Dahanu (Monsoon)**

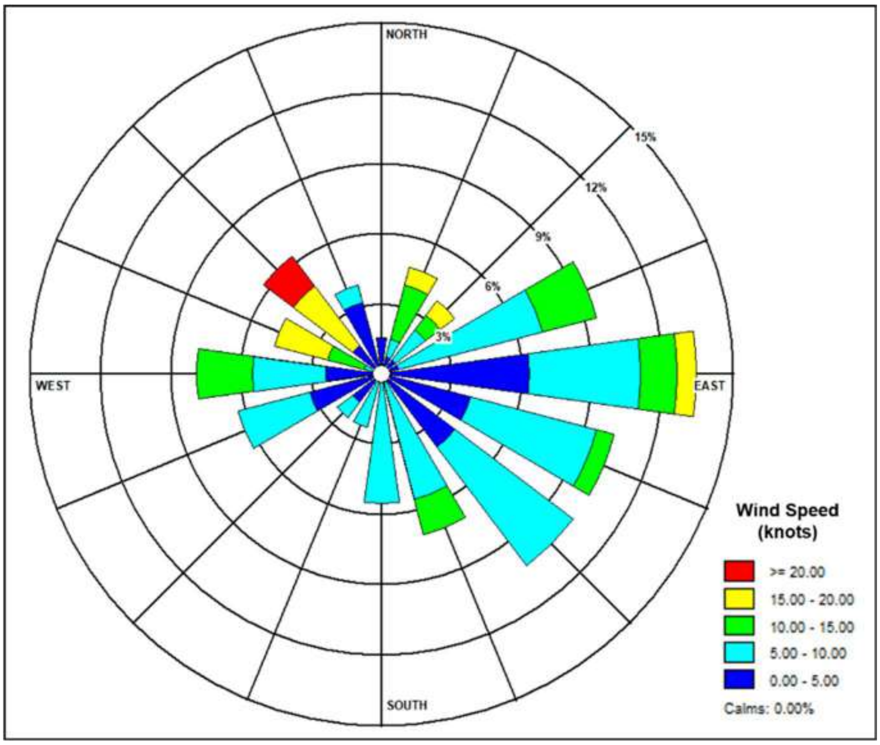



**FIG.17(B):Rose Diagram for Wind Data at Dahanu (Monsoon)**

The wind speeds during this 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.

# 4. MATHEMATICAL MODEL STUDIES

The mathematical model study provides the information on simulation of tidal hydrodynamics and siltation for the area in the vicinity of proposed port at Vadhavan in the Arabian Sea. The studies were carried out by using TELEMAC software suite 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

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

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

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

in which,

| | | | |
|---|---|---|---|
| h | (m) | ------------------------------------- | depth of water |
| u, v | (m/s) | ------------------------------------- | velocity components |
| g | ($m/s^2$) | ------------------------------------- | gravity acceleration |
| $\nu_t$ | ($m^2/s$) | ------------------------------------- | 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 of proposed port, Vadhavan, Tarapur and 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 in deeper part of Arabian Sea on the West side. The Dahanu creek along with topography up to +10 m contour w.r.t. CD in the control area is also considered in the model. The model domain is descritised 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 areas 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.

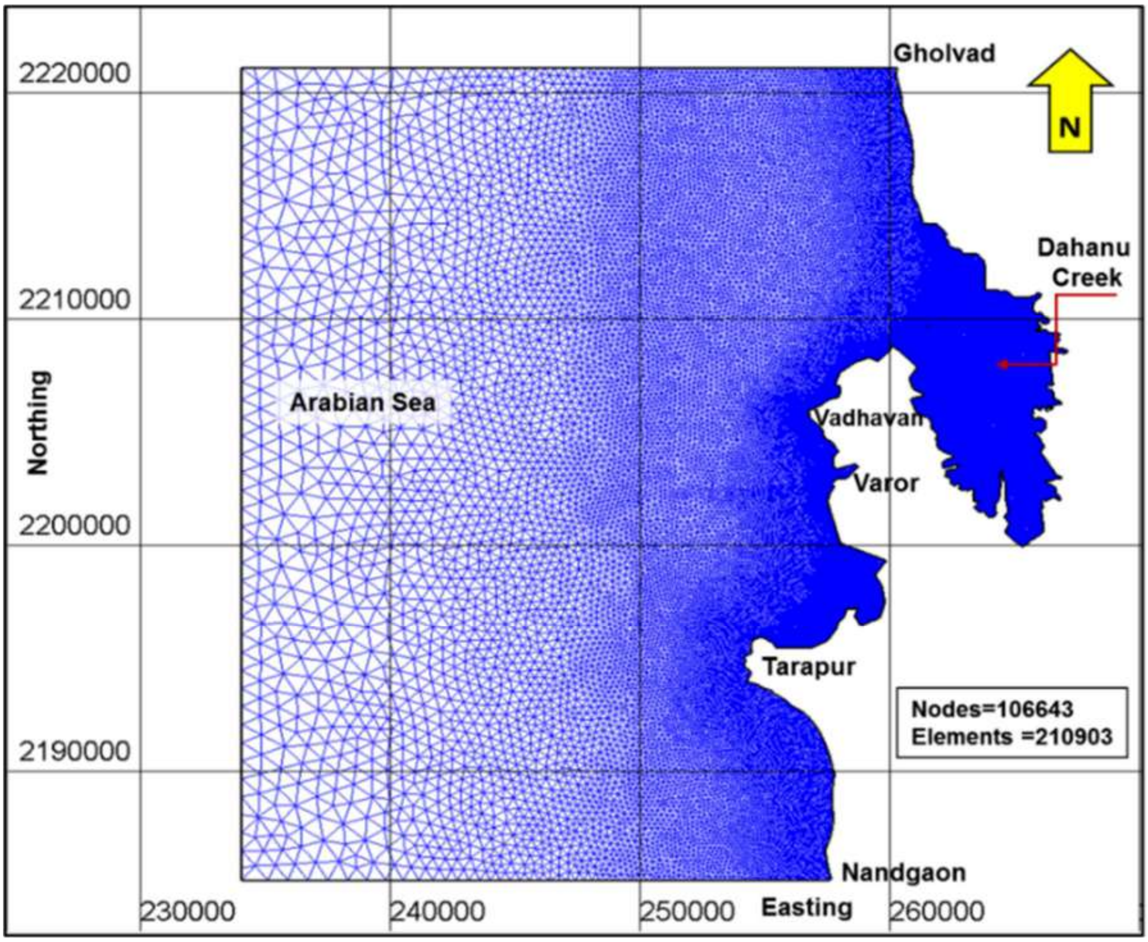



**FIG.18(A):Finite Element Mesh for Vadhavan Model**

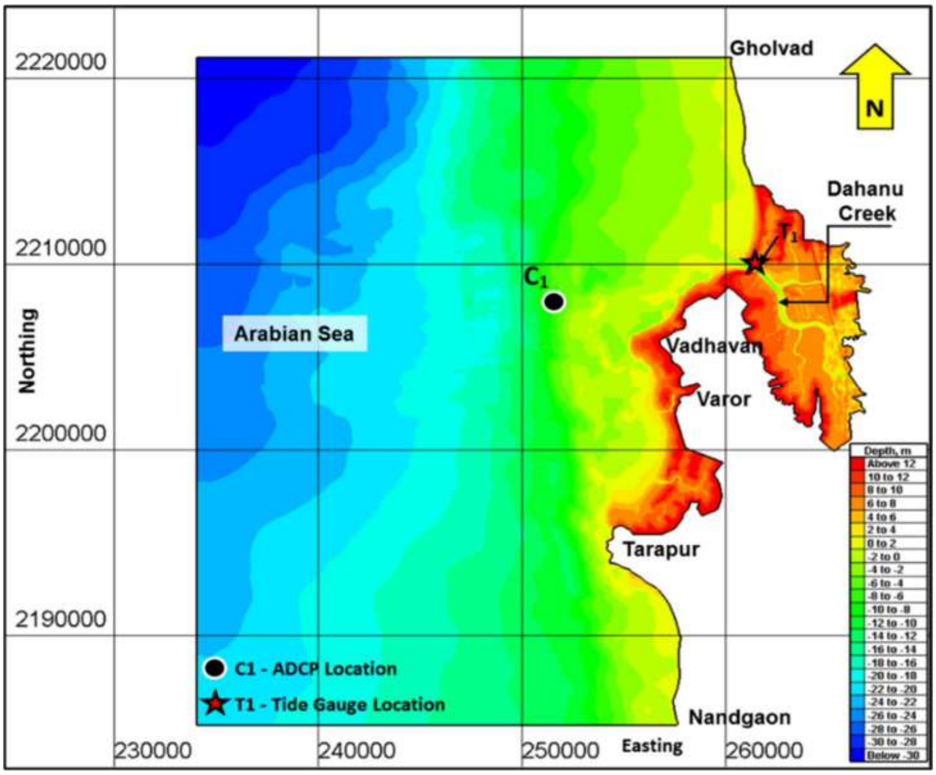



**FIG.18(B):Bathymetry of Vadhavan Area**

### 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 tidal 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 was collected. 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), (B) & (C) respectively.

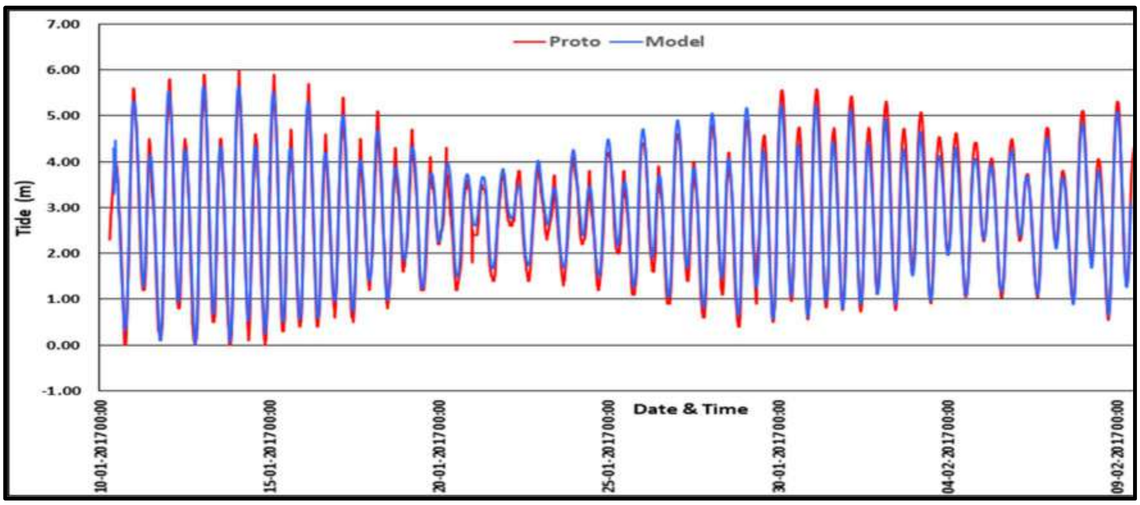



**FIG.19(A): Comparison of Proto and Model Tide at T1 Location (Non-monsoon)**

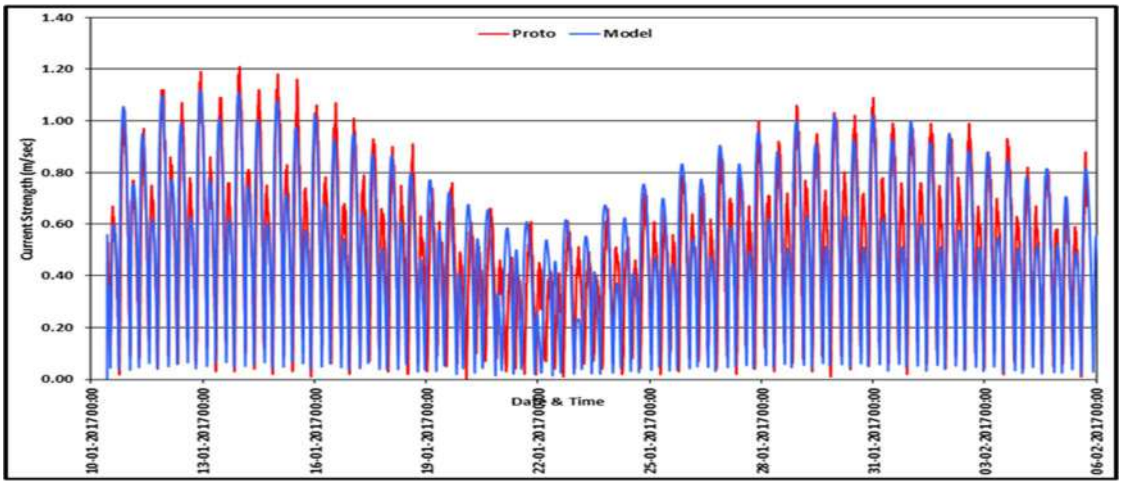



**FIG.19(B): Comparison of Proto and Model Current Strength at C1 (Non-monsoon)**

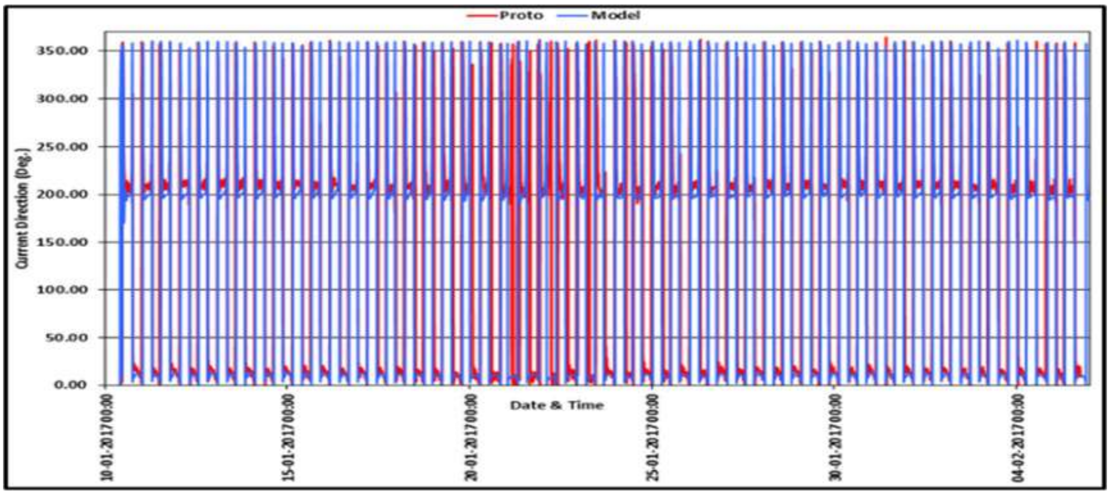



**FIG.19(C): Comparison of Proto and Model Current Direction at C1 (Non-monsoon)**

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), (B) & (C) respectively.

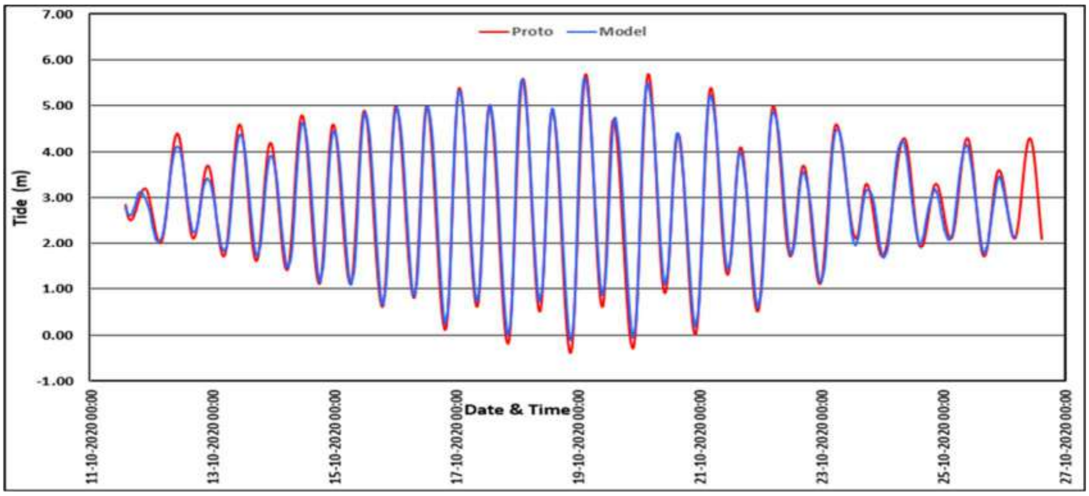



**FIG.20(A): Comparison of Proto and Model Tide at T1 Location (Monsoon)**

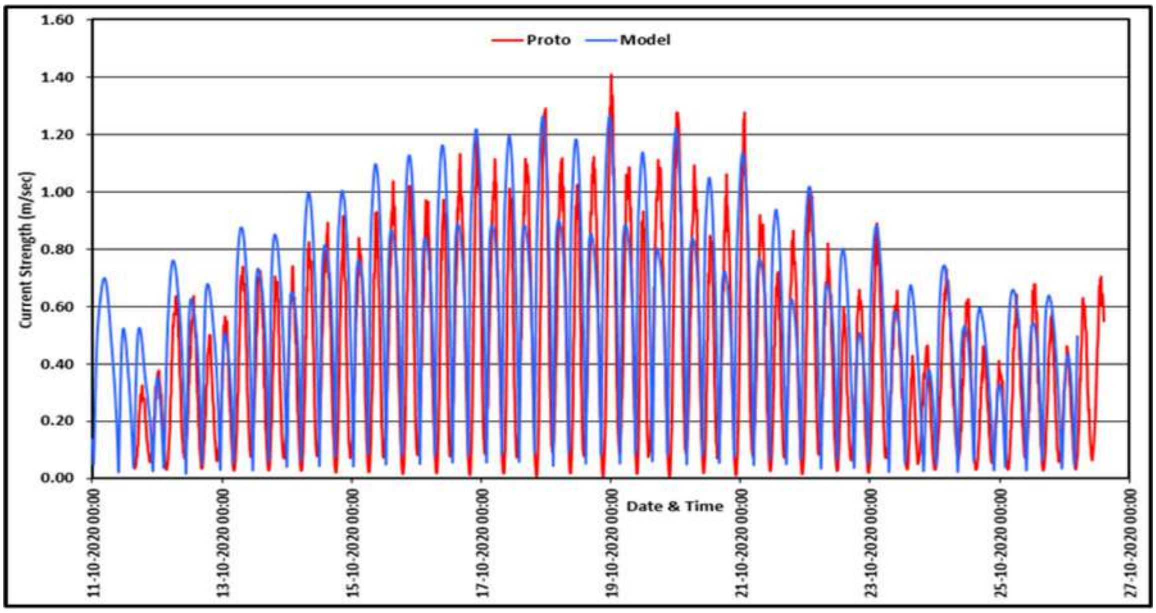



**FIG.20(B): Comparison of Proto and Model Current Strength at C1 (Monsoon)**

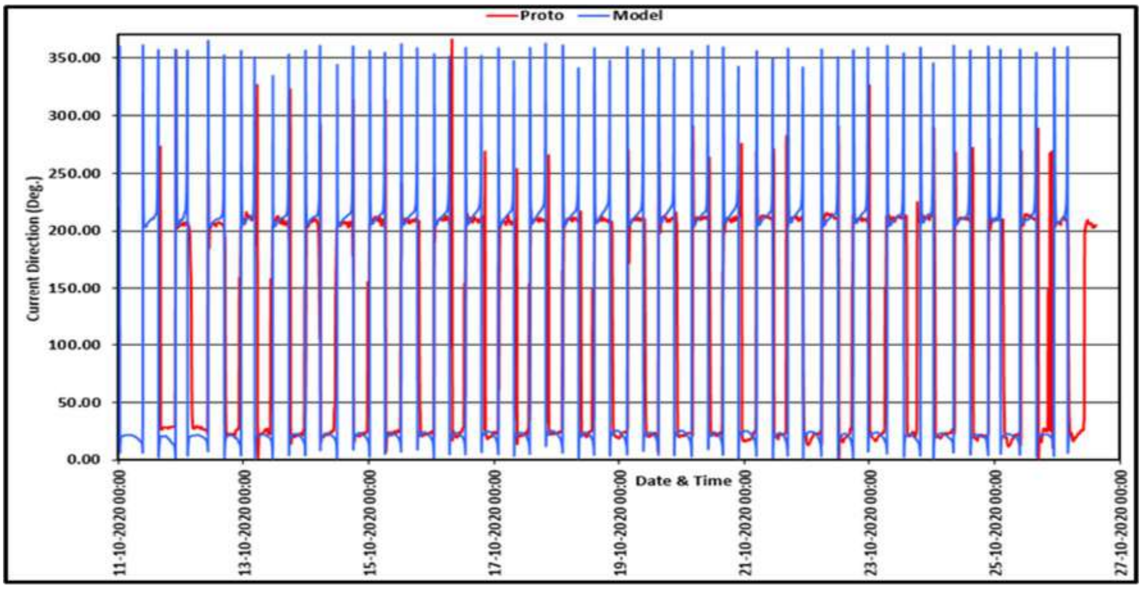
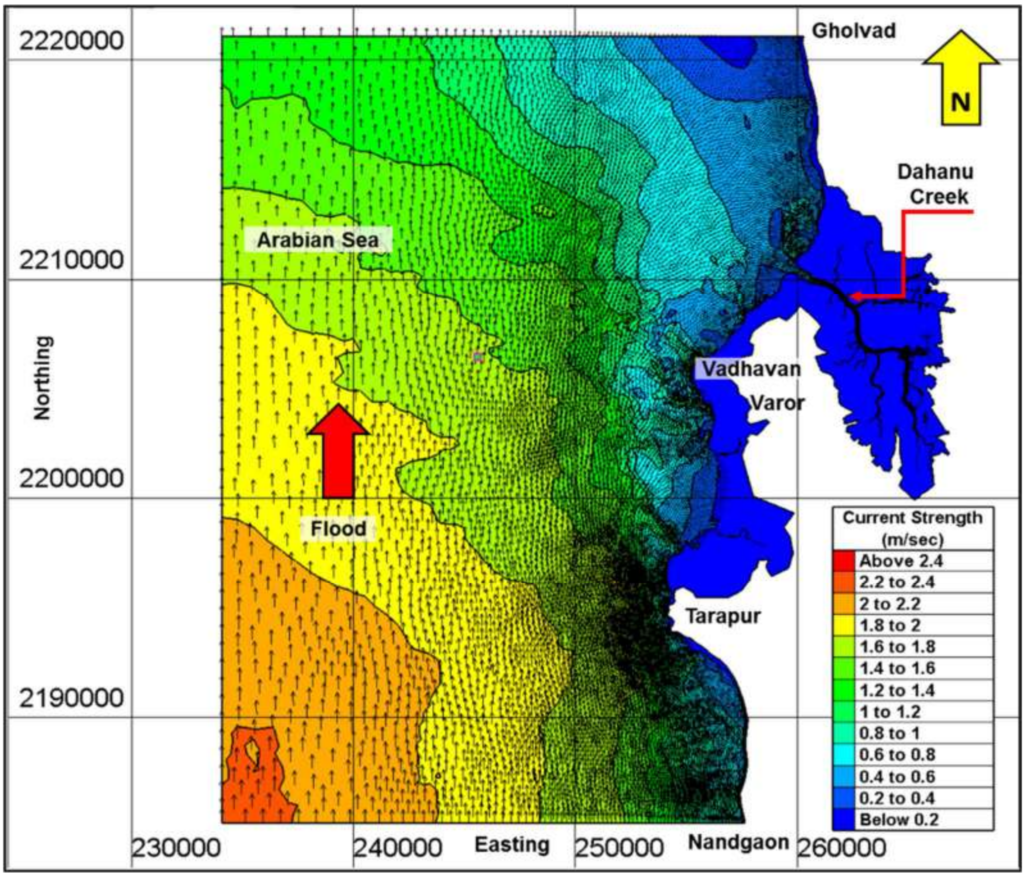
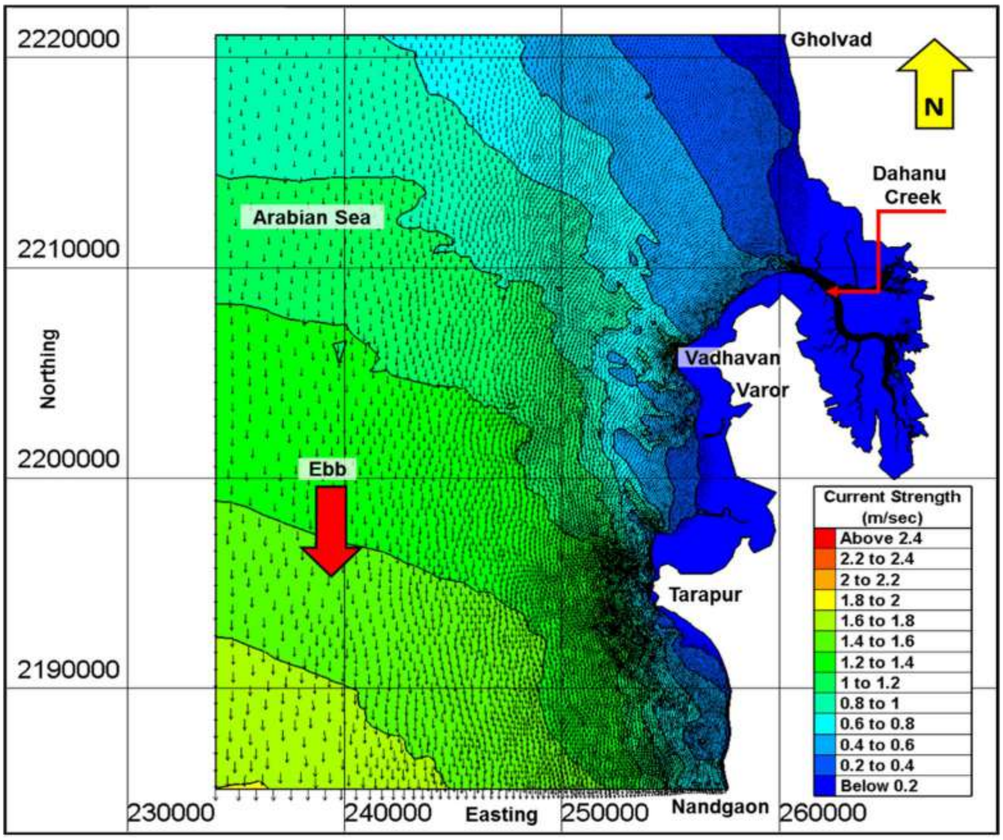



**FIG.20(C): Comparison of Proto and Model Current Direction at C1 (Monsoon)**

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**

### 4.3 Simulation and Calibration of Model for Siltation

The siltation studies to estimate the likely rate of siltation in various dredged areas (Berth pocket, approach channel etc.) of the harbour area under consideration requires coupling of the calibrated hydrodynamic model with sediment transport module. The sediments present in suspension being cohesive in nature, the erosional and depositional behaviour of sediment is estimated based on Krone (1962) & Parthenaides (1962) formulation. In order to determine the rate of siltation in proposed harbour area, the various factors which contribute to the process of siltation considered for the model are: grain size of bed material and suspended sediments, SSC, settling velocity of suspended sediment, salinity, temperature, current strength etc. The field data on SSC provided by JN Port for non-monsoon as well as monsoon seasons was considered to calibrate concentration profile as well as to evolve the likely rate of siltation in the harbour area.

The proposed port location is being in the region wherein there is no development carried out till date (virgin area) the information on rate of deposition of material is not available for the calibration of silt model. Thus the calibration of silt model for existing condition for Monsoon & Non-monsoon Seasons was carried out only by comparing SSC observed at Site with that in the model. The typical plot of concentration for existing bathymetry condition obtained from model is shown in FIG.22 while the comparison of SSC at site and from model for typical tidal range of 2.5 m is shown in FIG. 23.

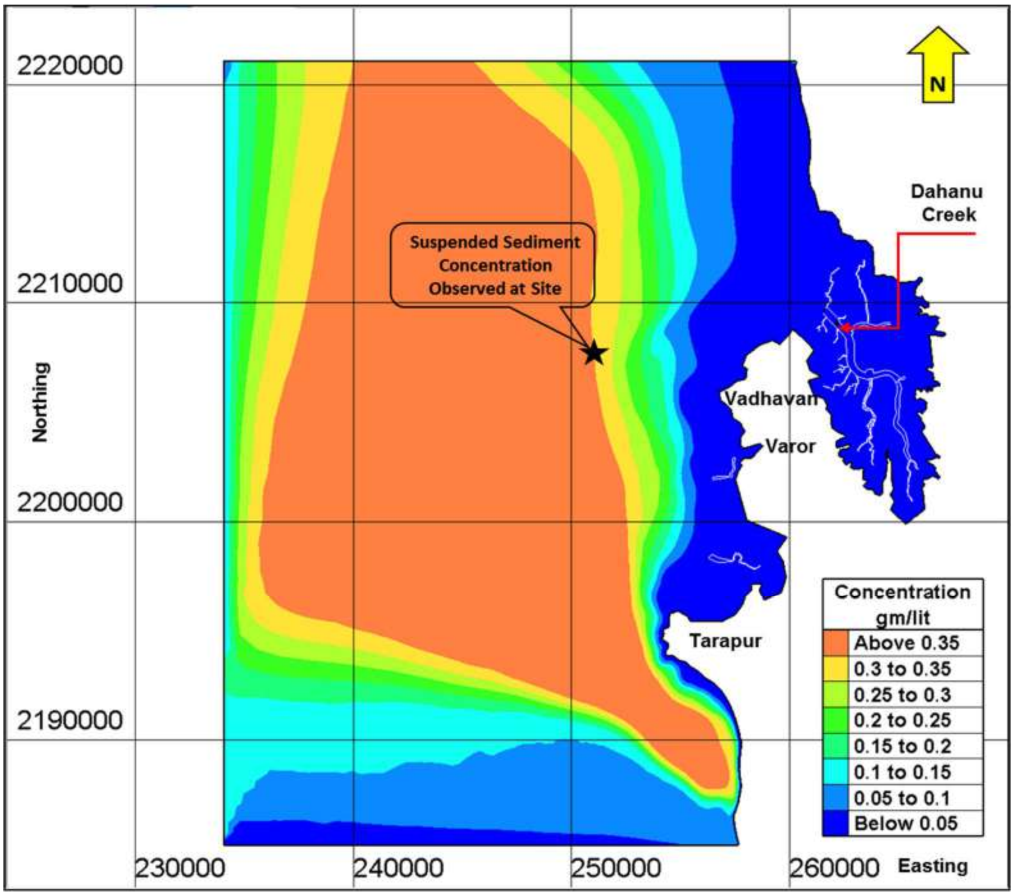



**FIG.22: Typical Plot of Concentration from Model –Existing Condition**

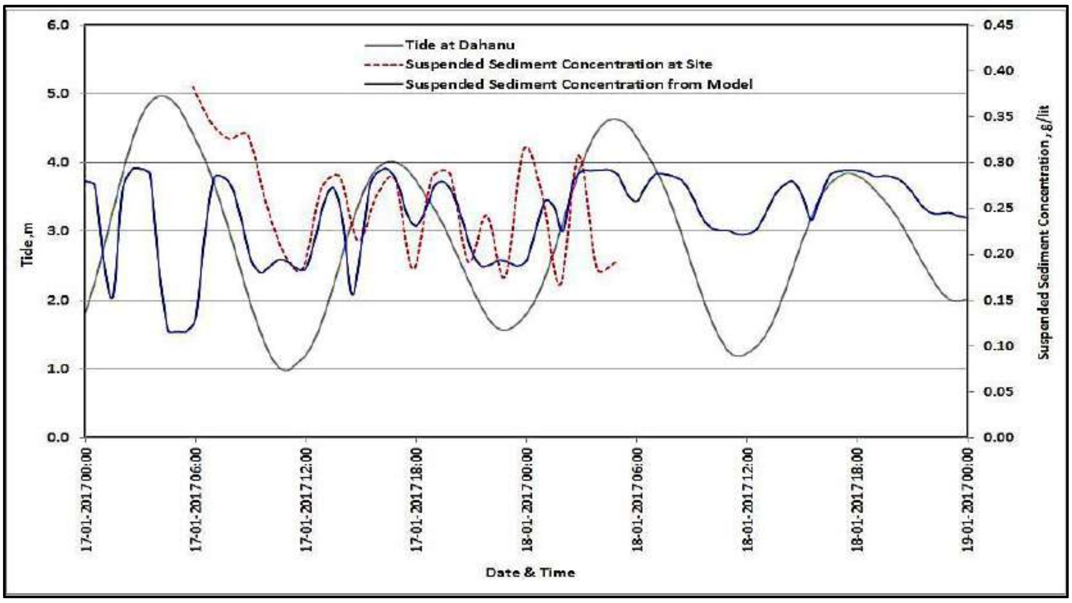



**FIG.23: Typical Plot showing Comparison of SSC at Site and from Model**

The above plot indicates that calibration of SSC in silt model is reasonably in good agreement for suspended sediment concentration measured at site.

