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No: PH-III/2014/ Dated: 07/04/2014

The Chief Engineer
Mumbai Metropolitan Road Development Authority,
Bandra Kurla Complex,
Bandra (East)
**Mumbai 400 051.**

Sub: Submission of Technical report on Hydraulic model studies for proposed Mumbai Trans Harbour Link (MTHL), at Mumbai.

Sir,

Please find enclosed herewith Technical Report No.**5165** of **March 2014** on "Hydraulic model studies for the proposed Mumbai Trans Harbour Link (MTHL) Project at Mumbai" in duplicate.

Kindly acknowledge receipt of the same.

Thanking you,

Yours faithfully,

7/4/14

(M.D. Kudale)
Joint Director

Encl: As above

Government of India
Ministry of Water Resources

भारत सरकार
जल संसाधन मंत्रालय

सत्यमेव जयते


# केन्द्रीय जल और विद्युत अनुसंधान शाला
# CENTRAL WATER AND POWER RESEARCH STATION

**Technical Report No: 5165**
**March 2014**

# HYDRAULIC MODEL STUDIES FOR THE PROPOSED MUMBAI TRANS-HARBOUR LINK (MTHL) PROJECT AT MUMBAI

**S. Govindan**
**Director**

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COASTAL AND OFFSHORE ENGINEERING LABORATORY

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MARCH 2014

# HYDRAULIC MODEL STUDIES FOR THE PROPOSED MUMBAI TRANS-HARBOUR LINK (MTHL) PROJECT AT MUMBAI

S. Govindan
Director

## REPORT DOCUMENTATION SHEET

**Technical Report No: 5165** **Date:** March 2014

**Title:**

# HYDRAULIC MODEL STUDIES FOR THE PROPOSED MUMBAI TRANS-HARBOUR LINK (MTHL) PROJECT AT MUMBAI

**Officers Responsible for conducting the studies:**

The studies were carried out by Shri A A Purohit, Chief Research Officer with the assistance of S/Shri M. M. Vaidya, RO and K.A. Chavan, Research Assistant. The studies were carried out under the supervision of Shri. M. D. Kudale, Joint Director.

**Name and address of the organization conducting the studies:**

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**Name and address of Sponsoring Authority:**

Chief Engineer,
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Mumbai-400051

**Synopsis:**

The report describes the hydraulic model studies carried out by developing a mathematical model for Mumbai harbour (Thane creek) region to study the effect of proposed Mumbai Trans Harbour Link project on the flow conditions in Mumbai/Jawaharlal Nehru harbour area from tidal hydrodynamic considerations.

The oceanographic data such as tide, current etc required for model studies was provided by MMRDA at stipulated locations recommended by CWPRS. Based on latest bathymetry data for this region available at CWPRS, unstructured mesh (Finite Element) model is developed and is calibrated for prevailing tidal hydrodynamic conditions. The model developed is modified by incorporating substructure characteristics of all bridge piers (piles) at specified locations proposed by MMRDA for MTHL. The modified model is run for prevailing hydrodynamic conditions and information on tide levels, current strengths at various calibration points is extracted and compared with and without MTHL bridge condition. Also at various existing infrastructure facilities in the nearby area such as Pir-Pau, Mazgaon dock, BARC, NSICT & BPCL berth at JNPT and Marine oil terminal near Jawahar Dweep, comparison is made on current strength and water levels to assess effect of MTHL bridge on flow conditions. The model was well calibrated for prevailing hydrodynamic conditions. The effect of bridge piles is seen on current pattern near few calibration points on western part (Island city), as these locations are in close proximity of alignment of MTHL. However, the effect of MTHL on existing facilities reveals that there is insignificant effect on facilities in Mumbai and JN port area. Due to close proximity of Pir-Pau jetty to MTHL alignment, there is seen to be reduction in current strength by about 10% with that of existing condition. However, overall effect of MTHL in Thane creek area is even less than 2% of total tidal flux entering or leaving Thane creek. As such, MTHL bridge will not have any detrimental effect on overall Thane creek area from tidal hydrodynamics considerations.

**Key Words:**

Calibration, Flood, Ebb, Tides, Finite Element Model, MTHL, Hydrodynamics, Flow Pattern etc.

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# HYDRAULIC MODEL STUDIES FOR THE PROPOSED MUMBAI TRANS-HARBOUR LINK (MTHL) PROJECT AT MUMBAI

**Technical Report No:** 5165 **Month:** March 2014

## 1. INTRODUCTION

Mumbai is a mega city of India amongst the four mega cities viz. New Delhi, Chennai, Kolkata and is situated on the west coast of the country in the state of Maharashtra. It is not only a Capital of the state but also a financial capital of the country. The city is well equipped with various infrastructures and connected to the rest of the country with transport facilities like rail, roads network and also to other countries with air and waterborne transport connectivity. Presently one airport and two major seaports like Mumbai Port (MbP) and Jawaharlal Nehru Port (JNP) caters for the demand of international traffic. These seaports are situated in Thane creek at Latitude 18° 54′ N, Longitude 72° 49′ E and Latitude 18° 56′ 43" N, Longitude 72° 56′ 24"E respectively. The harbour area of these ports is protected from waves by Salsette/Mumbai Island on the west and mainland on the east. The entrance to these ports is from south - west with a natural deep channel along the longitudinal axis of the harbour (Fig.1).


FIG-1:LOCATION OF MUMBAI AND JAWAHARLAL NEHRU PORTS IN THANE CREEK

The development of Salsette Island from 17th century onwards has seen large changes. The southern part of Salsette Island was a group of seven islands separated by shallow lagoons, narrow tidal channels and marshes. The East India Company was instrumental in reclaiming the area between these islands and joining them together and also for building docks. The joining of islands created a natural barrier to the ocean waves predominant from west to southwest directions and provides protection to the docks and other infrastructure facilities developed inside in Thane creek from external waves. The entrance to the harbour lies between Prongs reef marked by a lighthouse at the southernmost tip of Mumbai and Thal reef lying off the mainland to the southeast. The mainland to the east of harbour is dominated by the hills of Karanja, while the Mumbai city lies to the west. Three main docks viz. Indira, Princess and Victoria are located on eastern coast of Mumbai island. The approach to Indira dock is through a branch channel taking off from the main channel east of Middle ground while for Princess dock, the approach is from north of Cross island.

Two islands viz. Jawahar dweep (Butcher) and Elephanta are located to the north east of the harbour. The Marine Oil Terminal (MOT) berths (1, 2 and 3) are projected from Butcher Island towards east. The fourth oil berth is connected by an approach trestle originating from Butcher Island in the southward direction with berthing structure located alongside the main channel. Elephanta Island is about 2 km east of Butcher Island. To the northern extreme of Mumbai harbour is the old Pirpau pier. Approach to this pier is from the northern reach of main channel leading to Thane creek. West of this Trombay channel, there exists natural depth which has been dredged to the required levels. The new port viz. Jawaharlal Nehru Port is located on the east of Elephanta Island.

The peculiarity of Mumbai harbour is that it has ultra-wide estuarine entrance of about 10 km and it extends in Thane creek having water spread up to 30-40 km north. Also type of tide prevailing being macro in nature, large volume of tidal flux gets exchanged in and out of Thane creek during tidal cycle, which is semi-diurnal in nature. This results in generation of strong tide induced currents during flood/ebb tide. Due to rapid industrialisation and Mumbai being traditionally the epicenter of India's commerce, the narrow stretch of land (Mumbai Island) has seen a steady increase in population in the last three decades despite obvious spatial constraints. Hence the development of Navi Mumbai has been identified as an urgent requirement for easing the pressure on the island and many suburbs are being developed on the eastern side of Mumbai City in Thane, Panvel and Dharamtar creek areas either by various Governmental or Non-Governmental organisations.

However in view of lack of easy connectivity to the mainland, it has stunted the growth and the pressure on the island's infrastructure continues to mount. In order to cater for the need of road traffic and avoid the problem of traffic Jams, Maharashtra Govt. had constructed number of flyovers in the Mumbai city and still more are being built. However they are not sufficient and hence in order to solve the problem of traffic jams right from Fort area in Mumbai up to Vashi city and beyond, presently all vehicles has to pass Sion/Chembur area to reach Vashi bridge, which takes considerable time of about 2-3 hours during peak hours of traffic. Hence in order to connect Island of Mumbai (west side) to main land (east side) there is a great need to have Mega Bridge crossing the Thane creek. The Mumbai Metropolitan Region Development Authority (MMRDA), a Government of Maharashtra Undertaking, intends to provide a road and metro-link between Sewri on the island city of Mumbai with Chirle in Navi Mumbai on the mainland side (Fig.2).


**FIG-2: LOCATION PLAN OF PROPOSED MTHL BRIDGE OVER THANE CREEK**

The developments in Navi Mumbai area are in the form of real estates, road/rail networks, reclamations and waterfront structures in the form of Jetties, Wharfs etc. Major port like JNP is also developing at an alarming rate by planning a mega container terminal of the order of kilometers and reclamation in few hundred Hectares for stacking the containers. These developments will have some effect on siltation in the Harbour area. At present, the rate of siltation is not alarming, but it cannot be ignored also. In Mumbai Harbour, tidal action is dominant than waves, it creates movement of large water mass to fill and empty the creeks, resulting in movement of sediments. The bed material in the harbour is very fine in nature which is brought in suspension by disturbance and is transported to and fro depending on direction and speed of tidal current. Tidal current plays an important role in transportation and redistribution of bed material within the harbour. In view of MTHL bridge being planned entirely crossing the Thane creek, wherein many piers are to be constructed, it may affect flow field.

M/s MMRDA keeping in mind these aspects have referred the studies to CWPRS vide letter dated 8th Oct 2012 to study the impact of MTHL from tidal hydrodynamic considerations. This report describes the studies carried out to assess the effect of proposed development of MTHL on flow pattern/condition in Thane creek from tidal hydrodynamic considerations.

## 2. HISTORY OF PREVIOUS STUDIES AT CWPRS & MTHL PROPOSAL

The Government of Maharashtra earlier way back since 1970 referred various hydraulic model studies regarding a proposal to link Mumbai Island with the main land. These studies consist of primarily two alternatives i.e. 1) Southern link (Colaba to Uran) & 2) Northern link (Sewri to Nhava) as shown in Fig.3.

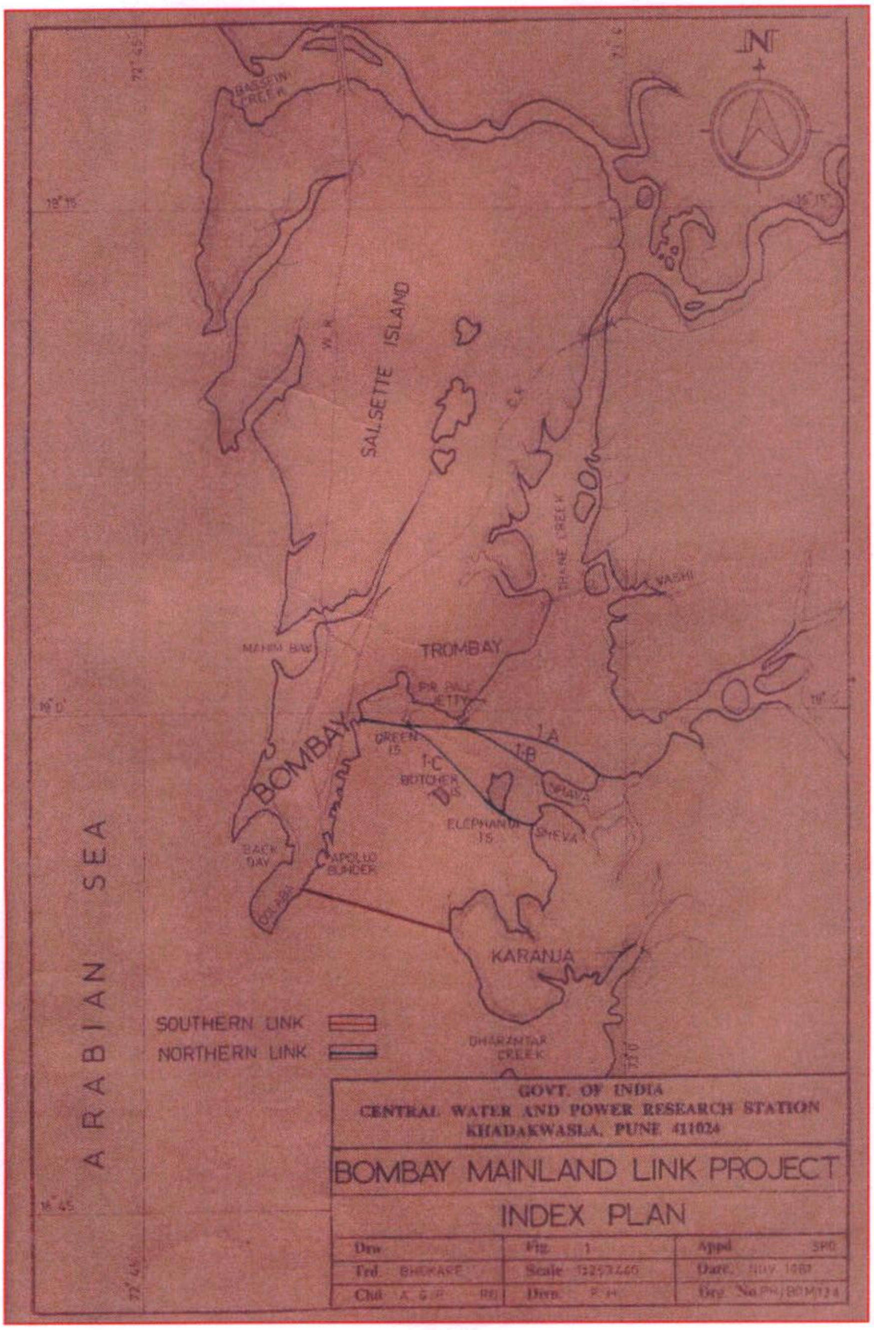


FIG-3: LAYOUT PLAN OF SOUTHERN & NORTHERN LINK STUDIED AT CWPRS

The studies related to Southern link include a complete submarine tunnel, or a bridge with adequate headroom for navigation or a link partly by bridge and partly by submarine tunnel below navigational channel. The results of these studies were reported vide CWPRS Specific Note No.1187 dated 22/11/1971. Subsequently in 1981 the studies related to Northern link were carried out at CWPRS and reported vide Specific Note No.2033, dated 20/3/1982. Further to these, nine (9) different alternatives based on recommendation of CWPRS and other considerations were studied on physical model of Mumbai harbour [Scale: 1:1000 (H), 1:100 (V)] available at CWPRS. Based on the tests carried out, notes were submitted bearing Nos. 2099 of 5/1/1983 and 2130 of 23/6/1983 indicating that before finalisation of particular proposal, detailed hydraulic model studies will have to be carried out. In 1982, an International Consortium of Consultants led by Peter Frankael and Partners (PFP), UK, was appointed by the Steering Group to carry out a feasibility study and to prepare detailed project report for the proposed Mumbai Trans-Harbour Link (MTHL). PFP submitted their feasibility study report in 1983. Six alternative alignments between Sewri on Mumbai Island and Nhava on the main land were identified and studied. All the alignments started from Sewri. Out of these, four were proposed to terminate to the north and two to the south of Jawaharlal Nehru Port (JNP). The route length varied from 20 Kms to 23 Kms.

The study recommended the northern most alignment for the preferred transportation link. The recommended alignment was 22.61 Kms long and comprised interchanges at Sewri and Nhava, sections across the mudflats over embankments on both sides of Sewri & Nhava, creek portion over viaducts/bridges and Nhava approach at grade. The recommended northern alignment was modified by the Expert Group by shifting it to south of the jetty head of BARC in order to satisfy requirements of Bhabha Atomic Research Center (BARC).This shifted alignment was approved by Prime Minister's Office (PMO) in 1984.This alignment is also as per the Regional plan of Mumbai – Metropolitan Region. Consulting Engineering Services (CES) were appointed to review and update the feasibility study for the recommended northern alignment in 1996 taking into account the subsequent developments after completion of 1982 study. During the study, CES suggested further modifications to the alignments.

M/s MMRDA, vide letter dated 10/2/2012, informed CWPRS that the task of implementation of MTHL is assigned by Govt. of Maharashtra to MMRDA vide letters dated 4/2/2009, 8/6/2011. The MTHL will be a 22 km long Sea link between Sewri on island city and Nhava (Chirle) on main land side to facilitate overall development of main land and alleviate the traffic congestion on island city. MMRDA seek the advice of CWPRS by way of offering the comments on alignment of MTHL under consideration. Based on detail drawings received, CWPRS offered comments about the Highest High Tide Level (HHTL), top level of pier caps, thickness of pile caps in mud flat region etc. A meeting was held at MMRDA Office, Mumbai, on 28/8/2012 and it was decided that in order to reduce obstruction to the tidal flow, the bottom of pile caps should be kept at +5.6 m, considering the HHTL at Apollo Bundar (+5.38 CD) plus allowance for the tide level difference at the bridge location with respect to tide at Apollo Bundar. In view of majority of the portion of MTHL is proposed to be crossing Thane creek, the MMRDA Official desires that even though bridge piers being on piles and there are no solid obstructions in the form of approach bund on tidal flats at both the approach ends and pile cap in these approach regions being below existing bed level and pile caps bottom in remaining area will be kept well above highest water level, mathematical model studies need to be carried out to study the effect of bridge piles on flow pattern in the creek from tidal hydrodynamics. Accordingly, for conducting mathematical model studies, oceanographic data required for the model studies are to be provided by MMRDA. Also, information about detailed dimensioned drawings of alignment of bridge, size of pile caps, piles, number of piles, spacing of piles, dimension of piers, grain size analysis of bed samples etc. are also to be provided by MMRDA.

## 3. SALIENT FEATURES OF MTHL

The Mumbai Trans Harbour Link (MTHL) is proposed to be developed as an Expressway link comprising of a six lane dual carriageway bridge connecting Sewri on Mumbai Island to Nhava on the mainland. MTHL is proposed to commence at grade from the east side of Sewri Railway Station on Harbour Line of Central Railway further to Timber Pond Depot along Sewri Container Depot and terminate north of Chirle village near Nhava through an interchange to National Highway-4B completed. MTHL will reduce the distance between the island city and the mainland by 17km viz-a-viz the existing road link and will help to save approximately an hour in travel time. Also, development of mainland along with the construction of the Navi Mumbai international airport will lead to increased traffic between the mainland and the island city. As such the MTHL will be useful to reduce the burden of traffic in future.

### 3.1 Key Features of the proposed MTHL

- The Link will have a 6-lane facility exclusively for the use of fast moving vehicles with controlled access and connection to Eastern Freeway in the Island city of Mumbai and NH-4B near Chirle village on the main land.
- A minimum vertical clearance of 25.2 m between the bridge deck and the Highest High Tide Level (HHTL) will be provided for navigational spans, while the minimum vertical clearance of 9.1 m is provided elsewhere.
- 1.5 m wide central median with appropriate landscaping to enhance the environment as well as to avoid glare.
- Overall width of deck (28 m) consists of 11.25 m wide carriageway with 1.2 m wide utility corridor on either side of the carriage way. Anti crash barriers are provided at the edge of carriageway for protection of fast moving traffic. Provision of fenders for the protection of foundations against ship impact in the navigational spans.

- Foundations are proposed on piles with substructure of wall type pier as shown in (Fig-4).

