World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:11, No:3, 2017

Application of Unstructured Mesh Modeling in Evolving SGE of an Airport at the Confluence of Multiple Rivers in a Macro Tidal Region

A. A. Purohit, M. M. Vaidya, M. D. Kudale

Abstract**—**Among the various developing countries in the world like China, Malaysia, Korea etc., India is also developing its infrastructures in the form of Road/Rail/Airports and Waterborne facilities at an exponential rate. Mumbai, the financial epicenter of India is overcrowded and to relieve the pressure of congestion, Navi Mumbai suburb is being developed on the east bank of Thane creek near Mumbai. The government due to limited space at existing Mumbai Airports (domestic and international) to cater for the future demand of airborne traffic, proposes to build a new international airport near Panvel at Navi Mumbai. Considering the precedence of extreme rainfall on 26th July 2005 and nearby townships being in a low-lying area, wherein new airport is proposed, it is inevitable to study this complex confluence area from a hydrodynamic consideration under both tidal and extreme events (predicted discharge hydrographs), to avoid inundation of the surrounding due to the proposed airport reclamation (1160 hectares) and to determine the safe grade elevation (SGE). The model studies conducted using the application of unstructured mesh to simulate the Panvel estuarine area (93 km^2), calibration, validation of a model for hydraulic field measurements and determine the maxima water levels around the airport for various extreme hydrodynamic events, namely the simultaneous occurrence of highest tide from the Arabian Sea and peak flood discharges (Probable Maximum Precipitation and 26th July 2005) from five rivers, the Gadhi, Kalundri, Taloja, Kasadi and Ulwe, meeting at the proposed airport area revealed that: (a) The Ulwe River flowing beneath the proposed airport needs to be diverted. The 120m wide proposed Ulwe diversion channel having a wider base width of 200 m at SH-54 Bridge on the Ulwe River along with the removal of the existing bund in Moha Creek is inevitable to keep the SGE of the airport to a minimum. (b) The clear waterway of 80 m at SH-54 Bridge (Ulwe River) and 120 m at Amra Marg Bridge near Moha Creek is also essential for the Ulwe diversion and (c) The river bank protection works on the right bank of Gadhi River between the NH-4B and SH-54 bridges as well as upstream of the Ulwe River diversion channel are essential to avoid inundation of low lying areas. The maxima water levels predicted around the airport keeps SGE to a minimum of 11m with respect to Chart datum of Ulwe Bundar and thus development is not only technologically-economically feasible but also sustainable. The unstructured mesh modeling is a promising tool to simulate complex extreme hydrodynamic events and provides a reliable solution to evolve optimal SGE of airport.

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Keywords**—**Airport, hydrodynamics, hydrographs, safe grade elevation, tides.

I. Introduction

THE various developing countries in the world especially in the Asian region, like China, Malaysia, Korea, Indonesia etc., are developing their infrastructure facilities in the form of roads, rail, airports and waterborne facilities. India is not an exception to this and is also developing its infrastructures in the form of new airports/sea-ports, flyovers, rail/road freight corridors at an exponential rate. The government, in order to overcome the crises of a lack of a transport system and to boost the trade with foreign countries as well as to avoid delays in developments, has liberated this policy. It has decided to build the infrastructures through joint ventures, private entrepreneurs as well as governmental/non-governmental organizations. Mumbai being the financial epicentre of India's commerce and trade, over the past few decades the population has grown up at an alarming rate and despite various flyovers and rail networks, the island city is facing the problem of traffic jams. Also, due to licenses issued to private airlines to provide aviation services the existing airports, both domestic/international at Santacruz and Andheri in Mumbai, are facing the problems of air traffic congestion. These airports got inundated and their operations were halted due to heavy rainfall of about 1000 mm/day on 26th July 2005 and simultaneous occurrence of highest tide from the Arabian Sea. The flooding of the airport area was not only due to the extreme hydraulic events but also due to a reduction in the flow carrying capacity of the Mithi River, as the airports were built by reclaiming the part of the river course of the Mithi River.

The government, due to the non-availability of space for further expansion of the existing airports and land being precious in Mumbai, and to relieve pressure on existing airports as well as to cater to the demand of future aviation traffic, has decided to develop a new international airport near Panvel township at Navi Mumbai. The location of the proposed airport is in the Panvel Creek area on the eastern side of island city of Mumbai, wherein the tidal waters from Arabian Sea, through Thane Creek, enters Panvel Creek. Most of the reaches of this region are under the influence of the tidal phenomenon prevailing in Thane Creek, Panvel Creek as well as the flood prone reaches of various Rivers debouching in this region.

The study of such an area under the prevailing hydrodynamic conditions and assessing the effect of the proposed airport, having an area of 1160 hectares, on the surroundings, and determination of the safe grade elevation (SGE) of the airport etc., are some of the prime considerations in the hydraulic design of such mega international airport proposed at the confluence of multiple rivers meeting Panvel Creek. The application of the hydraulic modelling technique to i) study complex hydrodynamic conditions (tide and extreme discharge hydrographs**)** and ii) determine the optimal SGE was made so that: airport will remain operable even under extreme environmental events and the development will be technologically and economically viable and sustainable.