## 5. MODEL STUDIES FOR OPTIMIZATION OF CURRENT DEFLECTING WALL (CDW)

CWPRS carried out tidal as well as wave hydrodynamics studies to finalize the layout of proposed port at Vadhavan. The layout recommended by CWPRS (FIG.2) is given in TR.No.5583 of March 2018. The port layout consists of offshore breakwater of 10.3 km length with Current Deflecting Wall (CDW) of 1.9 km on the leeward side of southern end of breakwater in the harbour area. As the breakwater is not shore connected, during flood tide at the southern end of breakwater an eddy is getting formed which further travels inside the harbour area and affect the berths which are on leeside of breakwater (Oil berths) as well as berths which will be used for port activities such as RO-RO, multipurpose etc. In order to avoid the undesirable flow conditions at above mentioned berths, the CDW was introduced in the layout of harbour. The location of CDW and its length is determined in such a way that the eddy will get trapped between CDW and breakwater. This was decided considering the maximum diameter of eddy at the point of generation while the length of CDW is determined based on the distance travelled by eddy, its path during flood phase of tide as well as locations of berths. Also, an emphasis was given to flow field in such a way that, during ebb phase of the tide the flow inside the harbour in the vicinity of CDW will not have adverse impact on the nearby berths. Considering the above aspects, current deflecting wall (CDW) of about 1.9 km with a clear gap of about 750 m was considered near the southern end of breakwater.

The consultants to JN port during detailed engineering of the project has revised the layout by altering the shape of reclamation and relocation of various berths viz. Multipurpose berths, Ro-Ro Berth etc. from southern end to northern end of harbour without modifying the layout of breakwater and CDW. It was proposed that the port will be developed in two phases viz. Phase-I & Master plan. Accordingly, JN Port provided two layouts to CWPRS vide e-mail dated 4th February 2021. (See FIG. 3 & 4). Further to this, during the visit of the Chairman, JN Port; Officials requested CWPRS to assess the possibility of optimization of length of Current Deflecting Wall (CDW) in view of relocation of berths proposed for port activities in the Master Plan layout. Considering the above facts, studies were undertaken to assess the possibility of curtailment of length of CDW.

### 5.1 Model Studies for Master Plan Layout with CDW of 1.9 km

The hydrodynamic studies for Master Plan layout with CDW of 1.9 km were carried out by modifying the well calibrated hydrodynamic model by incorporating the breakwater of 10.3 km length, revised proposed reclamation layout and designed dredge depths at berths and in the navigational channel as proposed in Master Plan layout along with CDW of 1.9 km length. The tidal range during monsoon season is being higher than that of non-monsoon season, tidal data of monsoon season was considered for these model studies. The zoomed portion of bathymetry for Master Plan layout with CDW of 1.9 km is shown in FIG.24 (A).

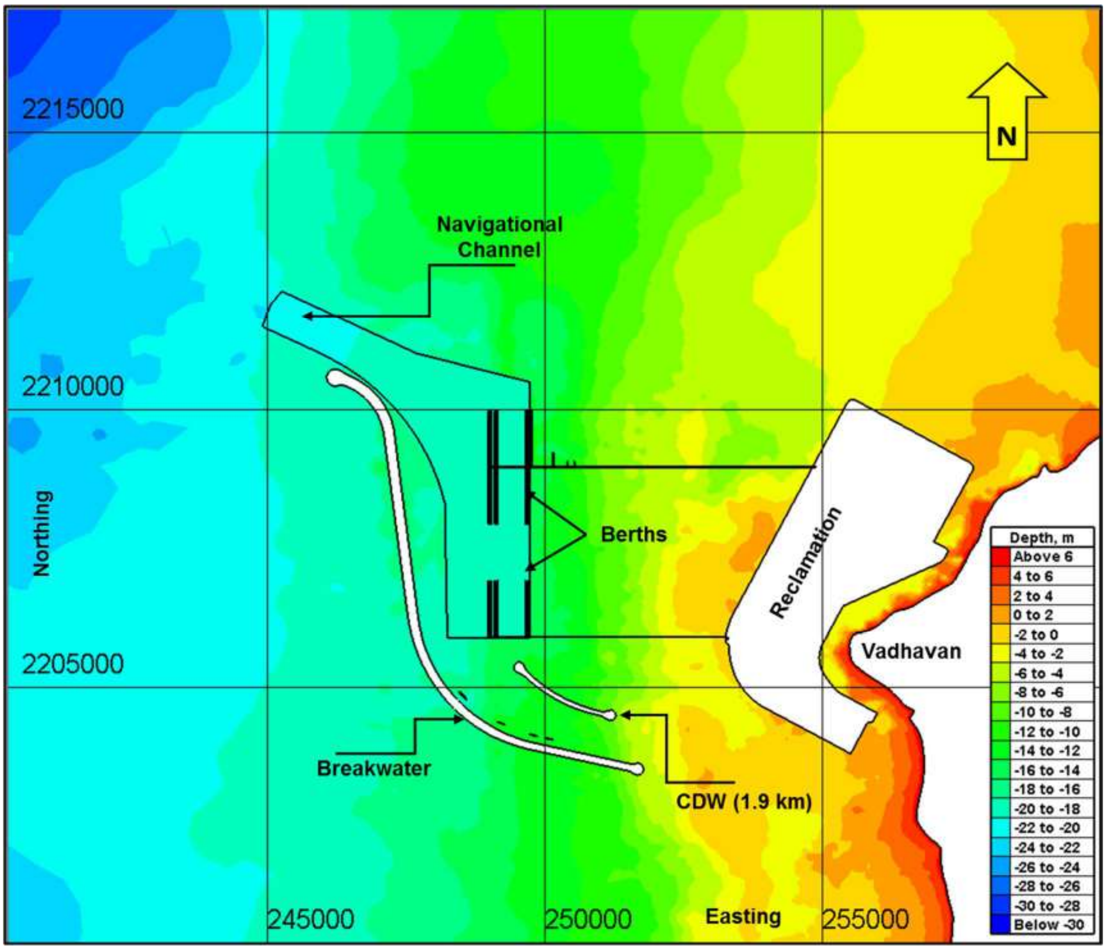



**FIG.24(A) :Zoomed Portion of Bathymetry for Master Plan Layout with CDW of 1.9 km**

The hydrodynamic simulation was carried out for Master Plan layout along with CDW of 1.9 km length by adopting same boundary conditions and other parameters considered for calibration of the tidal model. The flow field observed in the model during flood tide for monsoon season is shown in FIG.24 (B).

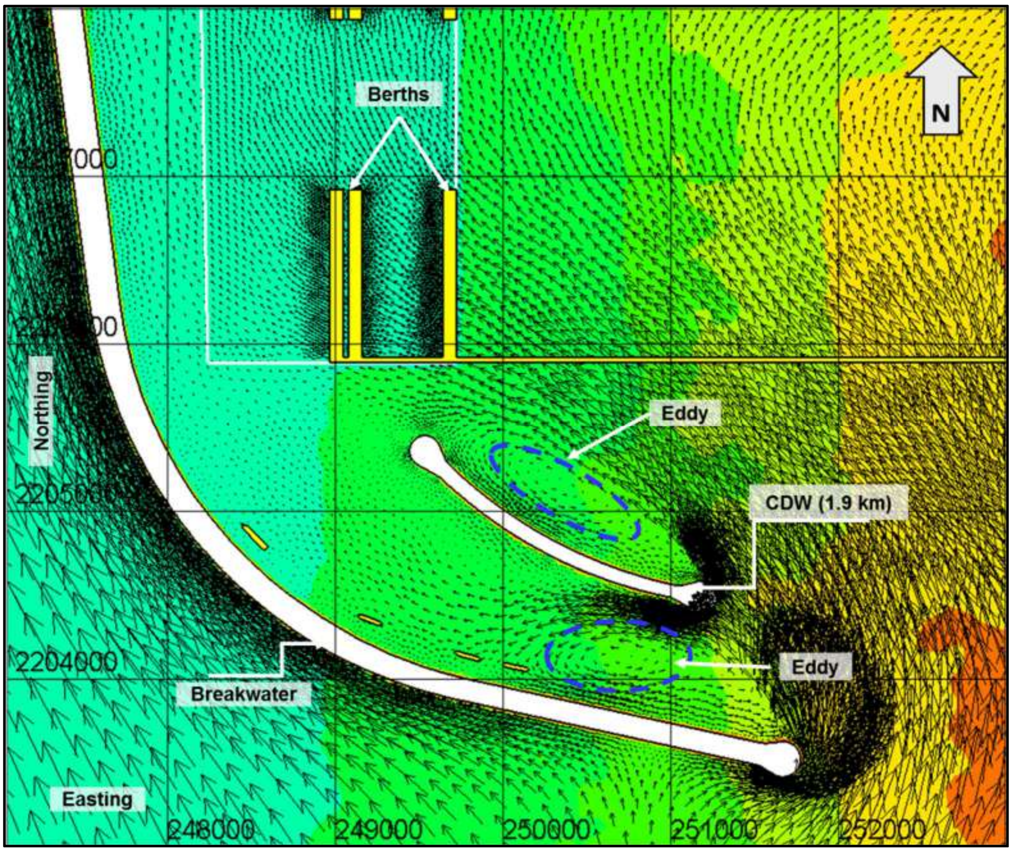



**FIG.24(B) :Zoomed Portion of Flow Field during Flood Tide**

The data on current (strength & direction) is extracted at various locations which are shown in FIG.25.

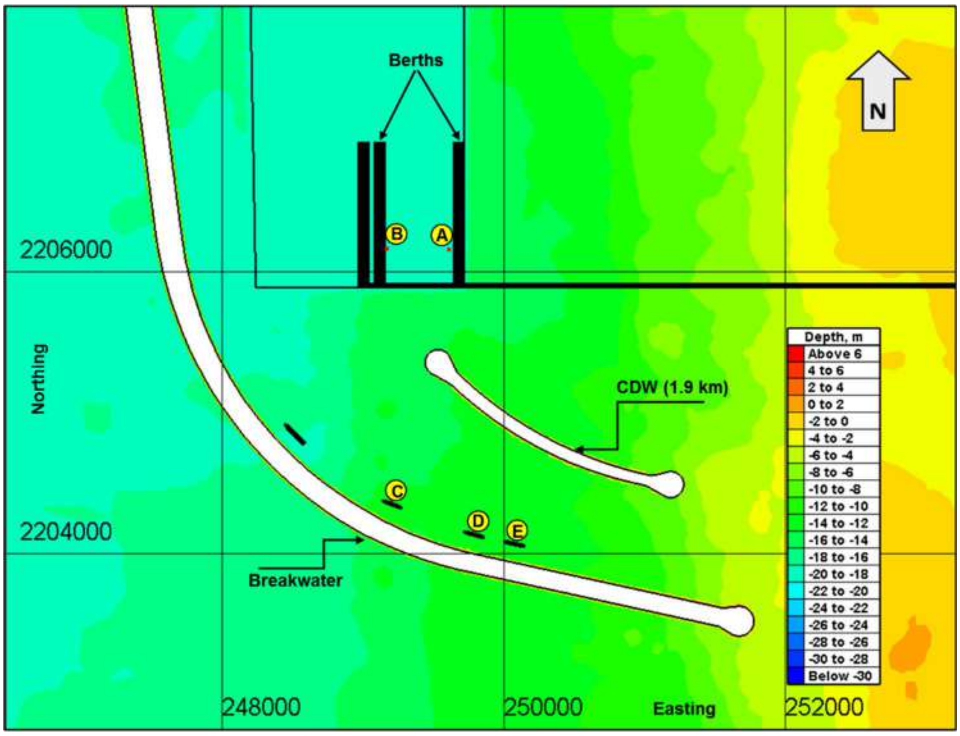



**FIG.25: Plan Showing Data Extraction Locations for Master Plan Layout**

The plots of current (strength & direction) for master plan layout with CDW of 1.9 km are shown in FIG. 26(A), (B), (C), (D) & (E).

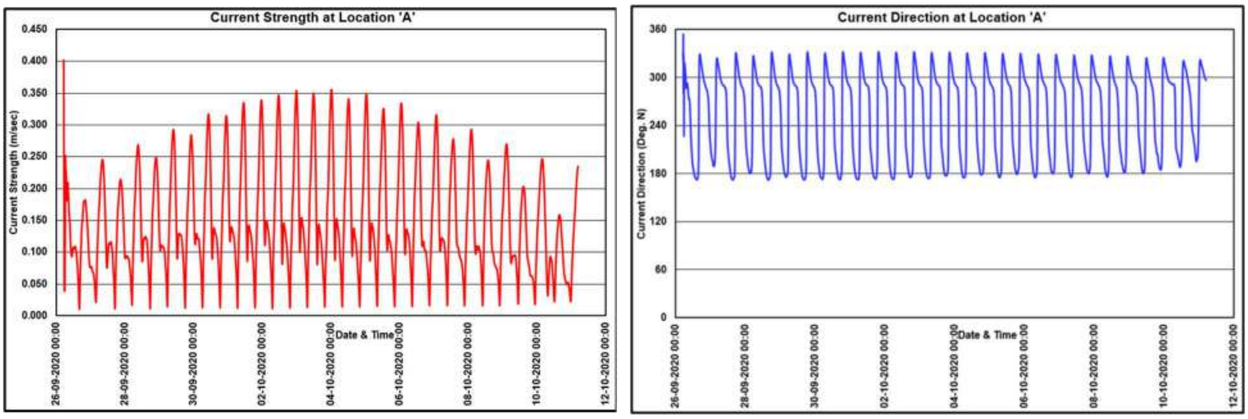



**FIG.26(A) : Current Strength & Direction at Location-A for CDW of 1.9 km**

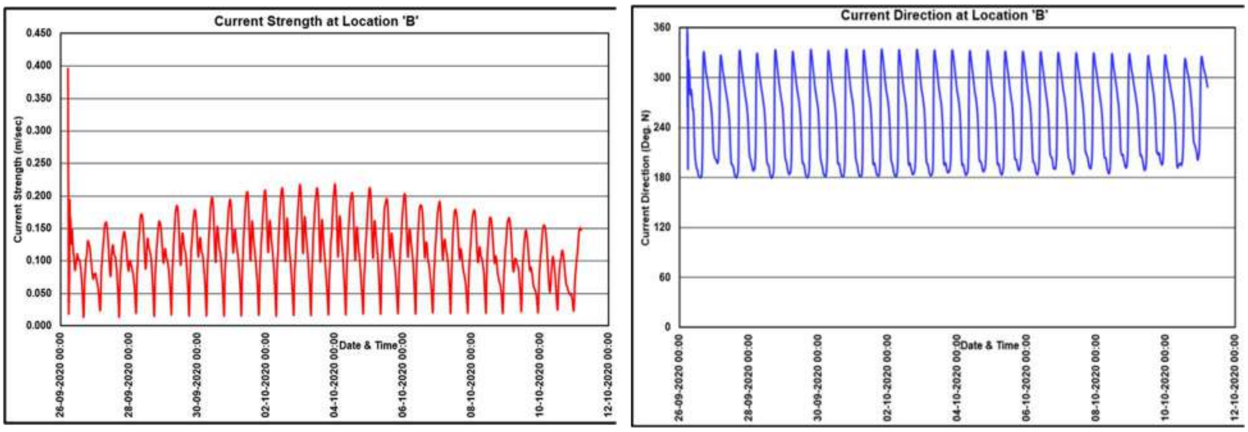



**FIG.26(B) : Current Strength & Direction at Location-B for CDW of 1.9 km**

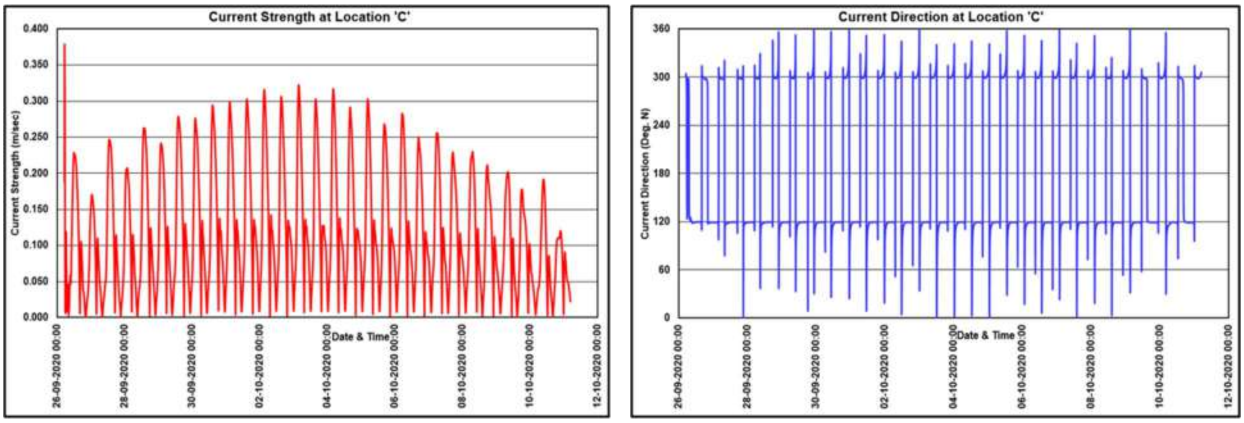



**FIG.26(C) : Current Strength & Direction at Location-C for CDW of 1.9 km**

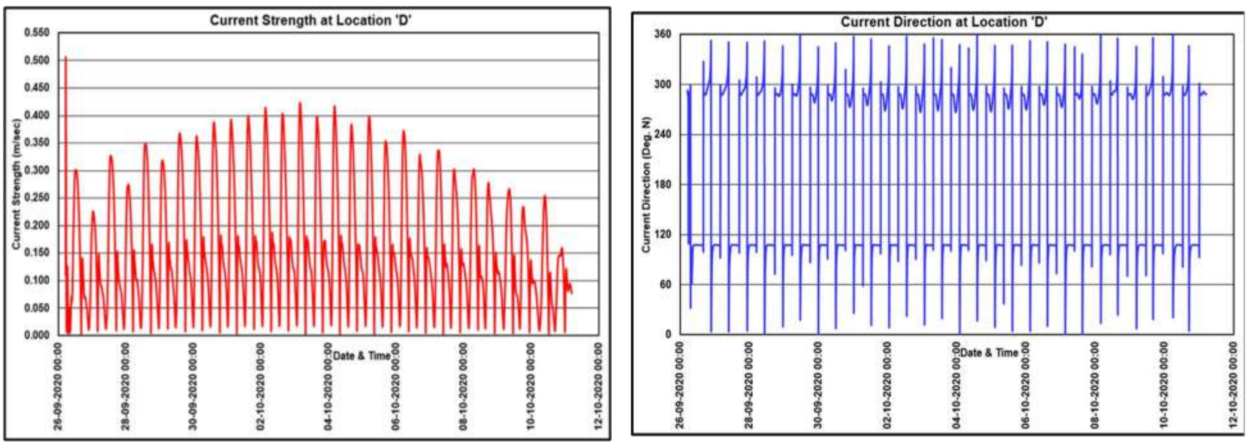
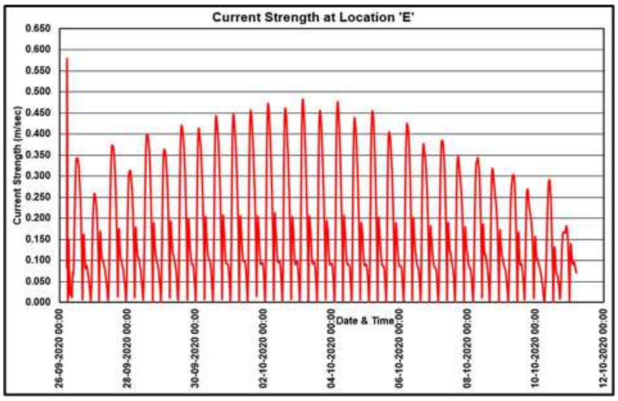



**FIG.26(D) : Current Strength & Direction at Location-D for CDW of 1.9 km**



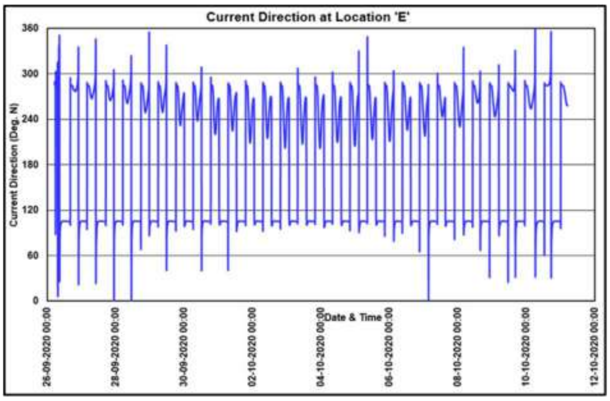




**FIG.26(E) : Current Strength & Direction at Location-E for CDW of 1.9 km**

The above plots reveal that at locations "A" & "B", current strength is less than 0.35 m/sec and current directions vary during ebb tide. Current strengths at locations "C" & "D" is less than 0.45 m/sec and flow is almost aligned to berths during flood & ebb phases while at Location "E" current strength is about 0.5 m/sec and current direction is more aligned during ebb phase as compared to flood phase.

### 5.2 Model Studies for Master Plan with CDW of 1.4 km

The hydrodynamics studies for Master Plan layout with 1.4 km long CDW were carried out by modifying the well calibrated hydrodynamic model by incorporating the breakwater, revised proposed reclamation, designed dredge depths at berths and in the navigational channel as proposed in Master Plan layout along with CDW of 1.4 km length. The zoomed portion of bathymetry for Master Plan layout with CDW of 1.4 km is shown in FIG.27 (A).

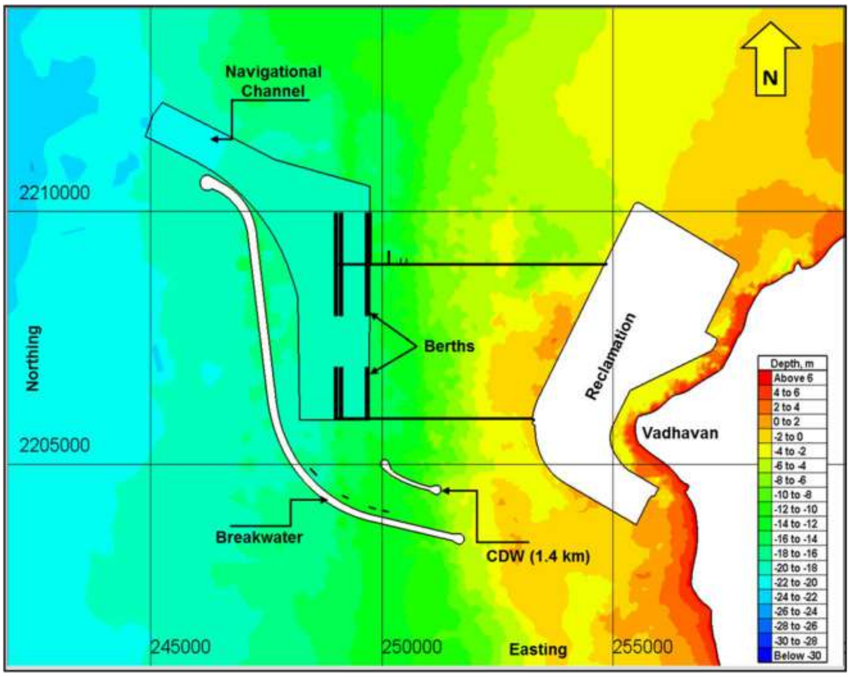



**FIG.27(A) :Zoomed Portion of Bathymetry for Master Plan Layout with CDW of 1.4 km**

The hydrodynamic simulation was carried out for Master Plan layout along with CDW of 1.4 km condition by adopting same boundary conditions which were considered for calibration of the tidal model. The flow field observed in the model during flood tide for monsoon season is shown in FIG.27 (B).

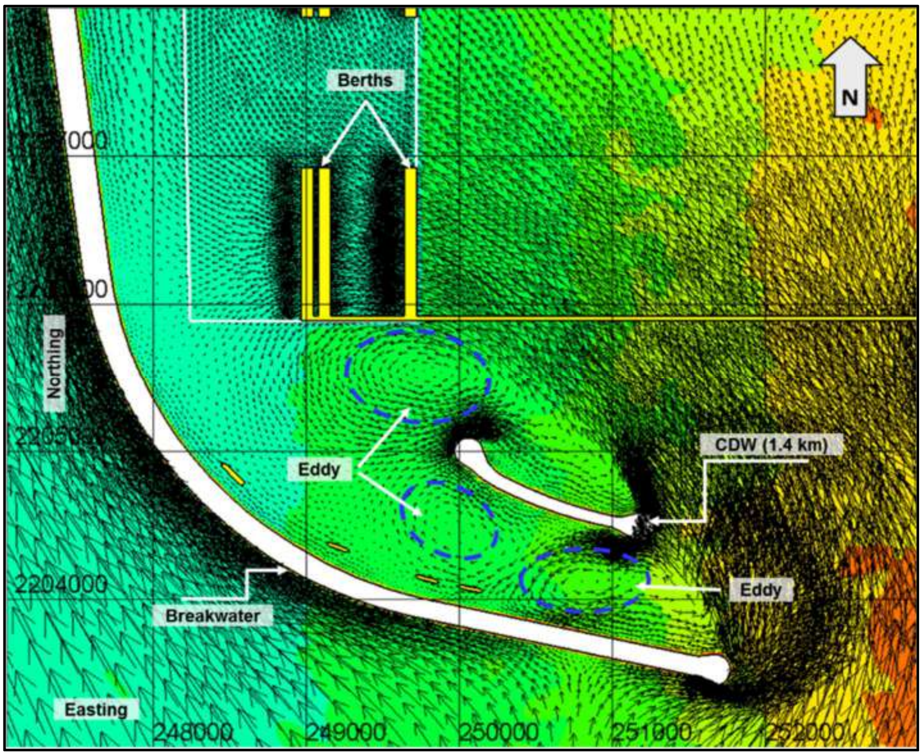



**FIG.27(B) :Zoomed Portion of Flow Field during Flood Tide**

The data on current (strength & direction) is extracted at various locations which are shown in FIG.25 and the plots of current (strength & direction) for master plan layout with CDW of 1.4 km are shown in FIG. 28 (A), (B), (C), (D) & (E).

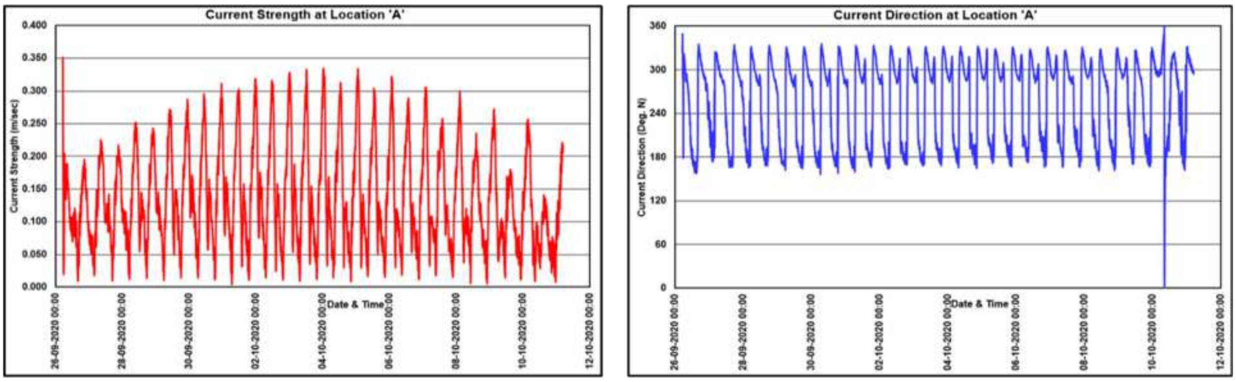



**FIG.28(A) : Current Strength & Direction at Location-A for CDW of 1.4 km**

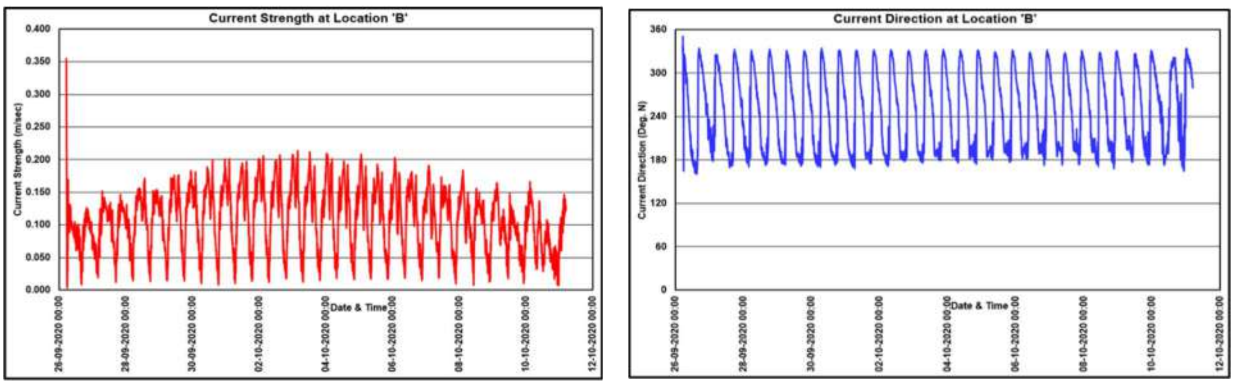



**FIG.28(B) : Current Strength & Direction at Location-B for CDW of 1.4 km**

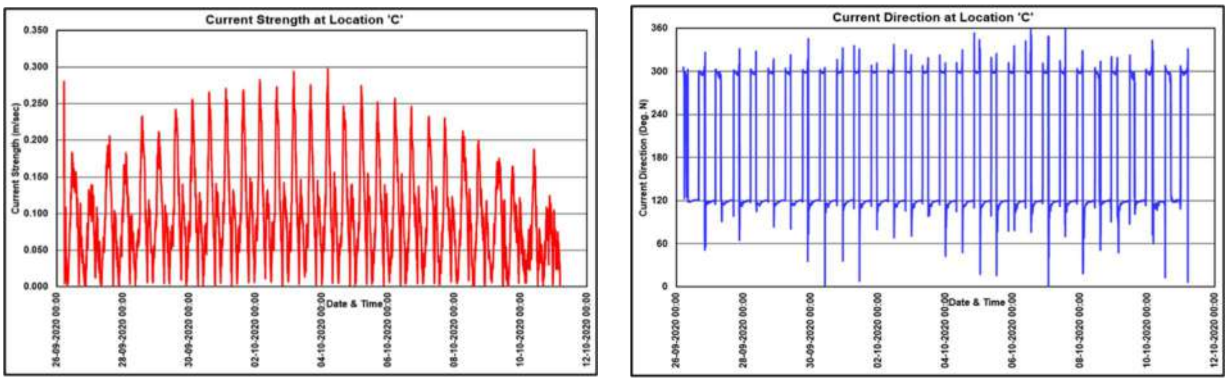



**FIG.28(C) : Current Strength & Direction at Location-C for CDW of 1.4 km**

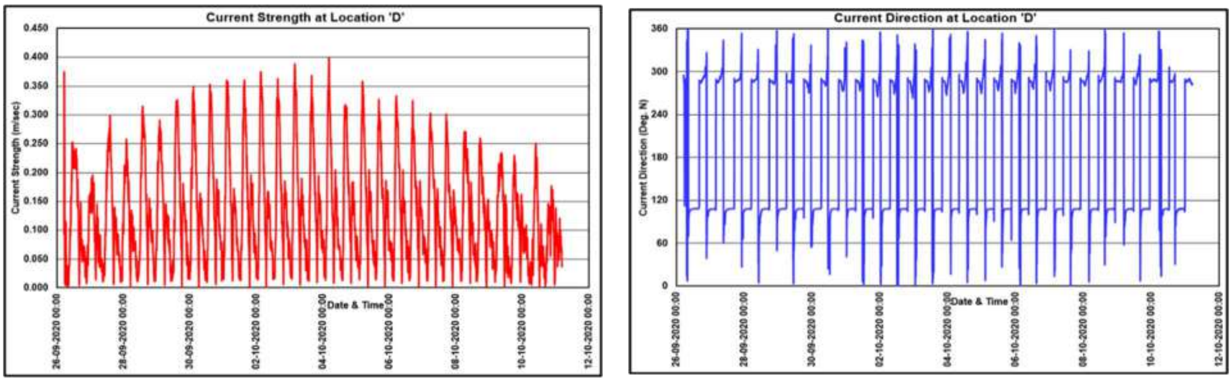



**FIG.28(D) : Current Strength & Direction at Location-D for CDW of 1.4 km**

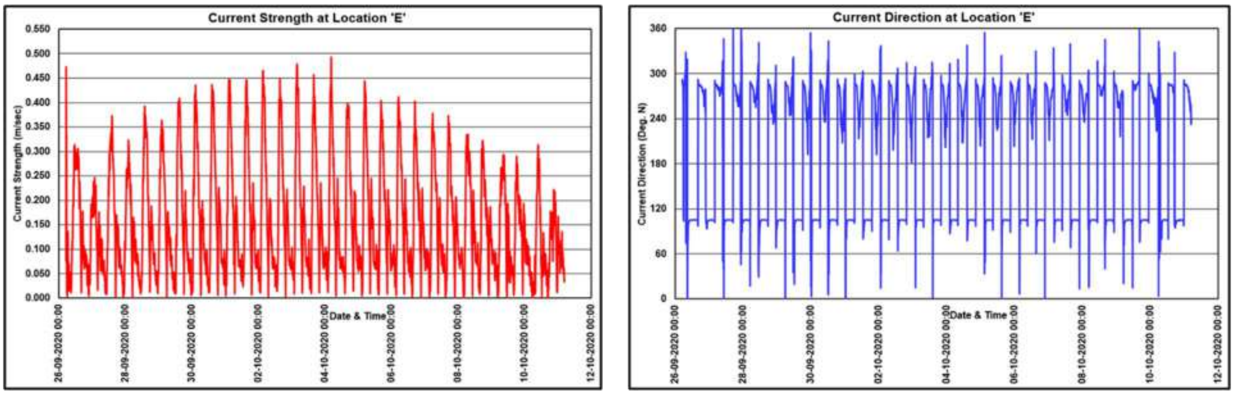



**FIG.28(E) : Current Strength & Direction at Location-E for CDW of 1.4 km**

The above plots reveal that current strengths and directions are similar with that for CDW of 1.9 km but it can be observed from flow field (FIG. 27(B)) that there will be generation of small eddy immediately on the north end of the CDW at the location of RO-RO, multipurpose, Tug berths proposed earlier and now relocated at the northern end, though eddy will not affect the current directions at Container terminals (Location A & B).