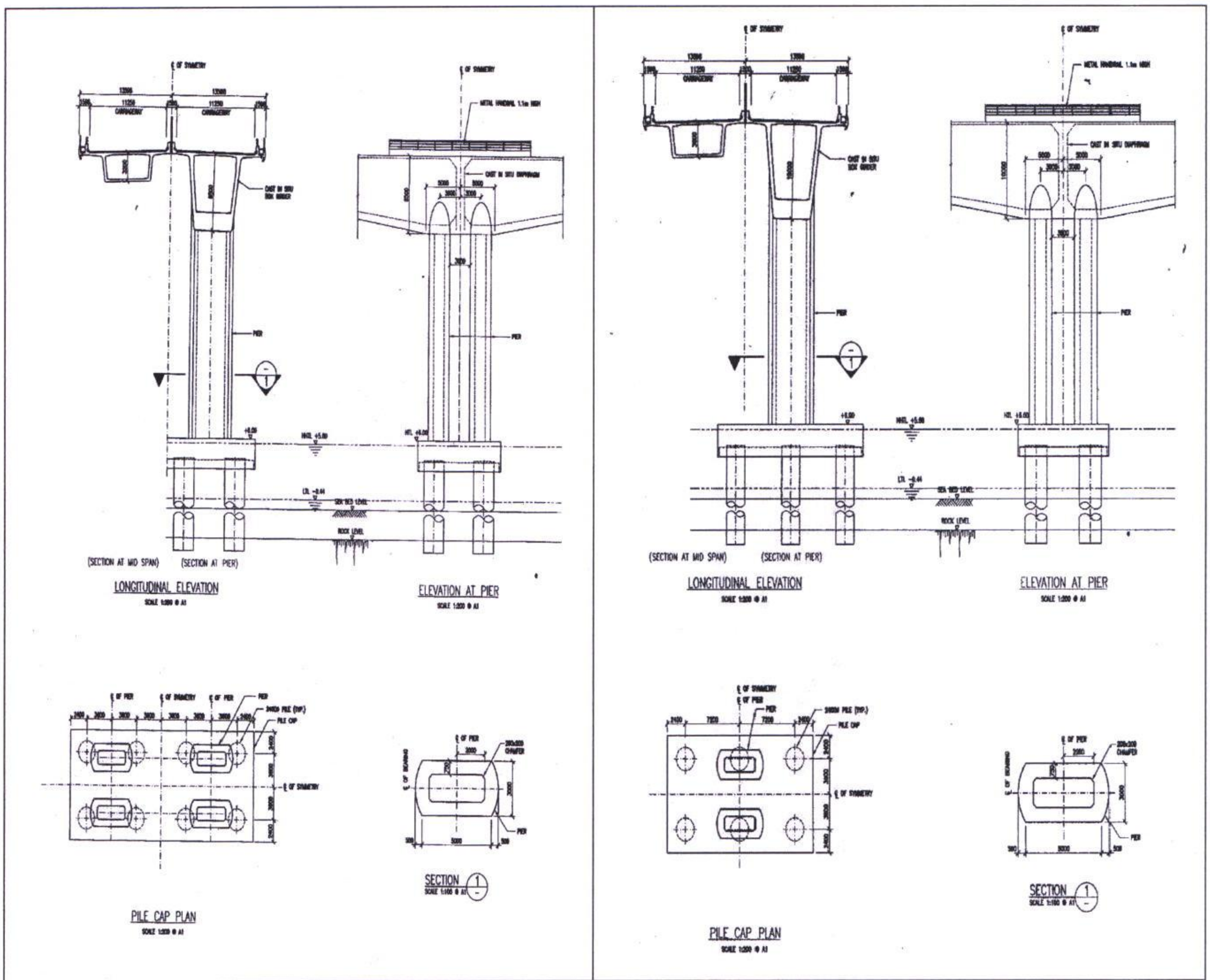


**FIG- 4: TYPICAL CROSS SECTION OF PIERS ALONGWITH PILES & PILECAPS**

## 4. SCOPE OF STUDIES

Following are the broad Terms of Reference considered to carry out the mathematical model studies and are reported by CWPRS letter No. TC/2012/1403/3987,dated 27th Nov.2012.

i) Develop a mathematical model of Thane creek including Port area of Mumbai, Jawaharlal Nehru and part portion of Panvel creek as well as islands in Thane creek up to Vashi bridge.

ii) Simulate tidal hydrodynamic conditions prevailing in Thane creek by calibrating the model for the field data supplied by MMRDA.

iii) Study the flow field at various locations and in the vicinity of proposed alignment of MTHL bridge under existing bathymetry condition.

iv) Incorporate proposed MTHL bridge with substructure of various piers for the alignment proposed on the developed model and study the effect of MTHL bridge on flow field at various locations mentioned above.

## 5. FIELD DATA COLLECTION

The various oceanographic parameters such as tides, currents and grain size analysis of bed material at various locations (Fig.5) were provided by MMRDA to CWPRS for conducting the model studies under consideration.

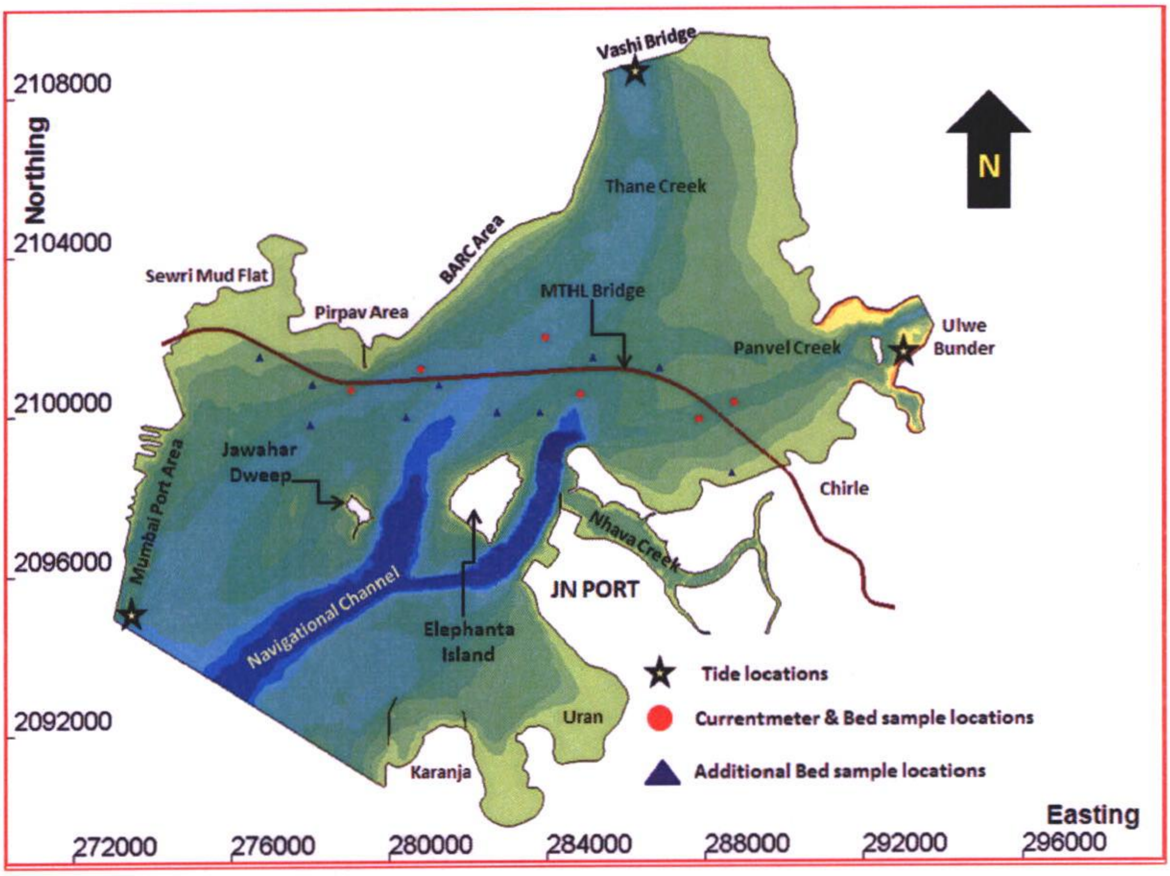


**FIG-5:LOCATIONS OF FIELD DATA COLLECTION IN THANE CREEK FOR MTHL**

### 5.1 Tidal Measurement and Analysis

Simultaneous tidal measurements were made at three stations viz. at Apollo bunder, Vashi bridge in Thane creek and Ulwe Bundar in Panvel creek from 08.05.2013 to 03.06.2013. The data was collected by M/s Fugro Survey India Pvt. Ltd for M/s MMRDA at above three locations w.r.t CD at Apollo Bundar. The locations of tidal observations are given in Table -I

**TABLE- I**

**Locations of Tidal Measurements in Mumbai Harbour**

| Location ID [WGS 84 Datum; UTM Zone 43N] | Latitude (N) | Longitude (E) | Easting (m) | Northing (m) |
|---|---|---|---|---|
| BPX (For Apollo Bunder) | 18°55'44.90" N, | 72°50'38.65"E | 272950 | 2094373 |
| Vashi Bridge | 19°03'37.52"N, | 72°57'51.26"E | 285778 | 2108756 |
| Ambuja jetty Ulwe | 18°59'32.35"N, | 73°01'42.37"E | 292451 | 2101140 |

The tidal data recorded at all above three locations is given in Figs.6 ( A), 6 (B ) and 6 (C) are at Apollo bunder, Vashi bridge and Ulwe Bundar respectively and all levels are with respect to CD at Apollo Bunder.

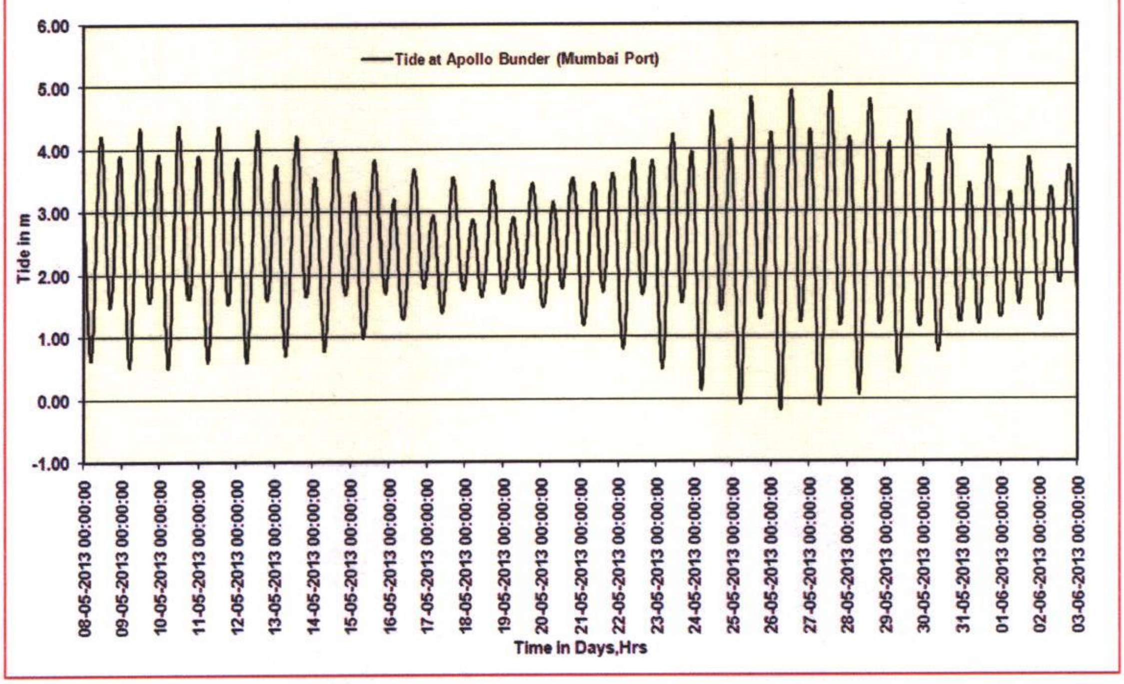


**FIG-6(A):TIDE MEASURED AT APOLLO BUNDER**

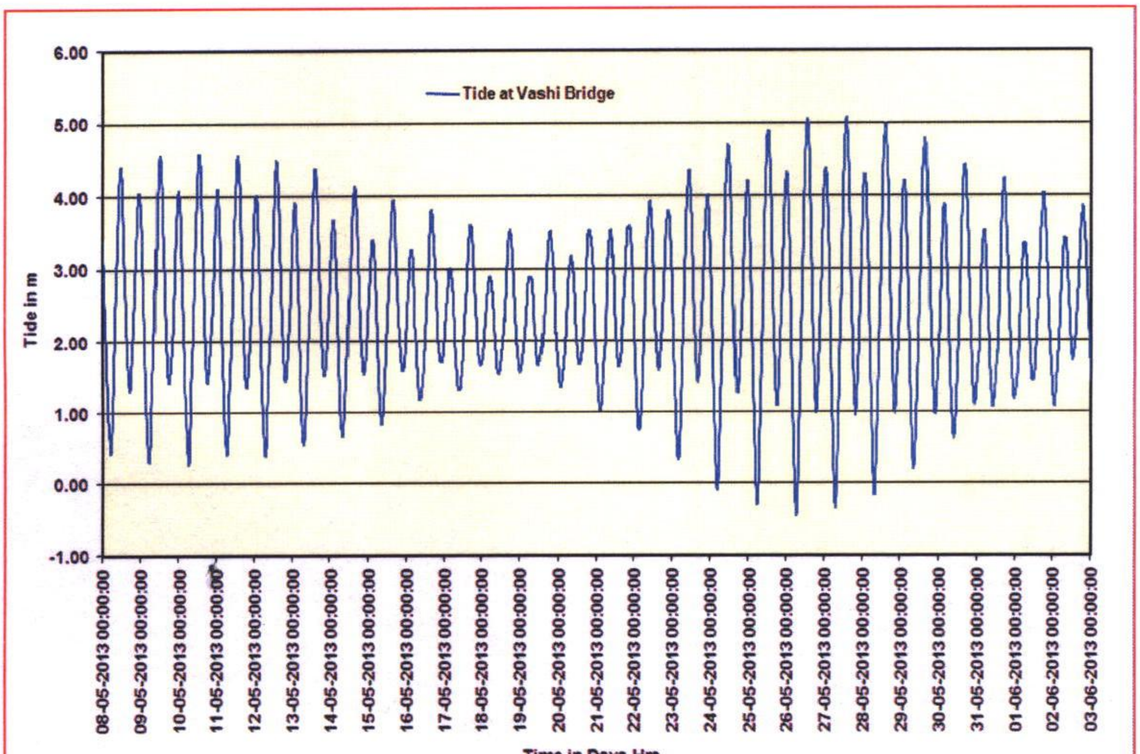


**FIG-6(B): TIDE MEASURED AT VASHI BRIDGE**

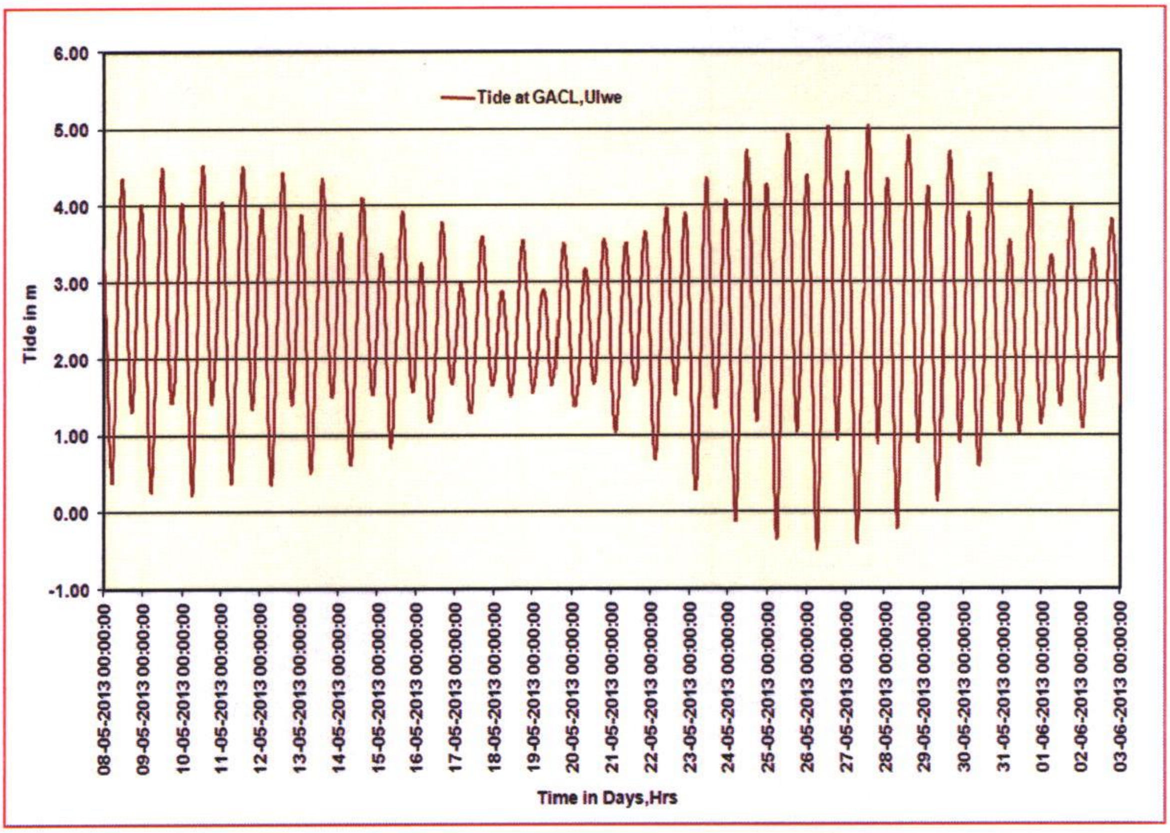


**FIG-6(C): TIDE MEASURED AT ULWE BUNDER**

The data collected during spring tides with tidal range of approximately 5 m, there appears to be amplification of tide between Apollo bunder and Vashi bridge by about 40 cm. The distance between these two sites is about 25 Km. The low water lag during spring tide is about 10-20 minutes, while high water lag varies up to 30 minutes. During neap tides, there is no tidal amplification between Apollo bunder and Vashi, while the time lags of low and high waters are about 10 minutes.

The tidal amplification between Apollo bunder and Ulwe bridge in Panvel creek during spring tides is around 42 cm. The high water lag during spring tide varies from 15 to 20 minutes, while low water lag is about 20 minutes. During neap tides the tidal amplification between Apollo bunder and Ulwe is insignificant, while high and low water lags are about 10 minutes. The data supplied by MMRDA indicates that there is no phase shift between tide at Vashi and Ulwe.

## 5.2 Current Measurements and Analysis

The actual position wherein measurement of current strength is carried out at six locations is given below in Table-II.

**TABLE-II**

**Locations of Current Measurements In Mumbai Harbour**

| Location ID [WGS 84 Datum; UTM Zone 43N] | Latitude (N) | Longitude (E) | Easting (m) | Northing (m) |
|---|---|---|---|---|
| Location 1 | 18°59'11.83" | 72°54'04.31" | 279044 | 2100663 |
| Location 2 | 18°59'28.98" | 72°55'04.06" | 280798 | 2101170 |
| Location 3 | 18°59'09.75" | 72°57'22.44" | 284839 | 2100531 |
| Location 4 | 18°59'55.88" | 72°56'52.27" | 283973 | 2101960 |
| Location 5 | 18°58'50.62" | 72°59'05.49" | 287847 | 2099908 |
| Location 6 | 18°59'04.35" | 72°59'36.04" | 288745 | 2100320 |

The data measured at various current locations from 27th May 2013 to 3rd June 2013 at mid depth is shown in Fig 7(A) to Fig 7(F).