The numerical model studies carried out as well as its findings and recommendations are described in this paper.

II. Necessity for Hydraulic Modelling

The location of the proposed airport is well inside in Panvel Creek, which is located about 30 km from the wide estuarine entrance to Mumbai Port, as shown in Fig. 1. The ships ply in/out of the port area through a navigational channel in the Arabian Sea. The airport area being far inside means waves do not propagate up to it, and as such, predominant flow phenomenon is the one resulted due to a combination of tidal and multiple river discharges during monsoon and tidal flow during non-monsoon conditions. Also, bathymetry described subsequently highlights the necessity of modelling to simulate the complex flow to have a technological and economically feasible development and is also a sustainable.

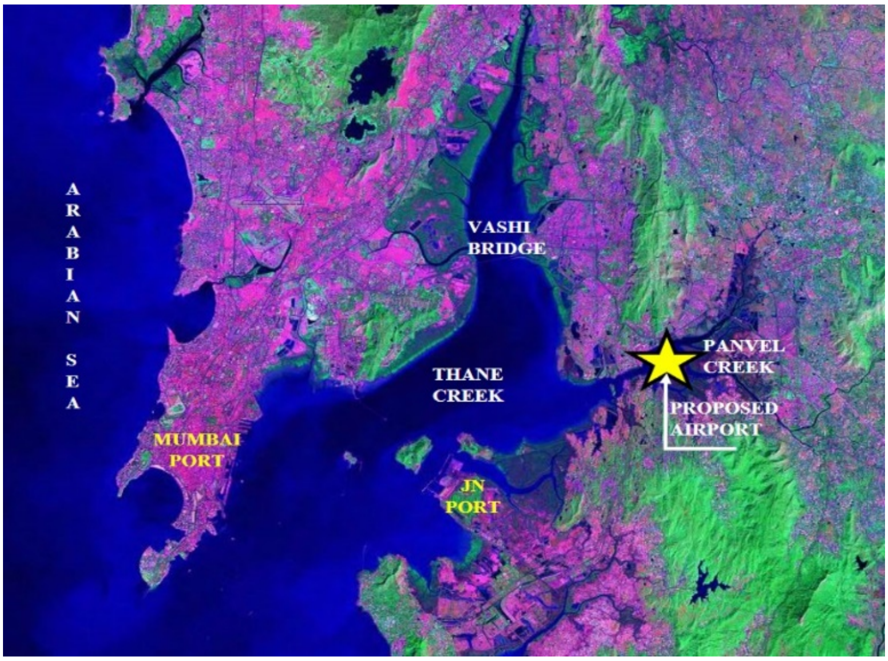


Fig. 1 Location plan of proposed international airport in Panvel Creek

A. Complex Topography and Bathymetry

The topographic region of Navi Mumbai, wherein the proposed international airport is planned, includes streams, creeks, hills and high-low water lines during tidal flows. The topographic details of this region are shown in Fig. 2.

The entrance to the Panvel Creek area is from Thane Creek, near Devale Island. Devale Island bifurcates the flow entering/leaving the Panvel Creek during flood/ebb tide. Sufficiently large depths of the order of about 10.0 m below Chart Datum (CD) of Apollo Bandar exist when the flood tide from Thane Creek enters the Panvel Creek. The Panvel Creek portion near the Ulwe – Belapur road bridge is initially narrow (about 350 m to 400 m wide with bed levels at about 5.5 m to 7.5 m with respect to the CD at Apollo Bandar), which subsequently thereafter gradually expands to about 3 km, and the bed levels in this area are up to 0.5 m to 2.5 m (with respect to the CD at Apollo Bandar). The waterway at the existing bridges at the mouth of Panvel Creek affects the total influx/out flux of Panvel Creek, while the creek channel north of Waghivali Island is relatively deeper than the south channel and carries the major discharge. Waghivali Island is in shallow depths with the flat area having ground levels 3.5 m to 6.5 m above CD at Apollo Bandar. Along Gadhi River, near Khanda, the new Panvel Township has been developed on the right bank. Reclamations, along Panvel Creek near Ulwe and south of Waghiwali Island are also proposed. A large portion of the above region gets submerged during the high tide. Most of the reaches are under the influence of tidal phenomenon prevailing in Thane Creek, Panvel Creek as well as flood prone reaches of the Gadhi, Kalundri, Taloja, Kasadi and Ulwe rivers.