### 5.3 Model Studies for Master Plan with CDW of 1.0 km

The hydrodynamics studies for Master Plan layout with CDW of 1.0 km length were also carried out by modifying the well calibrated hydrodynamic model with various components like breakwater, revised proposed reclamation, designed dredge depths at berths and in the navigational channel as proposed in Master Plan layout along with CDW of 1.0 km. The zoomed portion of bathymetry for Master Plan layout with CDW of 1.0 km is shown in FIG.29 (A).

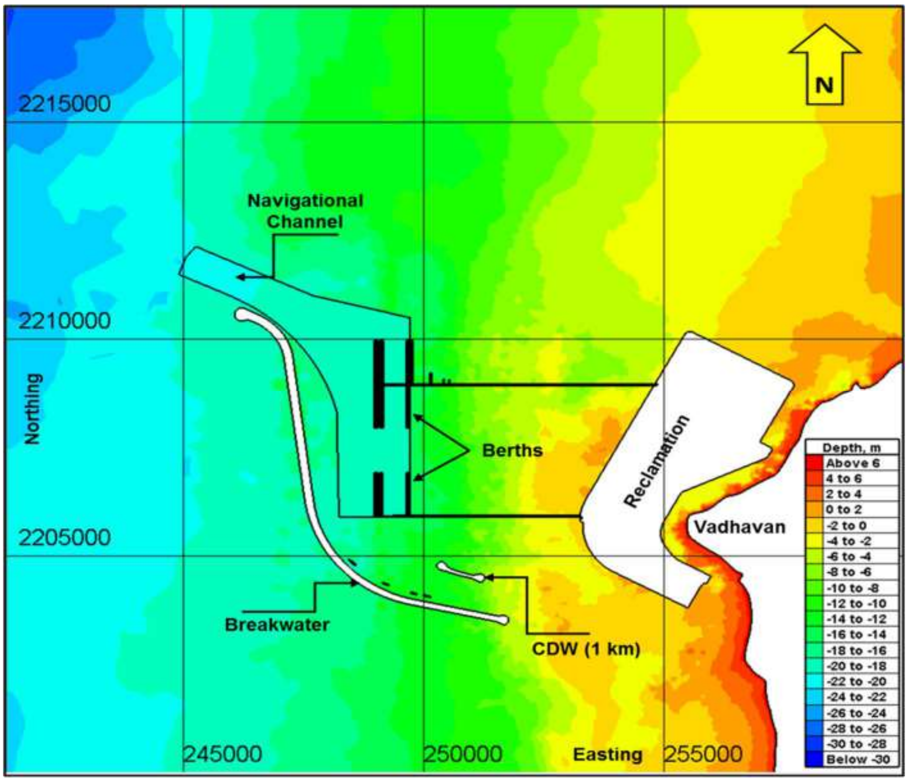



**FIG.29(A) :Zoomed Portion of Bathymetry for Master Plan Layout with CDW of 1.0 km**

The hydrodynamic simulation was carried out for Master Plan layout along with CDW of 1.0 km condition by adopting same boundary conditions as that considered for calibration of the tidal model. The flow field observed in the model during flood tide for monsoon season is shown in FIG.29 (B).

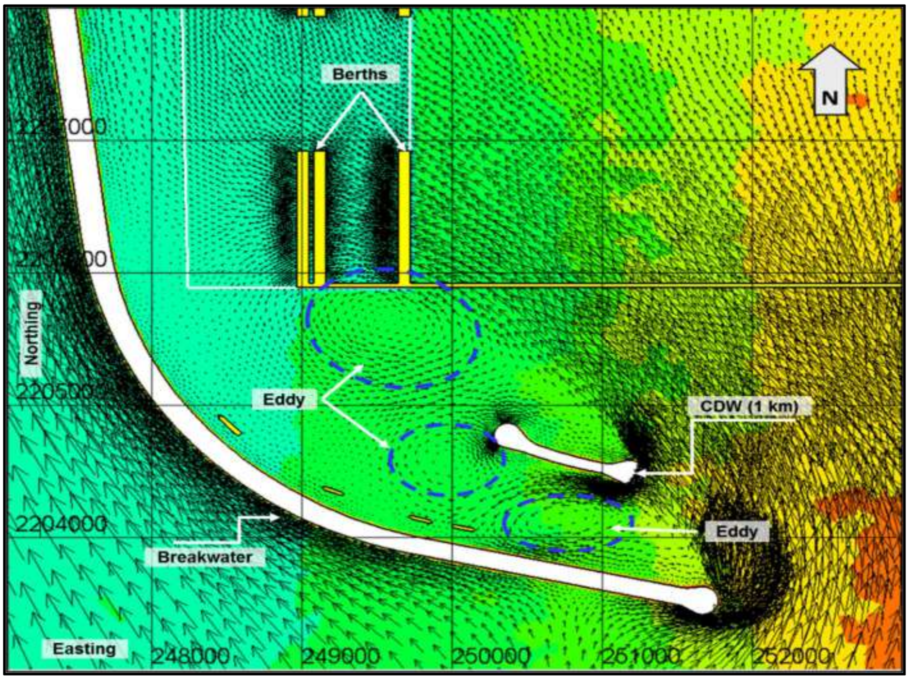



**FIG.29(B) :Zoomed Portion of Flow Field during Flood Tide**

The data on current (strength & direction) is extracted at various locations which are shown in FIG.25 and the plots of current (strength & direction) for master plan layout with CDW of 1.0 km are shown in FIG. 30(A), (B), (C), (D) & (E).

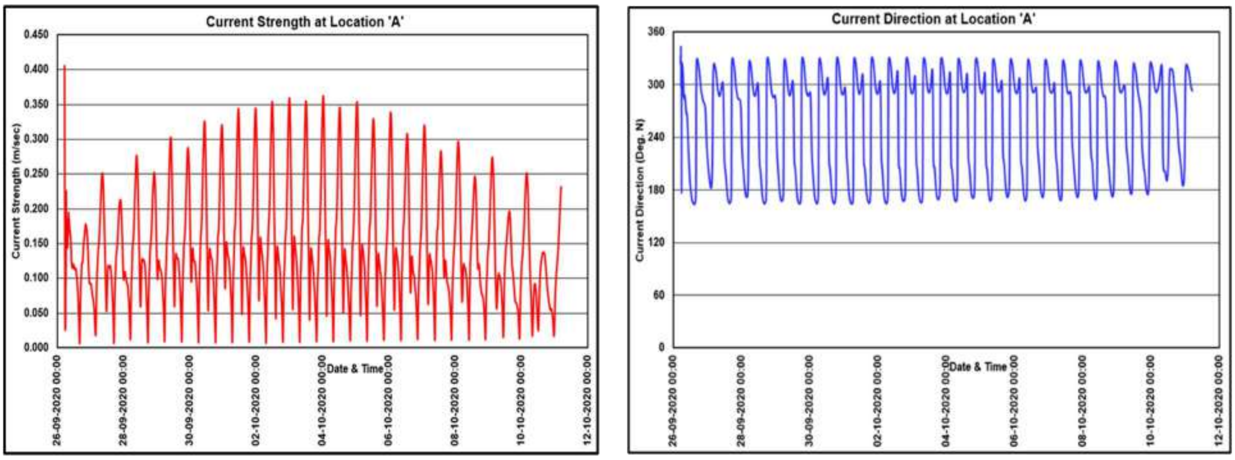



**FIG.30(A) : Current Strength & Direction at Location-A for CDW of 1.0 km**

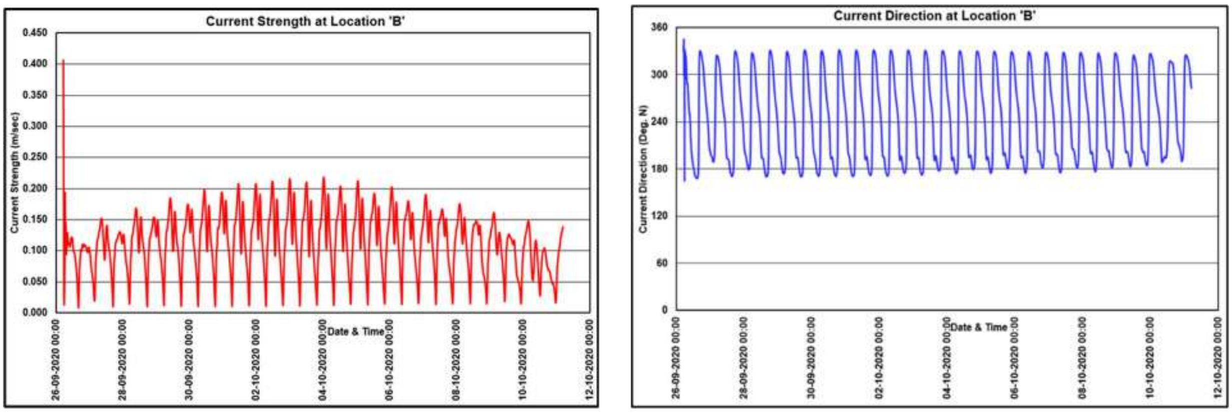



**FIG.30(B) : Current Strength & Direction at Location-B for CDW of 1.0 km**

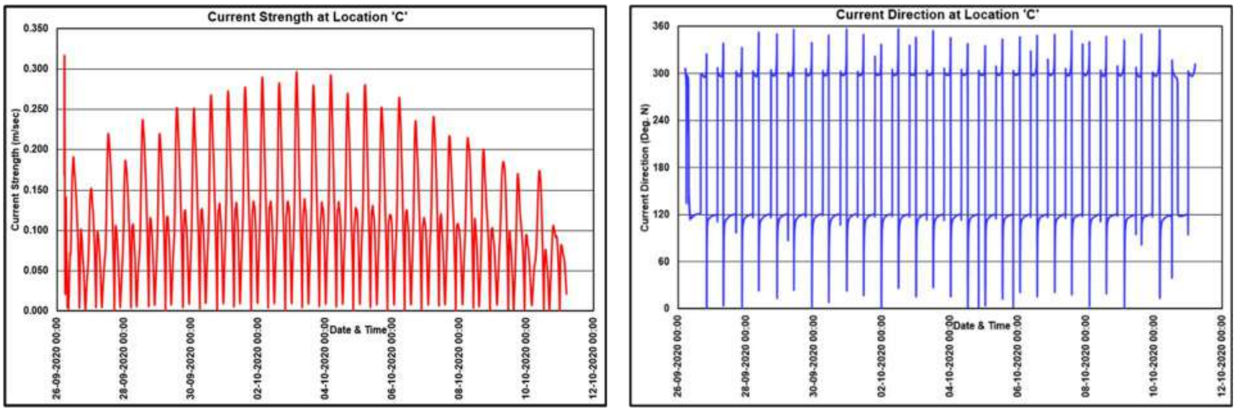



**FIG.30(C) : Current Strength & Direction at Location-C for CDW of 1.0 km**

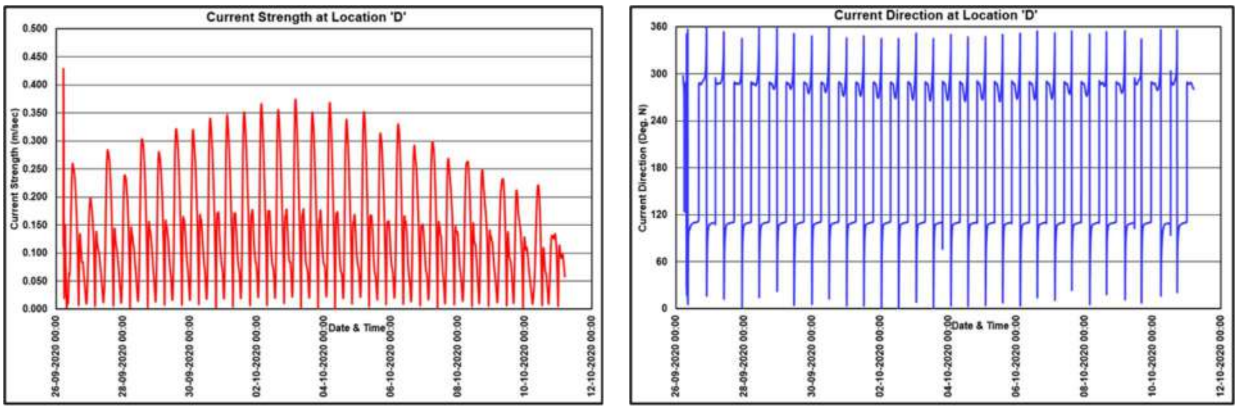



**FIG.30(D) : Current Strength & Direction at Location-D for CDW of 1.0 km**

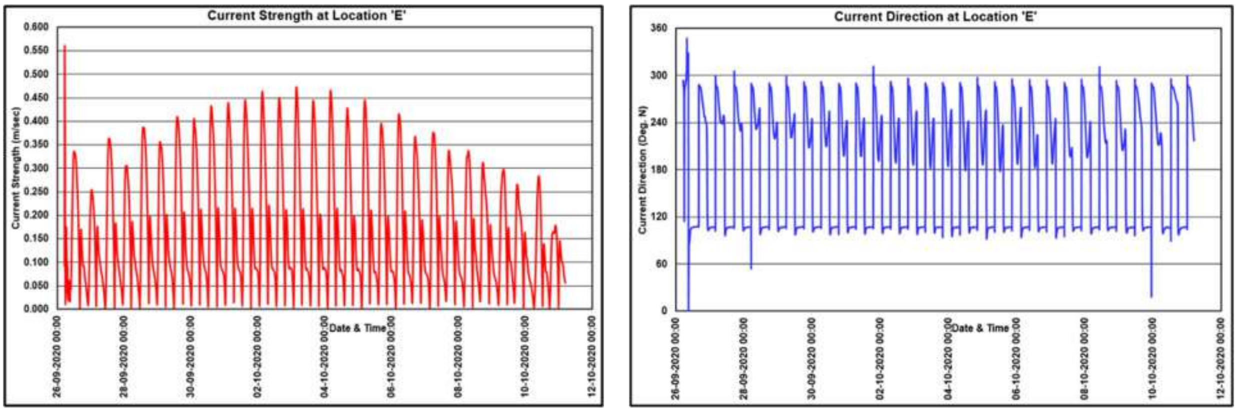



**FIG.30(E) : Current Strength & Direction at Location-E for CDW of 1.0 km**

The above plots reveal that at locations “A” & “B”, current strength is less than 0.35 m/sec and current directions vary continuously during flood/ebb tide due to large eddy getting formed at container terminals on the north of CDW. Current strengths at locations “C” & “D” is less than 0.45 m/sec and flow is almost aligned to berths during flood & ebb phases while at Location “E” current strength is about 0.5 m/sec and current direction is more aligned during ebb phase as compared to flood phase.

The comparison of current (strength & direction) data for all five (5) locations for master plan layout with CDW of 1.9 km, 1.4 km & 1.0 km was carried out and shown in FIG. 31(A) to (J).