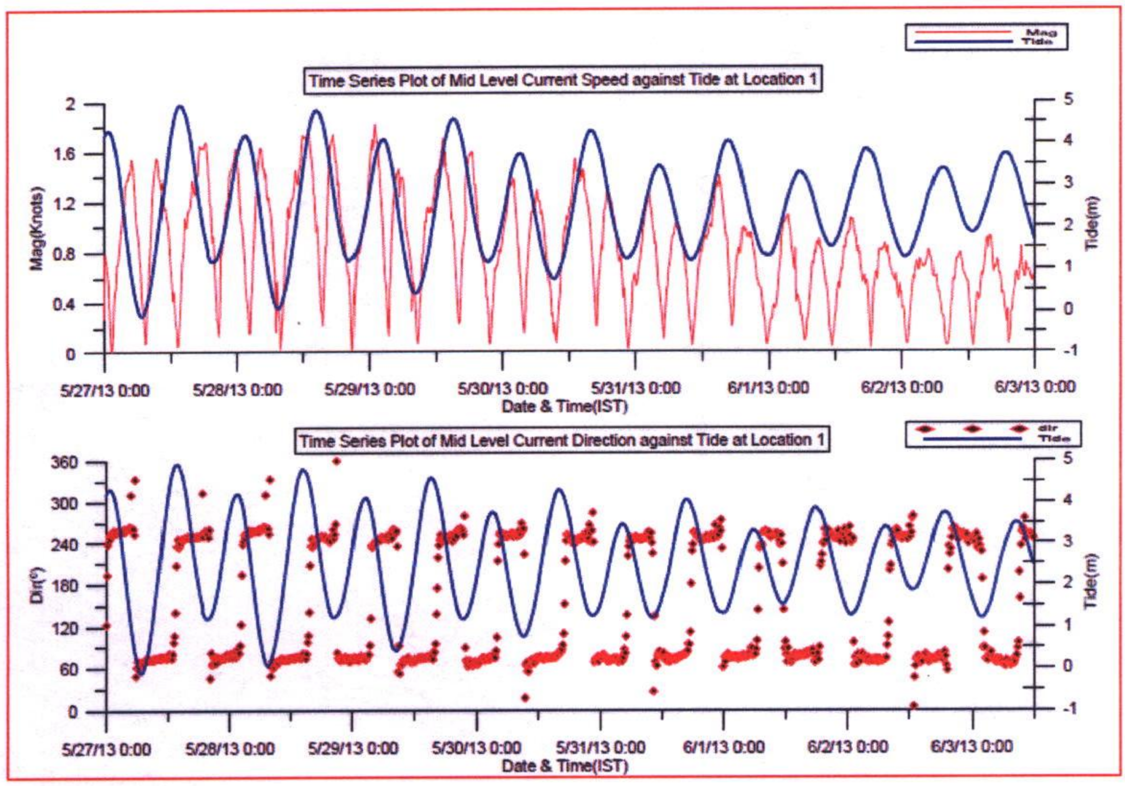


**FIG-7(A): MEASURED CURRENT STRENGTH & DIRECTION AT LOCATION-1**

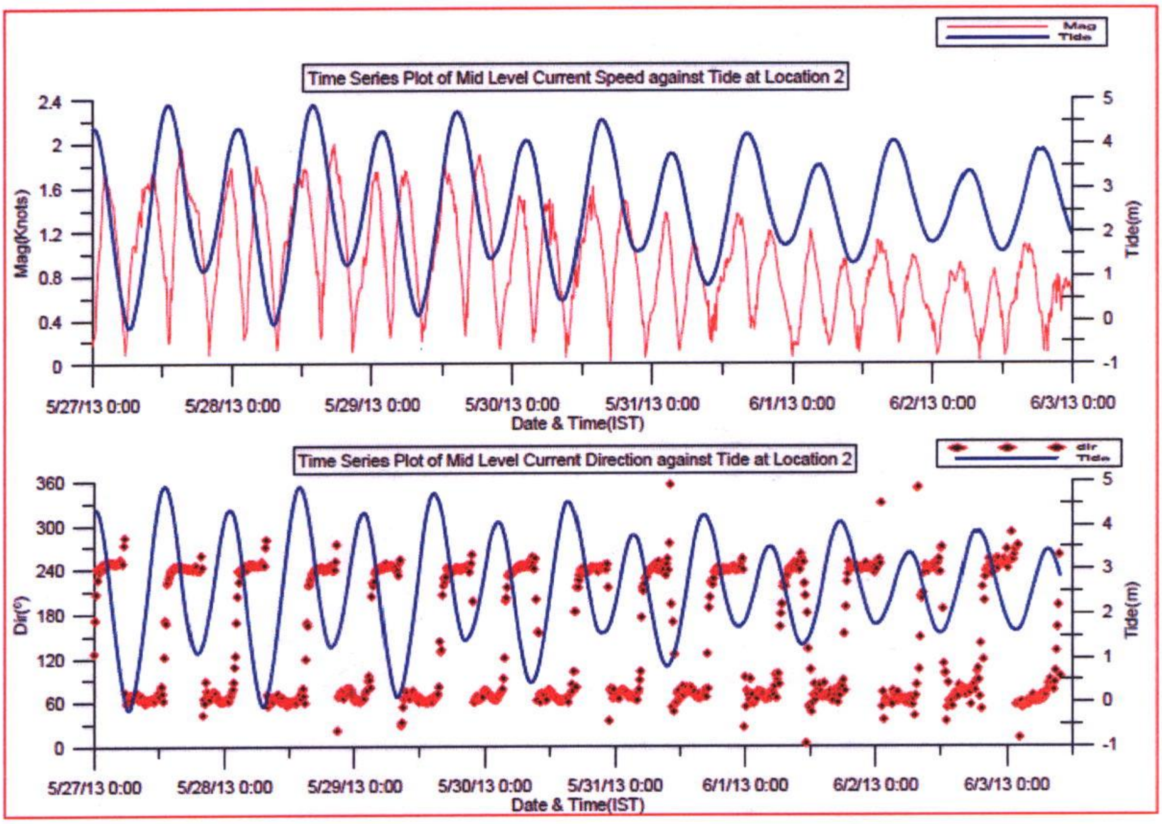


**FIG-7(B): MEASURED CURRENT STRENGTH & DIRECTION AT LOCATION-2**

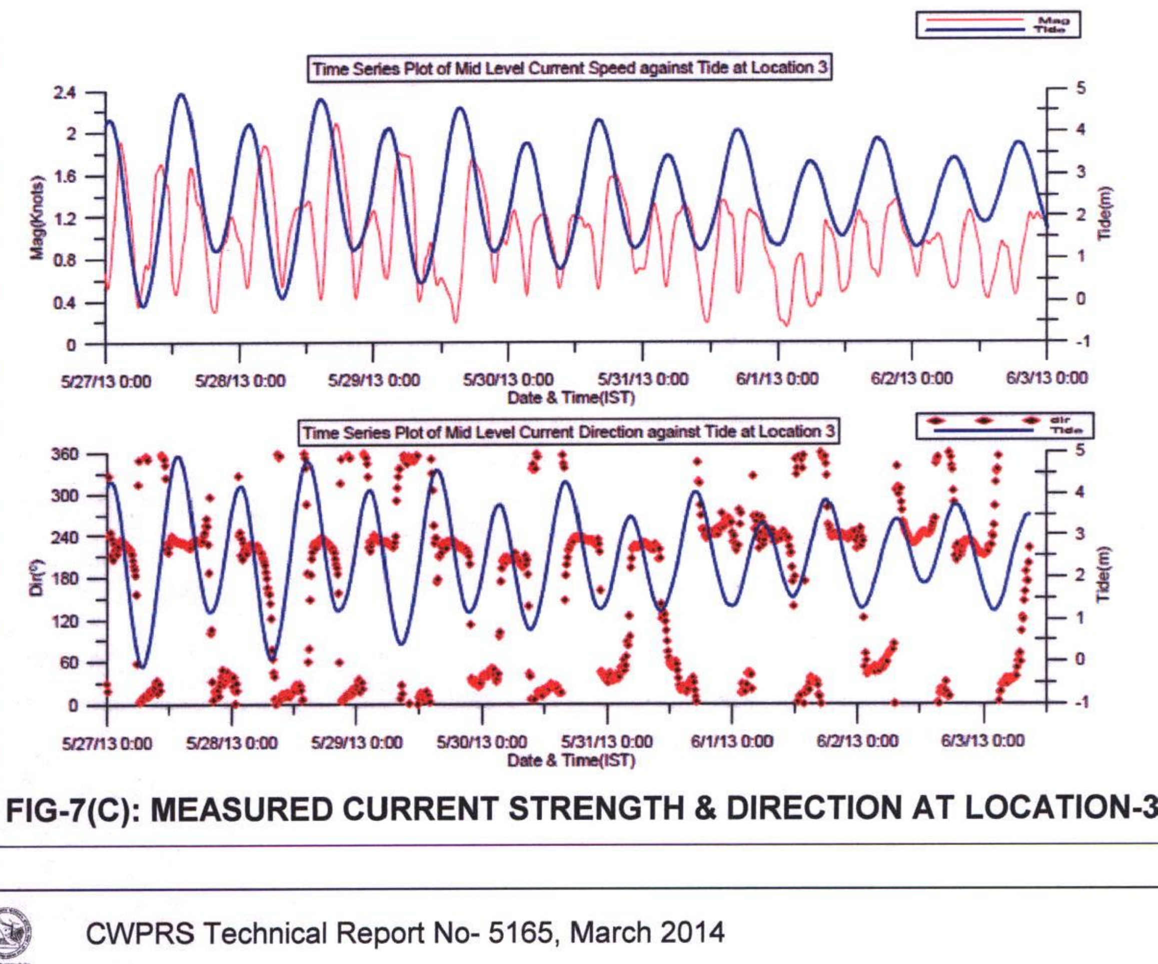


**FIG-7(C): MEASURED CURRENT STRENGTH & DIRECTION AT LOCATION-3**

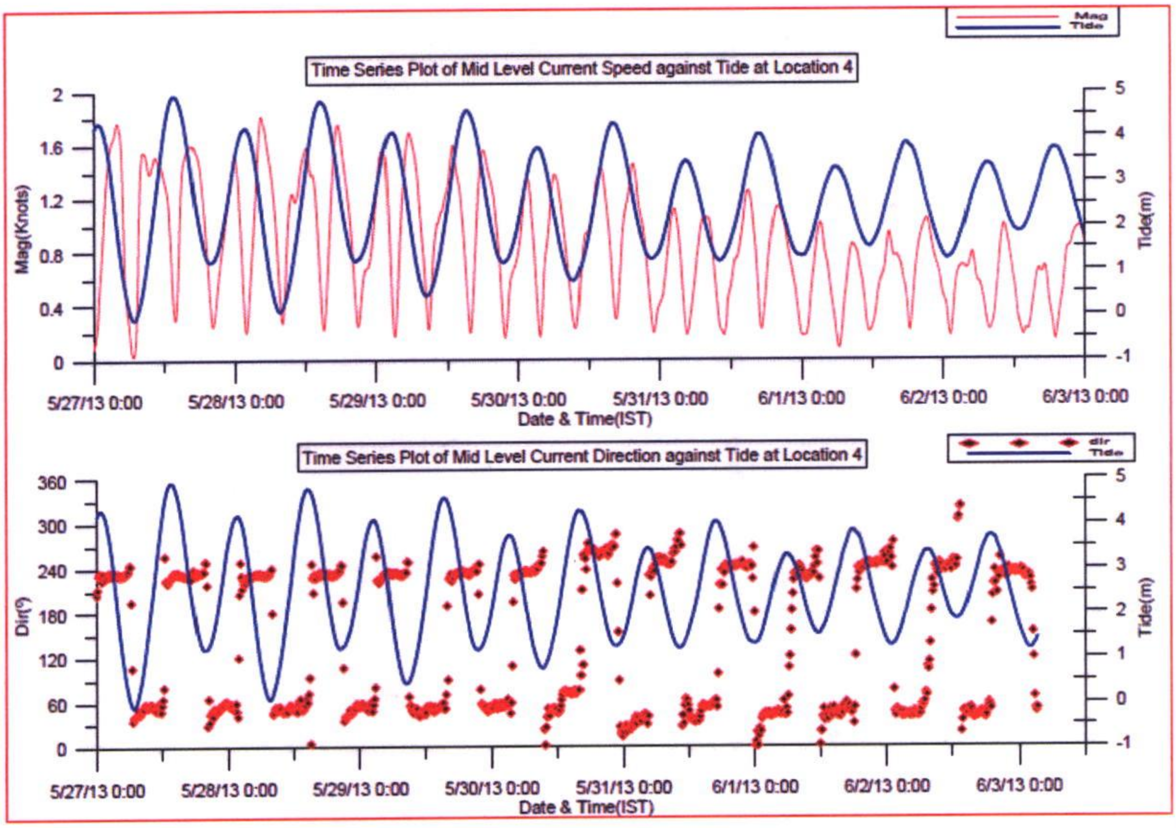


**FIG-7(D): MEASURED CURRENT STRENGTH & DIRECTION AT LOCATION-4**

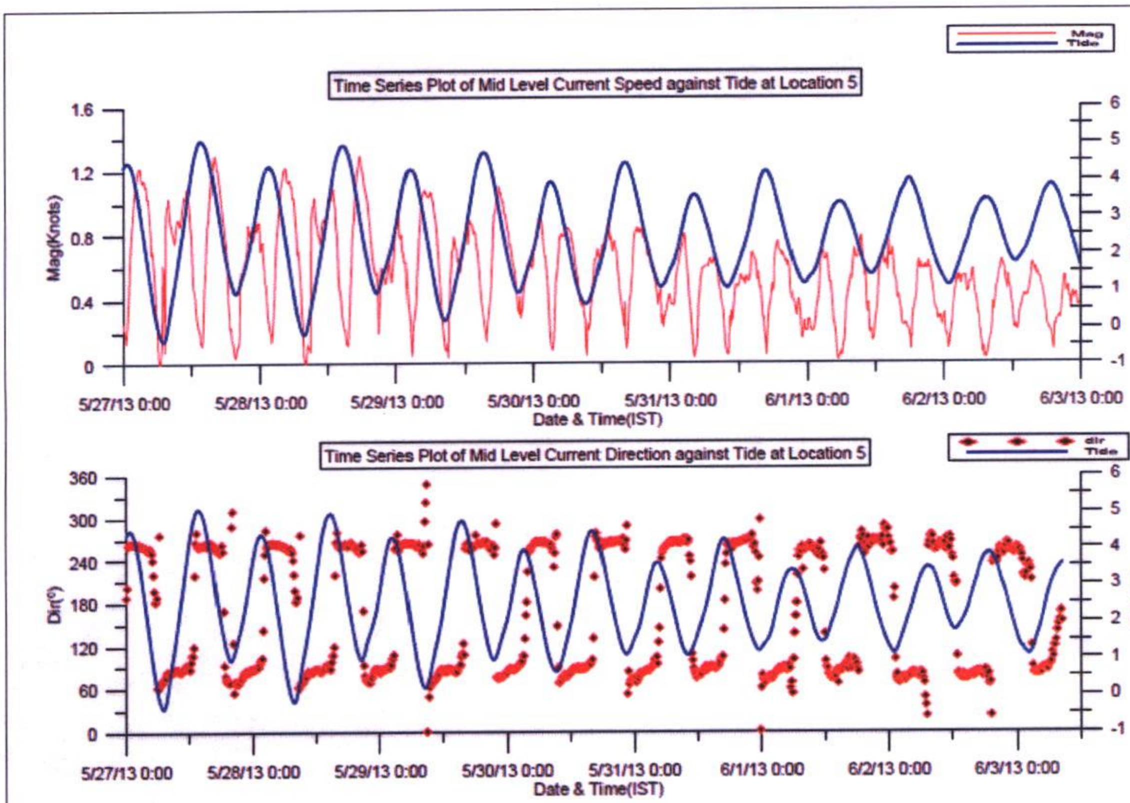


**FIG-7(E): MEASURED CURRENT STRENGTH & DIRECTION AT LOCATION-5**

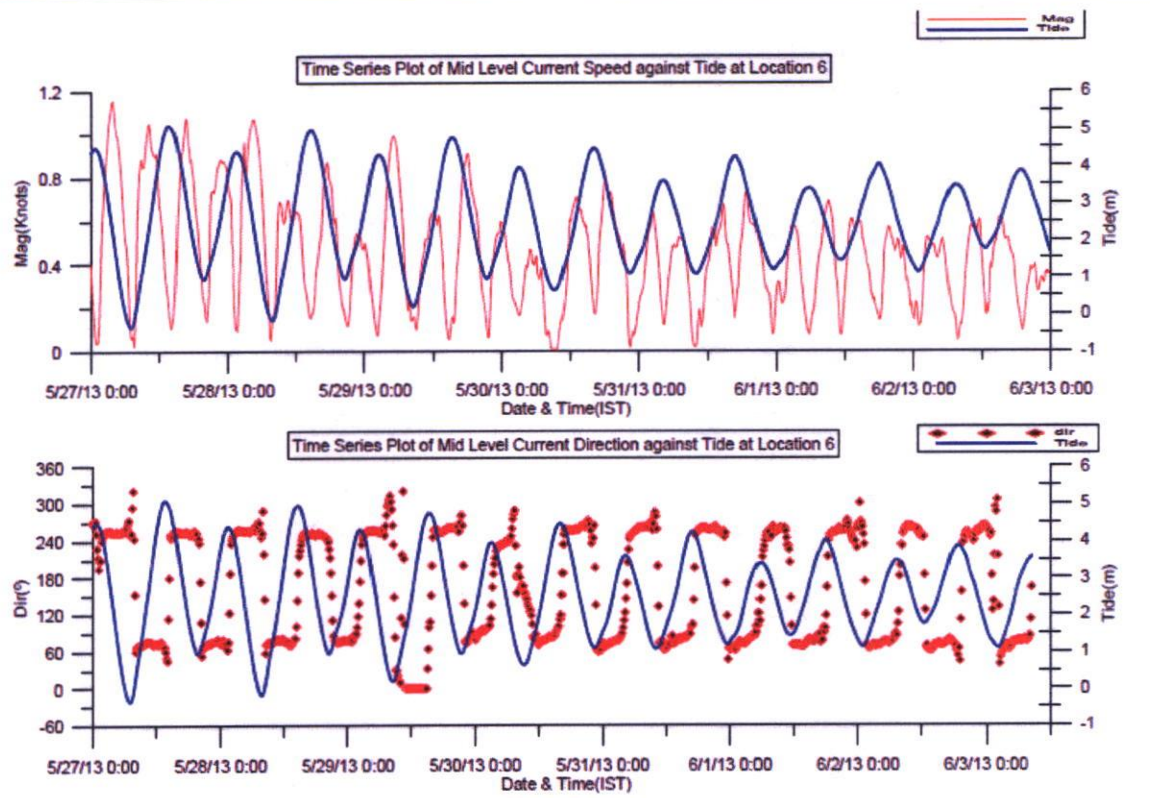


**FIG-7(F): MEASURED CURRENT STRENGTH & DIRECTION AT LOCATION-6**

From the above figures of current measurements, it can be seen that during spring tide, current strength is relatively more in western area of harbour than in eastern area. The peak spring flood currents in Thane creek area vary from 0.5 m/sec. to 0.93 m/sec., while the peak ebb current strength varies from 0.56 m/sec. to 1.07 m/sec. The strength of the current is observed to be maximum in the deeper portion of navigational channel leading to Vashi. The ebb current direction is fairly uniform. In general, it is observed that ebb currents are stronger than flood currents. The peak neap current strength during flood varies from 0.32 to 0.49 m/sec, while peak neap ebb current strength varies from 0.21 to 0.63 m/sec.