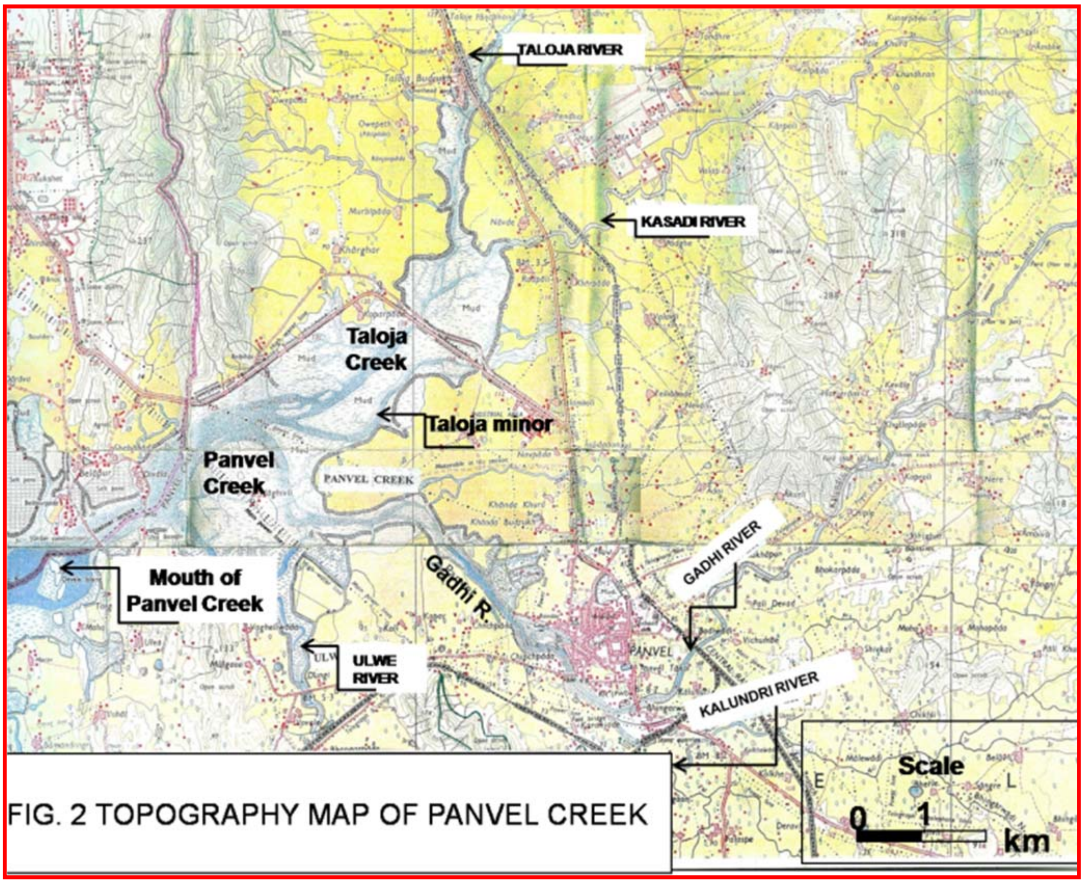


Fig. 2 Topography map of Panvel Creek

The major part of the area earmarked for developments along the creek gets submerged/inundated either during high tide/high floods or a combination of both. The area of the airport wherein the reclamation is proposed, is about 1160 hectares and an area being at the confluence of five rivers, wherein there is the presence of many islands/bridges of roads/rails/pipelines, low lying areas, macro type of tides etc., it is essential to have information about likely changes, which may take place in the flow pattern/conditions due to the developmental works, which would be useful for future storm drainage systems, roads etc.

B. Oceanographic and Hydrological Parameters

The information on tides available for the past 100 years at Apollo Bundar, Mumbai indicates that tides are semi-diurnal with diurnal inequality. The tides are of macro type with tidal range of about 5 m during spring tide. In view of the wide estuarine entrance of about 10 km facing the Arabian Sea and the tidal water flows 40 km inside the estuary up to Thane, a large volume of tidal mass gets exchanged during the tidal cycle. The measured field data available indicates that: there is amplification of the tide at the entrance to Panvel Creek near Ulwe Bundar by about 0.3 m – 0.4 m compared to Apollo tide and there is lag of about 10-20 minutes. The strength of the tidal current is about 1 m/sec during the non-monsoon season, while during the monsoon, it further increases. The width at the entrance to the Panvel Creek is narrow, about 400 m and it controls the entire flow entering/leaving the mouth of Panvel Creek.

The Panvel Creek area is also characterized by the confluence of multiple rivers, wherein the flow during monsoon season debouches from five rivers namely Gadhi, Kalundri, Taloja, Kasadi and Ulwe. Also, there are incidences of flash floods in July 1991 and 26th July 2005. The information on heaviest rainfall of about 1000 mm/day on 26th July 2005 and the increase in such events has really made hydraulic engineers to rethink the type of model to be used for finalizing the layouts of major project in such a riverine area. For the area of the proposed airport, being at the confluence wherein flash floods from the upstream side and macro type of the tide from downstream/seaside occurs over complex bathymetry, and topography features such as the presence of a number of bridges, islands etc., exists, the application of unstructured mesh (triangular finite element mesh) will be more appropriate to simulate the realistic flow field prevailing in this region with varying mesh size and to assess the effect of the proposed development of the airport on the surrounding, determination of optimal safe grade elevation of the airport as well as measures to be adopted to avoid inundation of low-lying area. Hence, rather than using a 1D model, application of a 2D model with a numerical modelling technique seems to be appropriate, wherein sedimentation is not of a major concern. Thus, the application of FEM software, TELEMAC-2D [1], which uses Saint Venant's equation, was made to derive the

SGE of the airport and the findings are described in this paper.