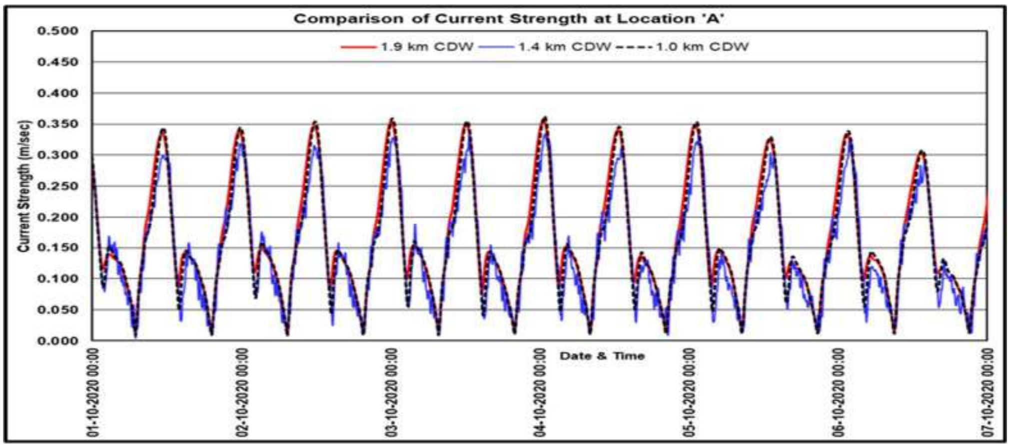



**FIG.31(A) : Comparison of Current Strength at Location-A**

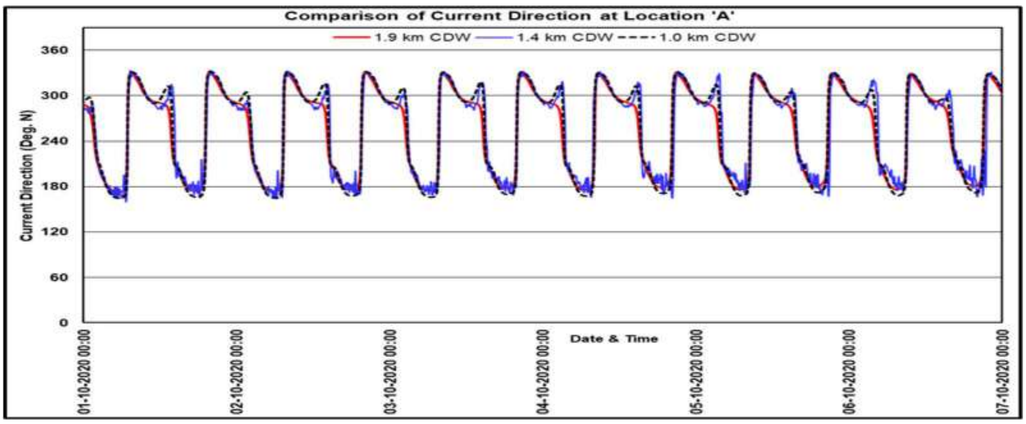



**FIG.31(B) : Comparison of Current Direction at Location-A**

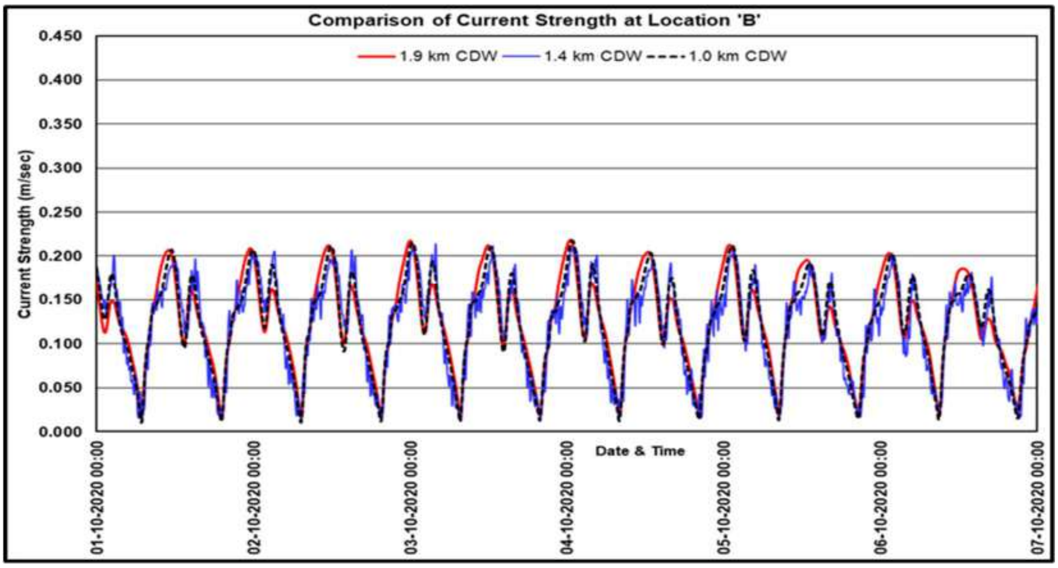



**FIG.31(C) : Comparison of Current Strength at Location-B**

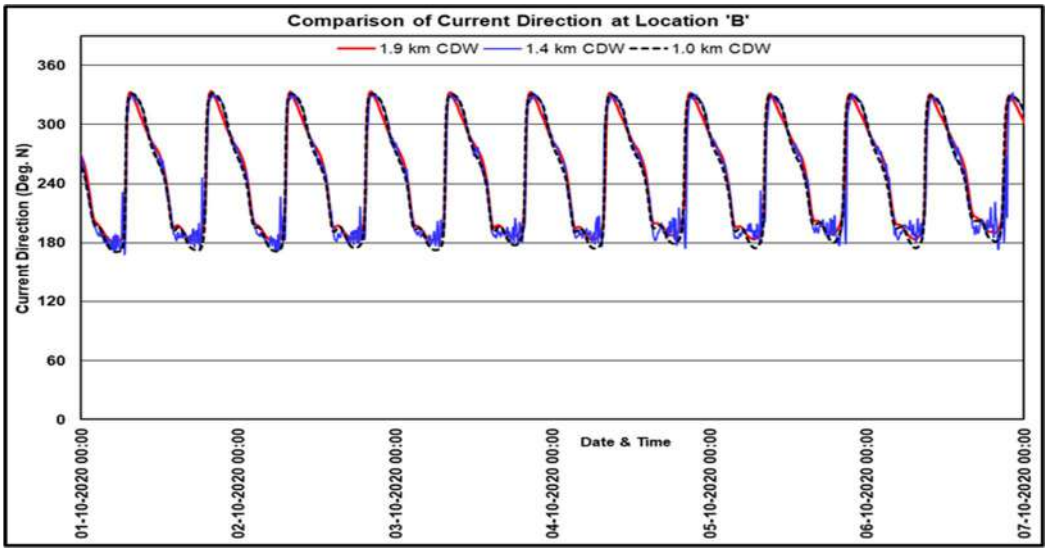



**FIG.31(D) : Comparison of Current Direction at Location-B**

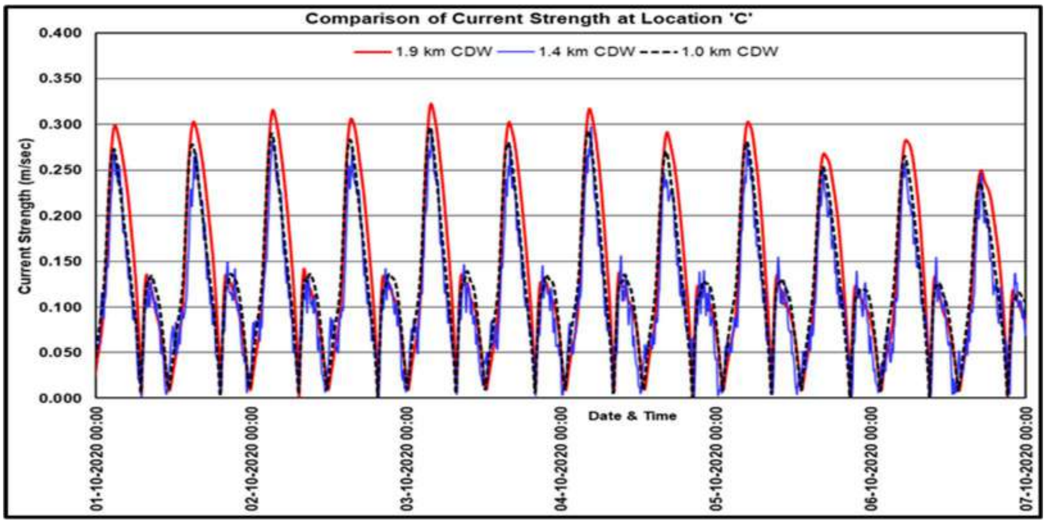



**FIG.31(E) : Comparison of Current Strength at Location-C**

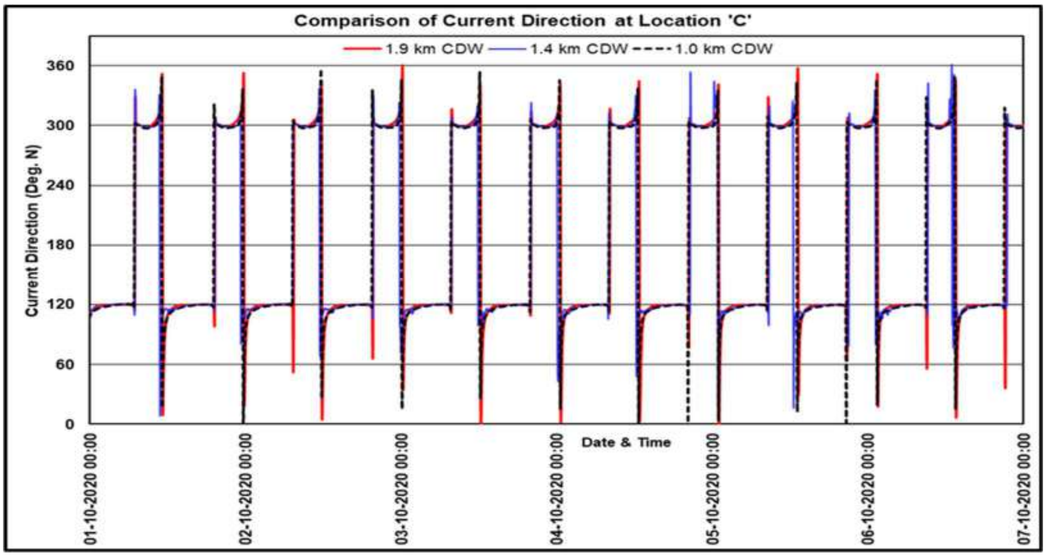



**FIG.31(F) : Comparison of Current Direction at Location-C**

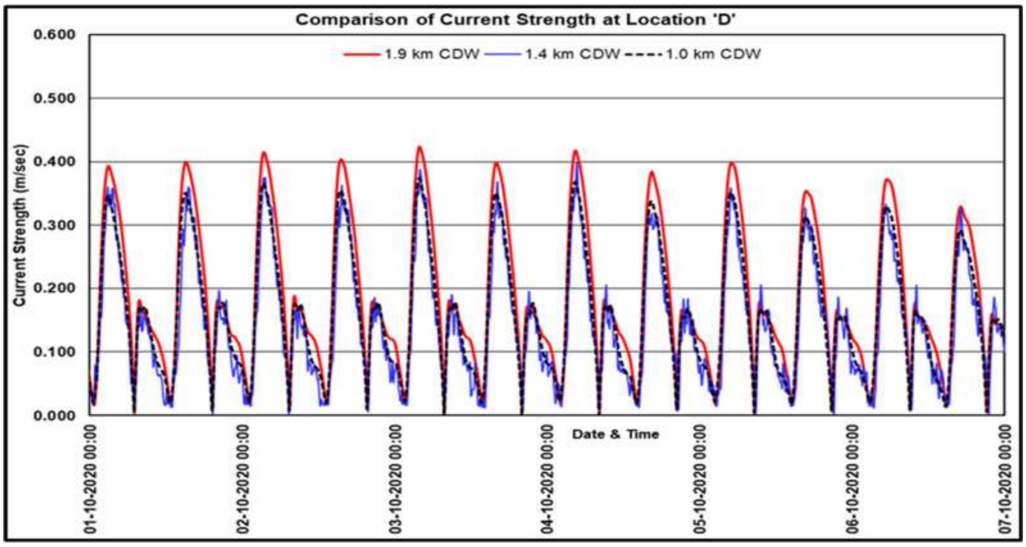



**FIG.31(G) : Comparison of Current Strength at Location-D**

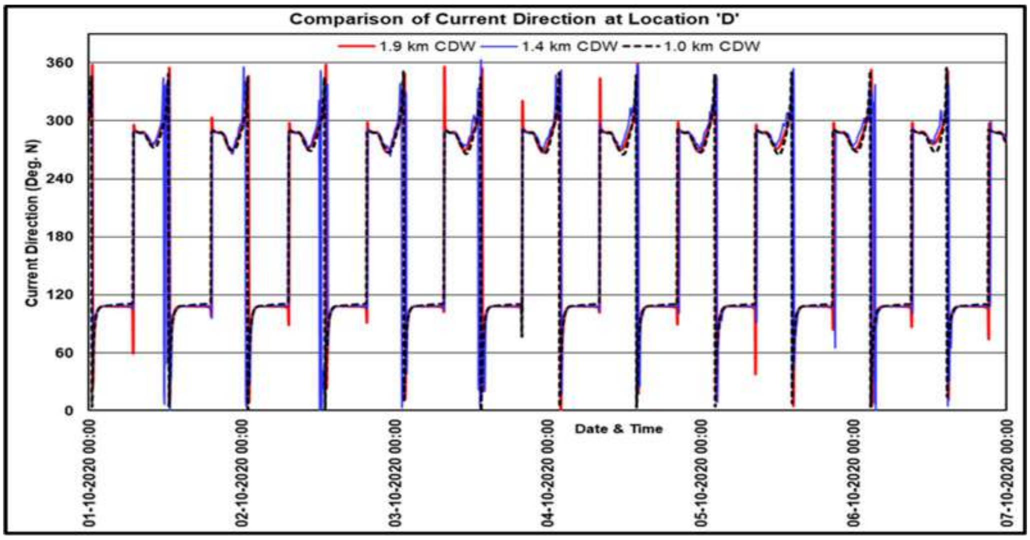



**FIG.31(H) : Comparison of Current Direction at Location-D**

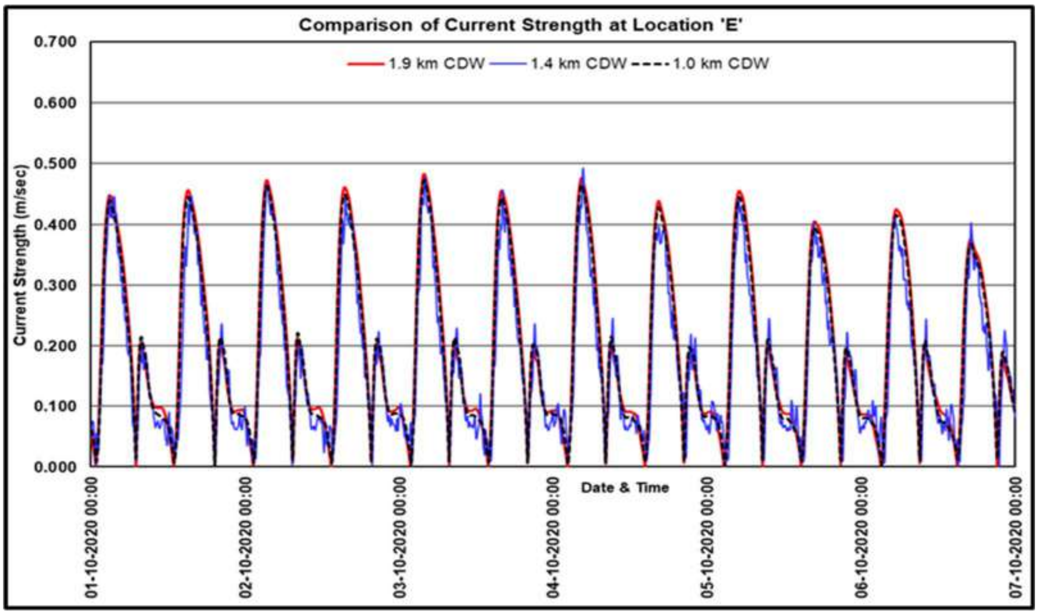



**FIG.31(I) : Comparison of Current Strength at Location-E**

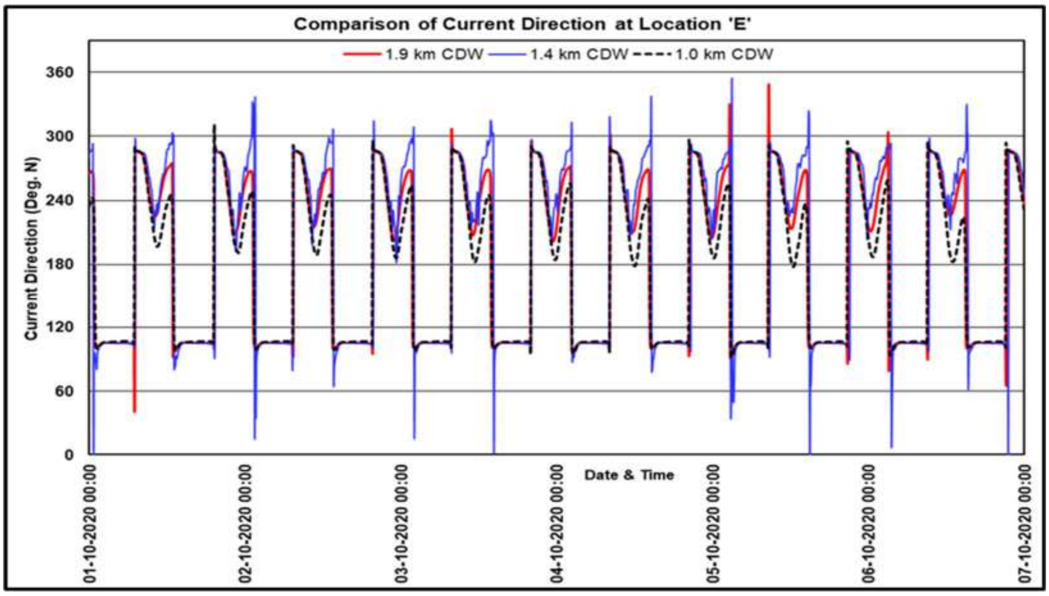



**FIG.31(J) : Comparison of Current Direction at Location-E**

The above plots indicate that the current strengths for all the lengths of CDW remain almost unchanged or there is unnoticeable reduction in current strength. The current directions for all locations except location “A” & “E” remains same however at location “A” & “E”, there is prominent variation in current direction during flood phase for CDW of 1.0 km than that for 1.9 km & 1.4 km which is likely to affect the operations at berth near to Location “A” & “E”. The above plots also indicate that current directions for CDW of 1.9 km & 1.4 km are almost remaining same. Considering the fact that, there is no change in current (strength & direction) at berths which are on leeside of breakwater and the berths which were earlier located on Northern side of CDW are now relocated to further Northern end of harbour, CDW of 1.4 km length will be an optimal length and may be considered as an optimised length of CDW for Phase-I as well as Master Plan layouts. The tidal hydrodynamics and siltation studies for these layouts are described in following paragraphs.

# 6. MODEL STUDIES FOR MASTER PLAN LAYOUT WITH CDW OF 1.4 KM

## 6.1 Tidal Hydrodynamic Model Studies

The modification in the calibrated hydrodynamic model was carried out by incorporating various components of port layout, optimised length of CDW of 1.4 km length as well as designed dredge depths proposed during Master Plan layout. The finite element mesh and zoomed portion of bathymetry of the model for Master Plan layout is shown in Fig.32 (A) & (B) respectively.

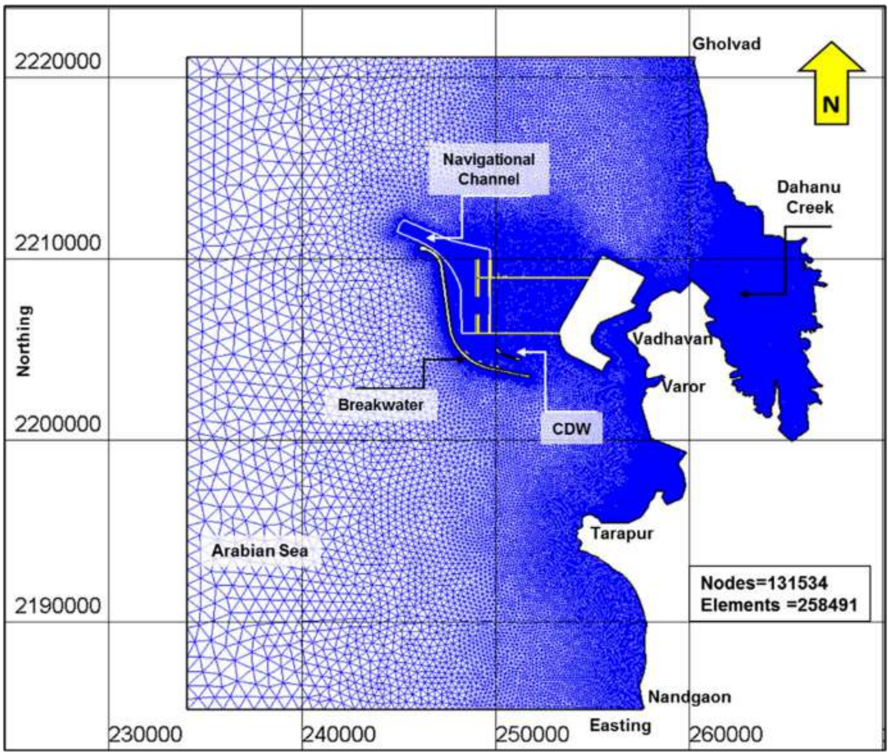



**Fig.32(A):Finite Element Mesh for Master Plan Layout**

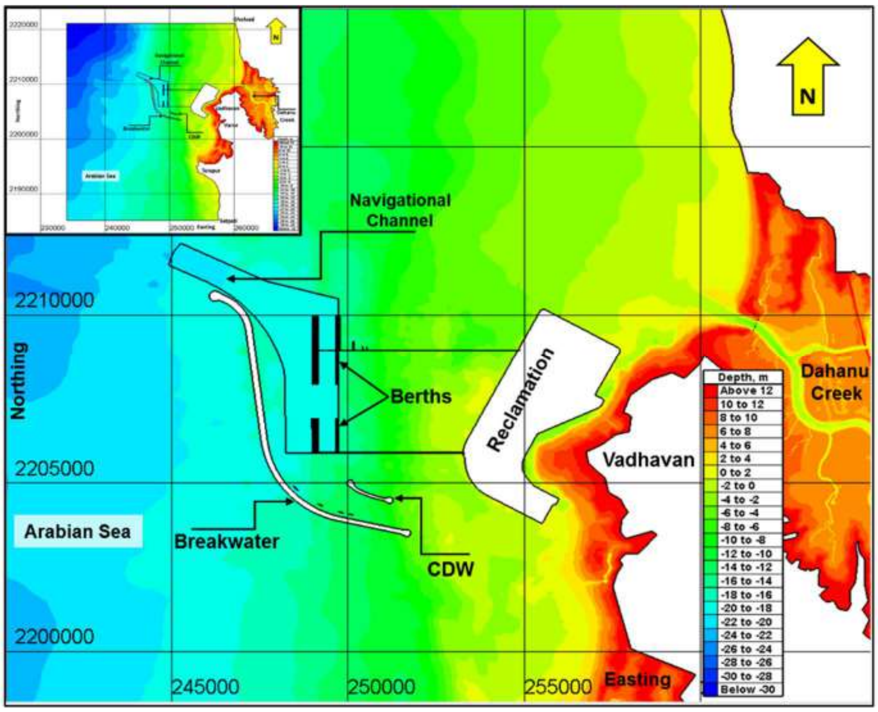



**Fig.32(B): Zoomed Portion of Bathymetry for Master Plan Layout**

The hydrodynamic simulation was carried out for master plan layout by adopting boundary conditions and other parameters considered for calibration of the tidal model. The flow field observed in the model during flood & ebb tide is shown in Fig.33 (A) & 33 (B) respectively.

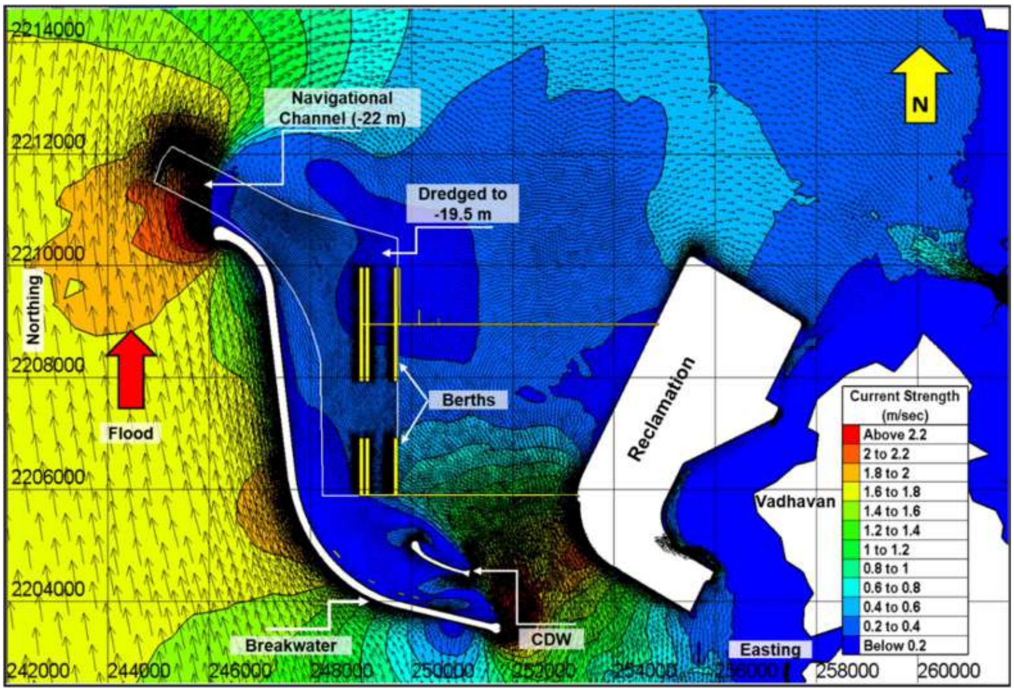



**Fig.33(A): Zoomed Portion of Flow Field during Flood Tide – Master Plan**

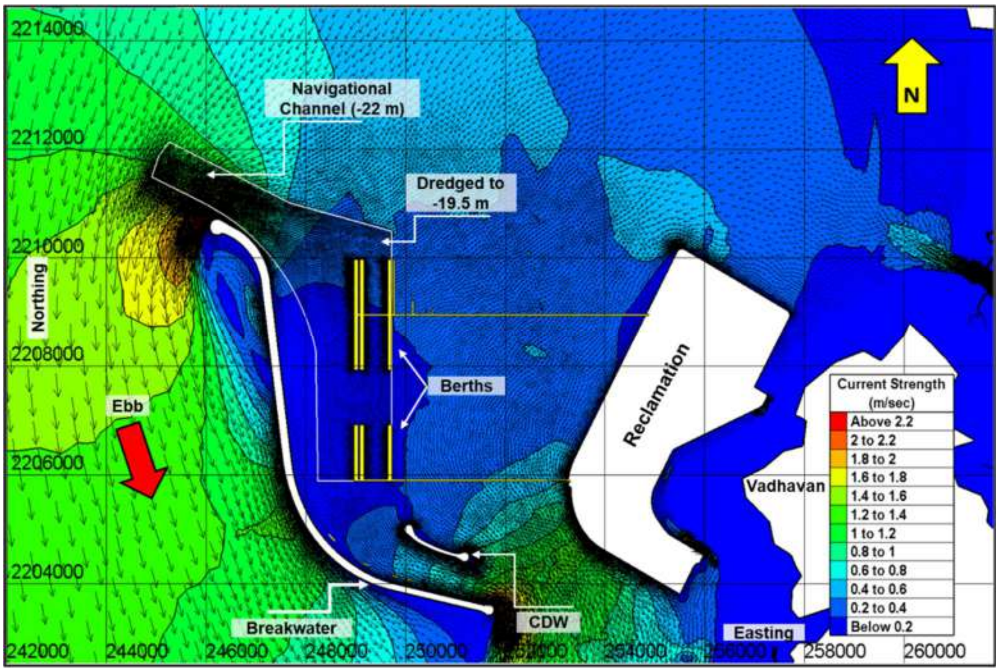



**Fig.33(B): Zoomed Portion of Flow Field during Ebb Tide – Master Plan**

It is observed from the model studies that maximum velocities at harbour entrance, turning circle are 2.5 m/s and 0.35 m/s respectively. The maximum currents at all container berths (CT-1 to CT-9), multipurpose & RO-RO berth vary between 0.25 m/s and 0.50 m/s. There is variation in current directions however average current strengths at all above berth locations are feeble i.e. less than 0.2 m/s.

### 6.2 Siltation Studies

The siltation studies were carried out to estimate the likely siltation per annum for master plan layout by coupling hydrodynamic models of monsoon & non-monsoon seasons with the sediment module. The parameters used for calibration of silt model were adopted to estimate the likely rate of siltation for master plan layout condition in the areas where dredging is proposed to be carried out. The siltation studies were carried out and the pattern of annual likely rate of siltation observed in model is shown in Fig.34.

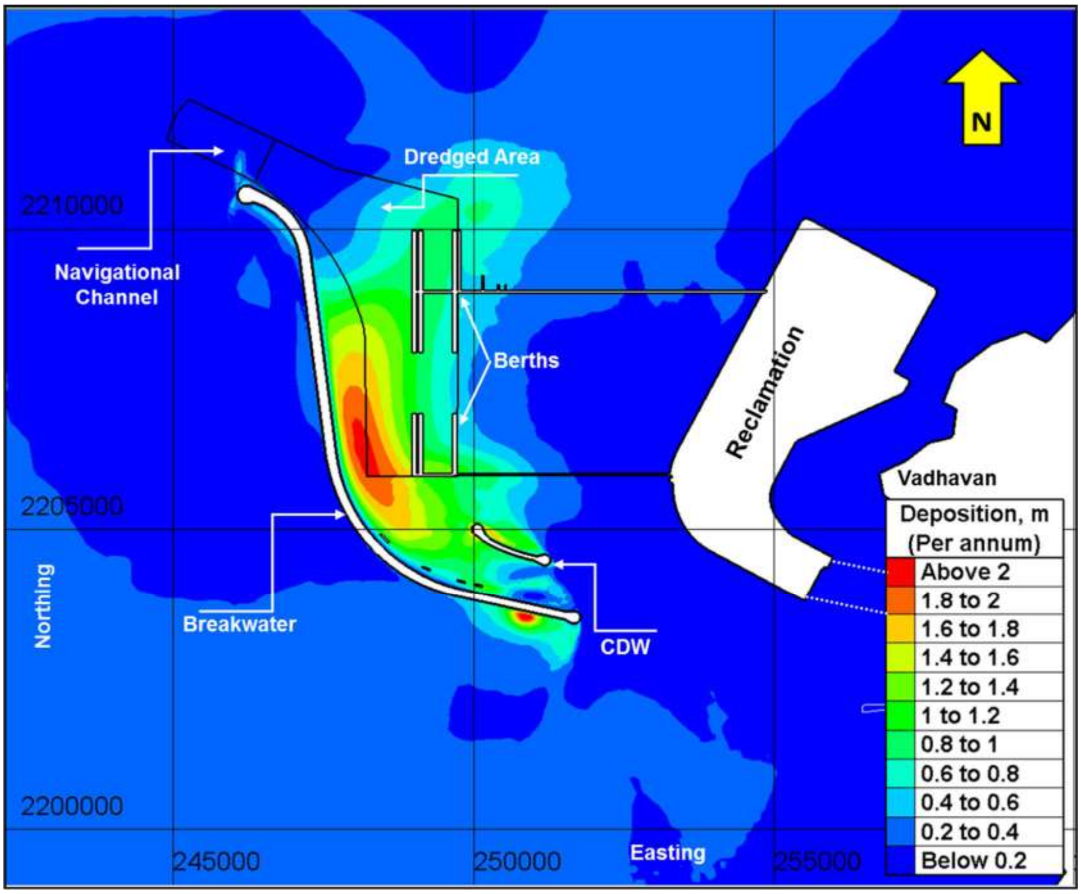



**Fig.34: Annual Siltation Pattern for Master Plan Layout**

The total quantum of likely siltation in the dredged areas estimated will be about 8 million cum per annum with maximum depth of deposition as 2.2 m per annum.

## 7. MODEL STUDIES FOR PHASE-I LAYOUT WITH CDW OF 1.4 KM

### 7.1 Tidal Hydrodynamic Model Studies

The calibrated hydrodynamic model was modified by incorporating the breakwater of 10.3 km length, optimised length of CDW of 1.4 km, proposed reclamation and design dredged depths proposed during Phase-I layout. The finite element mesh and zoomed portion of bathymetry of the model for Phase-I layout is shown in Fig.35 (A) & (B) respectively.

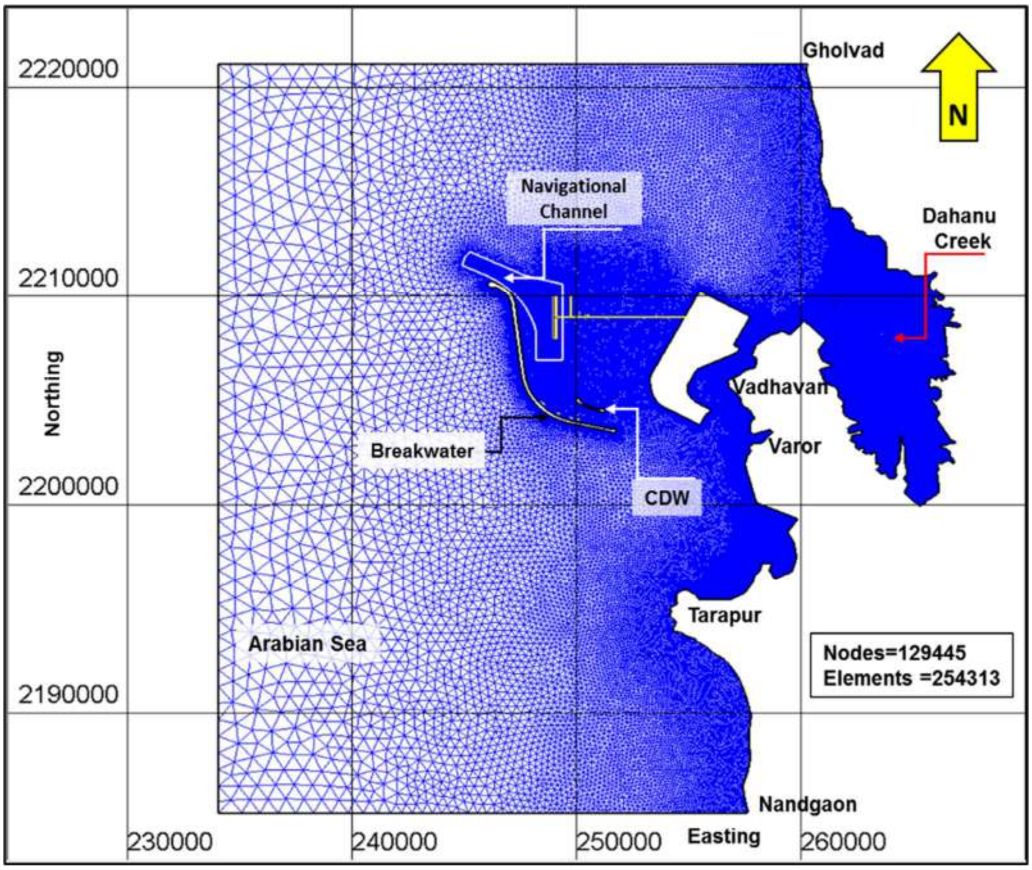



**Fig.35(A):Finite Element Mesh for Phase-I Layout**

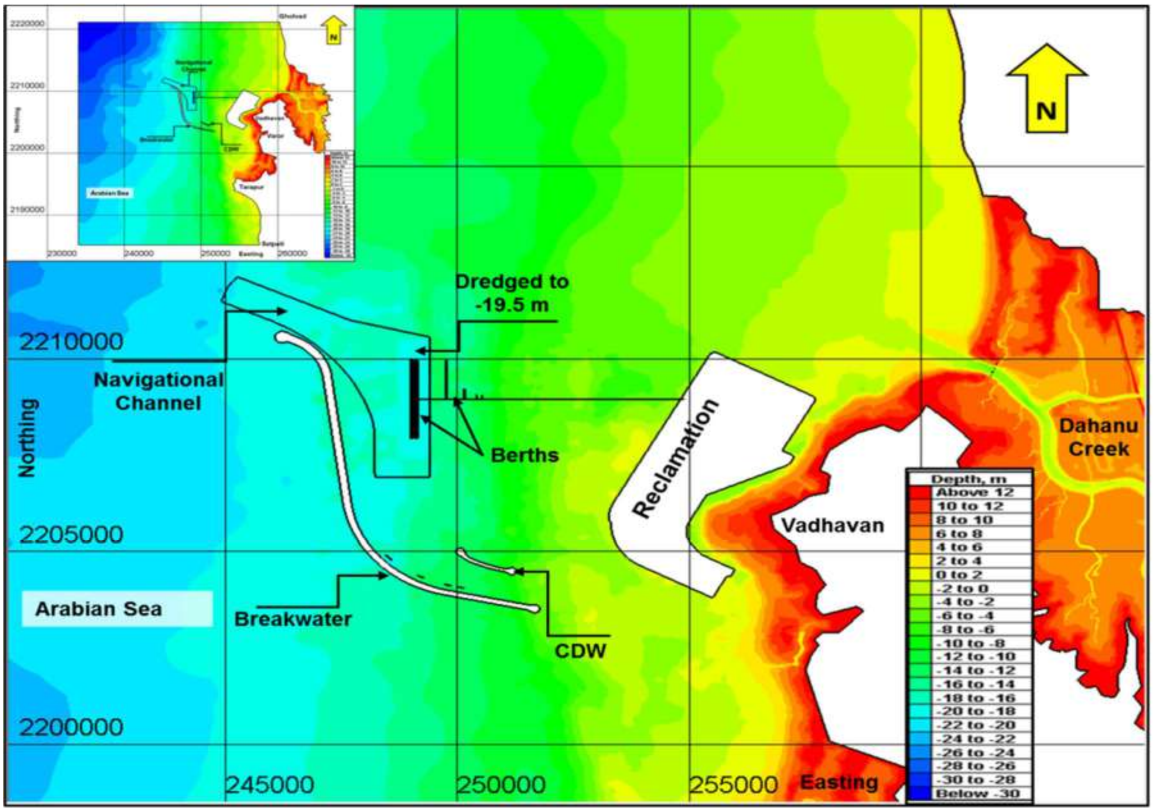



**Fig.35(B):Zoomed Portion of Bathymetry for Phase-I Layout**

The hydrodynamic simulation was carried out for phase-I layout by adopting boundary conditions and other parameters considered for calibration of the tidal model. The flow field observed in the model during flood & ebb tide is shown in Fig.36 (A) & 36 (B) respectively.

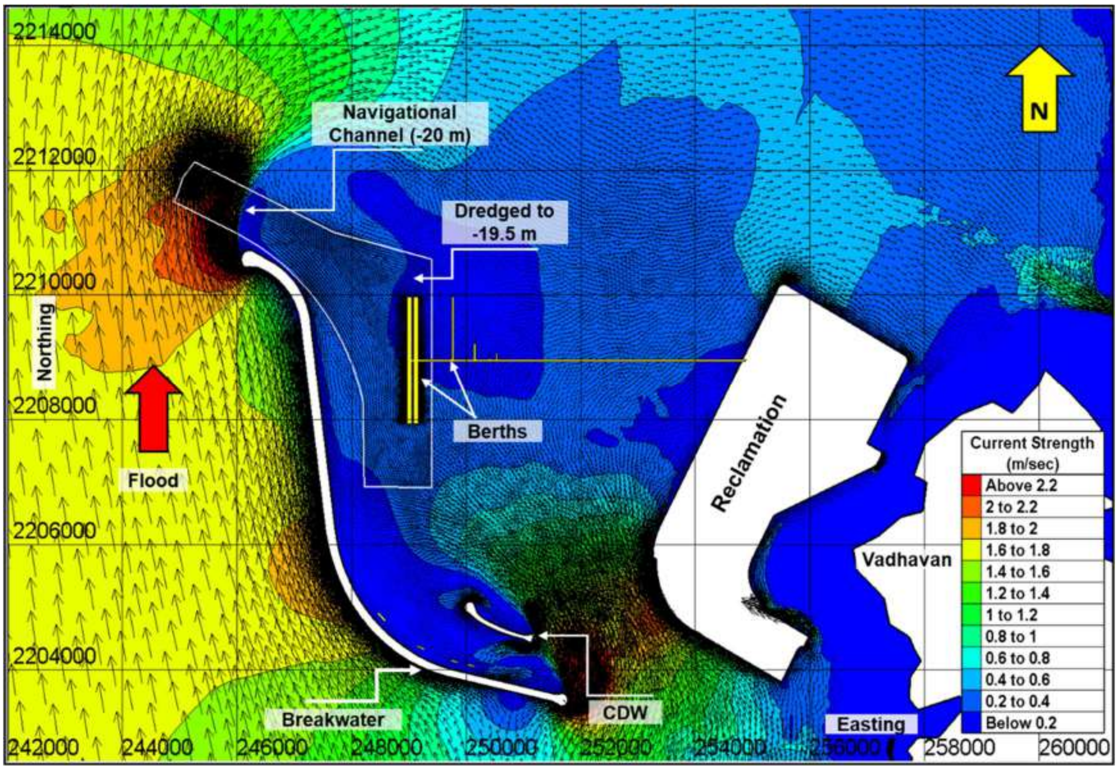



**Fig.36(A): Zoomed Portion of Flow Field during Flood Tide – Phase-I Layout**

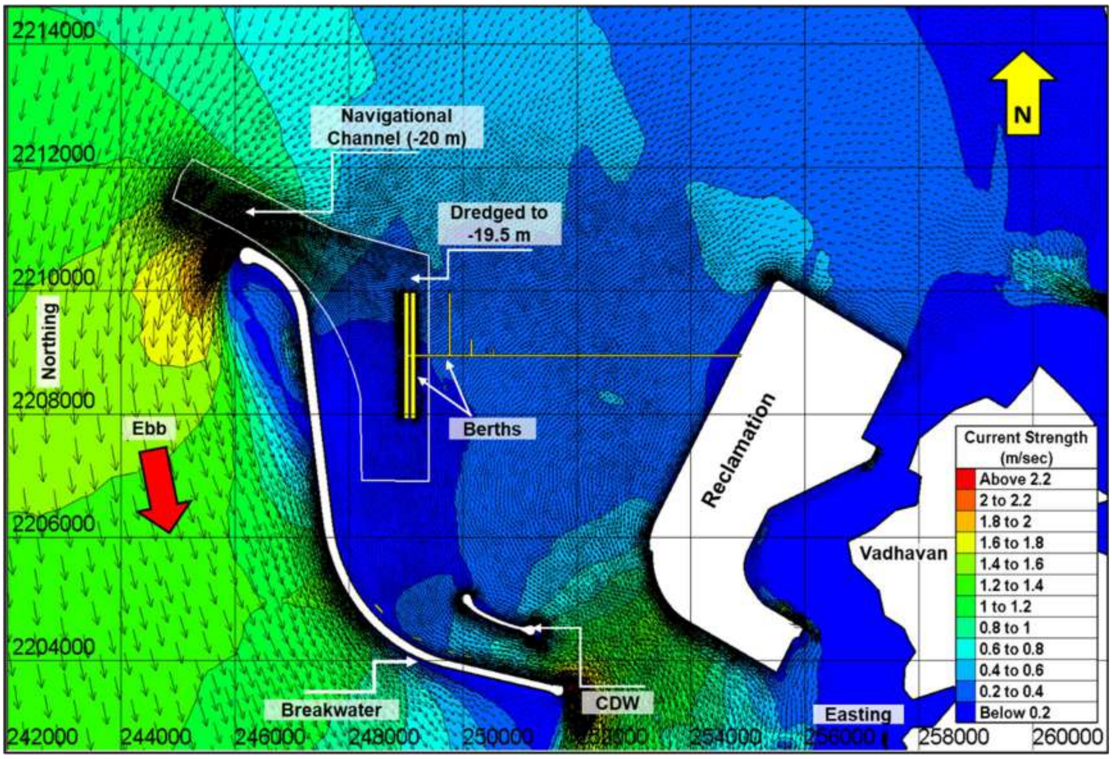



**Fig.36(B): Zoomed Portion of Flow Field during Ebb Tide – Phase-I Layout**

It is observed from the model studies that maximum velocities at harbour entrance, turning circle are 2.5 m/s and 0.35 m/s respectively. The maximum currents at the container berths (CT-1 to CT-4), multipurpose & RO-RO berth vary between 0.25 m/s and 0.37 m/s. There is variation in current directions, however average current strengths at all above berth locations are feeble i.e. less than 0.2 m/s.

### 7.2 Siltation Studies

The siltation studies were carried out to estimate the likely siltation per annum for Phase-I layout by coupling hydrodynamic models of monsoon & non-monsoon with the sediment module. The parameters used for calibration of silt model were adopted to estimate the likely rate of siltation for phase-I layout condition in the areas where dredging is proposed to be carried out. The siltation studies were carried out and the pattern of annual likely rate of siltation observed in model is shown in Fig.37.