The current directions observed during flood tide are seen to be varying between 60-85 degree north near western side (island city side), while at central portion behind the Elephanta wake zone, there is seen to be drastic change in current direction during flood tide and is between 20-50 degree north. The current direction at measurement locations near main land side happens to vary between 65-90 degree north in view of flow moving towards tidal flats approaching mouth of Panvel creek.

### 5.3 Grain Size Analysis of Bed Material

The collection of bed samples at various locations in the vicinity of proposed alignment of MTHL bridge from Sewri mud flat up to the coastline on Chirle side was collected at sixteen places and the details are given in Table-III. A typical grain size analysis curve to determine $D_{50}$ of bed material is shown in Fig. 8. The analysis reveals that bed material is silty clay.

**TABLE-III**

**ANALYSIS OF BED SAMPLES IN THANE CREEK FOR MTHL STUDIES**

**Laboratory Soil Test Summary**

| | | | |
|---|---|---|---|
| Project : | Laboratory testing of Soil samples for Fugro Survey India Pvt Ltd. | Job No. | 538/13 |
| Client : | Fugro Survey India Pvt Ltd. | Date | 01.06.2013 |

| Sr. No. | Sample Ref. | Co-ordinates | | CLASSIFICATION TEST Particle Size Distribution (%) | | | | | | Dia of Particle at 50% Finer than Particle size, $D_{50}$ | Remarks (**) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sand | | | | | |
| | | Easting | Northing | Clay | Silt | Fine | Medium | Coarse | Gravel | | |
| Quantity | | m | m | 16 | 16 | 16 | 16 | 16 | 16 | 16 | |
| 1 | CM 1 | 279135 | 2100644 | 49 | 50 | 1 | 0 | 0 | 0 | 0.0020 | |
| 2 | CM 2 | 280791 | 2101260 | 58 | 40 | 2 | 0 | 0 | 0 | 0.0010 | |
| 3 | CM 3 | 284817 | 2100526 | 60 | 36 | 4 | 0 | 0 | 0 | 0.0018 | |
| 4 | CM 4 | 284014 | 2102058 | 49 | 49 | 2 | 0 | 0 | 0 | 0.0020 | |
| 5 | CM 5 | 287700 | 2099934 | 68 | 30 | 2 | 0 | 0 | 0 | 0.0010 | |
| 6 | CM 6 | 288768 | 2100495 | 64 | 32 | 4 | 0 | 0 | 0 | 0.0012 | |
| 7 | 1 | 276723 | 2101506 | 43 | 55 | 2 | 0 | 0 | 0 | 0.0022 | |
| 8 | 2 | 278066 | 2100809 | 55 | 43 | 2 | 0 | 0 | 0 | 0.0018 | |
| 9 | 3 | 278008 | 2099807 | 54 | 44 | 2 | 0 | 0 | 0 | 0.0019 | |
| 10 | 4 | 280432 | 2099972 | 47 | 53 | 0 | 0 | 0 | 0 | 0.0021 | |
| 11 | 5 | 281260 | 2100779 | 52 | 46 | 2 | 0 | 0 | 0 | 0.0020 | |
| 12 | 6 | 282740 | 2100094 | 76 | 24 | 0 | 0 | 0 | 0 | 0.0010 | |
| 13 | 7 | 283826 | 2100095 | 45 | 45 | 9 | 1 | 0 | 0 | 0.0020 | |
| 14 | 8 | 285154 | 2101454 | 46 | 46 | 4 | 3 | 1 | 0 | 0.0020 | |
| 15 | 9 | 286852 | 2101204 | 12 | 6 | 40 | 33 | 4 | 5 | 0.2980 | |
| 16 | 10 | 288681 | 2098562 | 56 | 44 | 0 | 0 | - 0 | 0 | 0.0012 | |

| Sample No. | Sample Type | Sample ID No. |
|---|---|---|
| CM 1 | Grab Sample | 538/M- CM 1/D1 |

| Clay | Silt | Sand | | | Gravel |
|---|---|---|---|---|---|
| | | Fine | Medium | Coarse | |
| 49 | 50 | 1 | 0 | 0 | 0 |

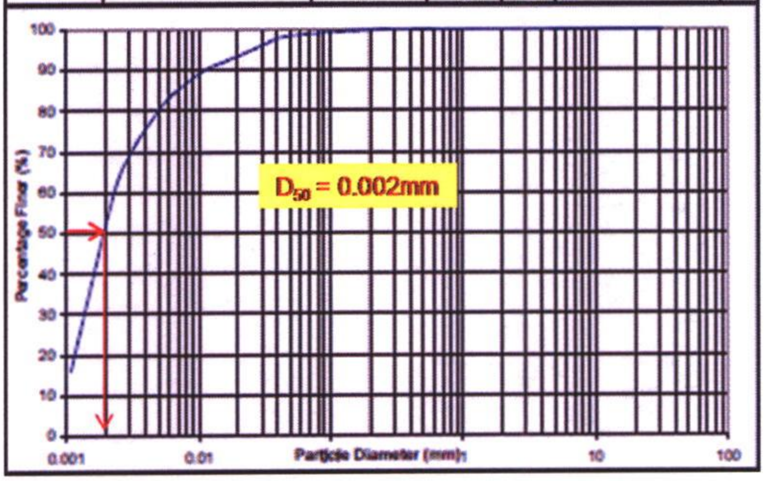


**FIG-8: SIEVE ANALYSIS INDICATING $D_{50}$ SIZE OF BED SAMPLE**

## 6. DEVELOPMENT OF MATHEMATICAL MODEL

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

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

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

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

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

$$\frac{\partial T}{\partial t} + \vec{u}.\vec{\nabla}(T) = S_T + \frac{1}{h}div(h\nu_t\vec{\nabla}T) \qquad \text{------------------------ Tracer conservation}$$

in which,

| | | | |
|---|---|---|---|
| h | (m) | ---------------------------------------- | depth of water |
| u,v | (m/s) | ---------------------------------------- | velocity components |
| T | (g/l ) | ---------------------------------------- | non buoyant tracer |
| g | ($m/s^2$) | ---------------------------------------- | gravity acceleration |
| $\nu_t$, $\nu_T$ | ($m^2/s$) | ---------------------------------------- | momentum and tracer diffusion coefficients |
| 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 |
| $S_T$ | (g/l/s) | ------------------------------------ | source or sink tracer |

u,v and T 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,v and T
2. Propagation, diffusion and source terms of the dynamic equation
3. Diffusion and source terms of tracer transport equation

### 6.1 Descritisation of the Domain Area

The domain area of the model for present study extends up to Karanja on south wherein about 11 m depth in navigational channel [with respect to Chart Datum (CD) of Apollo Bundar] represents deep portion of creek and the part portion of Panvel creek and Thane creek up to Vashi Bridge in the north. The total area of domain is about 193 sqkm and is shown in FIG 9(A). The latest bathymetry data available at CWPRS for Mumbai, Jawaharlal Nehru port area was considered for reproducing the bathymetry in the domain under consideration.

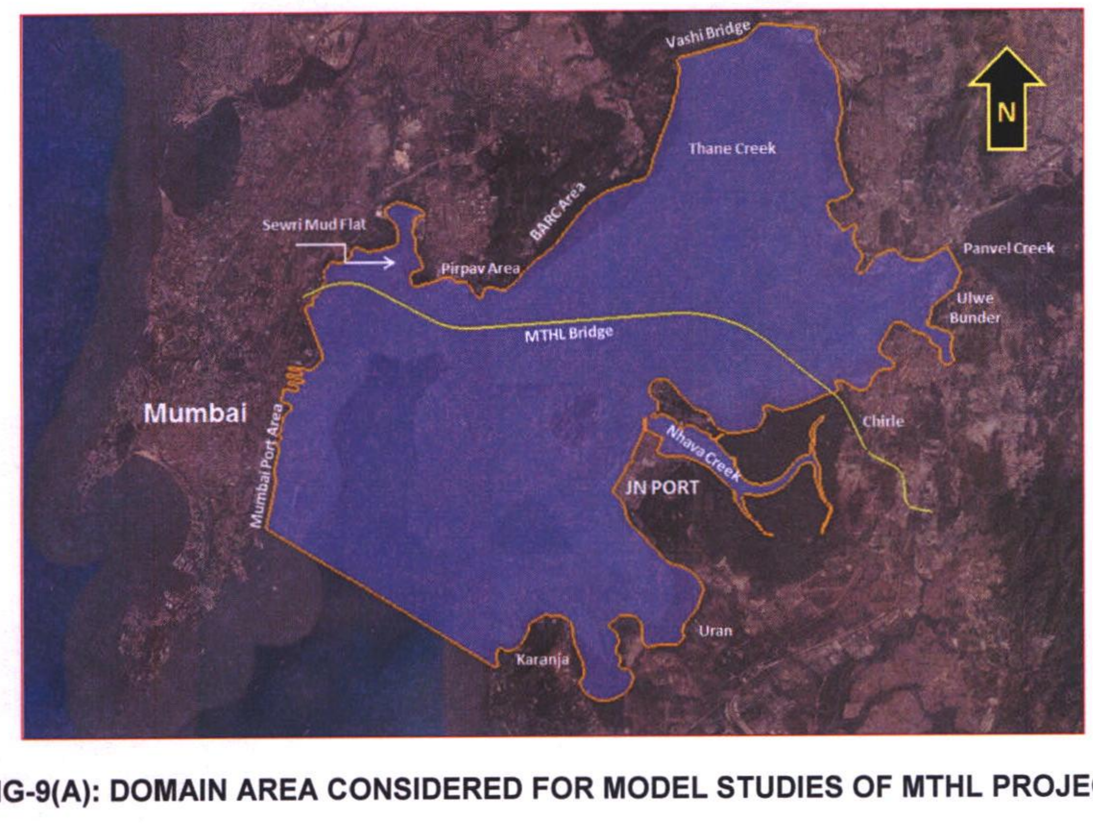


**FIG-9(A): DOMAIN AREA CONSIDERED FOR MODEL STUDIES OF MTHL PROJECT**

The area of about 193 sqkm considered for the hydrodynamic study was essential to cover location of calibration points as well as to see the effect of proposed alignment of MTHL bridge on flow conditions during flood tide and ebb tide and the bathymetry is shown in Fig 9(B).

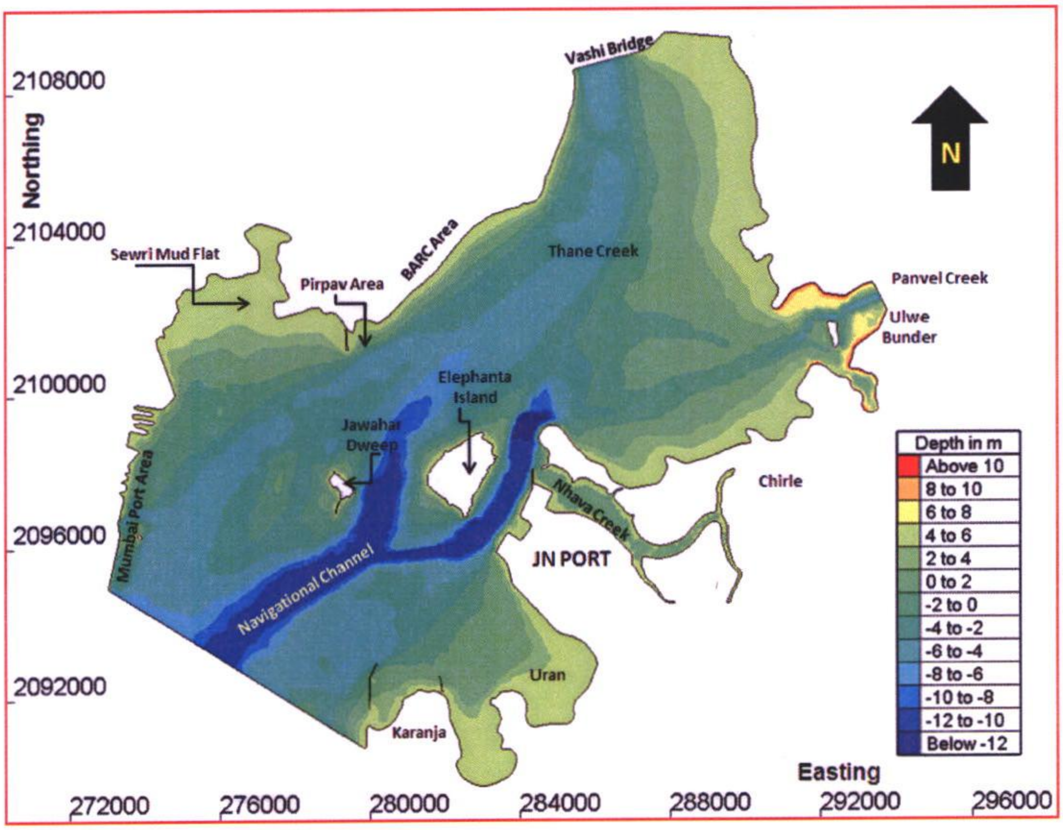


**FIG-9(B): BATHYMETRY LAYOUT (EXSITING) FOR MATHEMATICAL MODEL - MTHL PROJECT**

The triangular finite elements with fine resolution near shoreline, around islands/ substructure of bridge piers, navigational channel area etc. were adopted for true simulation of steep slopes, effect of structure on flow pattern and coarser in deeper areas to optimize number of elements to minimise simulation time. Thus mesh generated can effectively reproduce hydrodynamic condition 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 (FIG.10). The interpolated depths were assigned at nodal points of finite element to represent the depths and solve hydrodynamic equations in terms of water depth and velocity.

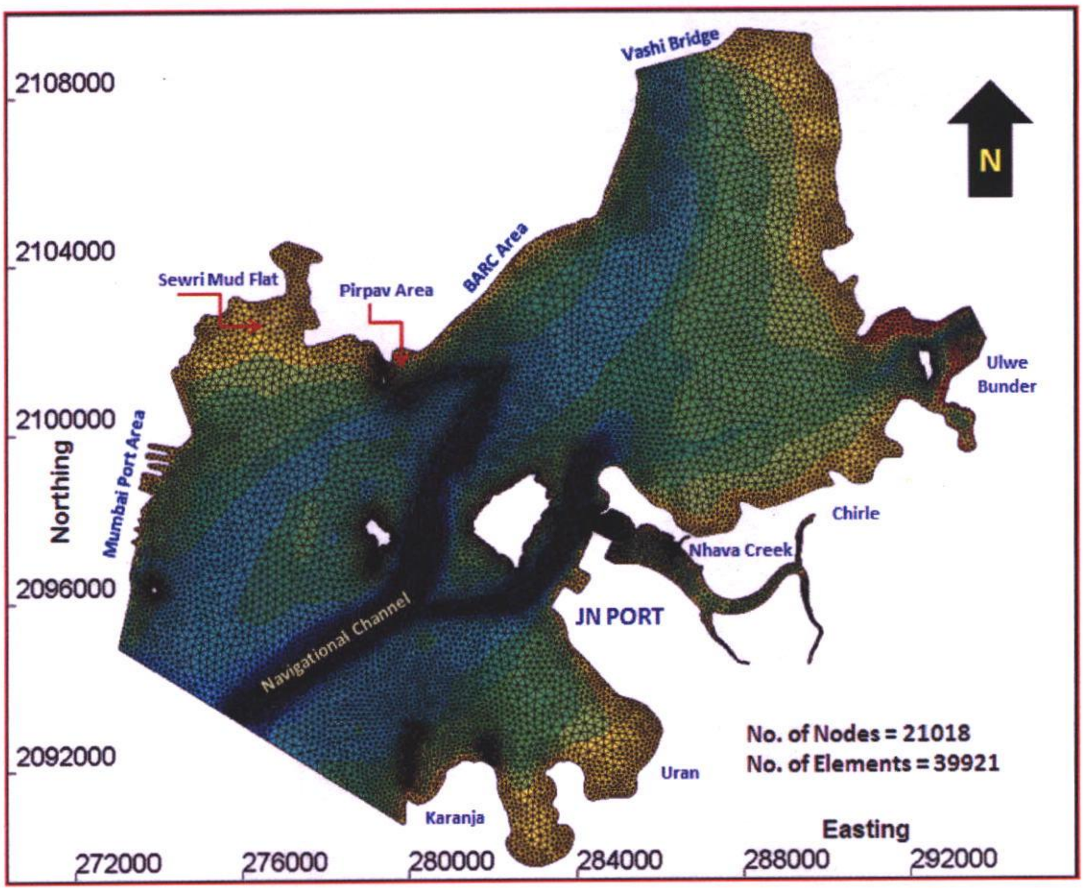


**FIG-10: FINITE ELEMENT MESH DESCRITISATION FOR EXISTING CONDITION**

## 6.2 Simulation and Calibration of Model for "Hydrodynamics"

The observed time series of water levels were used as boundary conditions at open boundaries of model area viz. Vashi bridge, Ulwe Bunder and southern boundary between Karanja & Mumbai port for model with existing bathymetry condition for simulating the hydrodynamics prevailing in the domain area by the mathematical models. The field data collected in respect of tides at different locations in Mumbai Harbour during year 2013 was used to derive these boundary conditions as well as current at different points for calibrating the model. The information about bed samples supplied by MMRDA in the vicinity of proposed MTHL and available in the rest of the area with CWPRS was used to apply friction of sea bed in the model. The information of bed samples indicate that majority of sediment is silty clay; however in some areas like Elephanta island, Butcher island, Butcher reef rocky outcrop exists. In area like BARC-Vashi bridge shore/coastline, mangroves do exists. As such appropriate variable friction factors were adopted for simulating hydrodynamic conditions. By imposing boundary conditions, the velocities predicted by mathematical model at few important locations wherein field data was collected (Fig.11 (A) - (D)), a comparison is made with the observed velocities.