III. Data Used for Model Studies

The basic data required for the development of a numerical model such as bathymetry for the Thane Creek area was taken from the data available from the Central Water & Power Research Station (CWPRS), Pune, while for Panvel Creek and the riverine area of multiple rivers including Gadhi, Kalundri, Taloja, Kasadi and Ulwe were collected during field measurements. Also, hydrological data from various sources, oceanographic data by actual field measurement and data on the past extreme event of 26th July 2005, was used for calibration and validation of the model, respectively.

A. Bathymetry and Topography Data

The hydrographic survey of Panvel Creek was supplied for various stretches, namely the Panvel Creek entrance up to Belapur on 1:10000, Belapur – Waghivali- Kharghar -Taloja stretches and Jui – Panvel on 1:5000 scales, while river cross sections at 100 m to 200 m with 5-10 m interval in deeper sections of the river with respect to CD of Ulwe Bundar [2]. The bathymetry of Thane Creek was taken from the available hydrographic survey.

B. Hydrological Data

The yearly maximum one-day rainfall for rain-gauge stations at Santacruz and Colaba, the highest recorded 24 hrs rainfall in and around Panvel Creek that includes rain-gauge stations at various locations such as Panvel, Karjat, Matheran, Bhivandi, Kalyan, Vada, Kurla, Murbad, and Dahanu etc., with short duration data available for other stations [3]. Hourly rainfall records of rain-gauge stations at Santacruz, Powai, Panvel, Kharghar, Nerul, Vashi and CBD Belapur during the 26th July 2005 case. Also, the yearly maximum rainfall intensity (mm/hr.) records of Colaba and Santacruz rain-gauge stations for the period 1969 – 2004.

C. Hydraulic Data

The recorded flood levels at different locations in Panvel Creek on 26th July 2005 and the July 1991 flood event were provided by CIDCO, the project authority [4].

D. Oceanographic Data

Oceanographic data such as tides, currents etc. were collected by the CWPRS, Pune along with the Maharashtra Maritime Board (MMB) and the entire compiled data was provided by CIDCO, the project authority [5]. The data collection was made from 16th May to 17th June 2007 and the locations are shown in Fig. 3.

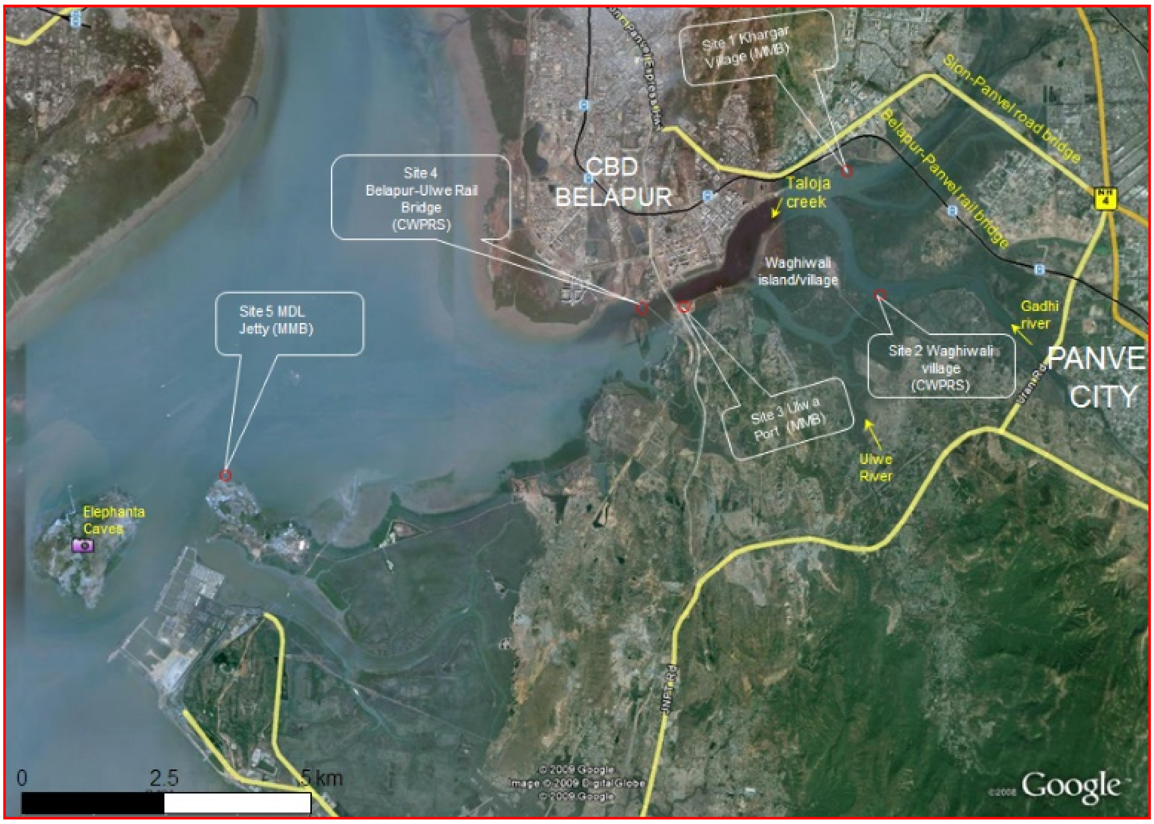


Fig. 3 Location plan for tide and current measurements

Tidal data was recorded at various locations including MDL Jetty, Ulwe Rail Bridge, Ulwe Bundar Jetty and Kharghar, while current measurements were recorded near MDL jetty, Ulwe Rail Bridge, Ulwe Bundar near Panvel Creek mouth as well as also at Kharghar and Waghivali. The typical tides and currents measured at the mouth of Panvel Creek which controls the flow in/out of the creek is shown as an example in Fig. 4.