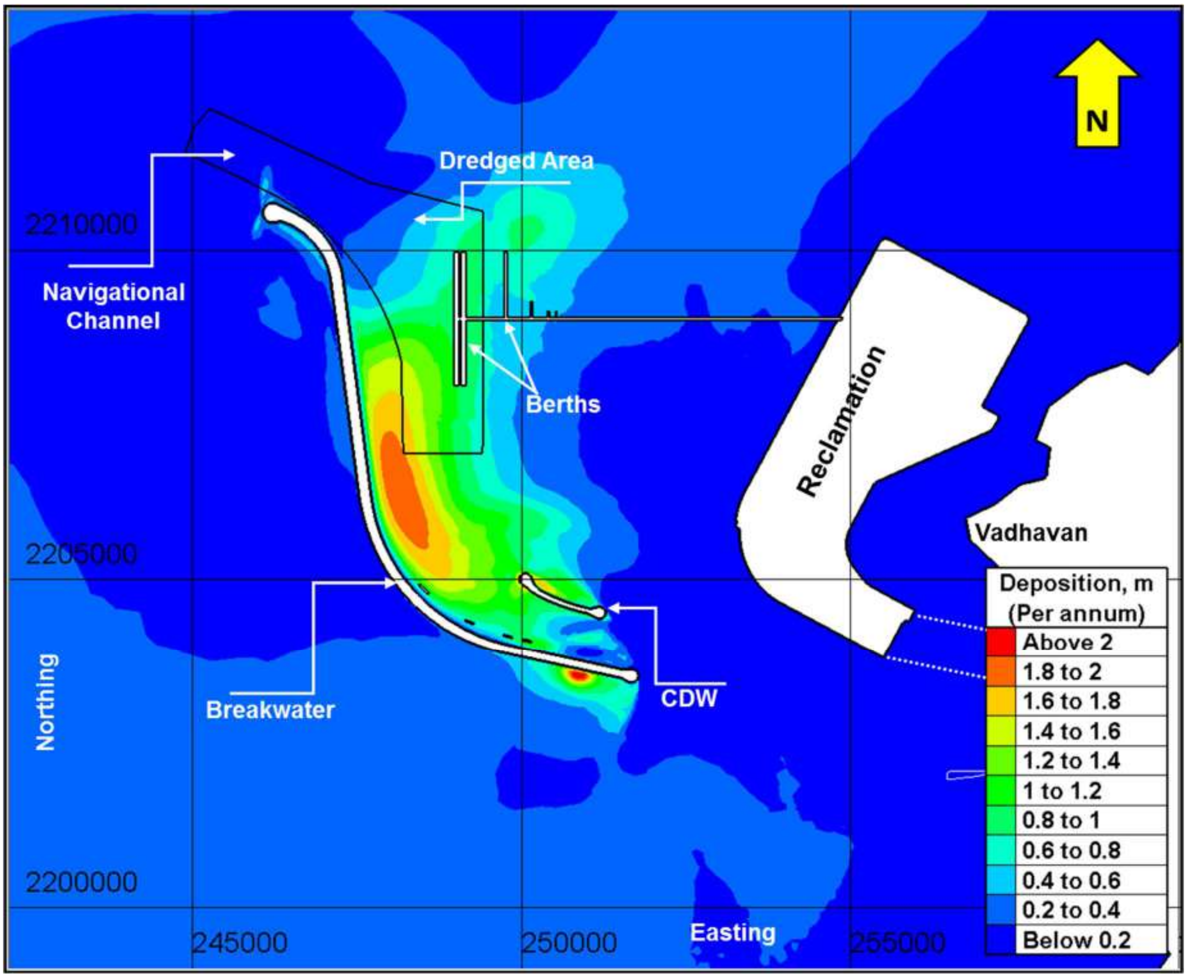



**Fig.37: Annual Siltation Pattern for Phase-I Layout**

The total quantum of likely siltation in the dredged areas estimated will be about 4.9 million cum per annum with maximum depth of deposition as 2.0 m per annum in the harbour.

The studies described above provides the information about rate of siltation in the proposed dredged area for master plan and Phase-I layouts as well as suitability of alignment of berths from tidal hydrodynamic consideration. 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 details of the various layouts under consideration and model studies carried out are described in following paragraphs.

# 8. MODEL STUDIES FOR FINALIZATION OF MASTER PLAN LAYOUT

The JN Port vide letter dated 04th June 2021 mentioned that the length of trestle provided between berths and reclamation in the earlier master plan layout (See FIG.3 & 4) is considerably more (about 6 km) and is likely to pose a problem of traffic congestion to & fro between berths in deeper depths and stack-yard proposed on tidal flats near the coastline at Vadhavan and increase in turnaround time. This will increase the operational cost of handling of the containers. In this context, JN Port in consultation with their Consultants has considered to shift the reclamation for stack/rail yard near to the berths so as to have free flow of traffic of containers. The JN Port initially proposed six (6) master plan layouts for discussions with CWPRS as well as Consultants of JN Port and are shown in FIG. 38(A) to 38(F).

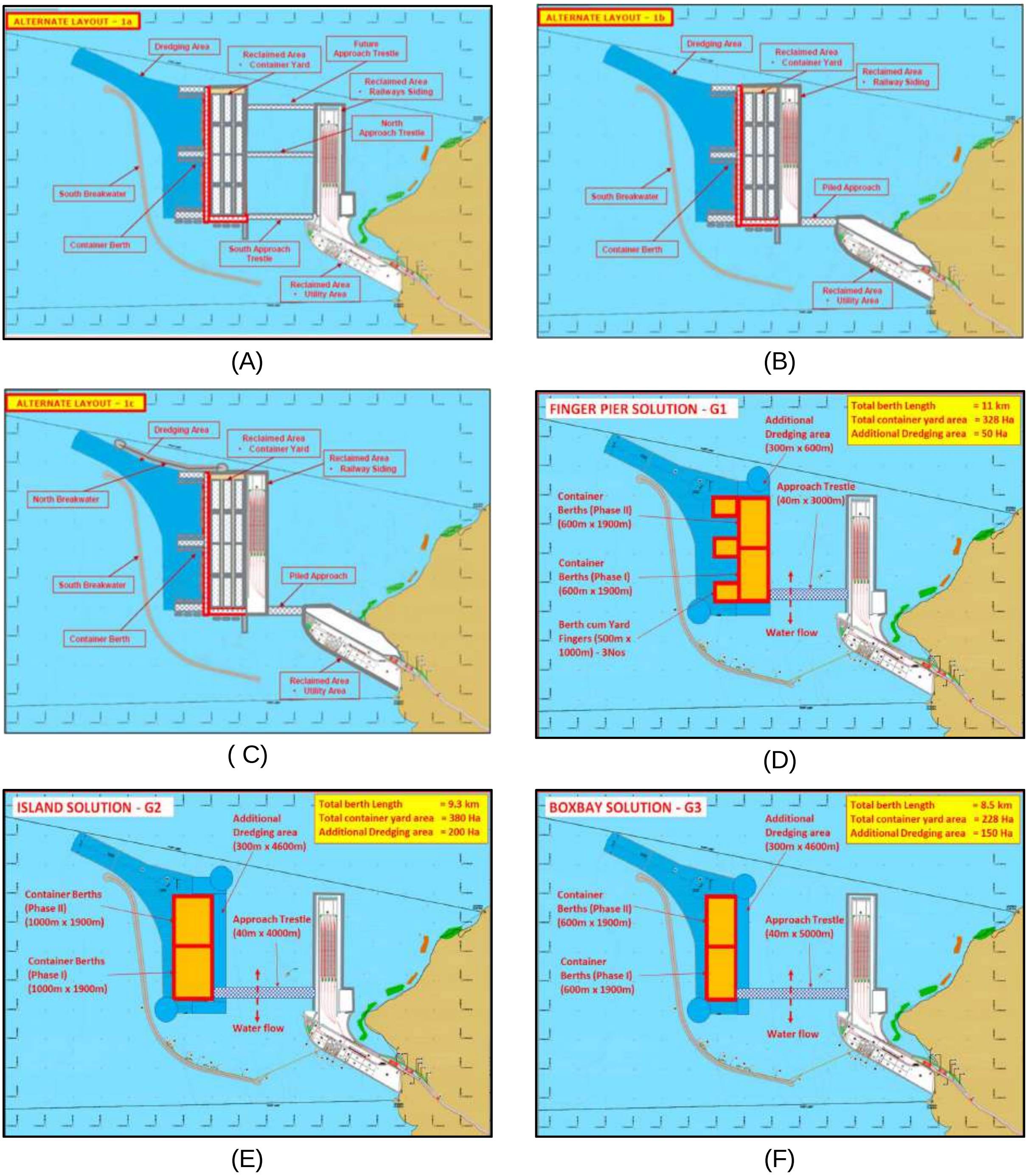



**FIG.38: Various Master Plan Layouts proposed by JN Port**

These layouts were discussed in virtual (VC) meetings held on 8th, 22nd & 29th June 2021 between JN Port and their consultants as well as CWPRS. The discussions were held in details on likely flow conditions for these layouts, additional dredging cost, operational benefits of separate rail yards/attached to stack yards, size of landward reclamation for utility area etc. Considering the pros and cons of these layouts in the discussions, the preferred master plan layout with North breakwater was considered to be studied and is shown in FIG.39. The layout was submitted to CWPRS to assess its suitability from tidal/wave hydrodynamics and siltation consideration for with and without North breakwater scenarios vide JN Port email dated 30.06.2021.

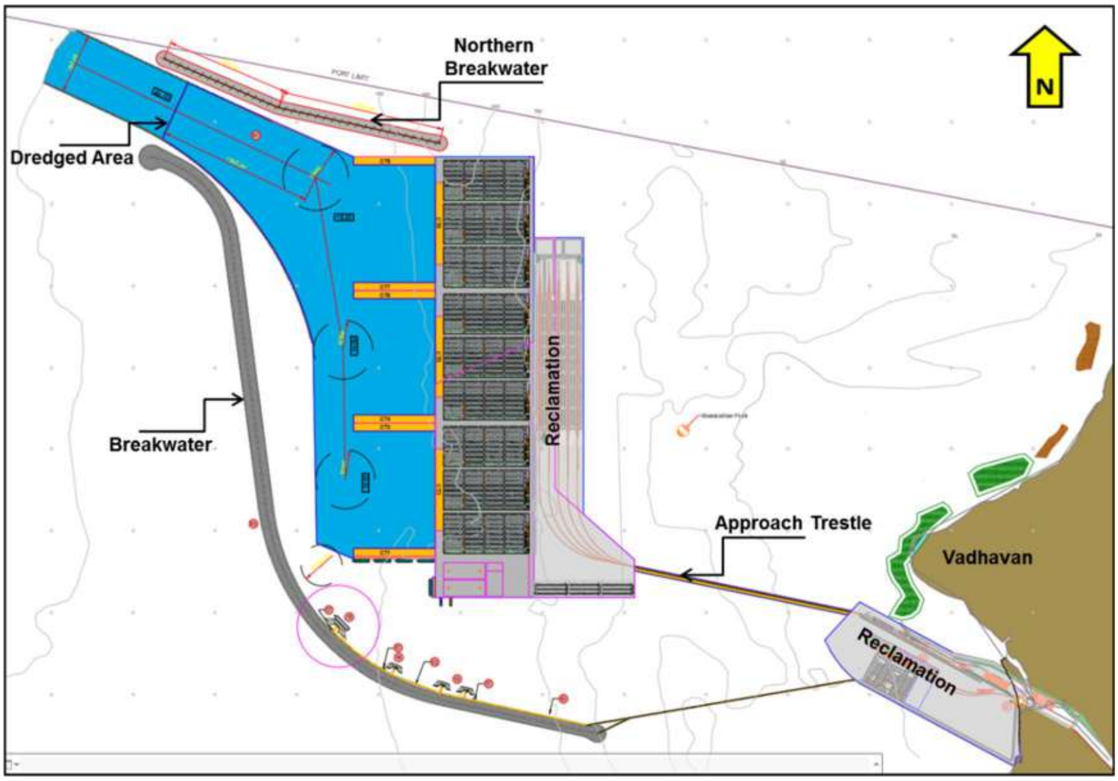



**FIG.39: Preferred Master Plan Layouts proposed by JN Port**

It was also decided that after finalising the master plan layout through tidal/wave hydrodynamics & siltation studies, the studies for Phase-I development also needs to be carried out for tidal/wave hydrodynamics and estimation of siltation in dredged area. The details of the studies for the finalization of master plan layout from tidal hydrodynamic and siltation aspects are discussed in following paragraphs.

## 8.1 Model Studies for Preferred Master Plan Layout with North Breakwater

### 8.1.1 Tidal Hydrodynamic Studies

The tidal hydrodynamic studies for preferred Master Plan layout with North breakwater was carried out by modifying the bathymetry of well calibrated hydrodynamic model by incorporating the main breakwater of 10.3 km length, the proposed reclamation area (Offshore reclamation of about 963 Ha. & Shore connected reclamation of about 222 Ha.), North breakwater of about 3.55 km length along with the proposed designed dredge depths viz. depths in approach channel (-22 m CD), manoeuvring & turning circle area (-19.5 m CD). The dredged area for the said layout is about 1052 Ha. The finite element (FE) model was developed for the said layout. The finite element mesh and zoomed portion of bathymetry of the model for preferred master plan layout is shown in FIG.40 (A) & (B) respectively.

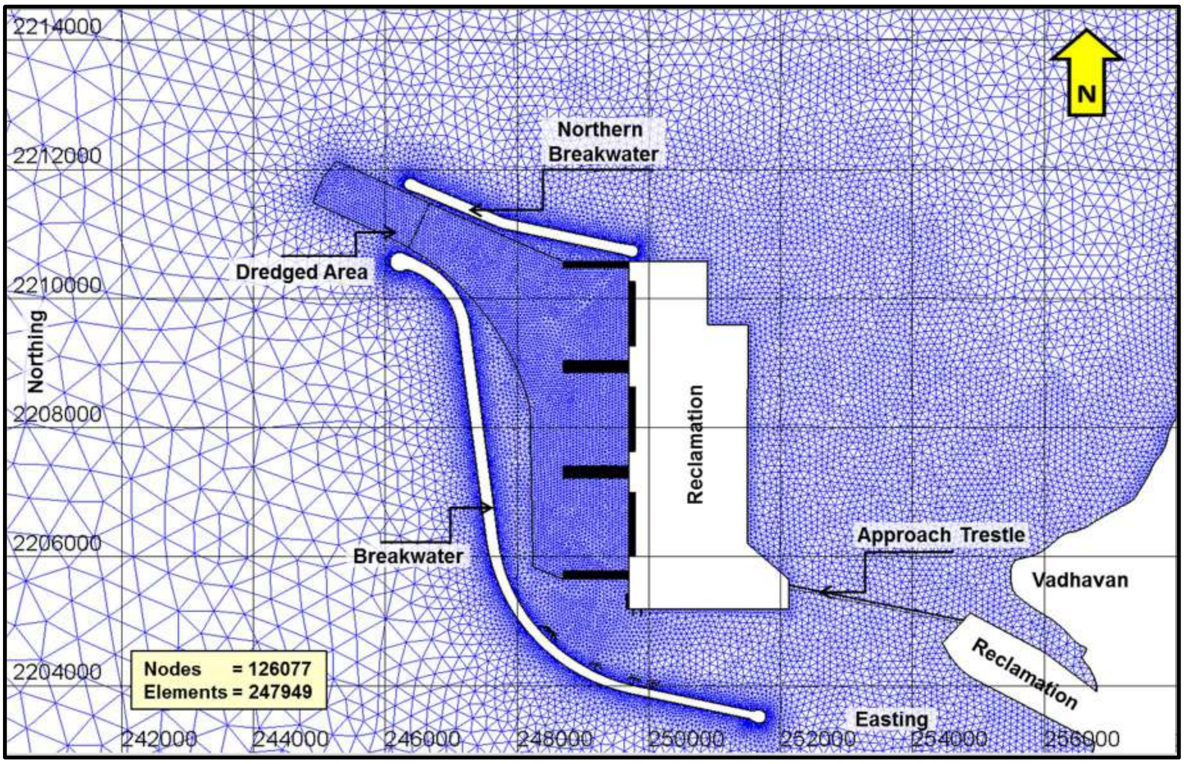



**FIG.40(A):Finite Element Mesh for Preferred Master Plan Layout with North Breakwater**

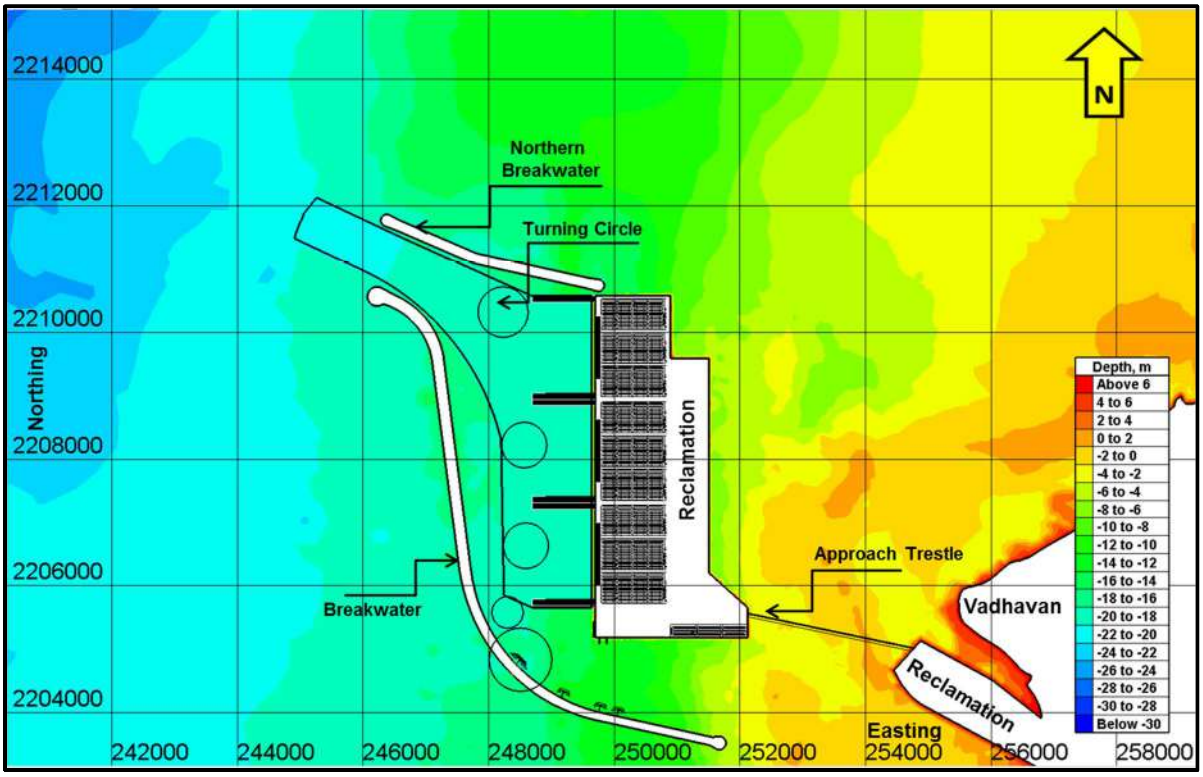



**FIG.40(B): Zoomed Portion of Bathymetry for Preferred Master Plan Layout with North Breakwater**

The hydrodynamic simulation was carried out for preferred master plan layout with North breakwater by adopting same boundary conditions and other parameters considered for calibration of the tidal model. The flow field observed in the model during flood & ebb tide is shown in FIG.41 (A) & (B) respectively.

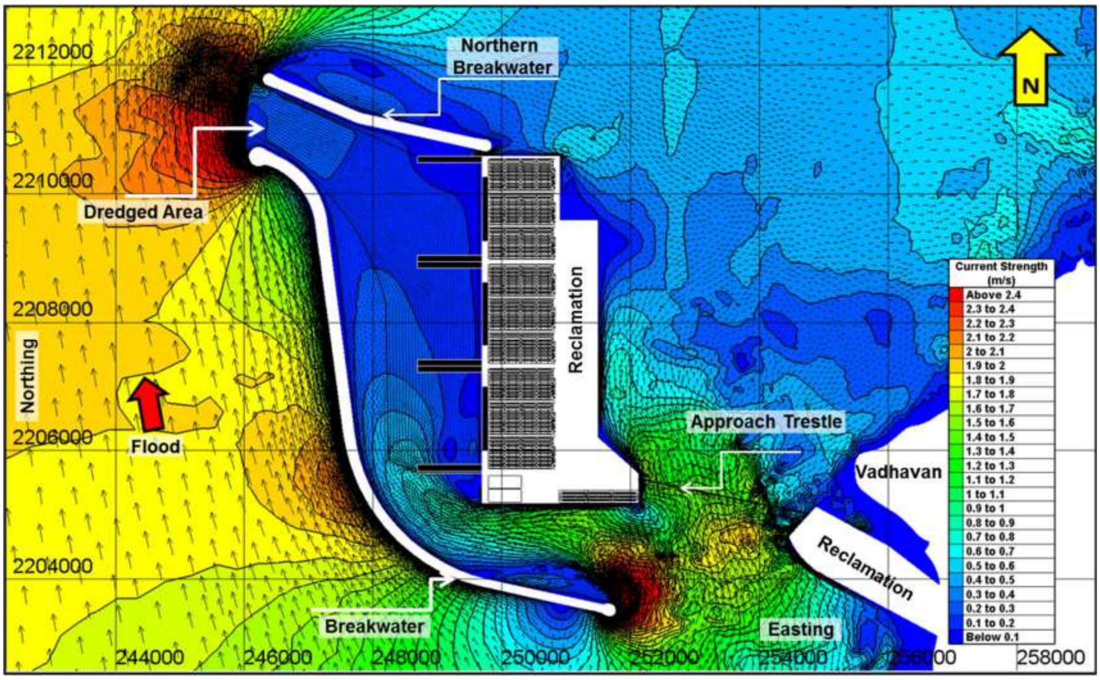



**FIG.41(A): Zoomed Portion of Flow Field during Flood Tide (Preferred Master Plan Layout With North Breakwater)**

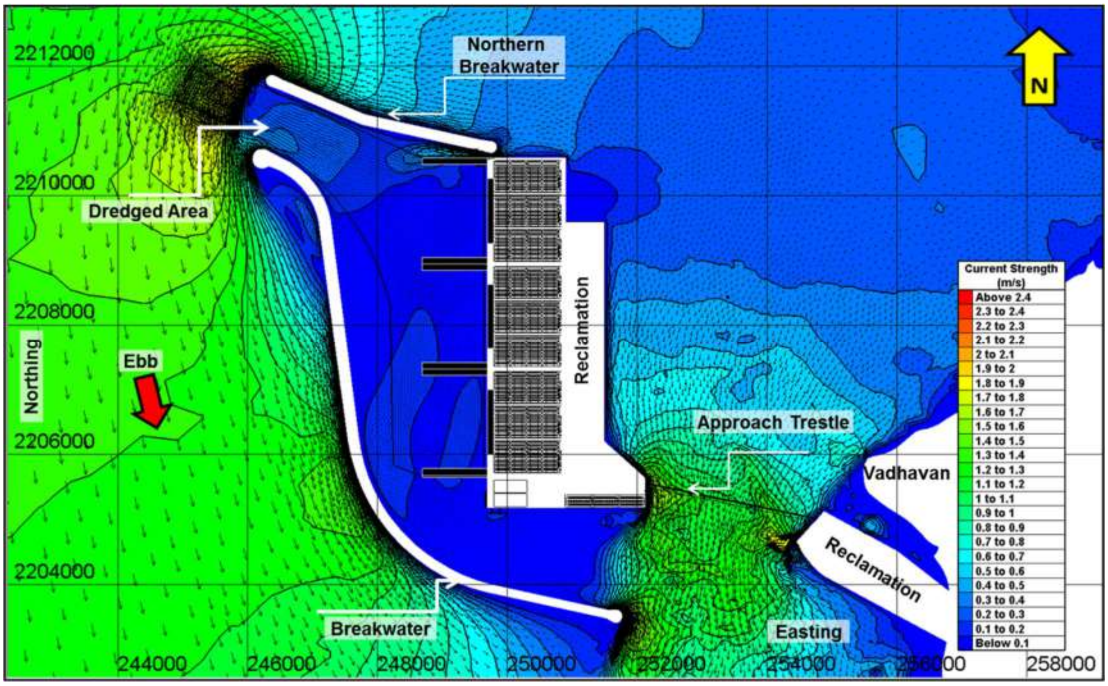



**FIG.41(B): Zoomed Portion of Flow Field during Ebb Tide (Preferred Master Plan Layout With North Breakwater)**

It is observed from the model studies that maximum velocities at harbour entrance, stoppage distance and turning circle are 2.5 m/s, 0.4 m/s and 0.3 m/s respectively. The maximum currents at the berths vary between 0.15 m/s and 0.30 m/s and its directions are perpendicular to the orientations of berths which are proposed normal to the reclamation face. It is also observed that there is reduction in velocity by 2 m/s in 400 m distance from stoppage distance to turning circle.

### 8.1.2 Siltation Studies

The siltation studies were carried out to estimate the likely siltation per annum for preferred master plan layout by coupling hydrodynamic models of monsoon & non-monsoon seasons with the sediment module. The parameters used for calibration of silt model were adopted to estimate the likely rate of siltation for preferred master plan layout condition in the areas where dredging is proposed to be carried out. The siltation studies were carried out and the pattern of annual likely rate of siltation observed in model is shown in FIG.42.

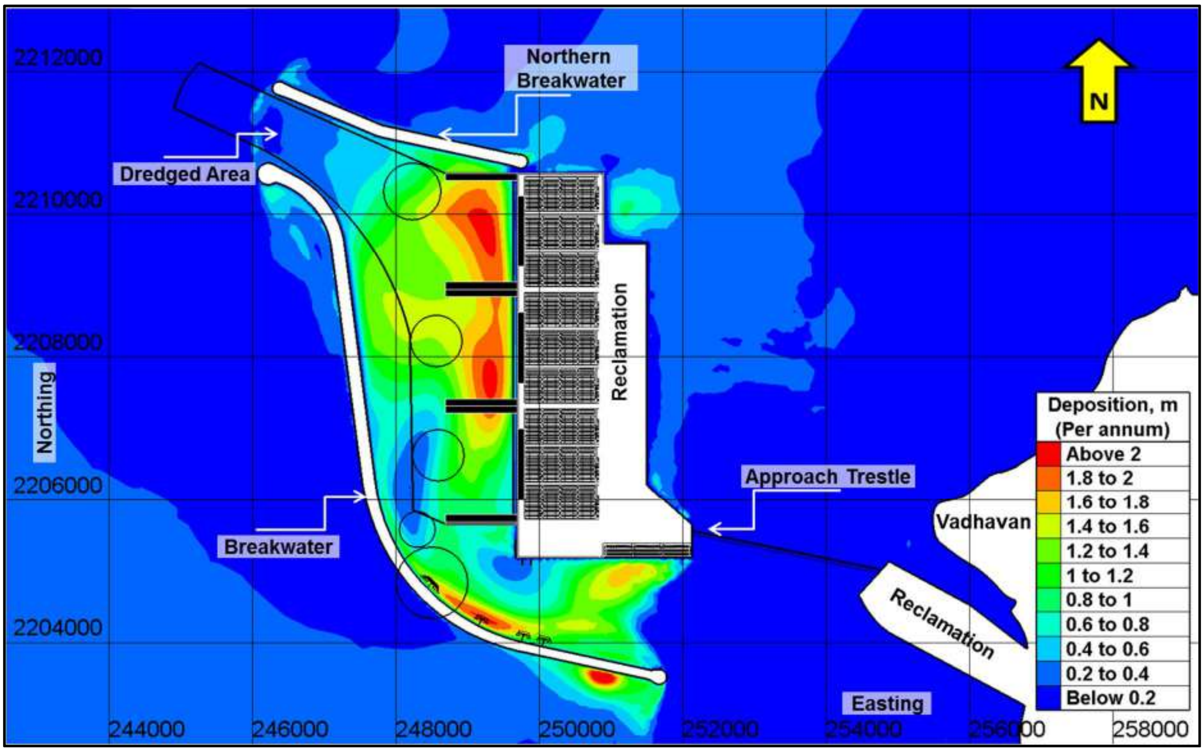



**FIG.42: Annual Siltation Pattern for Preferred Master Plan Layout with North Breakwater**

The total quantum of likely siltation in the dredged areas estimated will be about 11 million cum per annum with maximum depth of deposition as 2.2 m per annum.

## 8.2 Model Studies for Preferred Master Plan Layout without North Breakwater

### 8.2.1 Tidal Hydrodynamic Studies

The tidal hydrodynamics studies for preferred Master Plan layout without North breakwater were carried out by modifying bathymetry of the well calibrated hydrodynamic model by incorporating the breakwater of 10.3 km, the proposed reclamation area (Offshore reclamation about 963 Ha. & Shore connected reclamation of about 222 Ha.) along with the proposed designed dredge depths considered in the layout shown in FIG.40(B). The dredged area for the said layout is about 1052 Ha. The finite element mesh (FEM) model was developed for the said layout. The finite element mesh and zoomed portion of bathymetry of the model for preferred master plan layout without North breakwater is shown in FIG.43 (A) & (B) respectively.

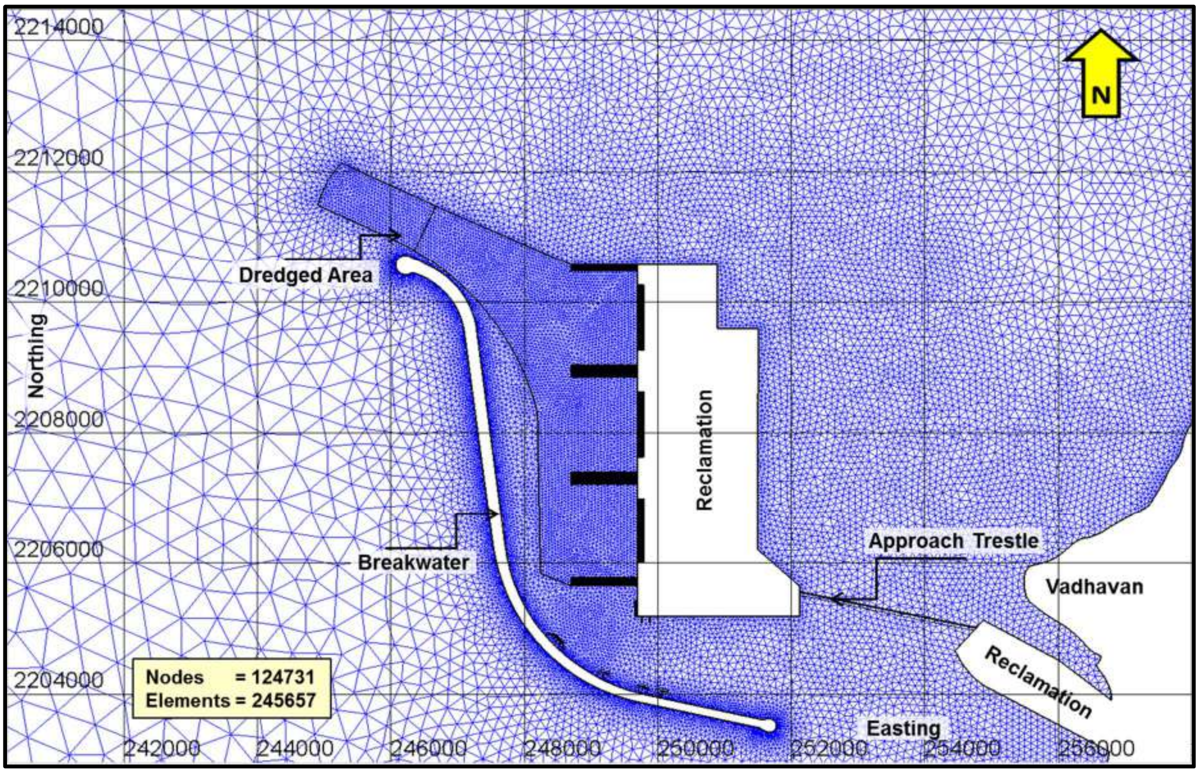



**FIG.43(A): Finite Element Mesh for Preferred Master Plan Layout without North Breakwater**

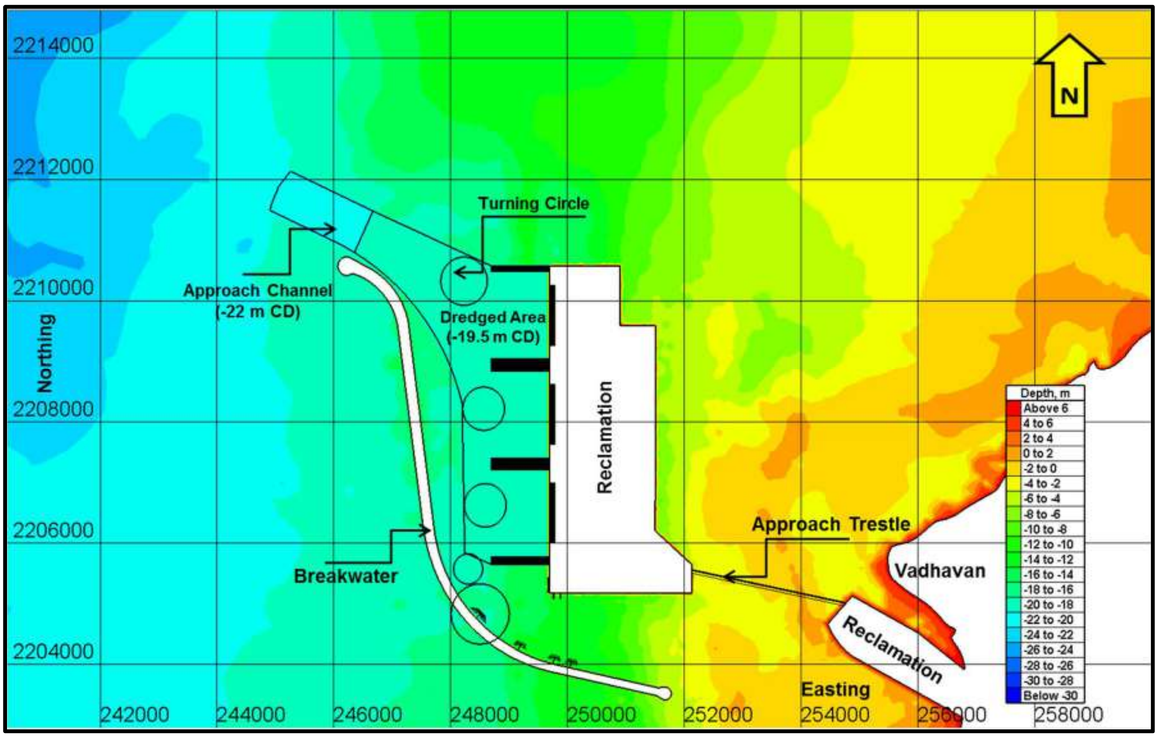



**FIG.43(B): Zoomed Portion of Bathymetry for Preferred Master Plan Layout without North Breakwater**

The hydrodynamic simulation was carried out for preferred master plan layout without North breakwater by adopting same boundary conditions and other parameters considered for calibration of the tidal model. The flow field observed in the model during flood & ebb tide is shown in FIG.44 (A) & 44(B) respectively.