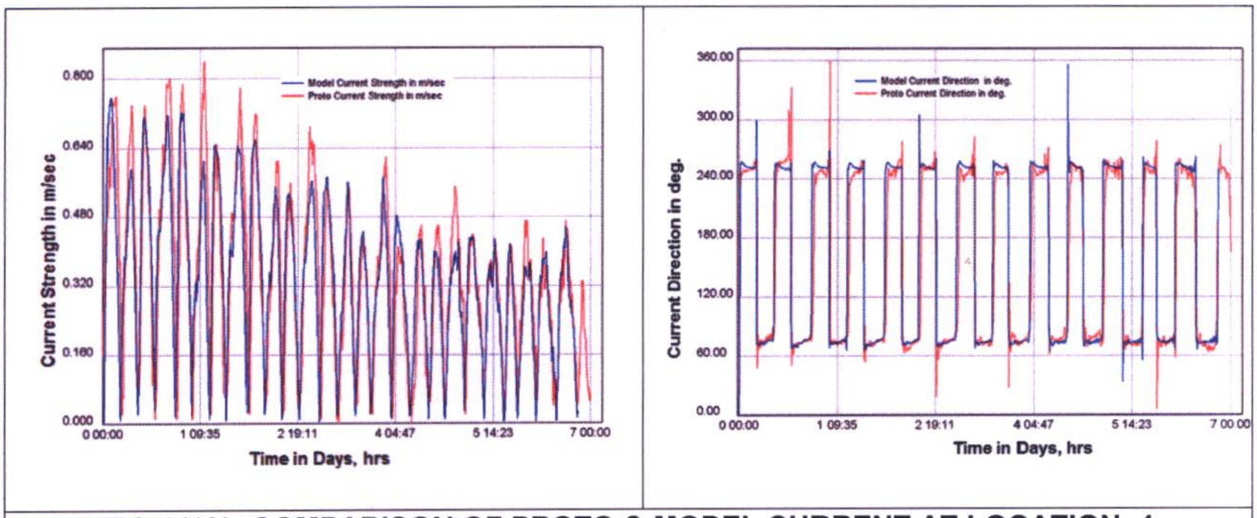


**FIG-11(A): COMPARISON OF PROTO & MODEL CURRENT AT LOCATION -1**

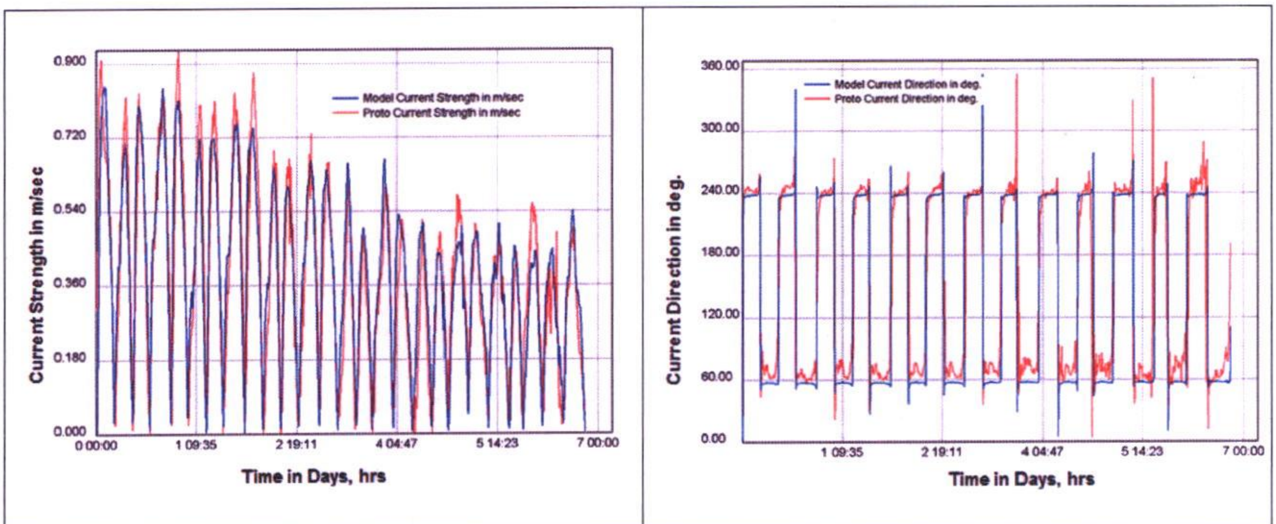


**FIG-11(B): COMPARISON OF PROTO & MODEL CURRENT AT LOCATION -2**

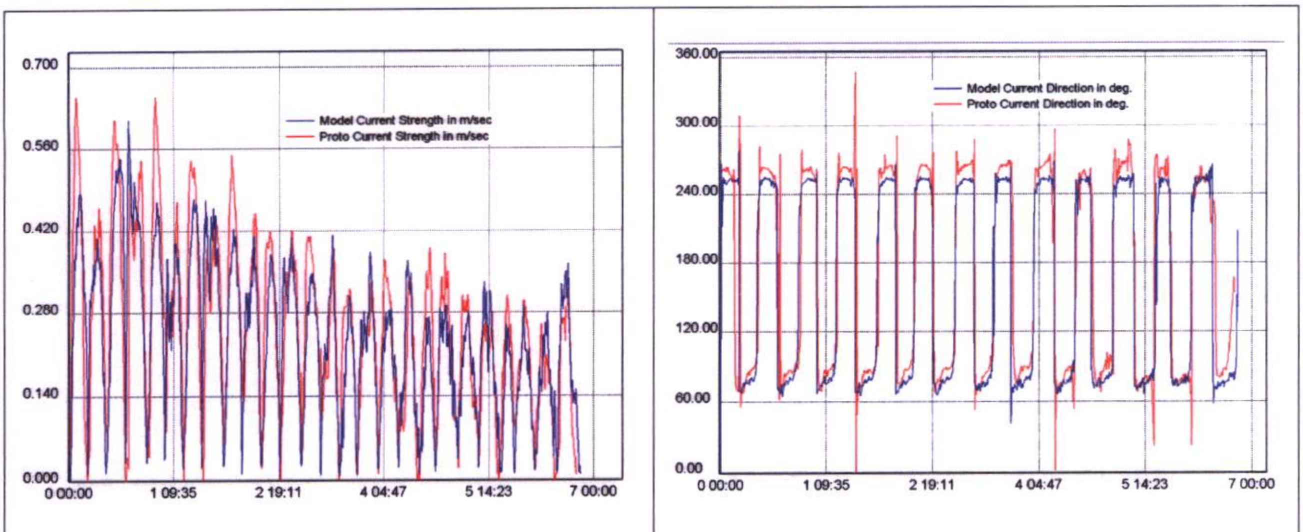


**FIG-11(C): COMPARISON OF PROTO & MODEL CURRENT AT LOCATION -5**

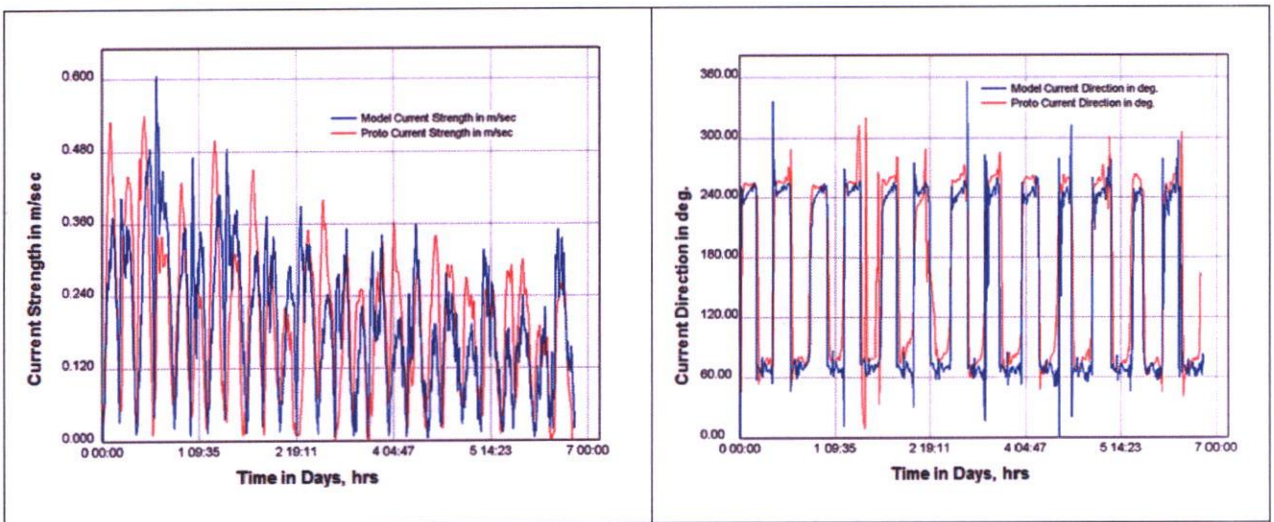


**FIG-11(D): COMPARISON OF PROTO & MODEL CURRENT AT LOCATION -6**

It can be seen from the figures that observed and computed velocities at the corresponding locations compare well. Hence, it can be inferred that mathematical model is well calibrated with respect to flow velocities along the alignment of MTHL bridge.

The comparison of water levels observed at Apollo Bunder and at Jawaharlal Nehru port in model is given in Fig. 11(E).

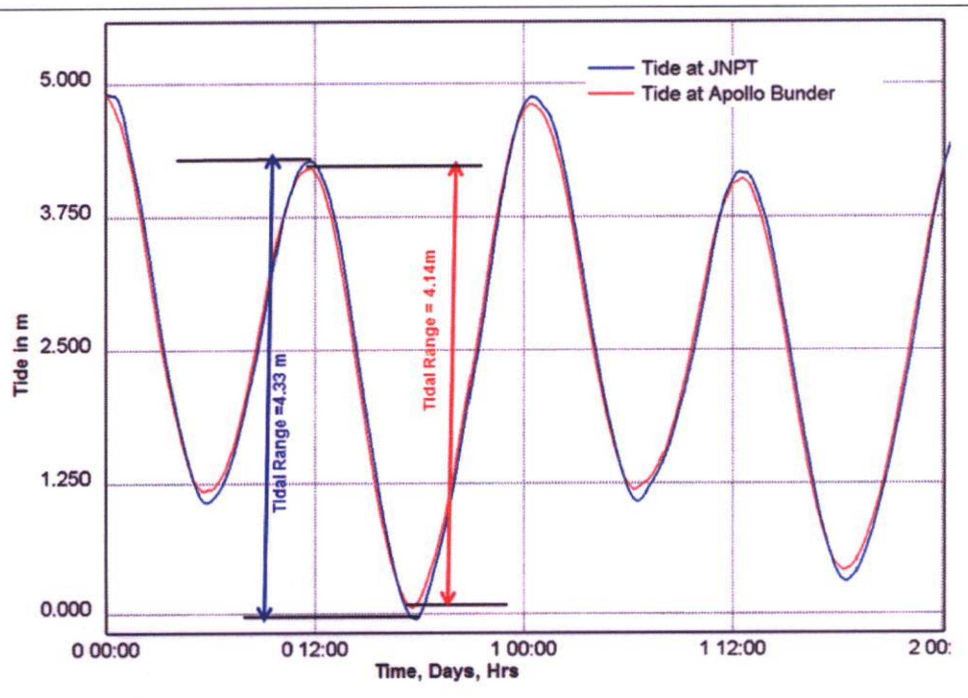


**FIG-11(E): COMPARISON OF TIDE LEVEL AT APOLLO & JNPT IN MODEL**

The tide levels observed in model for locations of Apollo Bunder and JNP area indicate that there is amplification in tidal range between these two locations.

The flow patterns for a typical flood and ebb tidal cycle obtained from calibrated hydrodynamic model are shown in Fig.12 (A) and 12(B) respectively.

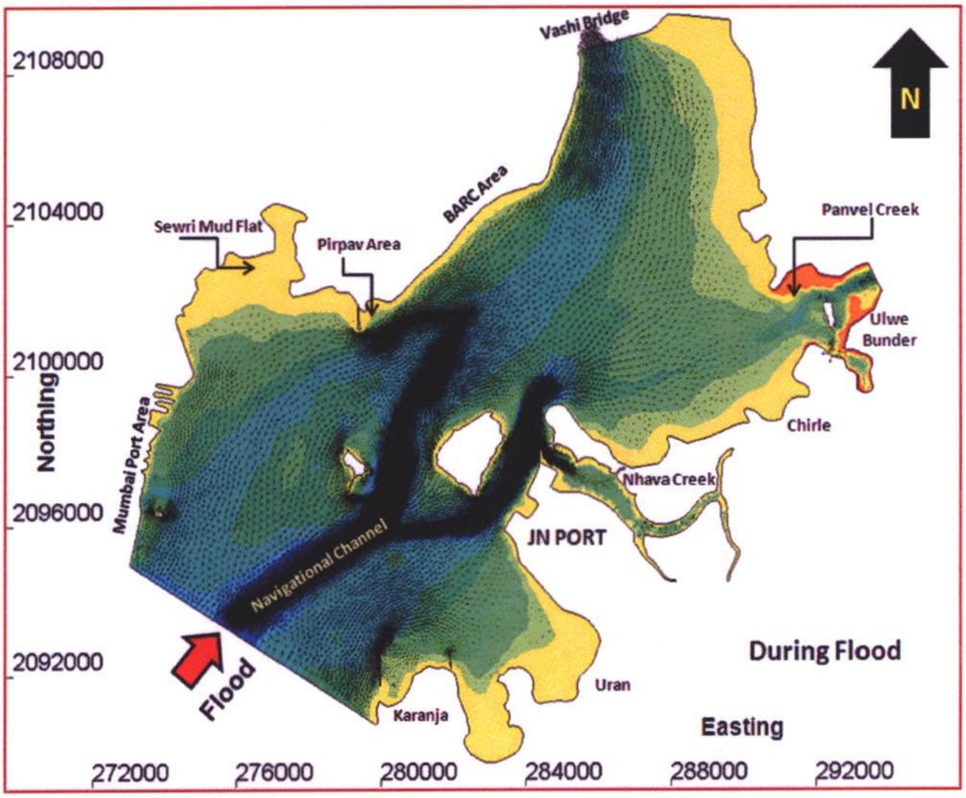


FIG-12(A): TYPICAL FLOW PATTERN OBSERVED DURING FLOOD TIDE

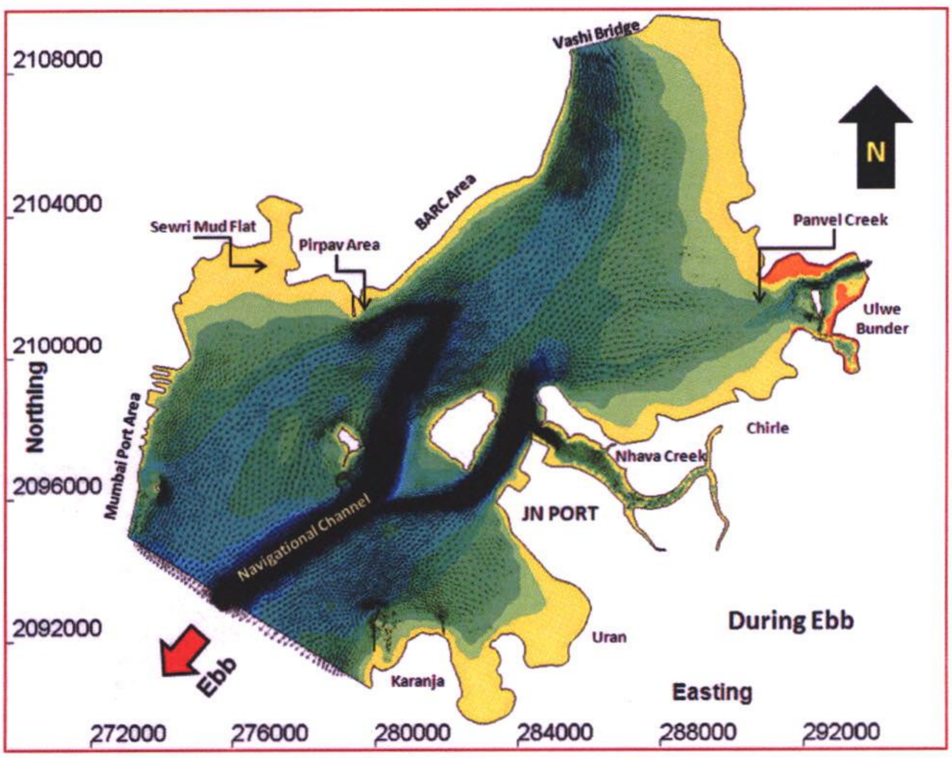


FIG-12(B): TYPICAL FLOW PATTERN OBSERVED DURING EBB TIDE

## 6.3 Study of Flow Hydrodynamics with MTHL Bridge in Thane Creek

The well calibrated hydrodynamic model developed for studying flow hydrodynamics in Thane creek area was amended by incorporating the MTHL bridge piers/piles all along the alignment of bridge proposed by MMRDA. The bathymetry of model and finite element mesh generated are shown in Fig. 13 and 14.

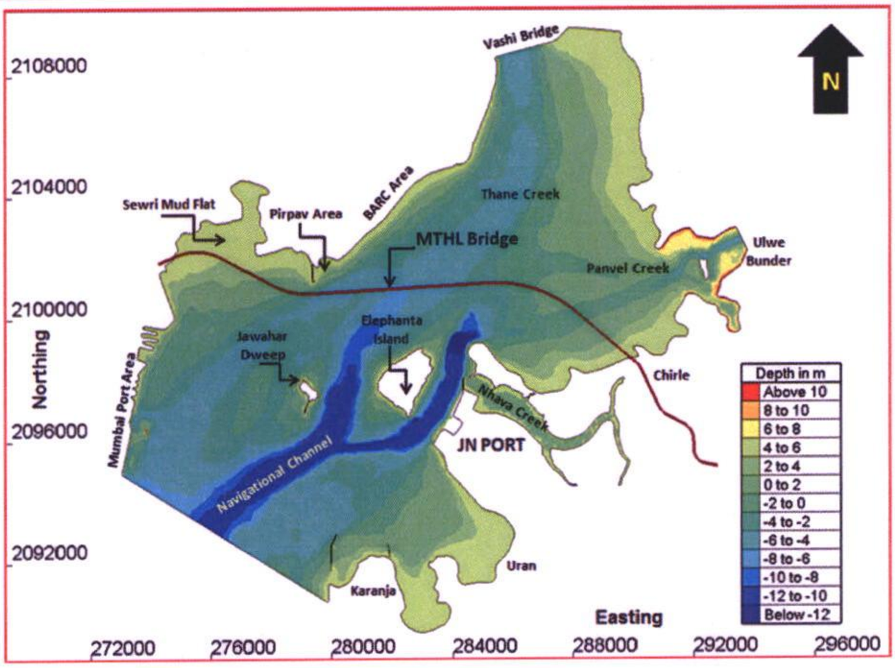


**FIG-13: ALIGNMENT OF MTHL BRIDGE ON BATHYMETRY OF THE MODEL**

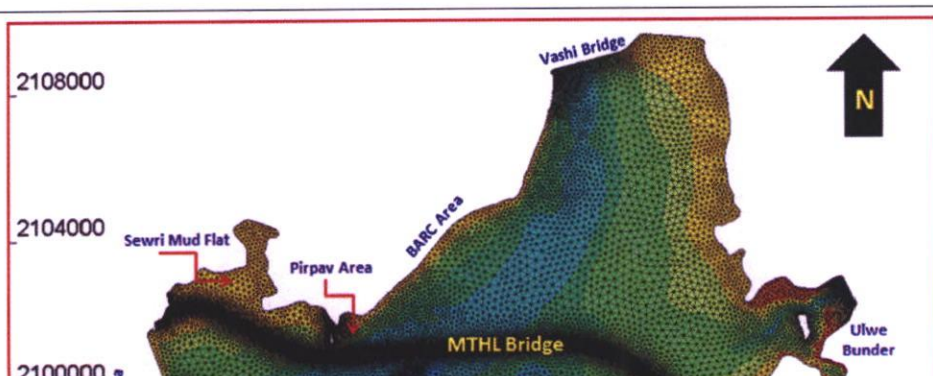


**FIG-14: FINITE ELEMENT DESCRITISATION AFTER INCORPORATION OF MTHL**

The most of the portion of bridge consists of its piers resting on twin piles with centre to centre distance between piers as 50 m. The piers resting on group of piles with 4, 6 and 8 piles are also simulated in the model along with pile caps provided for few piers with spans of 150m, 180m etc. The longer spans are provided for the portion near TATA jetty, Pir-Pau channel, navigational channel towards Panvel creek/Thane creek etc. All the piles with their C/C distances for the entire alignment were simulated in the mathematical model. The details of mesh generated at various locations are shown in Fig.15.