A summary of the analysis of the tide and current measurements at various locations is given in Table I.

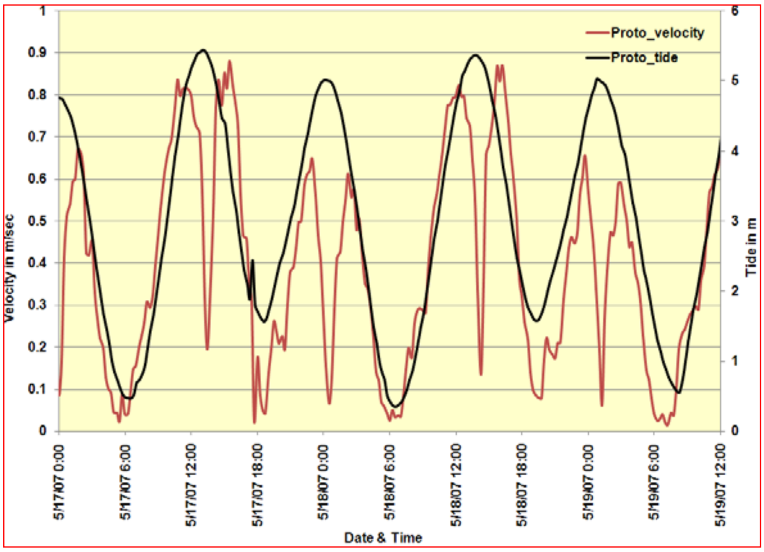


Fig. 4 Typical tide and current measurement at Ulwe Bundar

TABLE I
TIDAL RANGE AND CURRENT STRENGTH DURING SPRING TIDE

Location	Spring Tide			Neap tide		
	Tidal range in m	Flooding velocity in m/sec	Ebbing Velocity in m/sec	Tidal range in m	Flooding velocity in m/sec	Ebbing Velocity in m/sec
MDL jetty	5.74	0.67	0.75	2.25	0.40	0.40
Ulwe Rail Bridge	5.49	0.82	0.90	2.00	0.13	0.26
Ulwe jetty	5.19	0.82	0.86	2.16	0.35	0.28
Kharghar	5.44	0.70	0.90	2.50	0.37	0.37
Waghivali	5.12	0.48	0.75	2.17	0.24	0.24

E. Analysis of Suspended Sediment and Bed Material

The suspended sediment data for three locations in Panvel Creek indicated low concentration in the range 300 ppm to 500 ppm. The analysis of bed samples taken in all five rivers reveal that material mainly consists of sand (60%) and silt (30%) with remaining percentage made up of gravel and clay.

F. Flood Hydrograph

Using the time-area relationships and hourly rainfall distribution data for storms of different duration and return period, the flood hydrographs were estimated. The peak flood discharges for rainfall corresponding to Probable Maximum Precipitation (PMP, 6-hour storm duration) having 700 mm rainfall for five rivers and 26th July 2005 are given in Table II.

TABLE II
ESTIMATED FLOOD HYDROGRAPHS FOR VARIOUS RIVERS

River	Estimated peak flood discharges (m^3/s)	
	PMP, 6-hour storm	26th July 2005 rainfall
Gadhi	2082	2515
Kalundri	1973	1978
Kasadi	1001	1270
Taloja	1234	1060
Ulwe	916	722

IV. DEVELOPMENT OF NUMERICAL MODEL

The domain area of the model extends up to Vashi Bridge in Thane Creek on the north and extends up to the Pir-Pau area on the south-west, including the area of the proposed international airport at Panvel Creek. The area of the proposed airport is on east side of the Panvel Creek entrance and is immediately downstream of the confluence of five rivers meeting at Panvel Creek. These rivers are the Gadhi, Kalundri, Taloja, Kasadi and Ulwe, as shown in Fig. 5.

The simulation of about 93 km^2 area for the hydrodynamic study was essential to cover the locations of calibration and validation points as well as to determine water levels at various locations around the proposed international airport. It also includes various bridges. The triangular finite element mesh developed to simulate domain area is shown in Fig. 6.

The Domain area of the model is discretized with fine mesh around the bridge piers/Islands, river banks/coastline for better simulation of complex flow field, while the deeper areas and tidal flats are simulated with coarser mesh.