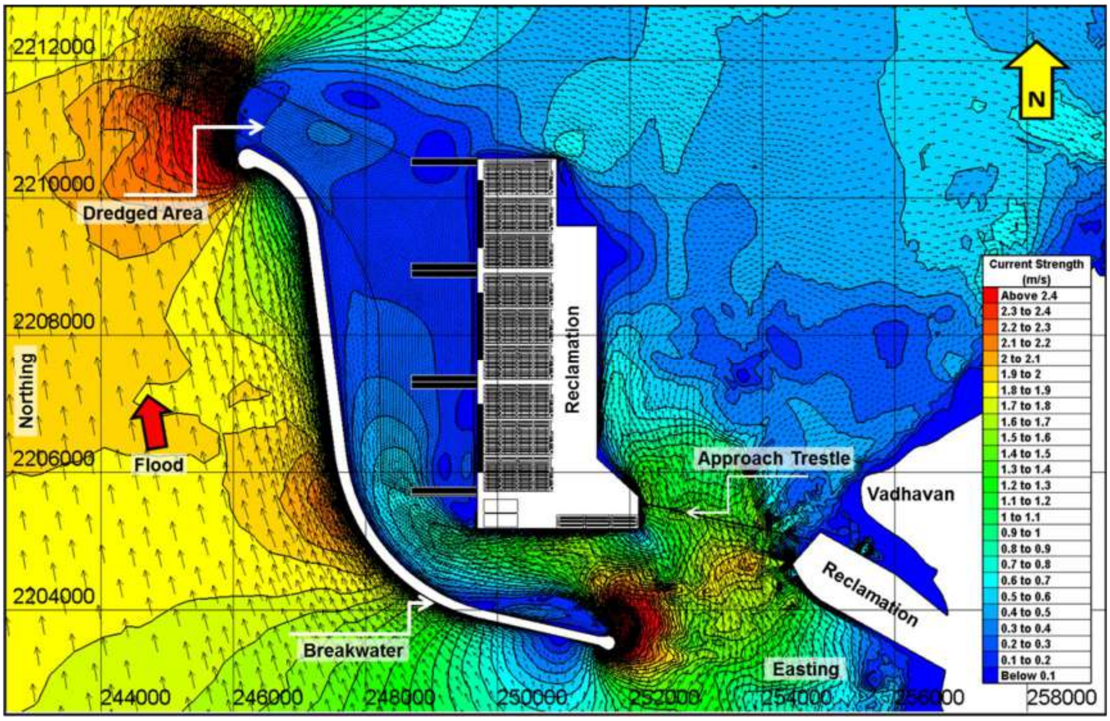



**FIG.44(A): Zoomed Portion of Flow Field during Flood Tide (Preferred Master Plan Layout Without North Breakwater)**

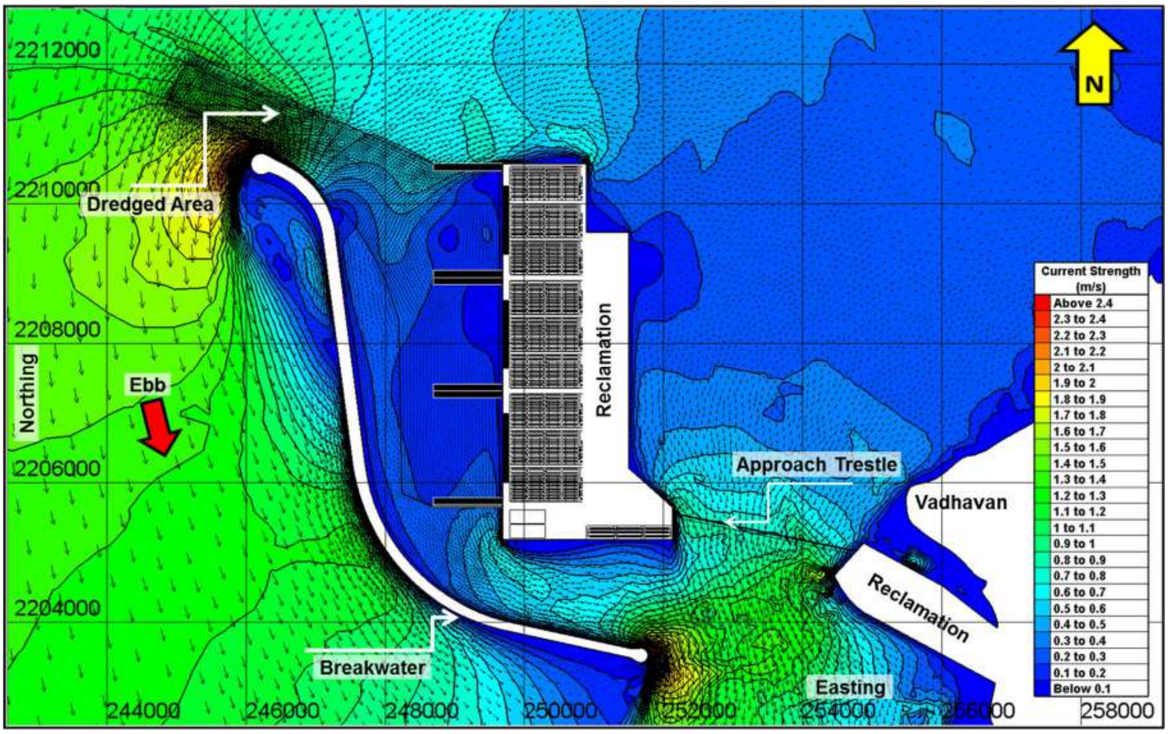



**FIG.44(B): Zoomed Portion of Flow Field during Ebb Tide (Preferred Master Plan Layout Without North Breakwater)**

It is observed from the model studies that maximum velocities at harbour entrance, stoppage distance and turning circle are 2.5 m/s, 1.2 m/s and 0.5 m/s respectively. The maximum currents at the berths vary between 0.27 m/s and 0.45 m/s and its directions are perpendicular to the orientations of berths. It is also observed that there is reduction in velocity by 0.9 m/s in 400 m distance from stoppage distance to turning circle. The comparison of current profile near the harbour entrance (locations ‘A’ to ‘D’ as shown in FIG. 45(A)) for the preferred masterplan layout with & without north breakwater is shown in FIG. 45(B).

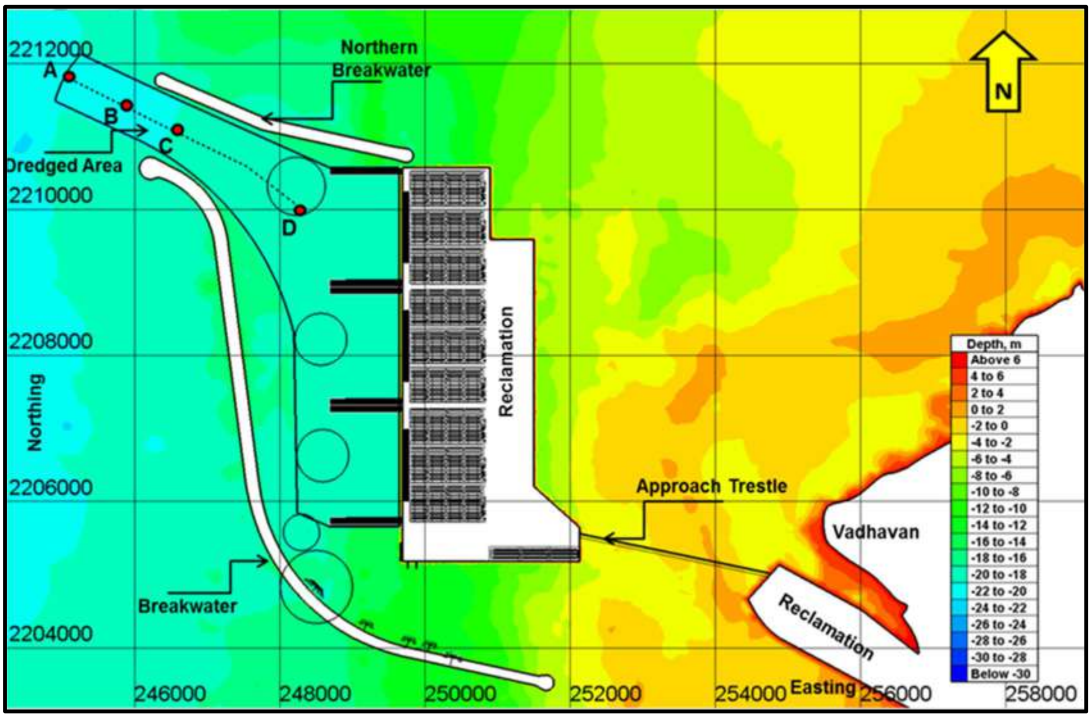



**FIG.45(A): Locations for Comparison of Current Profile near Harbour Entrance**

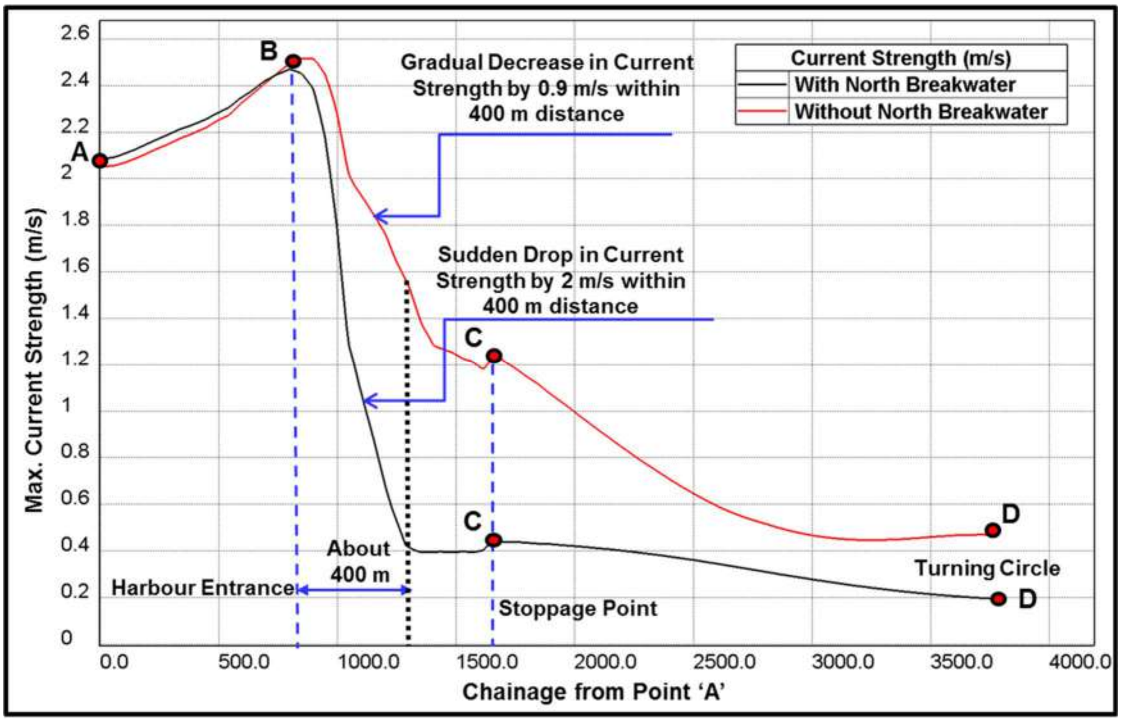



**FIG.45(B): Comparison of Current Profile near Harbour Entrance**
**(With & Without North Breakwater)**

### 8.2.2 Siltation Studies

The siltation studies were carried out to estimate the likely siltation per annum for preferred master plan layout without North breakwater by coupling hydrodynamic models with the sediment module wherein similar parameters were used for those used for with north breakwater scenario. The siltation studies were carried out and the pattern of annual likely rate of siltation observed in model is shown in FIG.46.

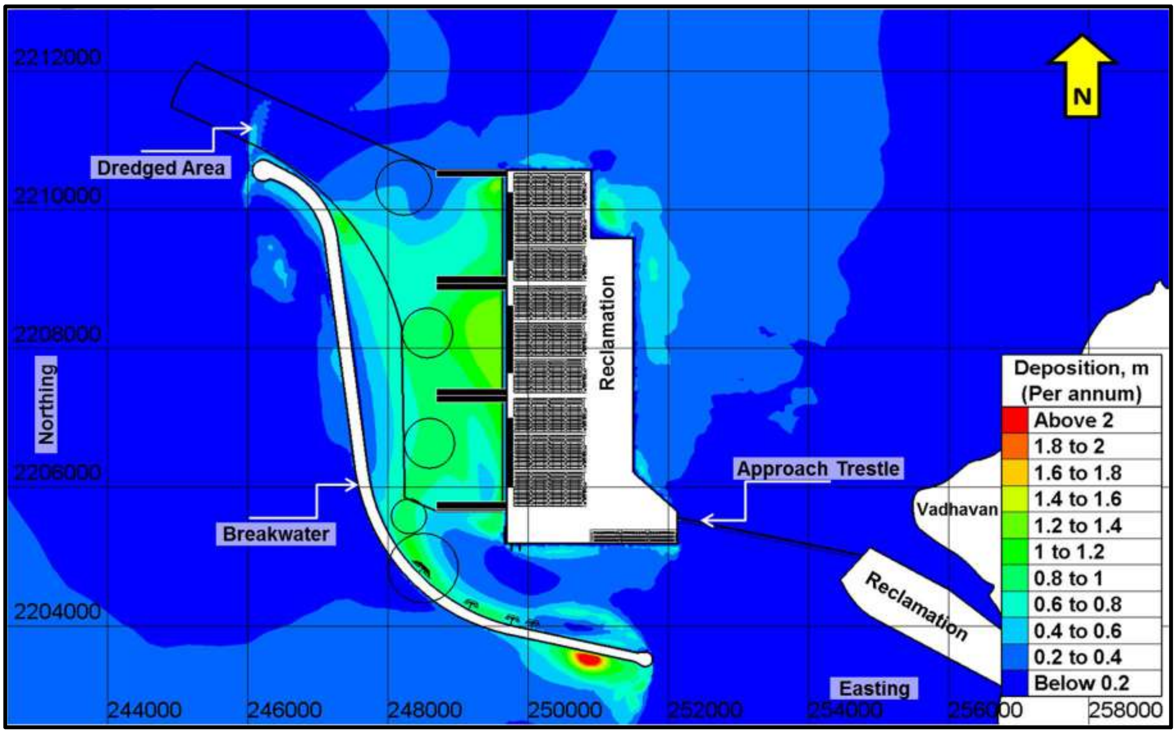



**FIG.46: Annual Siltation Pattern for Preferred Master Plan Layout without North Breakwater**

The total quantum of likely siltation in the dredged areas will be about 6.5 million cum per annum.

The tidal hydrodynamic studies for preferred master plan layout with and without North breakwater conditions referring FIG. 45(B) it can be concluded that there is drastic reduction in current strength by a magnitude of 2.0 m/s over a shorter distance of about 400 m from the harbour entrance for layout with north breakwater. Thus ships plying in/out of harbour entrance are likely to face problem of ship manoeuvring due to complex flow phenomenon (very steep velocity gradient) and restricted width between main breakwater and north breakwater. However, without north breakwater the reduction in current strength is comparatively gradual i.e. 0.9 m/s over the distance of 400 m. Moreover, ample space is available for safe ship manoeuvring due to absence of north breakwater. In addition to this, the 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. This exceeds the PIANC guidelines recommended for transverse current of 0.1 m/s during berthing/de-berthing. Also, siltation studies carried out reveal that the total quantum of likely siltation per annum for preferred layout with North breakwater is higher by about 70% with that for preferred layout without North Breakwater.

These results were discussed in VC meeting held between JN Port Officials, Consultants and CWPRS on 20th July 2021 and it was decided unanimously that the North breakwater may be excluded from the said preferred master plan layout. Further to this, during VC meeting held on 02nd & 14th August 2021, the consultant to JN Port submitted revised master plan layout (Alt3_updated). The revised master plan layout includes modifications in offshore reclamation & dredging footprint and is shown in FIG. 47. The JN Port desires that the tidal hydrodynamics and siltation studies for the said layout needs to be carried out.

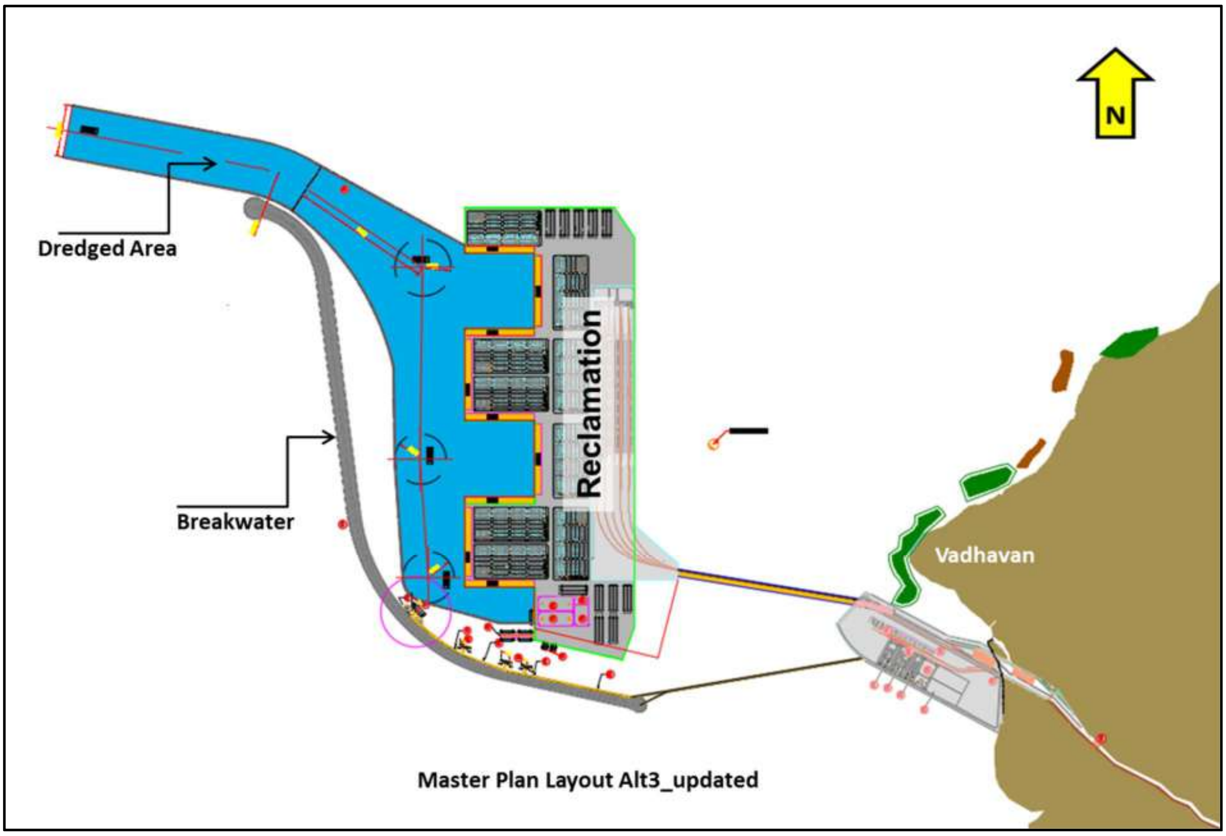



**FIG.47: Revised Master Plan Layout proposed by JN Port**

The details of studies undertaken for revised master plan layout (Alt3_updated) are described in following paragraphs.

### 8.3 Model Studies for Revised Master Plan Layout

#### 8.3.1 Tidal Hydrodynamics Studies

The well calibrated hydrodynamic model was modified by incorporating various components of revised master plan layout viz. the breakwater, the proposed reclamation area (Offshore reclamation about 1231 Ha. & Shore connected reclamation of about 222 Ha.) along with the proposed designed dredge depths in manoeuvring & turning circle area for carrying out tidal hydrodynamics studies for revised Master Plan layout. The dredged area for the said layout is about 1210 Ha. The finite element mesh developed for the said layout and zoomed portion of bathymetry of the model for revised master plan layout is shown in FIG.48 (A) & (B) respectively.

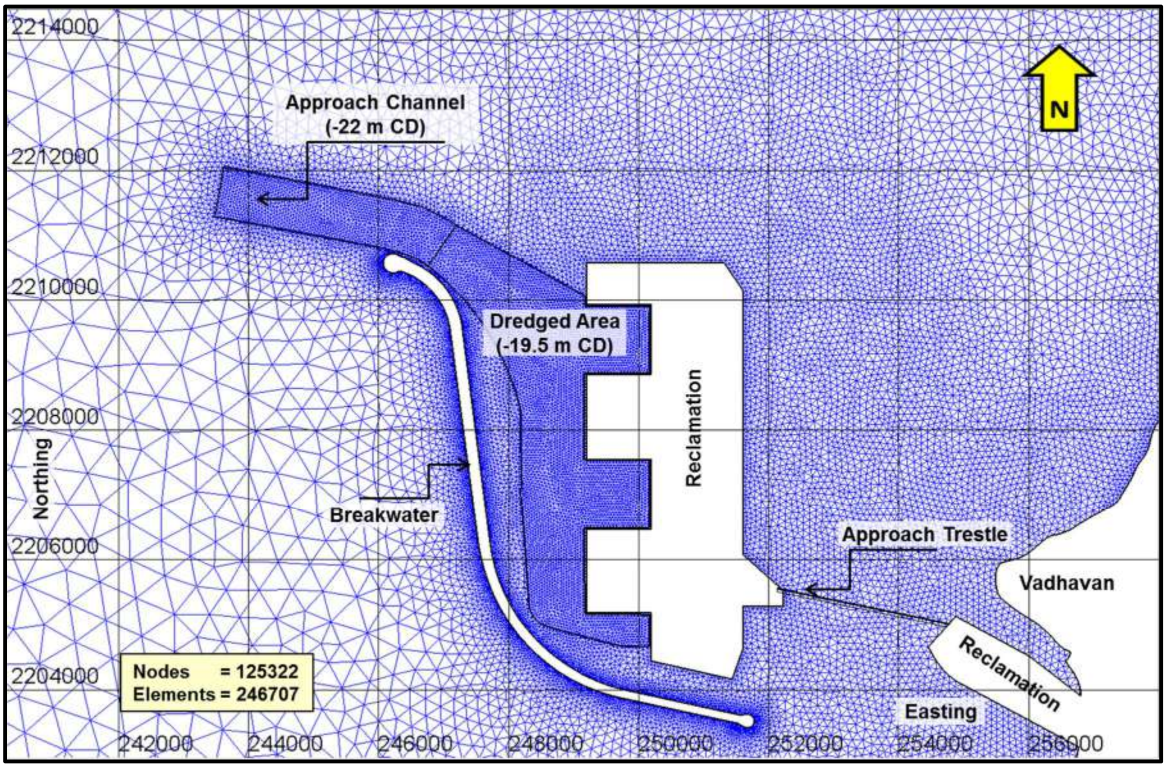



**FIG.48(A):Finite Element Mesh for Revised Master Plan Layout**

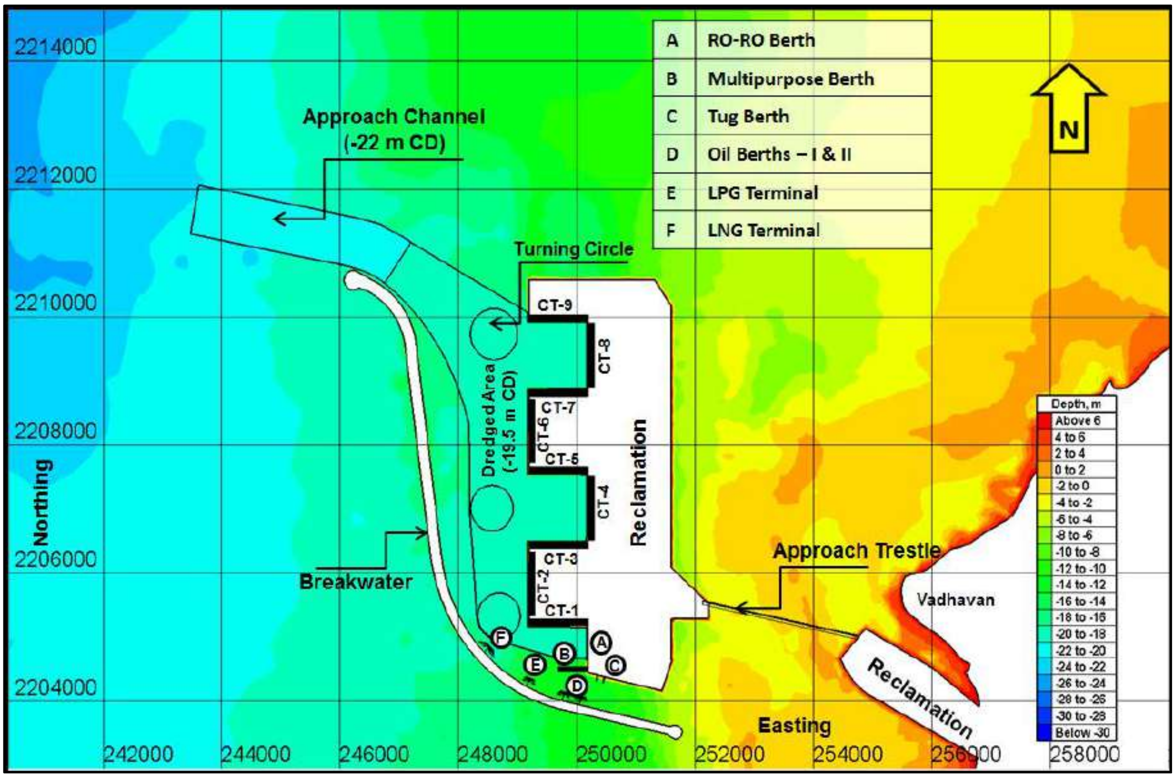



**FIG.48(B):Zoomed Portion of Bathymetry for Revised Master Plan Layout**

The hydrodynamic simulation was carried out for revised master plan layout by adopting same boundary conditions and other parameters considered for calibration of the tidal model. The flow field observed in the model during flood & ebb tide is shown in FIG.49 (A) & (B) respectively.

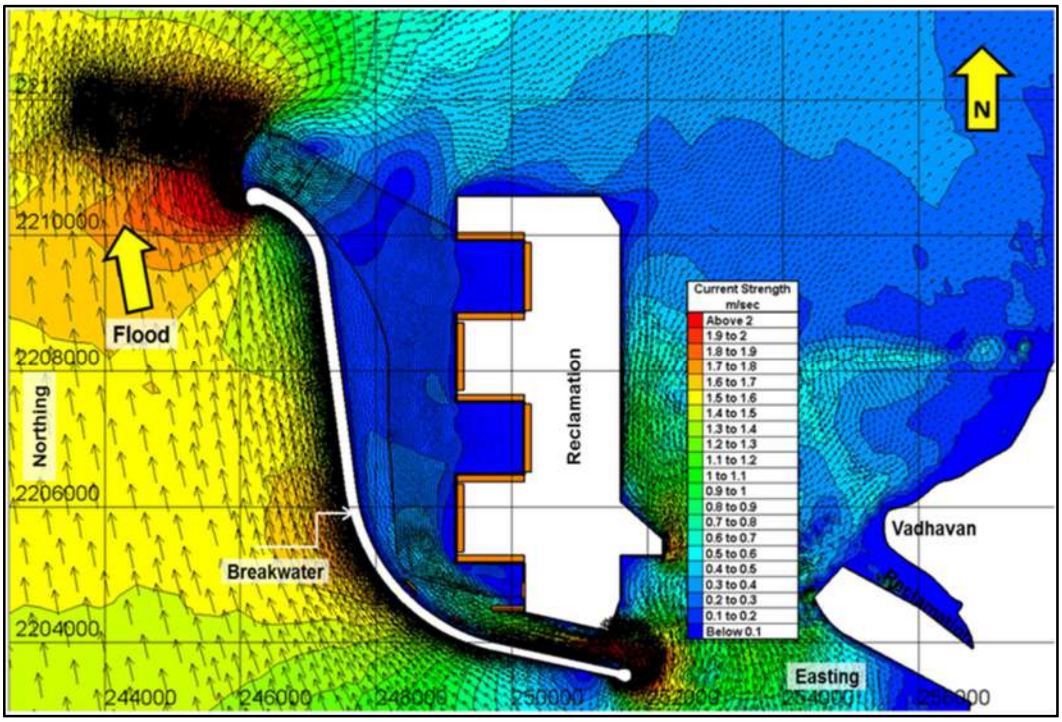



**FIG.49(A): Zoomed Portion of Flow Field during Flood Tide (Revised Master Plan Layout)**

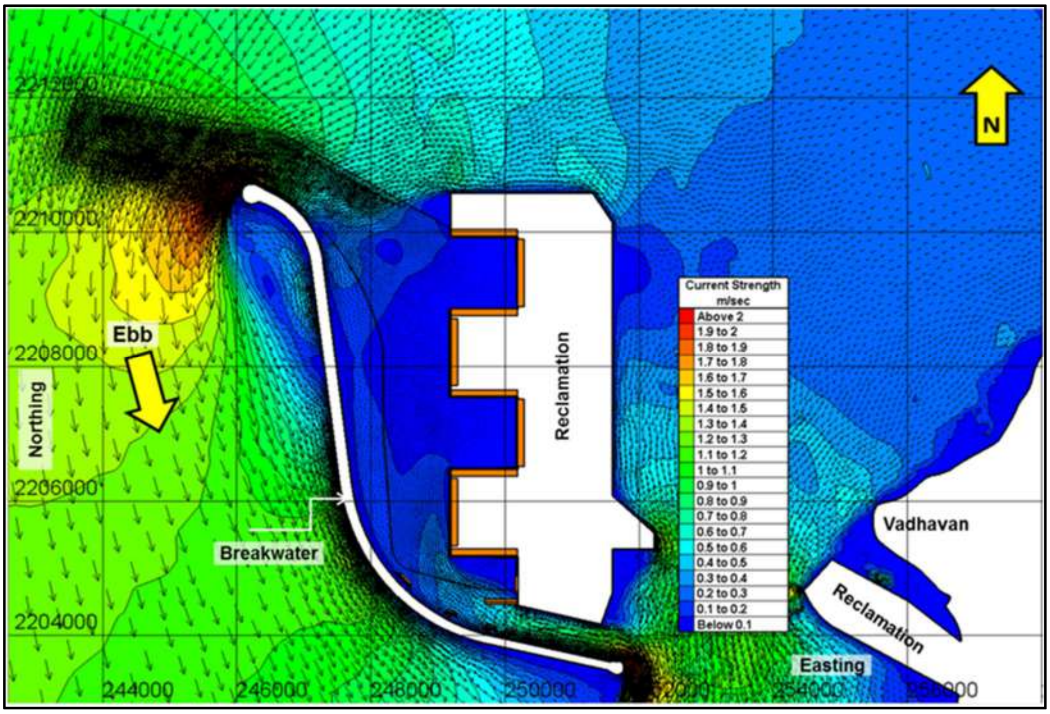



**FIG.49(B): Zoomed Portion of Flow Field during Ebb Tide (Revised Master Plan Layout)**

It is observed from the model studies that maximum velocities at harbour entrance, stoppage distance and turning circle are 2.55 m/s, 1.3 m/s and 0.4 m/s respectively. The maximum currents at the container berths are about 0.05 m/s. It is also observed that at southern end of proposed reclamation, flows are aligned to reclamation face during ebb tide however during flooding; eddy is getting formed between the reclamation and southern end of breakwater which will affect the flow field at LNG, LPG and other oil terminals which are located on the lee-side of breakwater. Similarly, flow approaches multipurpose berths (Oriented to 0° N – 90° N) at an angle 300° N during flood while at about 130° N during ebb and hence vessels approaching these berths may face problem during berthing/de-berthing.