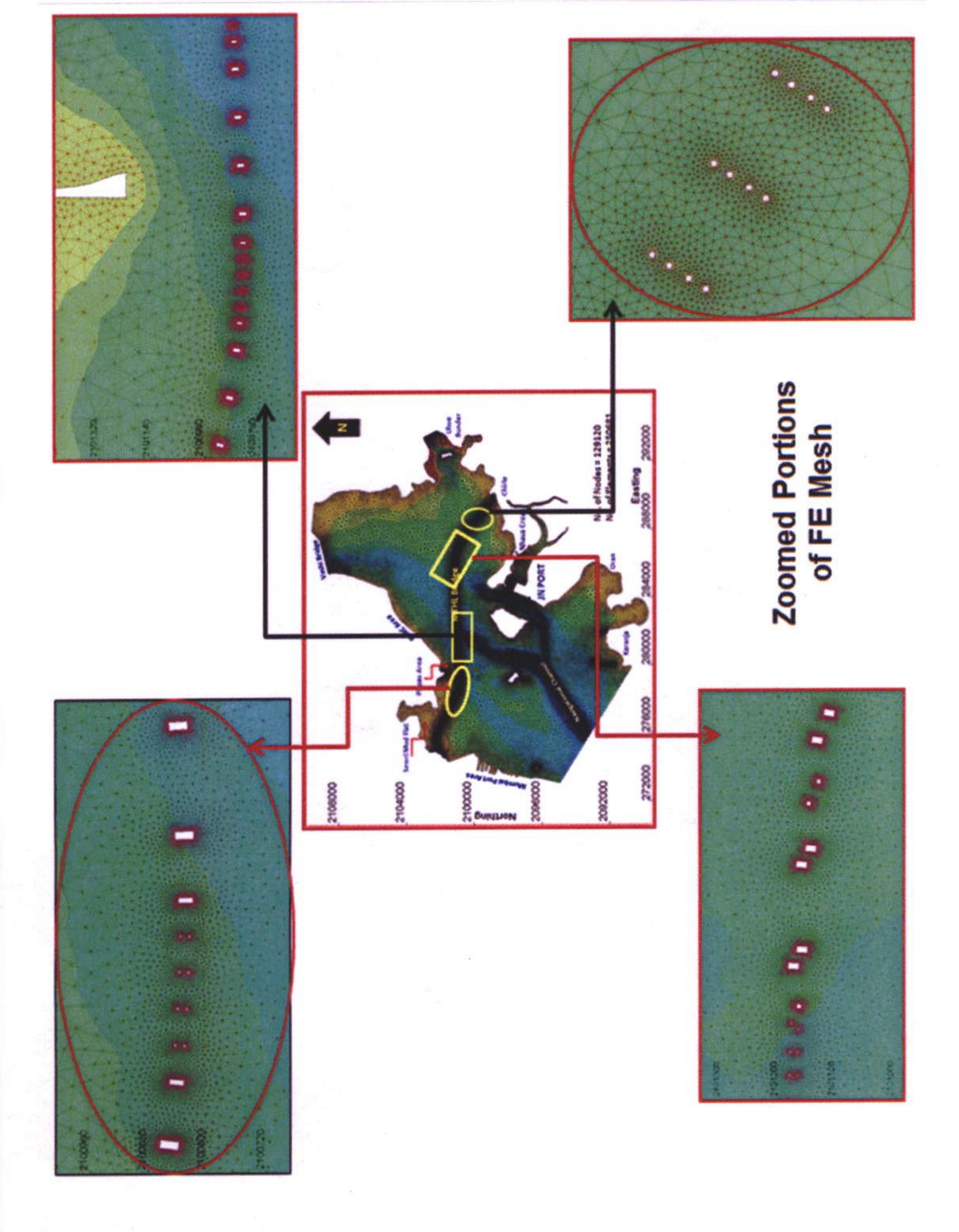


FIG-15:FINITE ELEMENT MESH IN DIFFERENT STRETCHES OF MTHL WITH PILES & PILE CAPS

The model developed with incorporation of MTHL bridge was run for the hydrodynamic boundary conditions considered for calibrating the model and the hydrodynamic parameters were retrieved from the model. The flow field during flood and ebb tide observed in the model is shown in Fig 16(A) and 16(B) respectively.

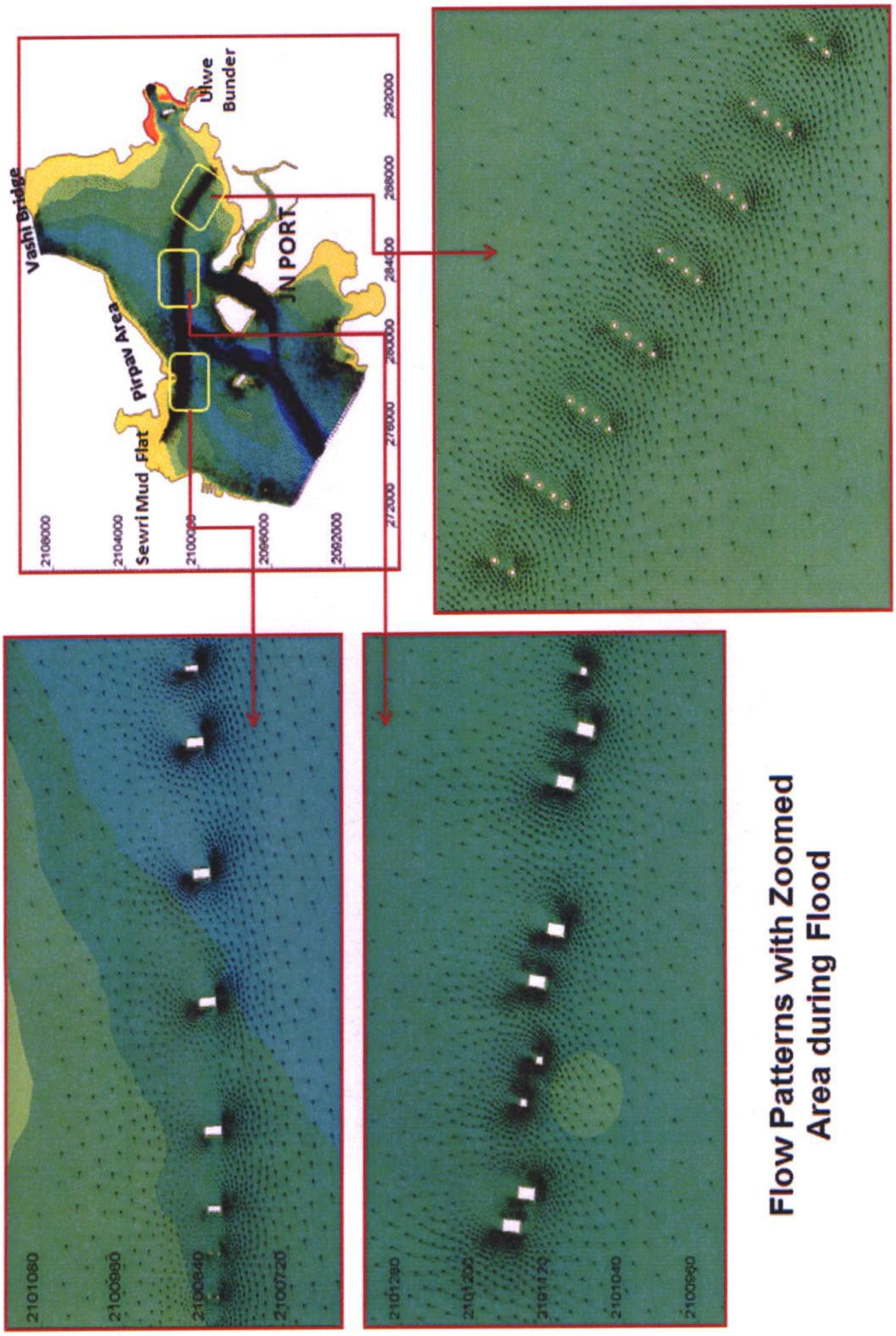


FIG 16(A): FLOW PATTERN AROUND PILES OF MTHL BRIDGE DURING FLOOD TIDE

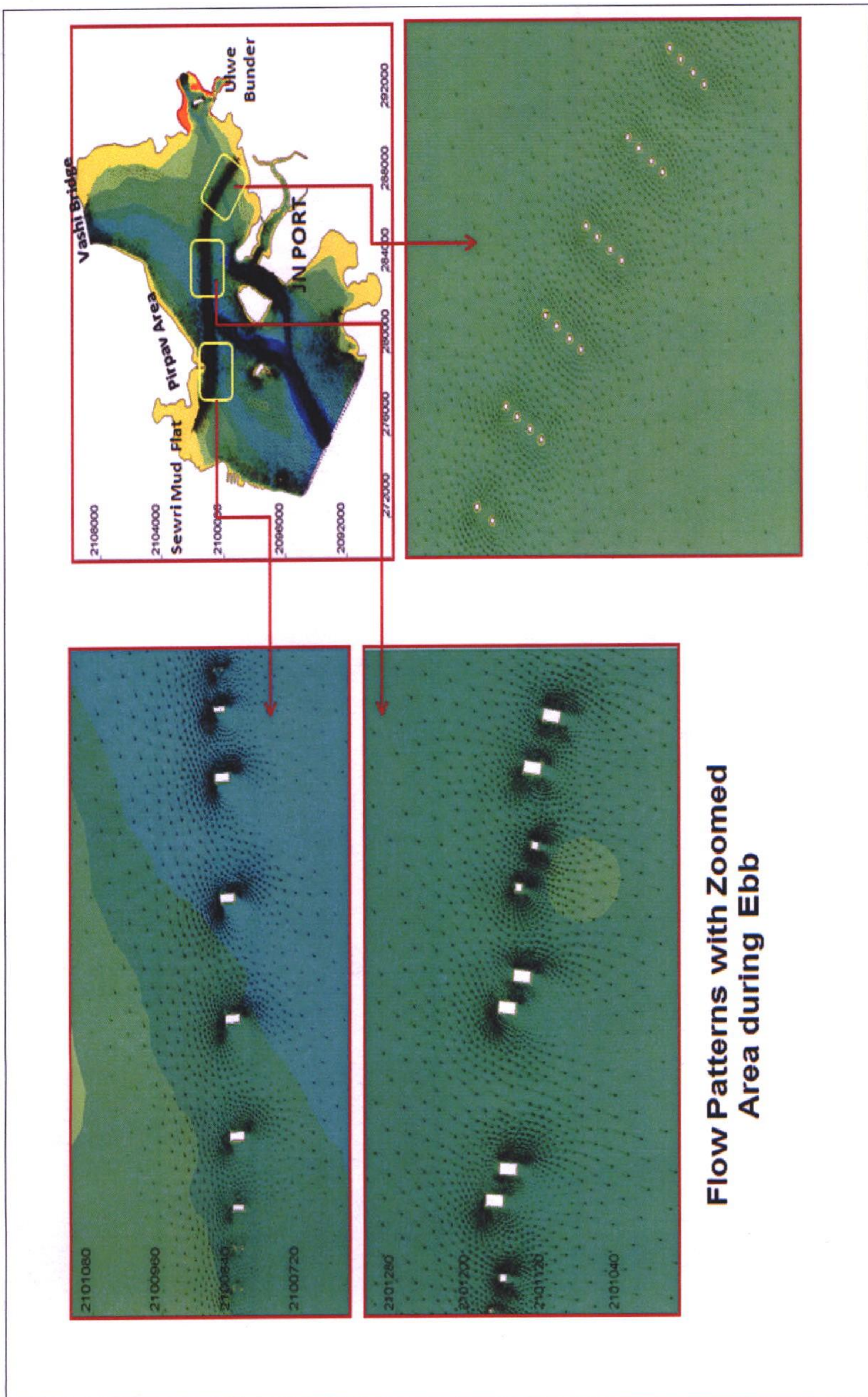


FIG 16(B): FLOW PATTERN AROUND PILES OF MTHL BRIDGE DURING EBB TIDE

The comparison of current strength measured at some field data locations are shown in Fig 17(A) to 17(C).

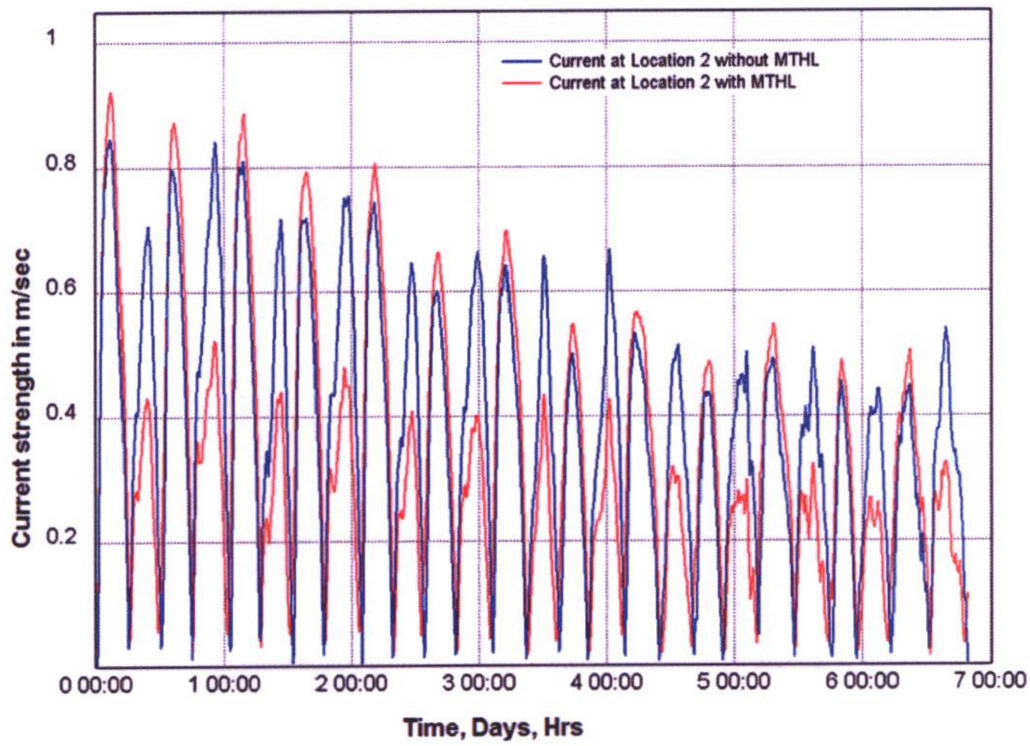


**FIG-17(A):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT LOCATION- 2**

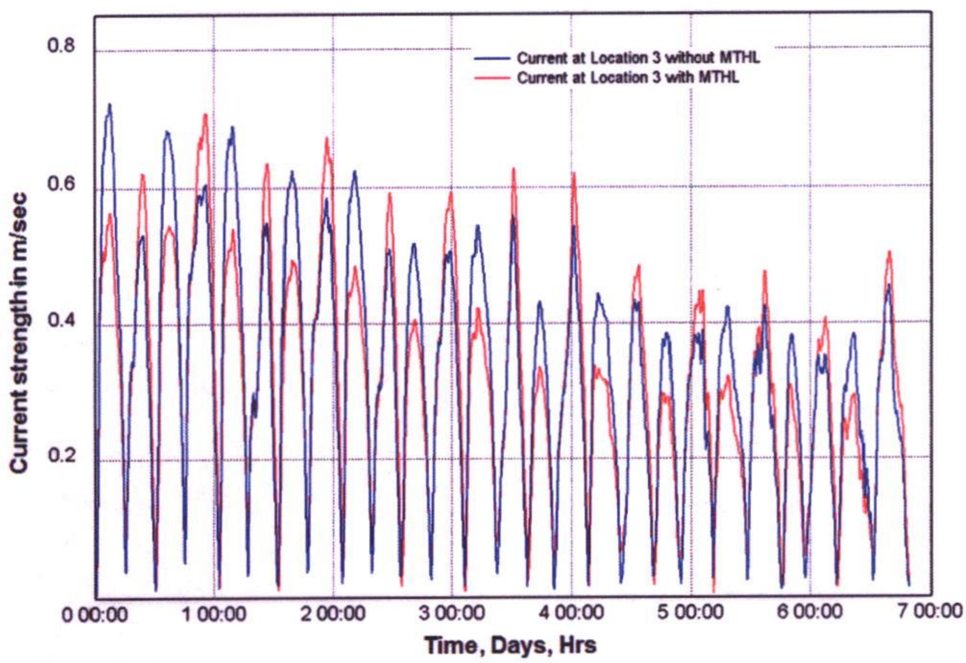


**FIG 17(B):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT LOCATION- 3**

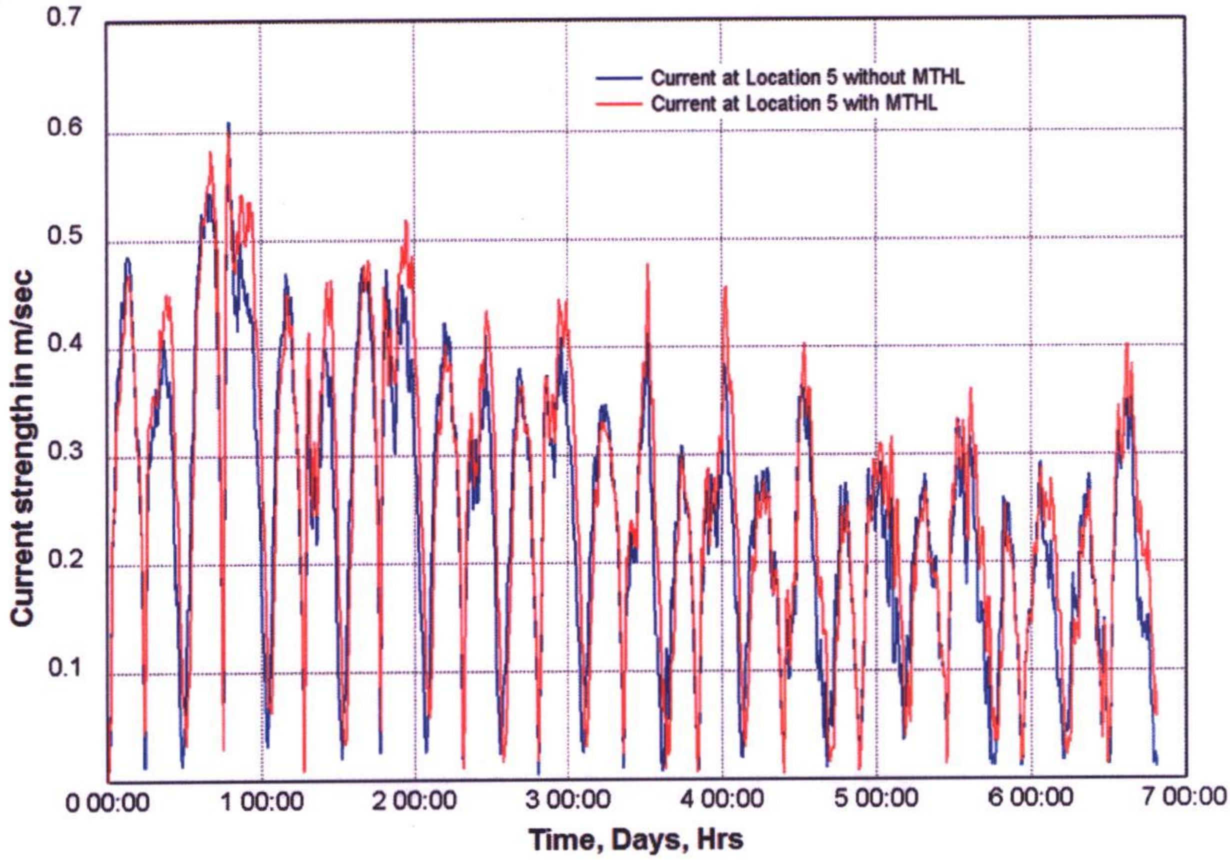


**FIG 17(C):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT LOCATION- 5**

The comparison of current strength given in above figures reveals that there is reduction in strength of current due to presence of MTHL bridge, as these locations being in close proximity and in shadow zone of piers. Also depending upon whether location is on north/south of the alignment of MTHL, there is reduction in current strength during flood phase at location-2, while during ebb phase at location 3. This reduction is due to the fact that majority of flood/ebb flow passes through stretch between Pir-Pau and Thane creek navigational channel near JNPT. While at location towards Chirle side (location-5), the variation in current strength is significantly less as negligible flow movement takes place on this side due to tides. However in order to see the effect of MTHL bridge at some of the existing important establishments in Thane creek area such as PV docks, Pir-Pau jetty, BARC, JNPT area, Mazgaon dock, Butcher island area which are shown in Fig 18, data on current strength was extracted from model and its comparison is shown in Fig. 19(A) to 19 (G).