Fig. 5 Domain area for the model studies

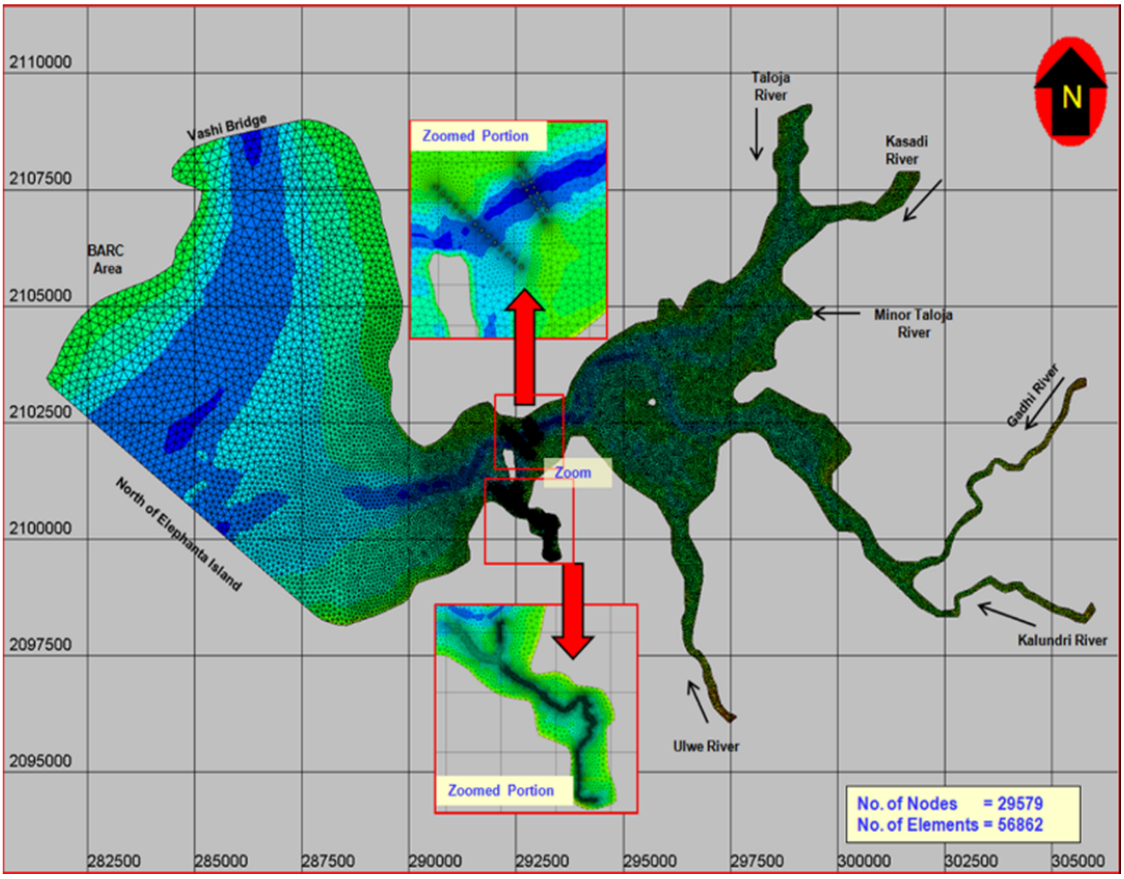
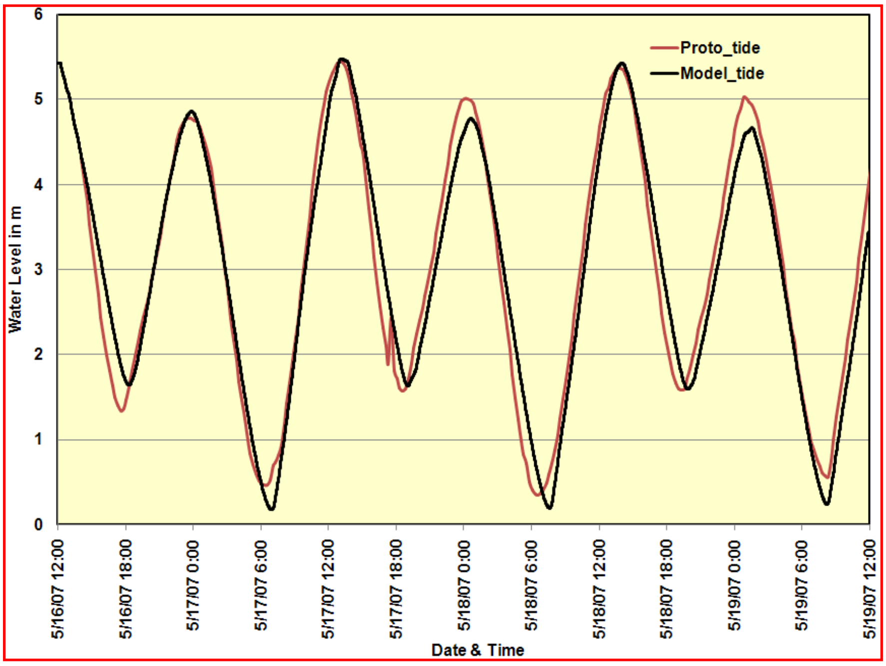