### 8.3.2 Siltation Studies

The siltation studies were carried out to estimate the likely siltation per annum for revised master plan layout by coupling hydrodynamic models of monsoon & non-monsoon with the sediment module. The parameters used for calibration of silt model were adopted to estimate the likely rate of siltation for revised master plan layout condition in the areas where dredging is proposed to be carried out. The siltation studies were carried out and the pattern of annual likely rate of siltation observed in model is shown in FIG.50.

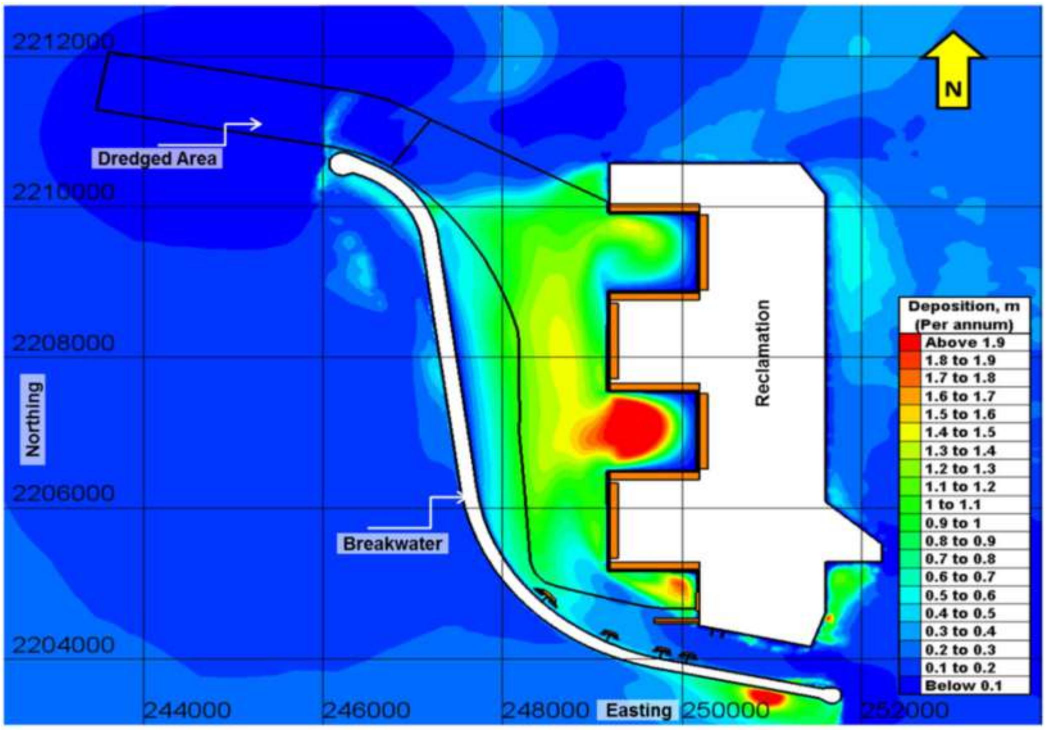



**FIG.50: Annual Siltation Pattern for Revised Master Plan Layout**

The total quantum of likely siltation in the dredged areas will be about 9.20 million cum per annum. The quantum of likely siltation for the revised master plan layout is higher than preferred master plan layout without North breakwater due to the fact that there is change in shape of reclamation as well as increase in dredged area by about 133 Ha.

This layout was discussed in VC meeting held on 02$^{nd}$ September 2021 and it is mentioned in the meeting that based on tidal hydrodynamics studies it was observed that tidal flow conditions are suitable at all container berths as well as in the manoeuvring area. However, flow field is more complex at the southern end of reclamation where multipurpose berths, tug berths are proposed and due to limited width at Southern end between reclamation and southern end of breakwater, eddies are getting formed on both side i.e. reclamation side and breakwater side during flood phase of tide as shown in FIG.51.

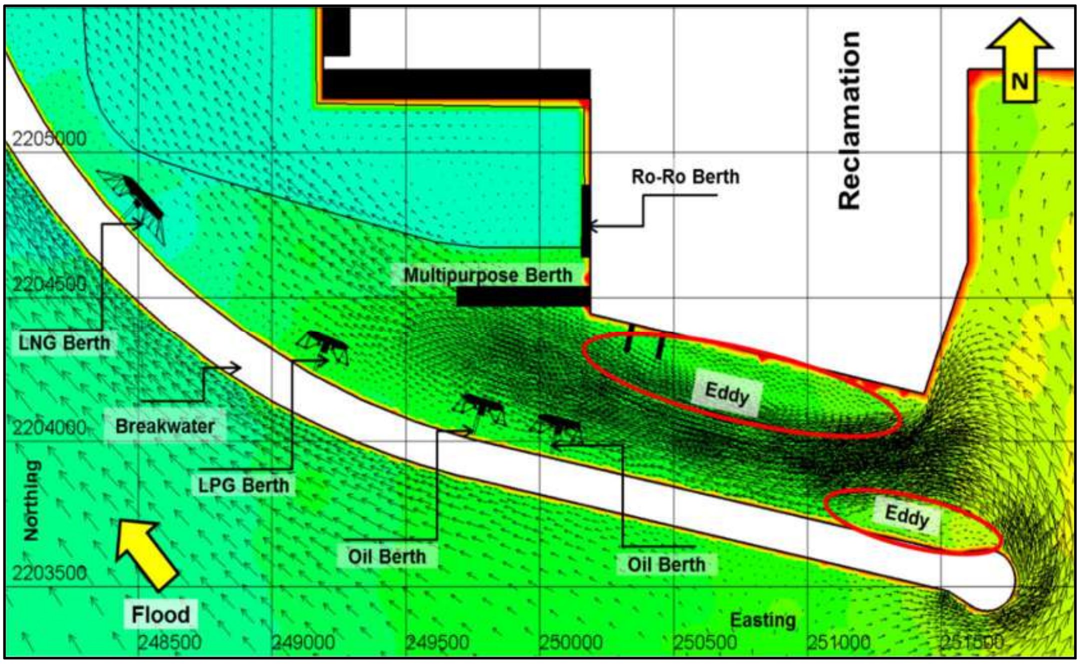



**FIG.51: Flow Pattern at Southern End of Reclamation during Flood**

In order to streamline the flow in this region, CWPRS suggested that the width between reclamation and southern end of breakwater may be increased from the existing opening of 500m and the multipurpose berths and tug berths may be placed along the reclamation face. Similarly, in order to reduce the velocities in this region, shallowing of the area was also proposed. The various modifications suggested by CWPRS for Revised Master Plan layout are shown in FIG. 52(A), (B) & (C).

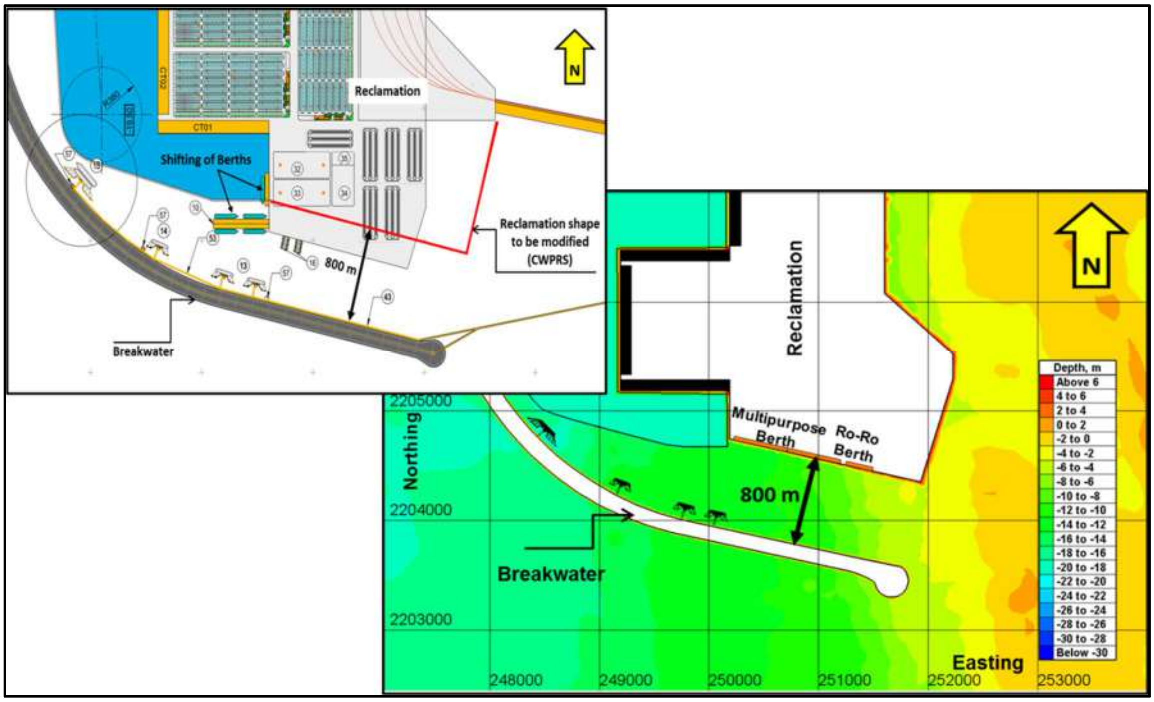



**FIG.52(A): 'Modification – I' at Southern End of Reclamation Suggested by CWPRS**

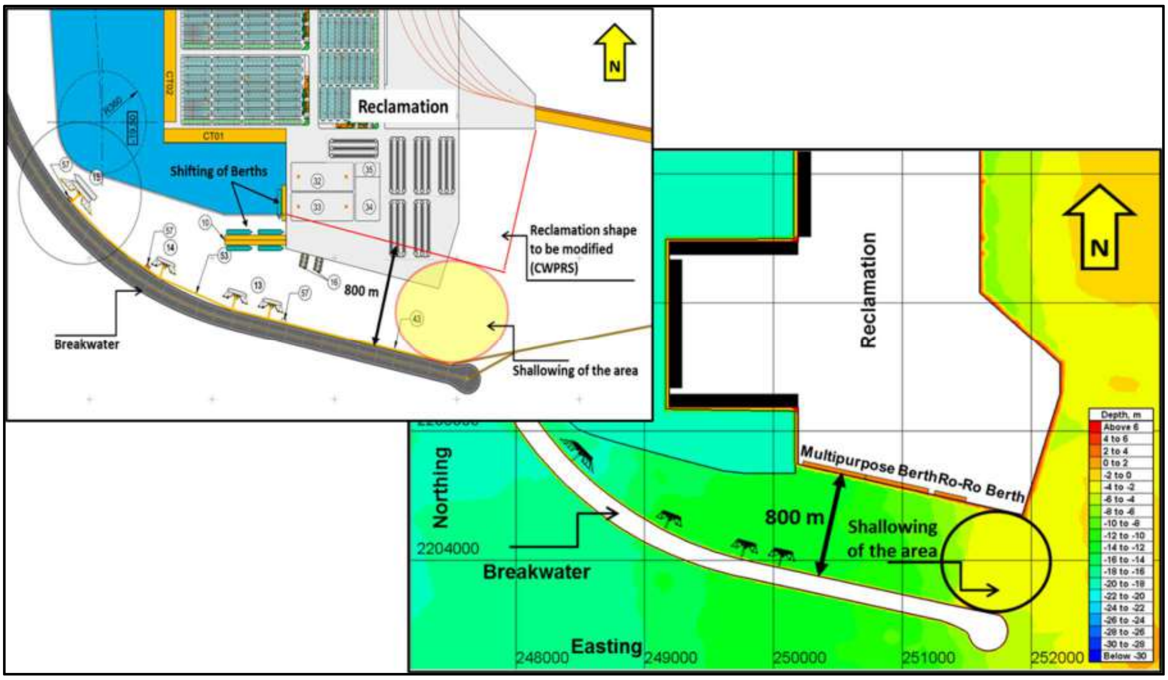



**FIG.52(B): 'Modification – II' at Southern End of Reclamation Suggested by CWPRS**

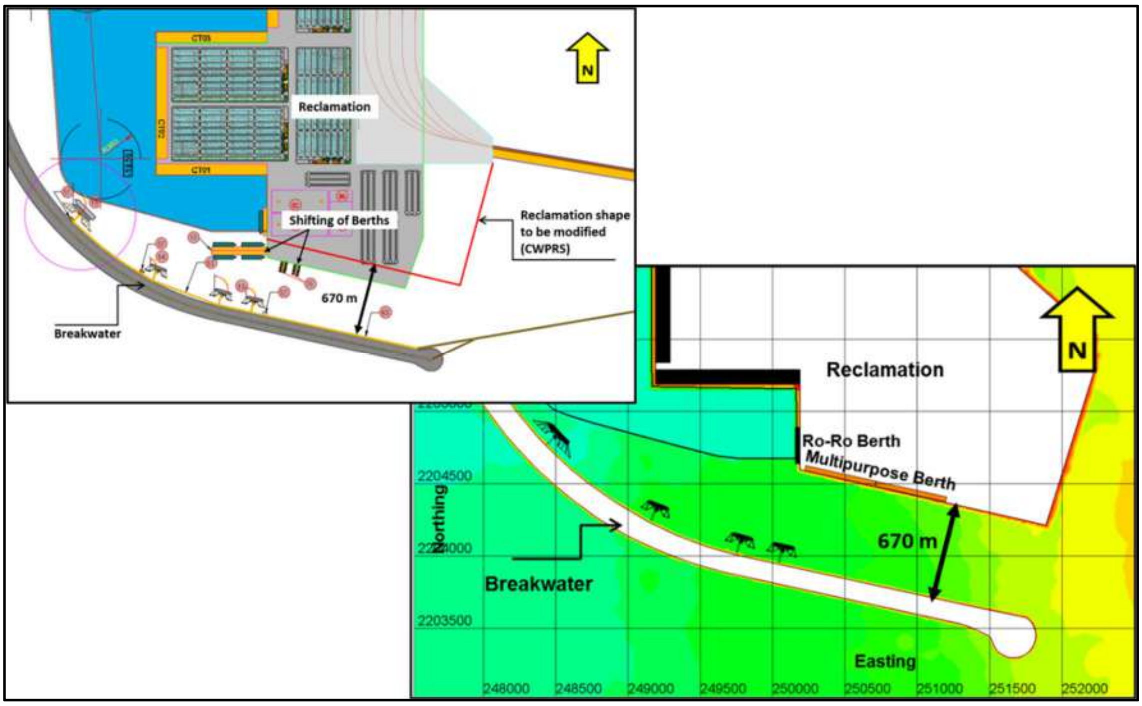



**FIG.52(C): 'Modification – III' at Southern End of Reclamation Suggested by CWPRS**

The preliminary tidal hydrodynamics studies for above three alternatives were carried out with the modifications and the results of the studies were discussed with JN Port Officials and their Consultants in VC meeting held on 9th September 2021 and considering all technical and operational aspects, the revised master plan layout with modifications viz. increase in width between reclamation and southern end of breakwater by 670 m and aligning multipurpose berths along reclamation face was considered for further tidal hydrodynamic, siltation as well as wave tranquillity studies. The modifications in the revised master plan layout at Southern end of reclamation are shown in FIG.53(A) while complete modified revised master plan layout is shown in FIG.53(B).

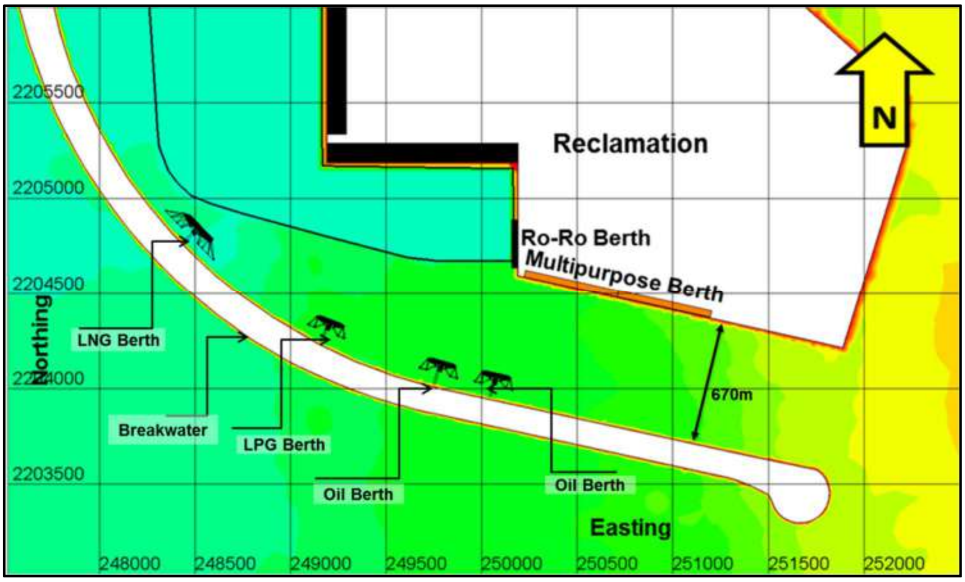



**FIG.53(A): Modifications in Revised Master Plan Layout Considered for Studies**

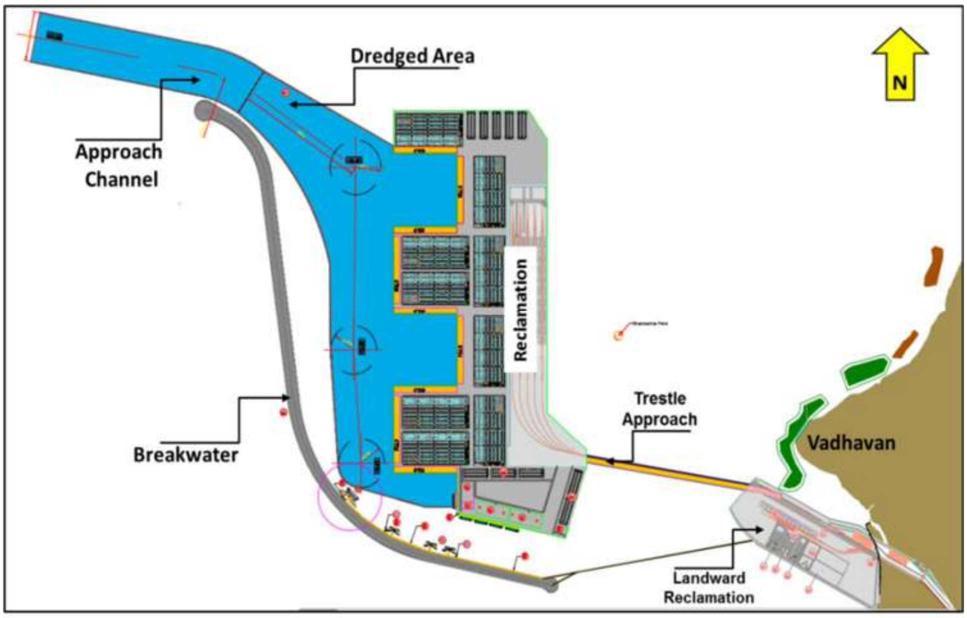



**FIG.53(B): Modified Revised Master Plan Layout Considered for Studies**

This layout was further considered for finalisation of master plan layout (Modified Revised Master Plan Layout) by carrying out tidal hydrodynamics and siltation studies which are described in the following paragraphs.

### 8.4 Model Studies for Modified Revised Master Plan Layout

#### 8.4.1 Tidal Hydrodynamics Studies

The modifications in the well calibrated hydrodynamic model were carried out by incorporating the breakwater of 10.3 km, the proposed reclamation area (Offshore reclamation about 1262 Ha. & Shore connected reclamation of about 222 Ha.) with the modifications at Southern end along with the proposed design dredge depths viz. depths in manoeuvring & turning circle area for carrying out tidal hydrodynamics studies for modified revised Master

Plan layout. The dredged area for the said layout is about 1210 Ha. The finite element mesh developed for said layout and zoomed portion of bathymetry of the model for the layout is shown in FIG.54 (A) & (B) respectively.

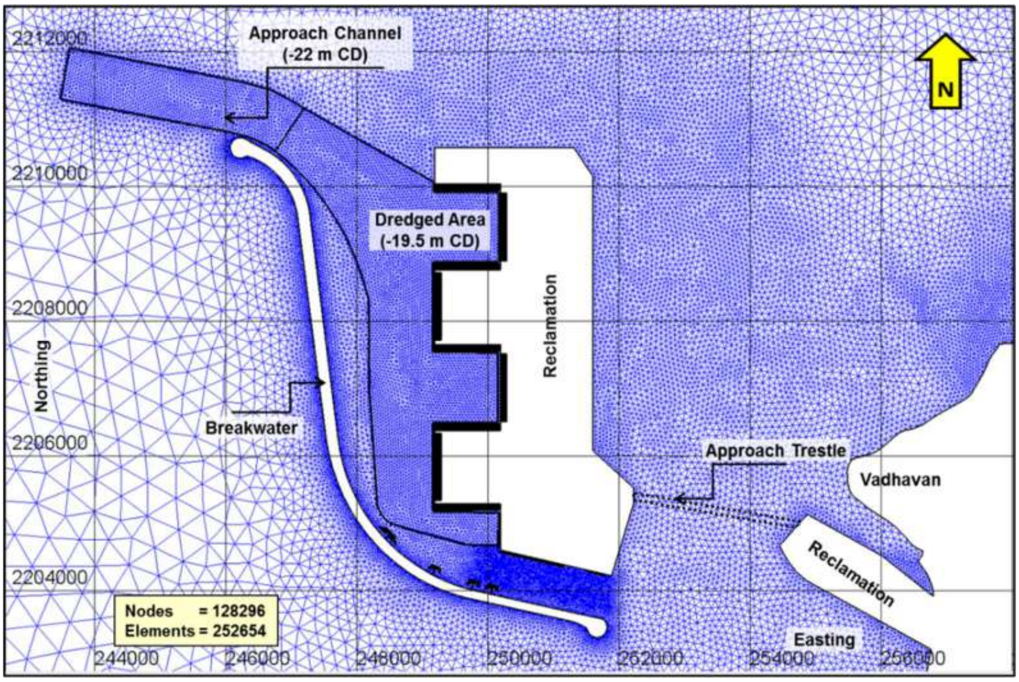



**FIG.54(A):Finite Element Mesh for Modified Revised Master Plan Layout**

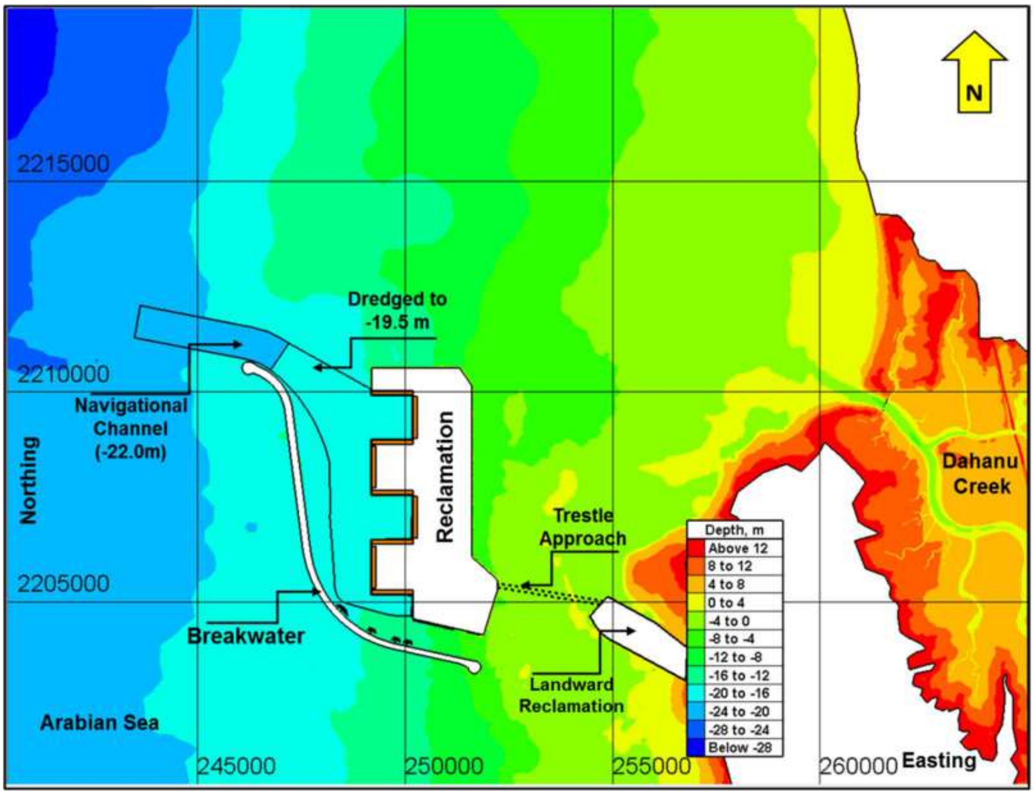



**FIG.54(B):Zoomed Portion of Bathymetry for Modified Revised Master Plan Layout**

The boundary conditions and other parameters considered for calibration was used for carrying out hydrodynamic simulation for the said layout. The flow field observed in the model during flood & ebb tide is shown in FIG.55 (A) & (B) respectively.

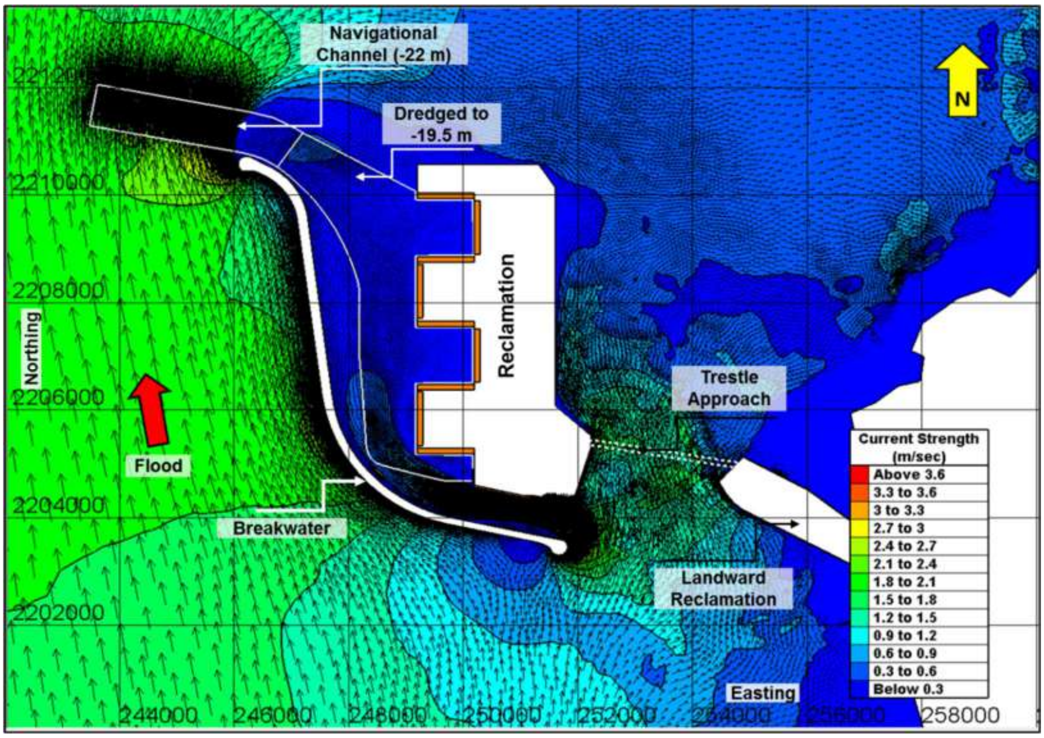



**FIG.55(A): Zoomed Portion of Flow Field during Flood Tide (Modified Revised Master Plan Layout)**

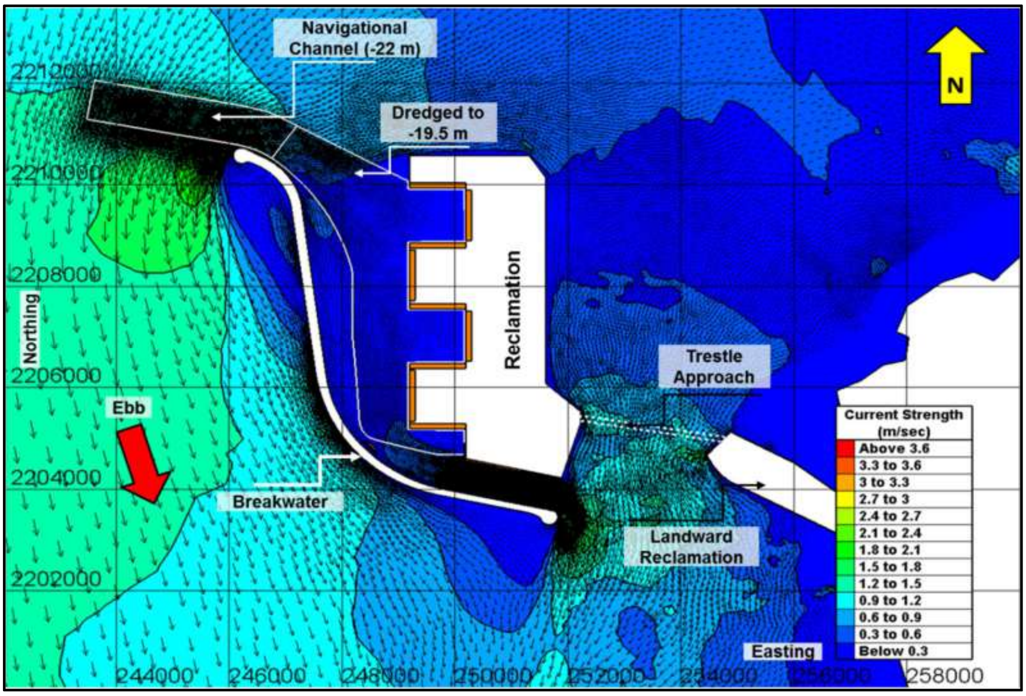



**FIG.55(B): Zoomed Portion of Flow Field during Ebb Tide (Modified Revised Master Plan Layout)**

It is observed from the model studies that maximum velocities at harbour entrance, stoppage distance, turning circle and at berths remain same as that of revised master plan layout. It is also observed that at southern end of proposed reclamation, flows are aligned to reclamation face during flood as well as ebb tide which may be useful in aligning the multipurpose berths along reclamation face at Southern end. The locations of various berths are shown in FIG. 56.