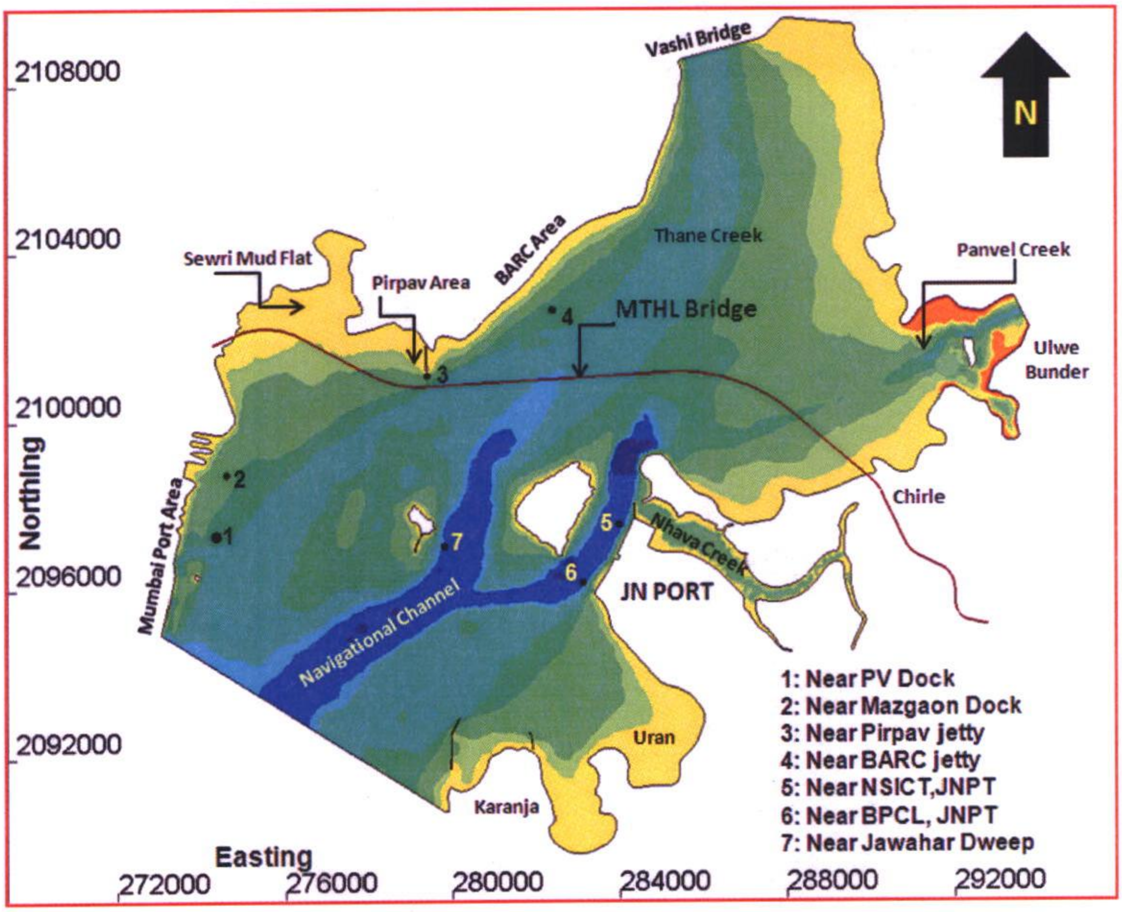


**FIG-18:LOCATIONS OF EXISTING FACILITIES CONSIDERED TO ASSESS EFFECT OF MTHL BRIDGE**

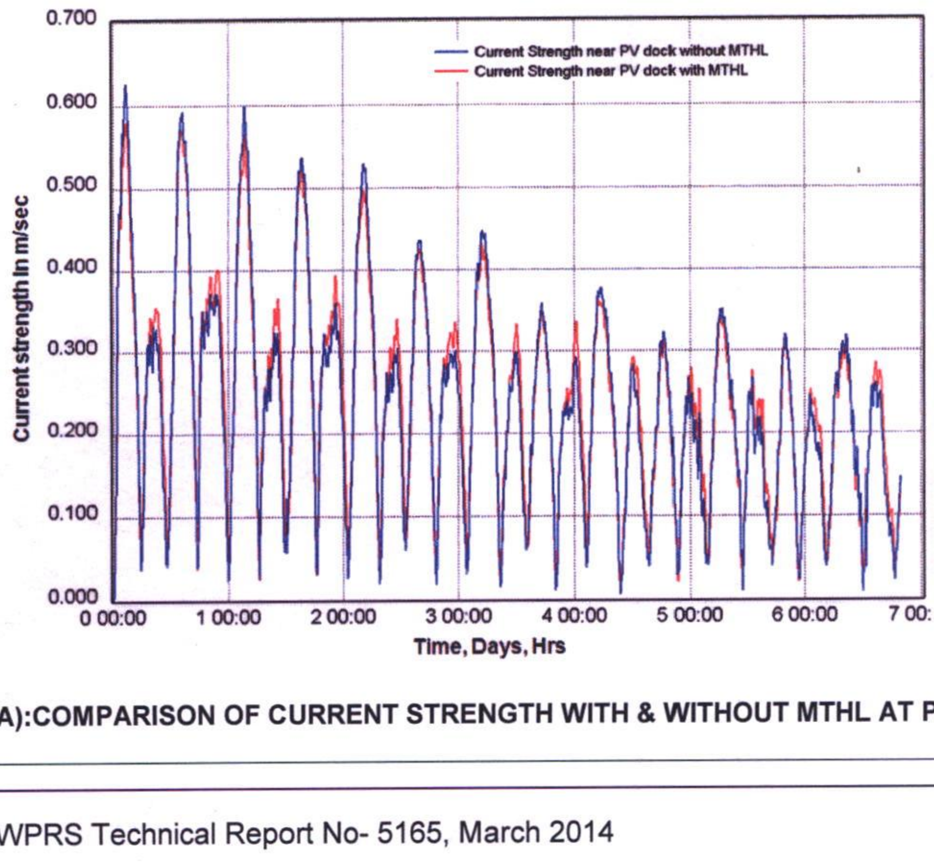


**FIG-19(A):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT PV DOCKS**

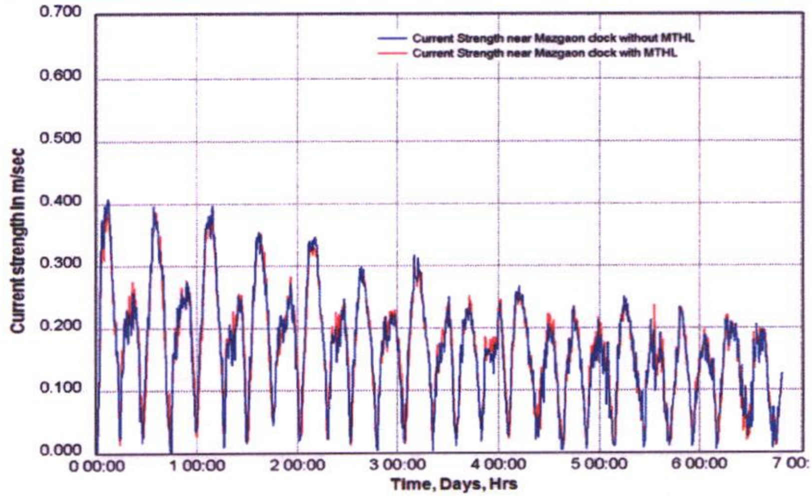


**FIG-19(B):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT MAZGAON DOCK**

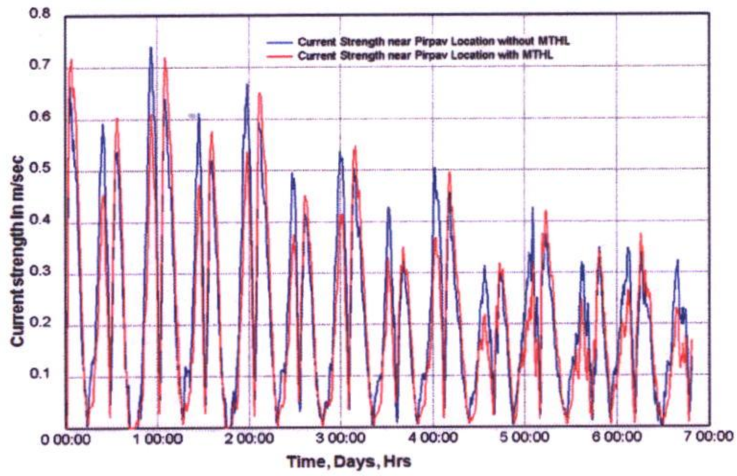


**FIG-19( C ): COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT PIRPAU JETTY**

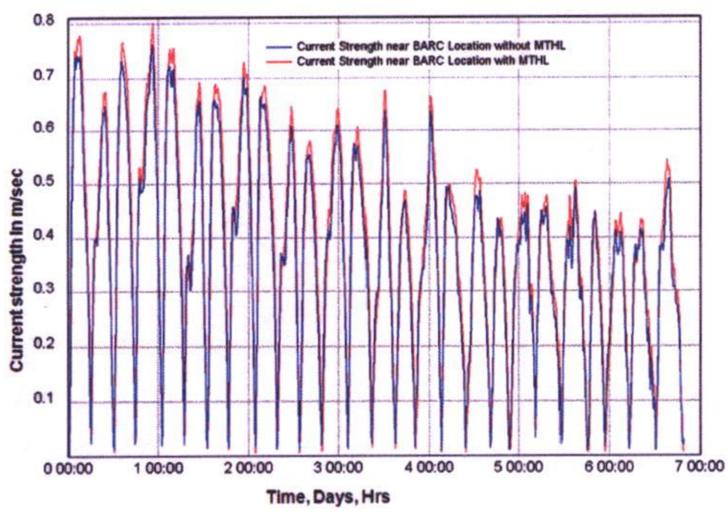


**FIG-19(D): COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT BARC JETTY**

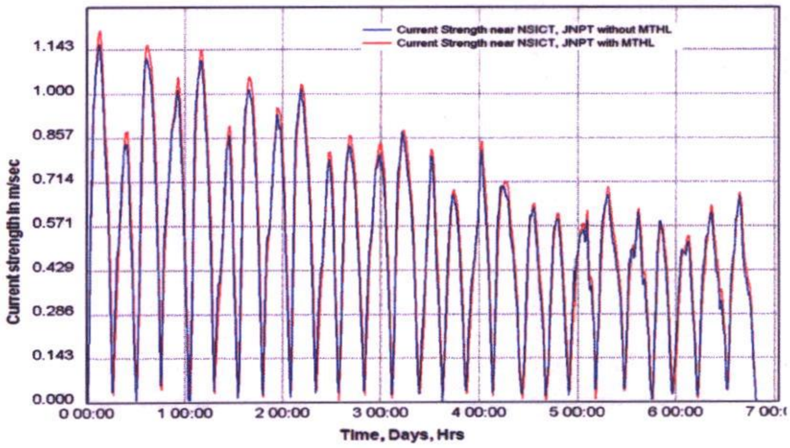


**FIG-19(E): COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT NSICT, JNPT**

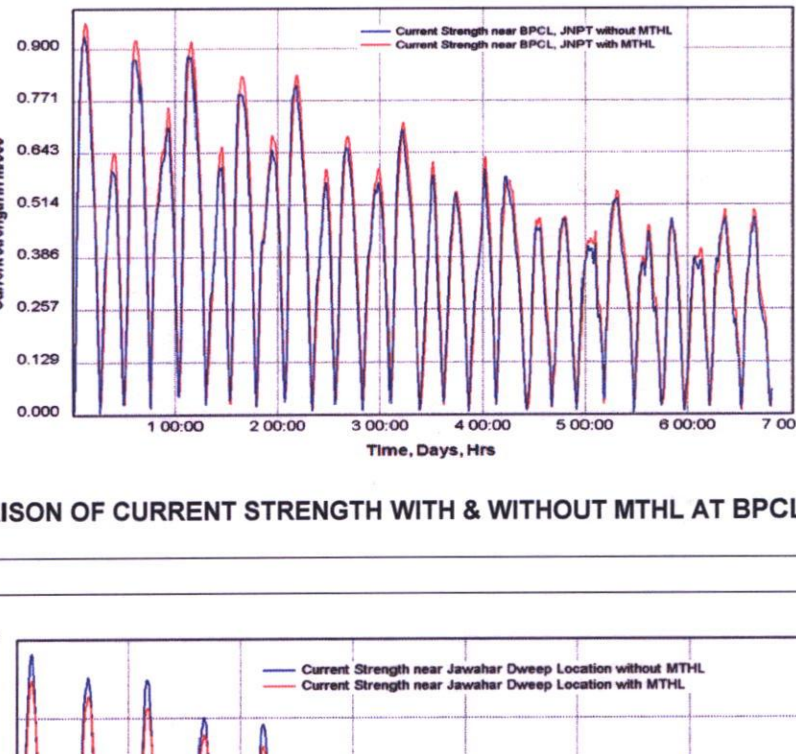


**FIG-19(F):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT BPCL, JNPT**

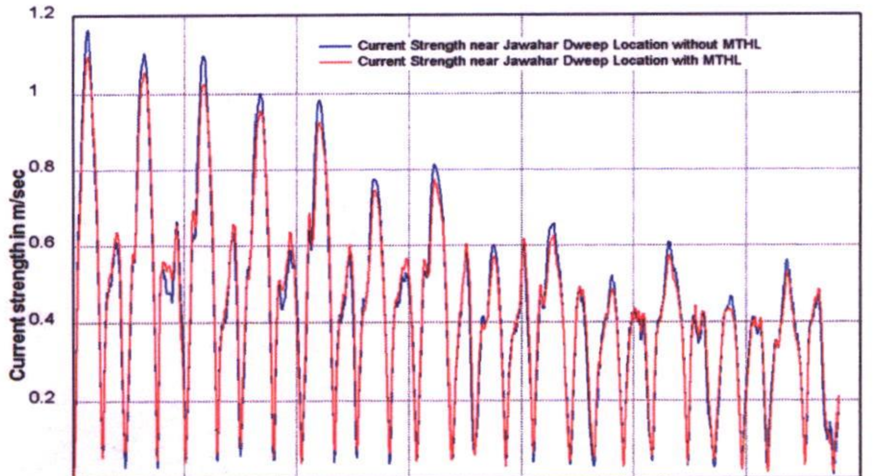


**FIG-19(G):COMPARISON OF CURRENT STRENGTH WITH & WITHOUT MTHL AT JAWAHAR DWEEP**

The above figures indicate that at locations along the Mumbai port side like at PV docks, Mazgaon dock there is some reduction in current strength during ebb tide, while during flood tide there is no change in current strength. As such there is overall reduction in current strength over the entire tidal cycle and it is not significant. While at Pirpau and adjacent area there is negligible increase in current strength during ebb tide, while reduction in current strength during flood tide as Pirpau being on north of MTHL. The overall effect is reduction in current strength for the entire tidal cycle. At location near BARC jetty which is further north of Pirpau whether it is flood tide or ebb tide, variation in current strength with and without MTHL bridge is negligible. It is observed that this increase in current strength, which is insignificant, may be due to thick growth of mangroves and resistance to the overall tidal flow irrespective of phase of tide on the leeward side of jetty head. Jawahar Dweep (Butcher island) is a Marine oil terminal (MOT) facility of Mumbai port, wherein there is seen to be reduction in current strength during ebb tide, while the no change in current strength during flood tide as the facility is on south of MTHL. As such MTHL bridge will not have any impact on functioning of MOT at Jawahar Dweep.

Even though the locations of BPCL and NSICT being in JNP navigational channel, where there is significant movement of tidal flow up to JNPT due to presence of Elephanta deep, there is seen to be overall reduction in current strength over the entire tidal cycle. This decrease is not significant and is on an average less than a percent. However there is seen to be negligible increase in velocity only at peaks. This will not have any adverse impact on movement/berthing of ships at JNPT. As such effect of MTHL will not have any adverse impact on JNP.

The overall likely percent increase or reduction in current strength at various existing facilities in Thane creek due to MTHL bridge is shown in Fig. 20.

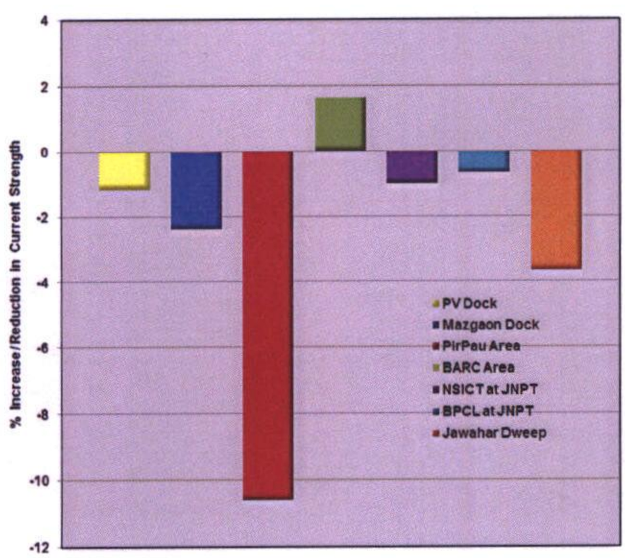


**FIG-20: PERCENT INCREASE/REDUCTION IN CURRENT STRENGTH DUE TO MTHL**

In addition to above in order to assess likely variation in water level at some of important locations like BARC, JNPT and Mazgaon dock for with and without MTHL bridge are shown in Fig. 21(A), 21(B) and 21(C).