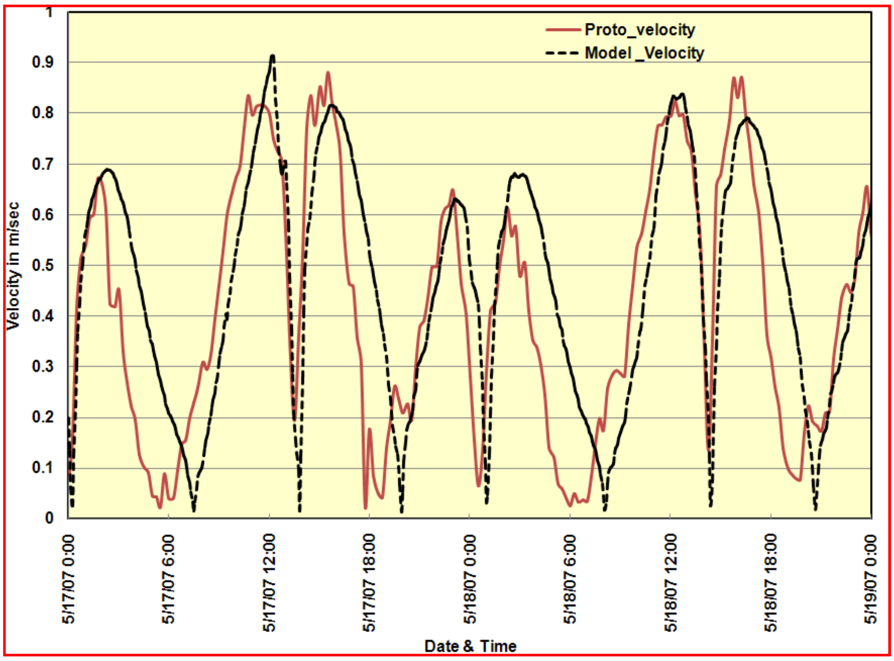
Fig. 6 Finite element mesh discretization for the model

A. Model Calibration

The flow in the model was simulated for the prevailing hydrodynamic conditions based on the field data collected. At the entrance to Panvel Creek, being the location which controls the flow in/out of the creek, where upstream of it the proposed international airport is planned, the model is calibrated and the results of the tides and currents measured are shown in Fig. 7.



(a)



(b)

Fig. 7 Calibration of model at Ulwe Bundar (a) tide and (b) current near mouth of Panvel Creek

B. Validation of the Model for an Extreme Rainfall Event

The flood of 26th July 2005, being the worst flood scenario, occurred in this region for which water levels observed/marked at various locations at site were considered for the validation of the model. The tidal levels of 26th July 2005, as per the tide table as the downstream boundary, and for the flood conditions, the hydrograph of 26th July 2005 as the discharge from all five rivers as the upstream boundary condition, were adopted. The various parameters used for calibrating the model such as roughness co-efficient (bed friction), phase lag for tide etc., were also used to run the model for determination of the water levels observed/measured after the 26th July 2005 rainfall event in the Panvel Creek area. The plot of water levels predicted from model studies is shown in Fig. 8. The comparison of water levels obtained from the model and measured at the site after 26th July 2005 event is given in Table III. The comparison reveals that it is in good agreement.

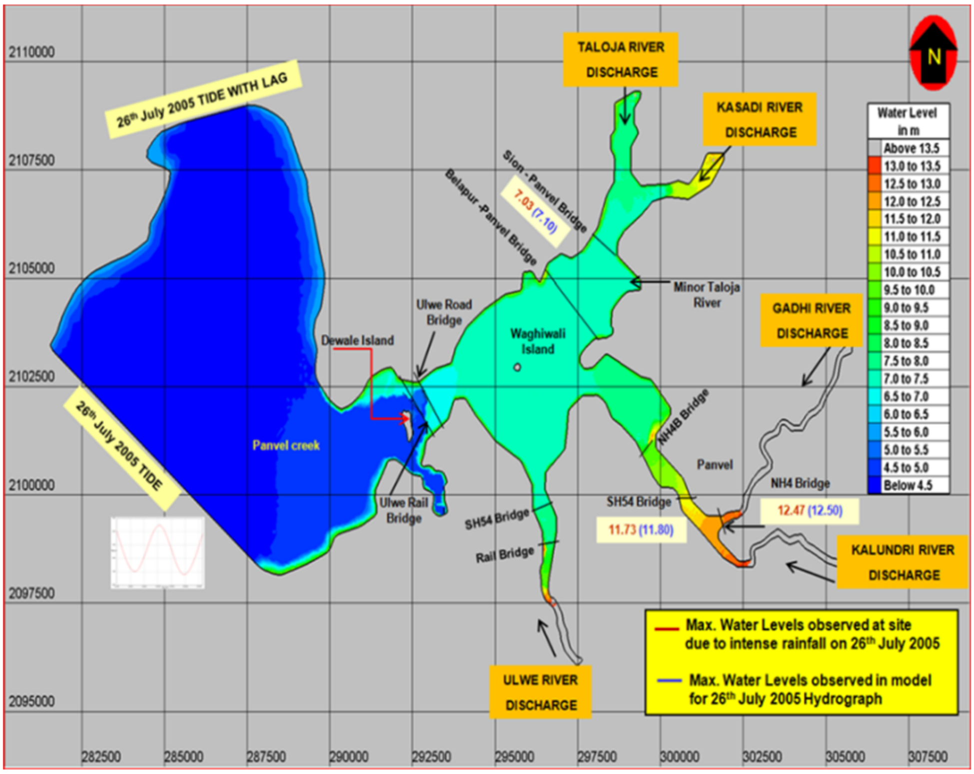


Fig. 8 Validation of model for 26th July 2005 rainfall event

TABLE III
FLOOD LEVELS DURING 26 JULY 2005 EXTREME RAINFALL EVENT

Location	Comparison of Flood Level in m	
	Water level at Site	Water level in Model
Sion-Panvel Bridge	7.03	7.10
NH4 Bridge on Gadhi	12.47	12.50
SH-54 Bridge on Gadhi	11.73	11.80