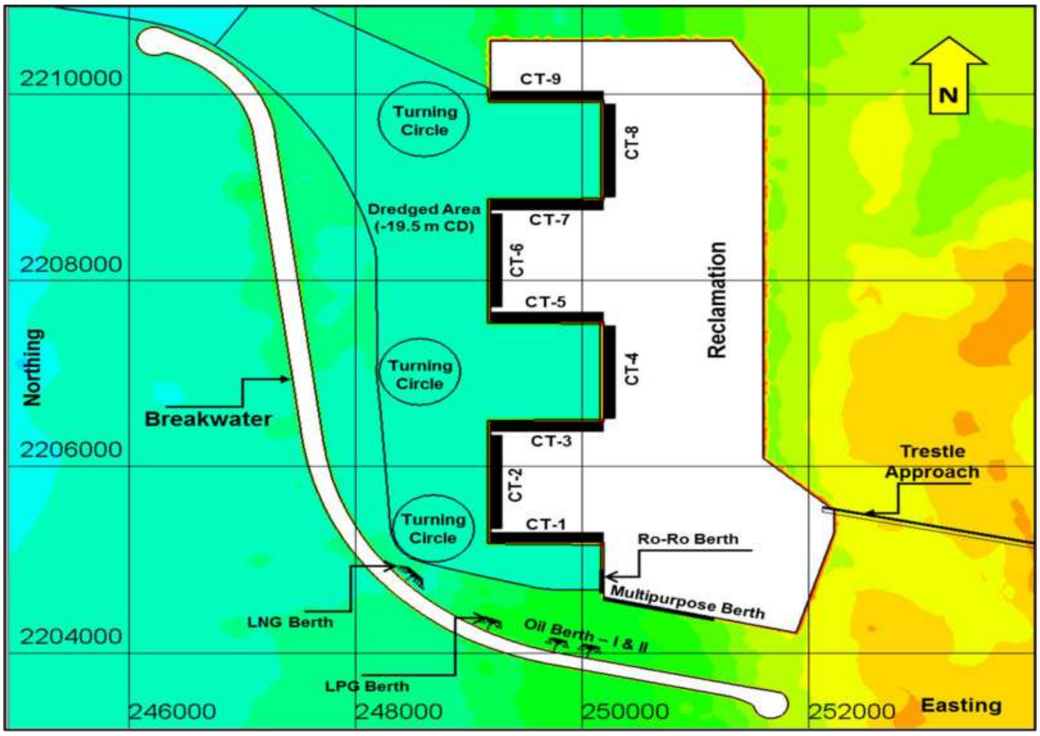



**FIG.56: Locations of Various Berths in Modified Revised Master Plan Layout**

The maximum current strengths at container terminals CT-1, CT-2 & CT-6 are 0.10 m/s, 0.15 m/s and 0.12 m/s respectively while for remaining container terminals, it is 0.05 m/s.

Similarly, the information about current strength along with direction at various other berths i.e. liquid terminals, RO-RO and multipurpose berths is given in Table-III.

**Table-III**

**Current Strength & Direction at Berths Other than Container Terminals**

| Location & Alignment of Berth | Maximum Current Strength during Flood (m/s) | Direction during Flood (Deg. N) | Maximum Current Strength during Ebb (m/s) | Direction during Ebb (Deg. N) |
|---|---|---|---|---|
| **Oil Berth – I** (102° - 282° N) | 0.60 | 282 | 0.64 | 106 |
| **Oil Berth – II** (105° - 285° N) | 0.50 | 287 | 0.51 | 108 |
| **LPG Terminal** (111° - 291° N) | 0.40 | 298 | 0.41 | 118 |
| **LNG Terminal** (135° - 315° N) | 0.30 | 316 | 0.23 | 140 |
| **RO-RO Berth** (0° - 180° N) | 0.28 | 180 | 0.12 | 180 |
| **Multipurpose Berth** (103° - 283° N) | 0.70 | 281 | 0.41 | 101 |

The above table indicate that for oil berths as well as LPG terminal the flow during flood and ebb approaches to the berths at an angle varying between 4° & 7° with reference to the alignment of these berths. Considering the above fact and effect of eddy generated at Southern end of breakwater on the flow field at oil berths, it is desirable to shift the locations of Oil berths, LPG & LNG terminals by about 500 m along the breakwater towards north to achieve favourable flow conditions irrespective of phase of tide.

### 8.4.2 Siltation Studies

The siltation studies were carried out by coupling hydrodynamic models of monsoon & non-monsoon with the sediment module to estimate the likely siltation per annum for modified revised master plan layout. The parameters used for calibration of silt model were adopted to estimate the likely rate of siltation for modified revised master plan layout condition in the areas where dredging is proposed to be carried out. The siltation studies were carried out and the pattern of annual likely rate of siltation observed in model is shown in FIG.57.

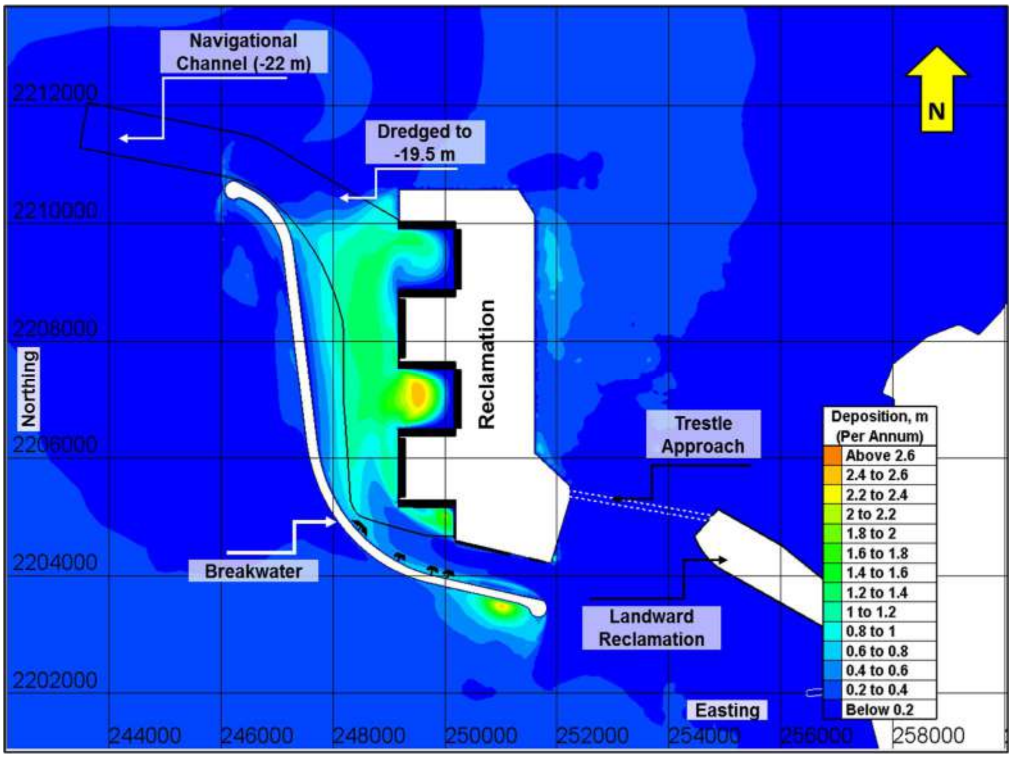



**FIG.57: Annual Siltation Pattern for Modified Revised Master Plan Layout**

The total quantum of likely siltation in the dredged areas will be about 8.45 million cum per annum. There is reduction in quantum of likely siltation per annum by about 0.75 million cum per annum for the said layout as compared to that for revised master plan layout. Considering the favourable tidal hydrodynamic conditions at berth locations as well as the reduction in quantum of annual likely rate of siltation, the modified revised master plan layout is considered as a suitable and final layout for the proposed port at Vadhavan and termed as “Master Plan Layout”.

## 9. MODEL STUDIES FOR PHASE-I LAYOUT

The JN Port, after finalising the master plan layout vide email dated 05$^{th}$ October 2021 submitted Phase-I layout (part portion of master plan layout) to study from tidal hydrodynamics considerations and to estimate the likely rate of siltation per annum for the layout. The Phase-I layout is shown in FIG. 58.

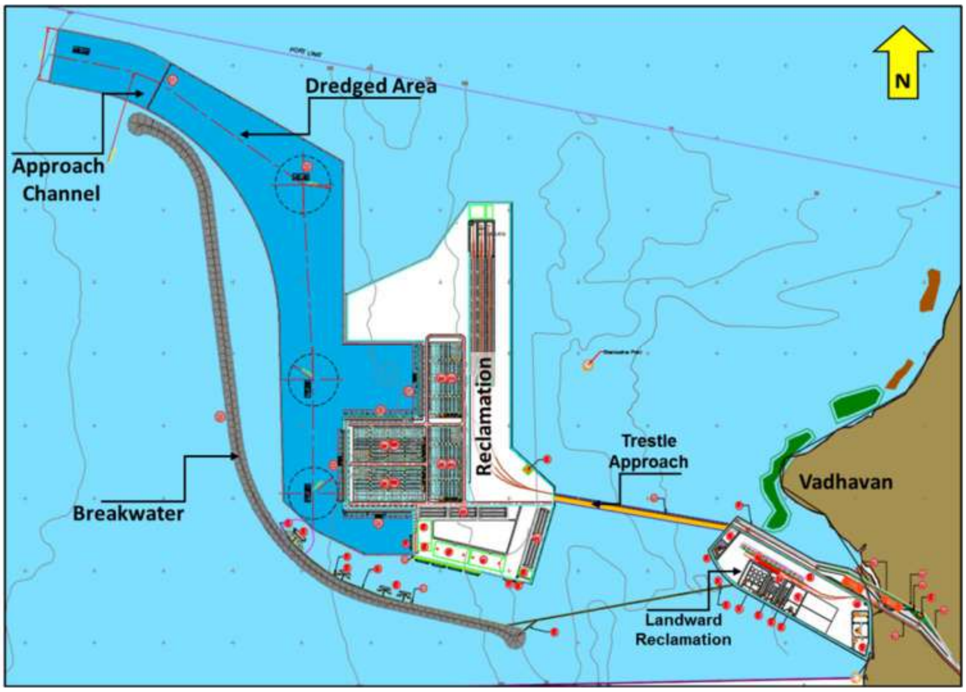



**FIG.58: Phase-I Layout of proposed port at Vadhavan**

The model studies were carried out for the Phase-I layout and are described as follows.

### 9.1 Tidal Hydrodynamics Model Studies

The modifications in the well calibrated hydrodynamic model were carried out by incorporating the breakwater of 10.3 km, the Phase-I layout reclamation area along with the proposed design dredge depths in manoeuvring, turning circle area and berth pockets for carrying out tidal hydrodynamics studies. The Phase-I layout reclamation area is about 970 Ha. while the dredged area for the said layout is about 981 Ha. The depths maintained in approach channel, dredged area will be 20 m and 17.5 m below CD respectively while in berth pockets, it is 19.5 m below CD. The finite element mesh and zoomed portion of bathymetry of the model for Phase-I layout is shown in FIG.59 (A) & (B) respectively.

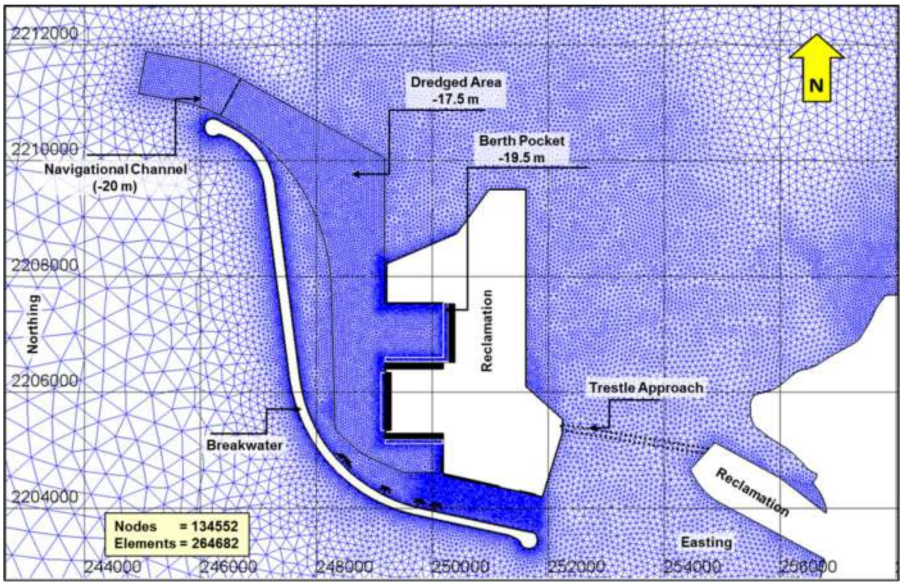



**FIG.59(A):Finite Element Mesh for Phase-I Layout**

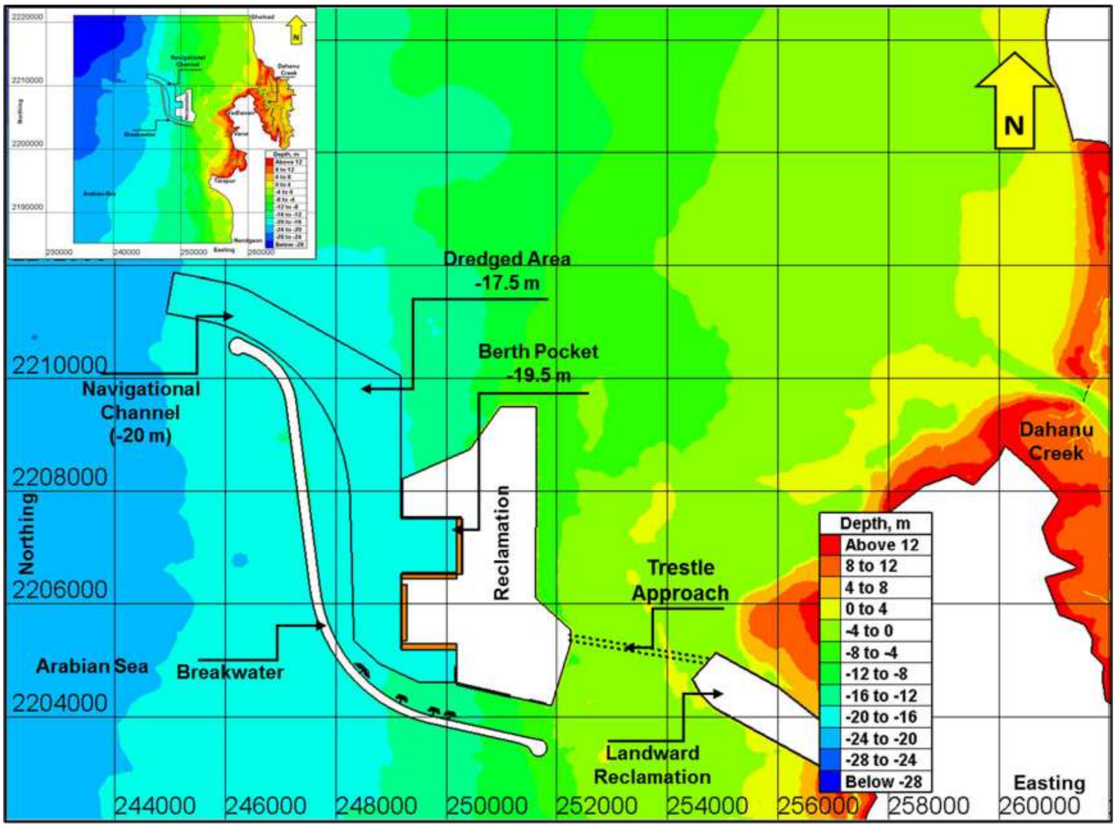



**FIG.59(B):Zoomed Portion of Bathymetry for Phase-I Layout**

The boundary conditions and other parameters considered for calibration was used for carrying out hydrodynamic simulation for the said layout. The flow field observed in the model during flood & ebb tide is shown in FIG.60 (A) & (B) respectively.

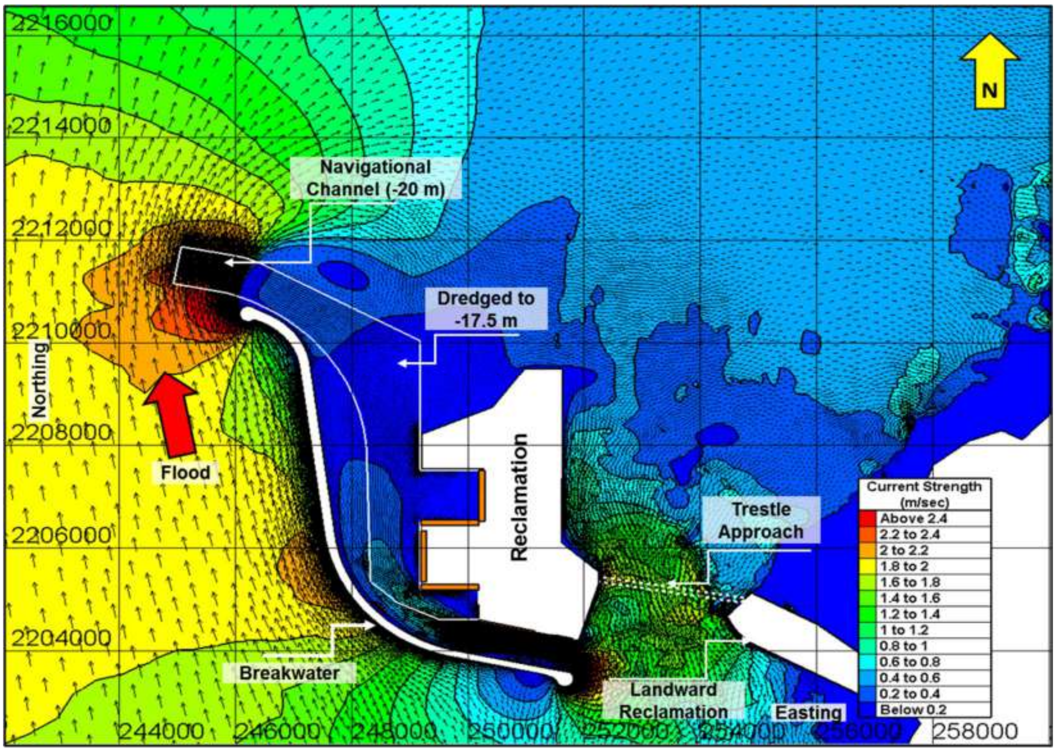



**FIG.60(A): Zoomed Portion of Flow Field during Flood Tide (Phase-I of Master Plan Layout)**

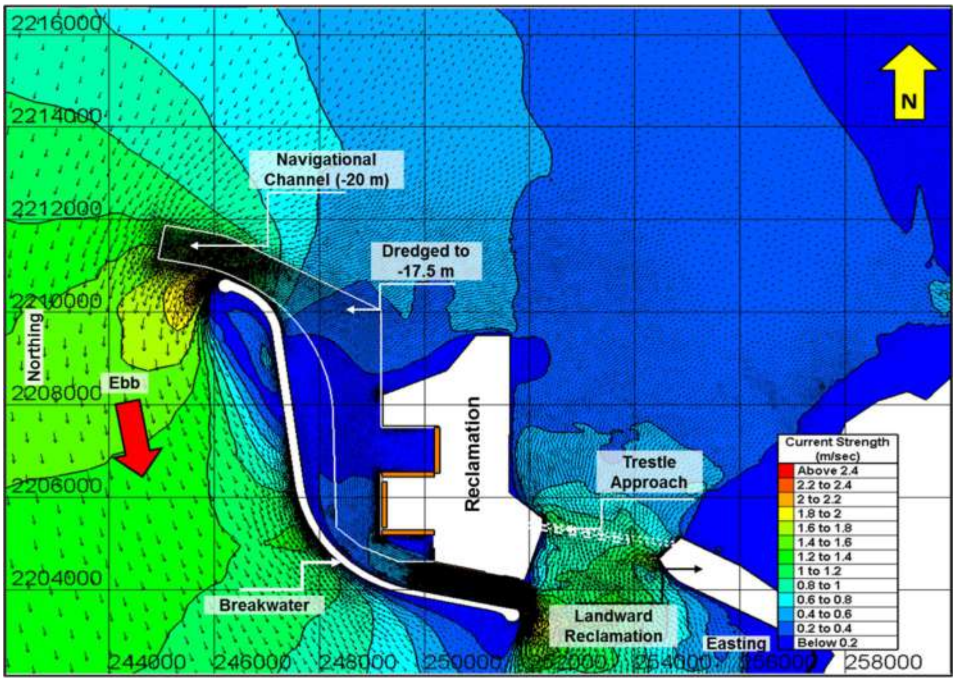



**FIG.60(B): Zoomed Portion of Flow Field during Ebb Tide (Phase-I of Master Plan Layout)**

It is observed from the model studies that maximum velocities at harbour entrance, stoppage distance and turning circle are 2.6 m/s, 1.2 m/s and 0.3 m/s respectively. The maximum current strengths at the berths are about 0.05 m/s.

### 9.2 Siltation Studies

The siltation studies were carried out to estimate the likely siltation per annum for Phase-I master plan layout by coupling hydrodynamic models of monsoon & non-monsoon with the sediment module. The parameters used for calibration of silt model were adopted to estimate the likely rate of siltation for Phase-I layout condition in the areas where dredging is proposed to be carried out. The siltation studies were carried out and the pattern of annual likely rate of siltation is shown in FIG.61.

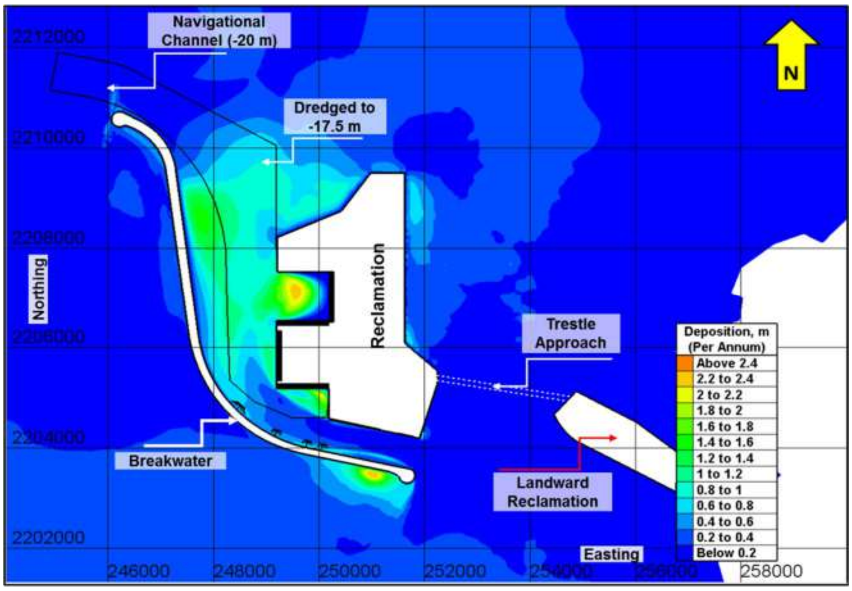



**FIG.61: Annual Siltation Pattern for Phase-I Master Plan Layout**

The total quantum of likely siltation in the dredged areas will be about 6.45 million cum per annum.

**Note-** The rates of siltation estimated from model are based on the fact that the entire dredged area is maintained to the required depths and deposition is due to the settlement of suspended sediments. It is also to mention that the entire area which will be dredged being virgin region, during the process of capital and maintenance dredging for initial few years (till the side slopes of dredged/nearby area gets stabilized), it is likely that there is possibility of increase in siltation than estimated by model studies. It is essential that the likely rate of siltation after the development of the port needs to be monitored seasonally and the information may be forwarded to CWPRS for modifying the parameters used for estimation of siltation to achieve better prediction of siltation for developments in future.

## 10. 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. indicate that the tides are semi-diurnal in nature with diurnal inequality. The maximum tidal range is about 5.87 m during spring tide and 2.1 m during neap tide during non-monsoon season, while it is 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 information on wave data indicate that the maximum significant wave height ($H_s$) is 1.19 m during non-monsoon season and the waves approaches from N-W quadrant while for monsoon season the maximum significant wave height ($H_s$) is 2.3 m and the waves approaches from SW-WNW quadrant. The data on Suspended Sediment Concentration (SSC) indicate that for non-monsoon season it varies from 380 mg/lit to 170 mg/lit while for monsoon season SSC varies from 473 mg/lit to 105 mg/lit. The grain size analysis of suspended sediments carried out reveal that the suspended sediments contain 68% of silt and 26% of clay and as such the sediment is classified as clayey silt having grain size $D_{50}$ as 0.008 mm. 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 the model compares well and is 95% in agreement. Similarly, current strength & direction are also in good agreement with that observed at site both for non-monsoon as well as monsoon seasons. 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 JN Port for non-monsoon and monsoon seasons.

3. The layout of port at Vadhavan recommended by CWPRS (CWPRS TR No. 5583 of March 2018) was revised by the consultants to JN Port in view of increase in quay length for container terminals as per the directives of port Authority. This layout was evolved by altering the shape of reclamation (on tidal flats) and relocation of various berths without altering the layout of main breakwater and Current Deflecting Wall (CDW). The development of the port in two phases viz. Phase-I & Master plan is also under consideration. In view of relocation of berths for port activities in revised layouts, the possibility of optimization of length of Current Deflecting Wall (CDW) was assessed by carrying out tidal hydrodynamics studies. The hydrodynamic studies carried out for the Master Plan layout with CDW of 1.9 km, 1.4 km and 1.0 km reveal that the length CDW of 1.4 km is optimal length and will not affect the berthing and de-berthing of vessels at lee-side of southern side of breakwater. The quantity of likely rate of siltation for Master Plan and Phase-I layouts with optimized CDW (1.4 km long) will be about 8 million cum/annum & 4.9 million cum/annum respectively.
4. The length of the approach trestles connecting berths in deeper depths with stack-yard reclamation on tidal flat being significantly more (about 6 km) it is likely to pose a problem of traffic congestion for to & fro movement of trailers and increase in turnaround time thereby affecting the operational efficiency of the container terminals vis-à-vis increase in the operational cost of handling of the containers. Thus port Authority in consultation with their Consultants has considered to shift the reclamation for stack/rail yard near to the berths so as to have free flow of traffic of containers from stack-yard to the container berths and thus reduces the turnaround time.
5. The preferred master plan layout was arrived at after discussing pros & cons of various six alternative layouts proposed by consultants to JN Port. The tidal hydrodynamic studies for preferred master plan layout with and without North breakwater conditions reveal that there is drastic reduction in current strength by a magnitude of 2.0 m/s over a shorter distance of about 400 m from the harbour entrance for layout with north breakwater. Thus ships plying in/out of harbour entrance are likely to face problem of ship manoeuvring due to complex flow phenomenon (very steep velocity gradient) and restricted width between main breakwater and the north breakwater. However, without north breakwater the reduction in current strength is comparatively gradual i.e. 0.9 m/s over the distance of 400 m. Moreover, ample space is available for safe ship manoeuvring due to the absence of north breakwater. In addition to this, the flow in the

berthing area being perpendicular to the orientation of those berths which are at right angle to the reclamation face and its magnitude is more than 0.1 m/s. This exceeds the PIANC guidelines recommended for transverse current of 0.1 m/s during berthing/de-berthing. The siltation studies indicate that total quantum of likely siltation per annum for preferred layout with North breakwater is about 11 million cum, while for without North breakwater layout is about 6.45 million cum. Thus the quantum of siltation for preferred layout with North breakwater is higher by 70% with that for preferred layout without North Breakwater. Hence the North breakwater was excluded from the said preferred master plan layout.

6. The JN Port to achieve desirable flow conditions at all container berths keeping in mind PIANC guidelines has modified the shape of reclamation proposed for stack-yard along with dredging footprint (FIG. 47) as a revised master plan layout. This layout was submitted to CWPRS to assess its suitability from tidal hydrodynamic and siltation consideration. The tidal hydrodynamic studies conducted reveal that the tidal flow conditions are suitable at all container berths. However, flow field is more complex at the southern end of reclamation where multipurpose berths, tug berths are proposed and due to limited width at Southern end between reclamation face and southern end of breakwater, elongated eddies are seen to be formed on both sides i.e. reclamation side and breakwater side during flood phase of tide as shown in FIG.51. The siltation studies carried out reveal that the total quantum of likely siltation in the dredged areas for the layout will be about 9.2 million cum per annum. Thus to improve the flow field at Southern end of reclamation and to reduce siltation in the dredged area, it is desirable to modify the shape of reclamation at Southern end.
7. CWPRS, in order to streamline the flow in the region between reclamation and southern end of breakwater, suggested to carry out model studies for various alternatives in the form of increase in width between reclamation and southern end of breakwater in stages from 500 m to 800 m and shallowing of the area to reduce the velocities and relocating the multipurpose berths and tug berths along the reclamation face.
8. The number of alternatives were studied and considering all technical and operational aspects, the revised master plan layout with modifications viz. increase in width between reclamation and southern end of breakwater by 670 m and aligning multipurpose berths along reclamation face happens to be the most suitable layout from tidal hydrodynamic consideration. The siltation studies carried out reveal that the total quantum of likely siltation in the dredged areas for the layout will be about 8.45 million cum per annum. Thus, there is reduction in quantum of likely siltation per annum by about 0.5 million cum per annum for the said layout as compared to that for revised master plan layout. Considering the above advantages, the layout (FIG. 53(B)) was finalized and termed as "Master Plan Layout".

9. The flow field at oil berths as well as LPG terminal reveals that the flow during flood and ebb approaches to the berths at an angle varying between 4° to 7° (during maximum current strength) with reference to the alignment of these berths. Similarly, the eddy generated at Southern end of breakwater will affect the flow field at oil berths. Considering above fact, it is desirable to shift the locations of Oil berths, LPG & LNG terminals by about 500 m along the breakwater towards north to achieve favorable flow conditions irrespective of phase of tide.
10. This master plan layout was used to evolve Phase-I layout (part portion of master plan layout) by JN port and was submitted vide email dated 05th October 2021 to CWPRS to study the same from tidal hydrodynamics considerations and to estimate the likely rate of siltation per annum. The reclamation area for Phase-I layout is about 970 Ha. while the dredged area for the same is about 981 Ha. The depths maintained in approach channel, dredged area will be 20 m and 17.5 m below CD respectively while in berth pockets, it is 19.5 m below CD. The studies carried out for Phase-I layout reveal that maximum velocities at harbour entrance, stoppage distance and turning circle are similar to that for Master Plan Layout. The current strengths at the berths are well below the permissible limits of PIANC guidelines. Hence, the said layout is suitable for Phase-I development of port at Vadhavan from tidal hydrodynamics considerations. The total quantum of likely siltation in the dredged areas will be about 6.45 million cum per annum.

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4. Design of breakwaters – Wave flume studies (CWPRS TR. No. 5648 of November 2018)
5. JNPT letter No. PPD/Manager/VP/2021/210 dated 11.03.2021
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7. Minutes of meeting held through VC dated 22.06.2021
8. Minutes of meeting held through VC dated 29.06.2021
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10. Minutes of meeting held through VC dated 20.07.2021
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## VISION

To be a world-class centre of excellence in hydraulic engineering research and allied areas; which is responsive to changing global scenario, and need for sustaining and enhancing excellence in providing technological solutions for optimal and safe design of water resources structures.

## MISSION

- To meet the country's need for basic & applied research in water resources, power sector and coastal engineering with world-class standards
- To develop competence in deployment of latest technologies by networking with the top institutions globally, to meet the future needs for development of water resources projects in the country effectively
- To disseminate information, build skills and knowledge for capacity-building and mass awareness for optimization of available water resources

## MAJOR FUNCTIONS

- Undertaking specific research studies relating to development of water resources, power and coastal projects
- Consultancy and advisory services to Central and State Governments, private sector and other countries
- Disseminating research findings and promoting/assisting research activities in other organizations concerned with water resources projects
- Contributions to Bureau of Indian Standards and International Standards Organization
- Carrying out basic and applied research to support the specific studies
- Contribution towards advancements in technology through participation in various committees at National and State Levels

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