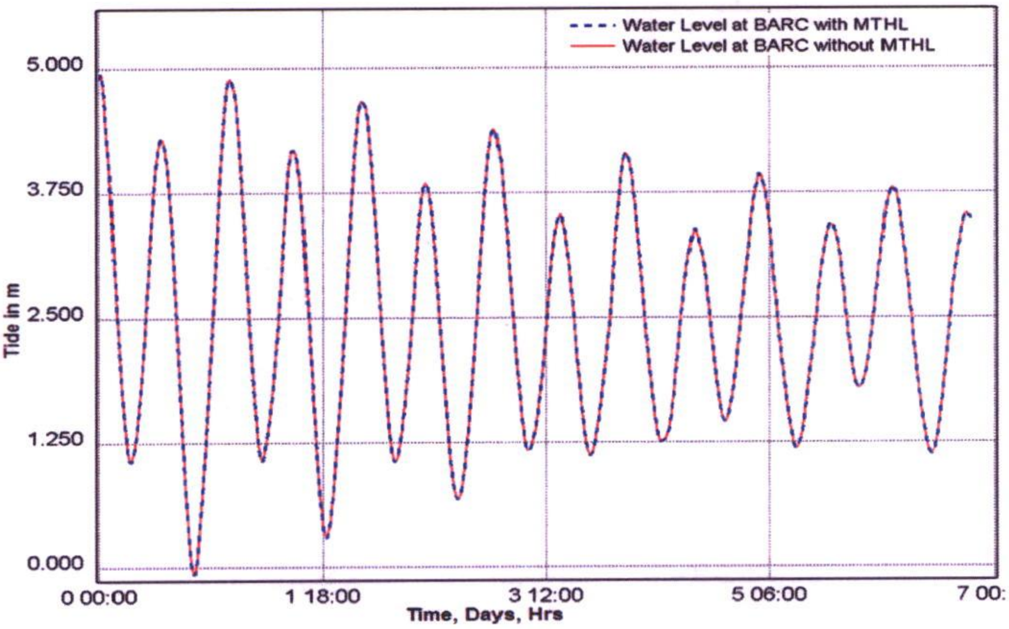


**FIG-21(A):COMPARISON OF TIDE LEVEL WITH & WITHOUT MTHL AT APOLLO BUNDER**

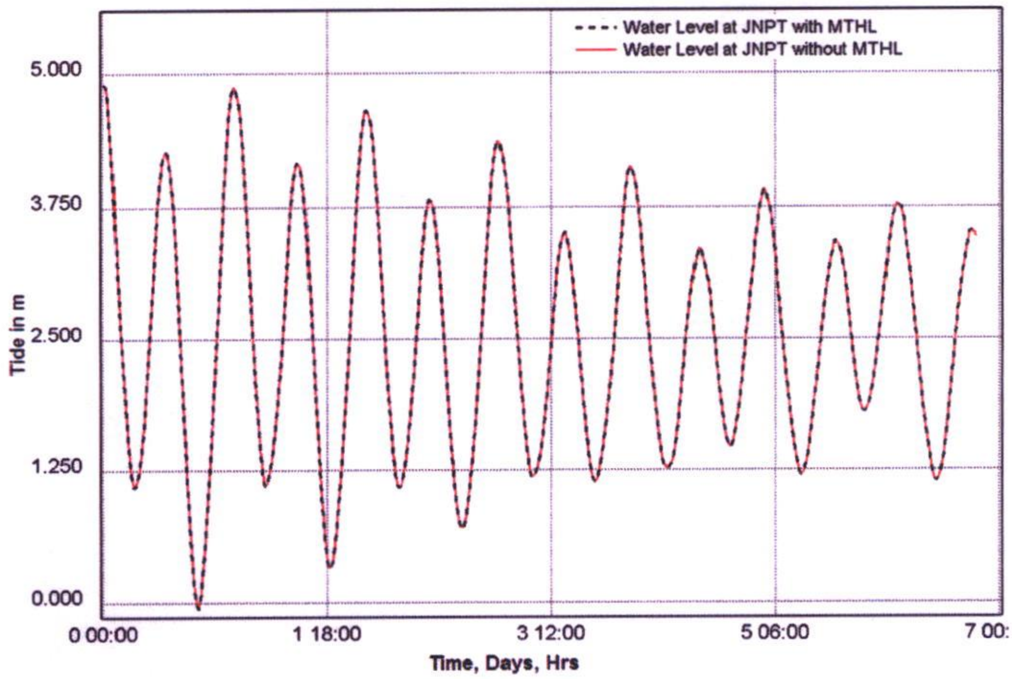


**FIG-21(B):COMPARISON OF TIDE LEVEL WITH & WITHOUT MTHL AT JNPT**

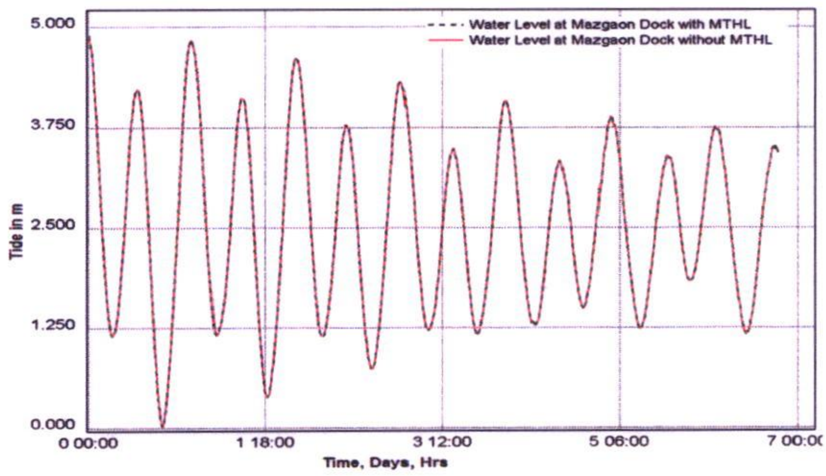


**FIG-21(C):COMPARISON OF TIDE LEVEL WITH & WITHOUT MTHL AT MAZGAON DOCK**

The figures reveal that there is no change in water levels at various locations like BARC, JNPT and Mazgaon Dock area. However in addition to above studies, in order to assess overall change in tidal influx/outflux in Mumbai/JNP harbour area, the information about current strength/discharge across the two sections with one on south of MTHL bridge and one on north of MTHL bridge were taken as shown in Fig. 22.

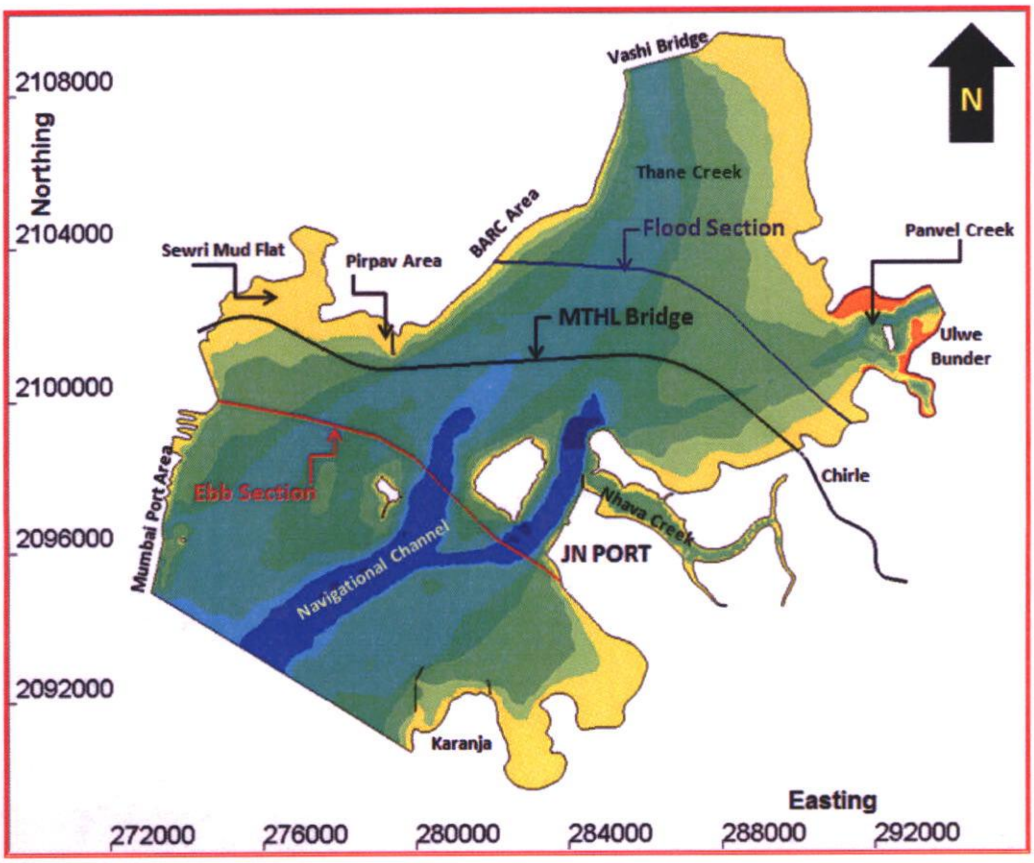


**FIG-22: LOCATIONS OF EBB & FLOOD CROSS SECTIONS TO ASSESS IMPACT OF MTHL ON TIDAL HYDRODYNAMICS IN THANE CREEK**

The comparison of velocity plots and tidal discharge/flux across two sections namely flood and ebb sections during Spring tide are shown in Fig 23(A);23(B) and 23(C);23(D) respectively, while during neap tides are shown in Fig 24(A);24(B) and 24(C);24(D)

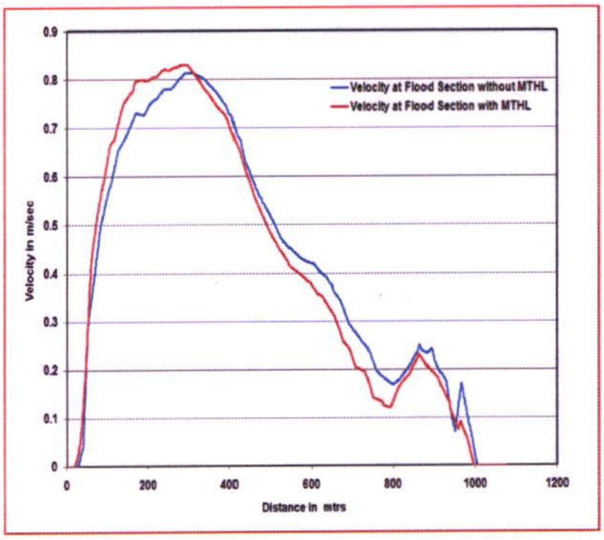


**FIG-23(A):COMPARISON OF VELOCITY AT FLOOD SECTION WITH & WITHOUT MTHL (SPRING)**

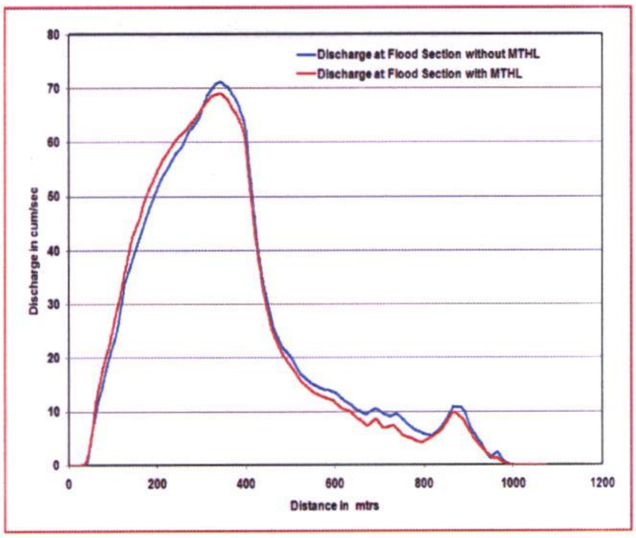


**FIG-23(B):COMPARISON OF DISCHARGE AT FLOOD SECTION WITH & WITHOUT MTHL (SPRING)**

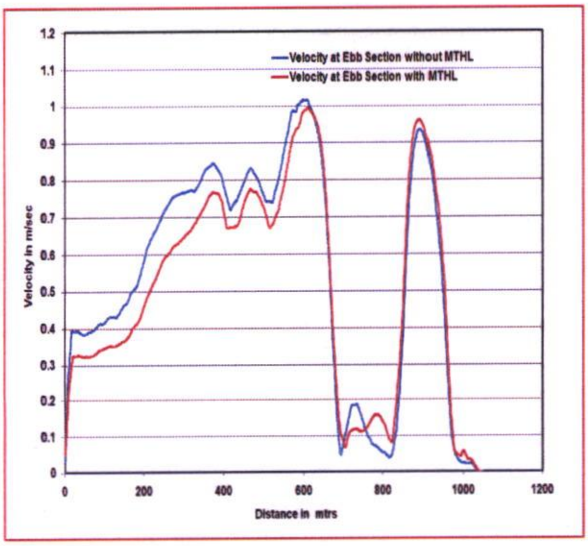


**FIG-23(C):COMPARISON OF VELOCITY AT EBB SECTION WITH & WITHOUT MTHL (SPRING)**

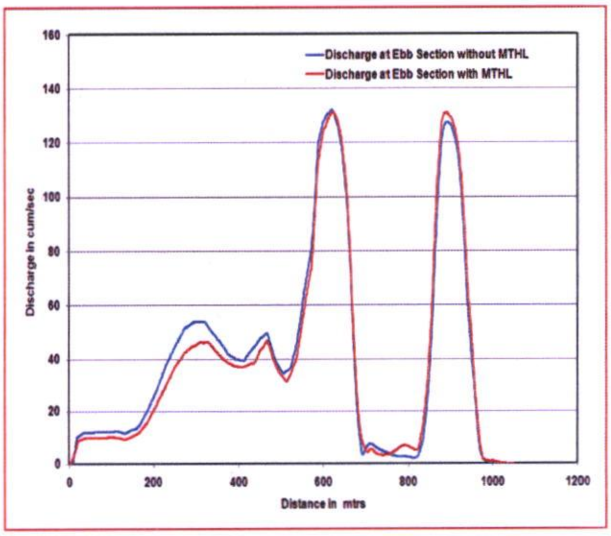


**FIG-23(D):COMPARISON OF DISCHARGE AT EBB SECTION WITH & WITHOUT MTHL (SPRING)**

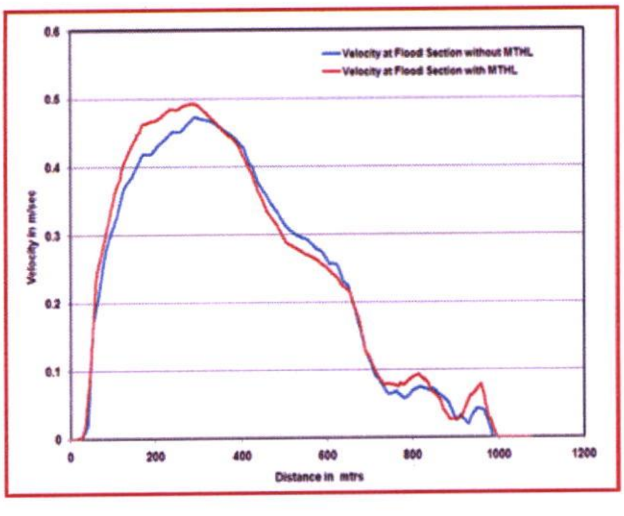


**FIG-24(A):COMPARISON OF VELOCITY AT FLOOD SECTION WITH & WITHOUT MTHL**

**(NEAP)**

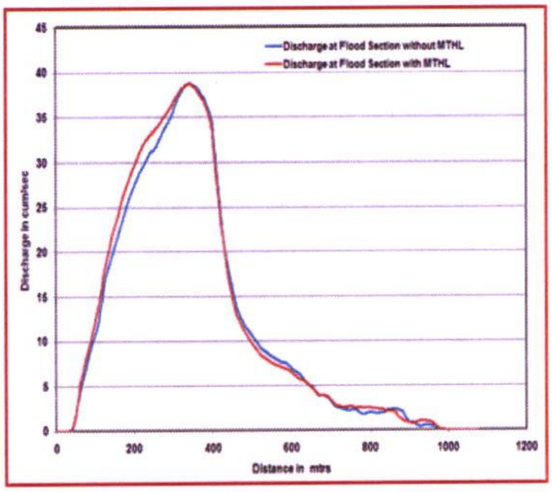


**FIG-24(B):COMPARISON OF DISCHARGE AT FLOOD SECTION WITH & WITHOUT MTHL**

**(NEAP)**

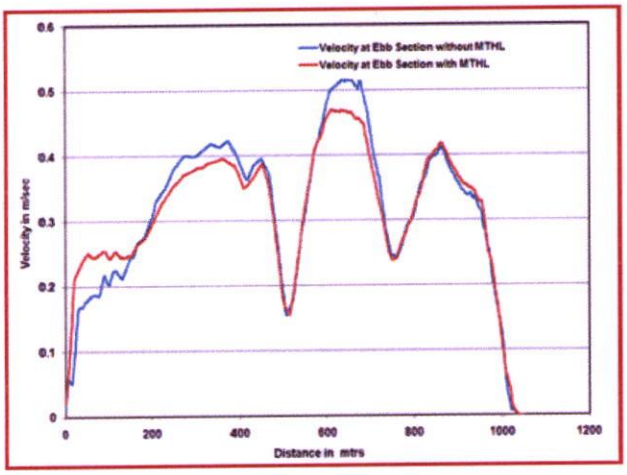


**FIG-24(C):COMPARISON OF VELOCITY AT EBB SECTION WITH & WITHOUT MTHL**

**(NEAP)**

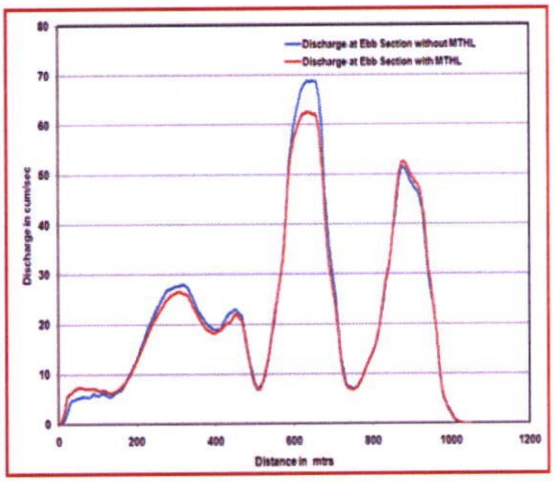


**FIG-24(D):COMPARISON OF DISCHARGE AT EBB SECTION WITH & WITHOUT MTHL**

**(NEAP)**

## 7. CONCLUDING REMARKS

The mathematical model studies were carried out to study the effect of proposed MTHL bridge on the flow pattern and various hydrodynamic parameters such as water level, current strength, and tidal flux in the Thane creek as well as on the existing water front facilities. Its effect on overall region in the creek wherein major ports like Mumbai and Jawaharlal Nehru port exist is also studied. Based on the studies conducted following broad conclusions are drawn:

1. The tide measured in model near JNP indicates amplification of tide level compared to that at Apollo Bundar indicating that propagation of tide in to Mumbai/JNP harbour area is appropriately simulated. This is in good agreement with that of the real time data CWPRS is having for the past records. The mathematical model is also showing good agreement with current strength as well as direction at current meter locations wherein measured data is available. Thus model is well calibrated for prevailing hydrodynamic conditions across the entire width of Thane creek.
2. The effect of MTHL bridge on tide levels measured at various locations say at BARC, JNPT, Mazgaon dock to represent various areas in Thane creek reveal that there is no variation in tide levels with and without MTHL bridge. Also, data obtained from model on current strength at field data locations in various areas like JNPT area, Pirpau navigational channel, Thane creek channel indicate that overall variation in current strength magnitude is insignificant. The currenmeter locations like CM1, CM2 being in close proximity of bridge (less than 400 m), show effect of bridge substructure (piles) on hydrodynamics at these two locations by way of reduction in current strength either during flood or ebb depending upon their location on south/north of MTHL. This area from model flow pattern indicates that it is very near to wake zone of bridge piles. The effect of MTHL bridge diminishes as one move away from MTHL alignment.
3. The location of Pirpau jetty area being in the close vicinity of MTHL (less than 250 m), there is seen to be overall reduction in current strength by about 10% compared to that without the project. This effect reduces towards other infrastructure facilities like PV docks, Mazgaon dock, JNPT area etc and effect is insignificant.
4. The effect of MTHL in overall Thane creek area especially water limits of two major ports i.e. Mumbai and Jawaharlal Nehru reveal (based on comparison of velocity/flux discharge for flood/ebb sections) that by inclusion of MTHL bridge, the overall change in hydrodynamics is negligible.

## 8. RECOMMENDATIONS

The development of 22 km long Mumbai Trans Harbour Link (MTHL) bridge by Mumbai Metropolitan Regional Development Authority (MMRDA) proposed between Sewri on Island city (Mumbai) and Chirle on Main land across the entire Thane creek will not have adverse impact on overall tidal hydrodynamics of the region under consideration and as such is recommended.