This well calibrated and validated model was used for assessing the flow condition for the existing bathymetry conditions at various locations and the effect of the proposed airport on the surrounding area, as well as the determination of SGE and other measures to be adopted to avoid inundation of low lying areas.

V. Studies for without and with Airport Condition

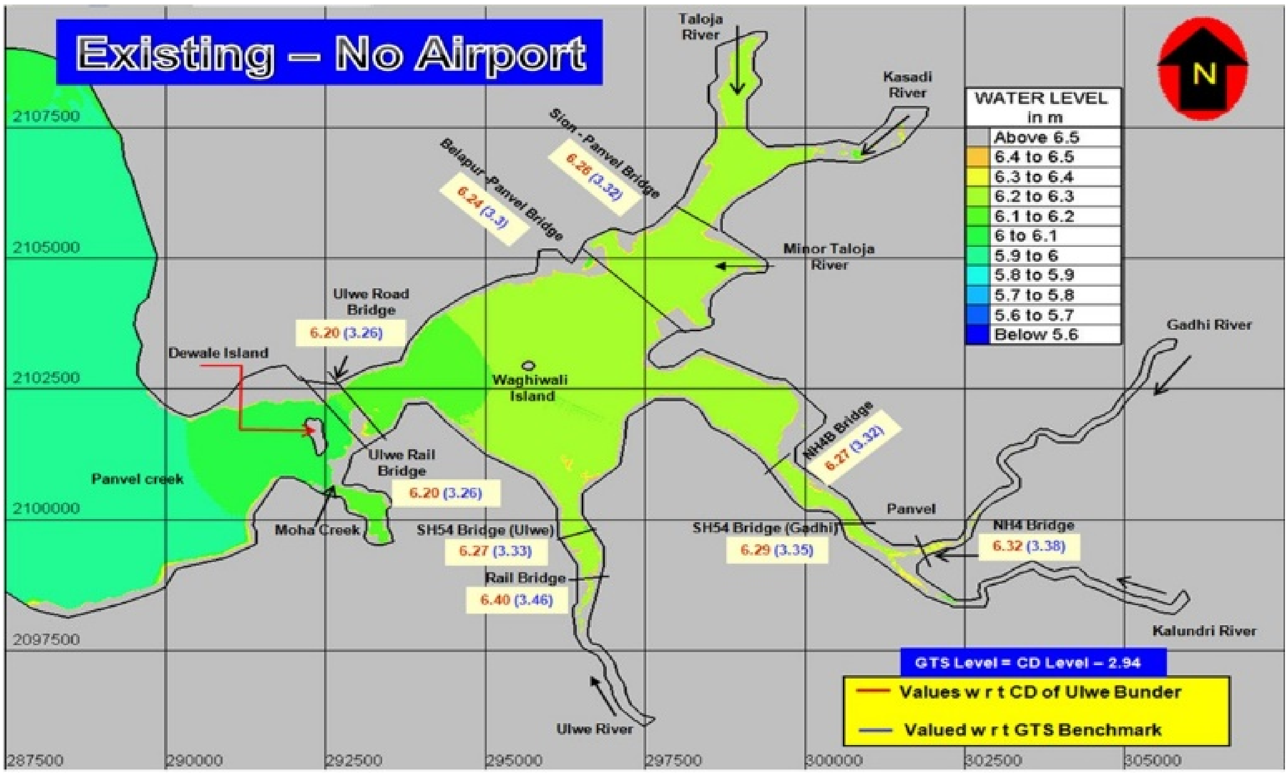
A. Without Airport Condition

The model studies for existing the bathymetry condition with all the bridges in the area of Panvel Creek were carried out for two hydrodynamic conditions namely no flow from the rivers, in other words, only design tide (maximum tidal range of 6.2 m with respect to CD at Ulwe Bundar) and tide with river discharges from all five rivers meeting the Panvel Creek confluence for PMP and 26th July case as extreme events. The information obtained from the model studies reveal that for no river flow, tidal water reaches upstream beyond NH4 Bridge on Gadhi River, while on Ulwe River in the south; it reaches beyond the existing Rail Bridge upstream of the SH54 Road Bridge. However, the hydrographs from all the rivers reveal that there is a rise in water levels, but the bridges on the Gadhi, Kalundri, Kasadi and Taloja do not cross the existing bridge deck levels. Only the deck level of SH54 Road Bridge on Ulwe River got submerged. The typical plot for water levels at various locations is shown in Fig. 9.

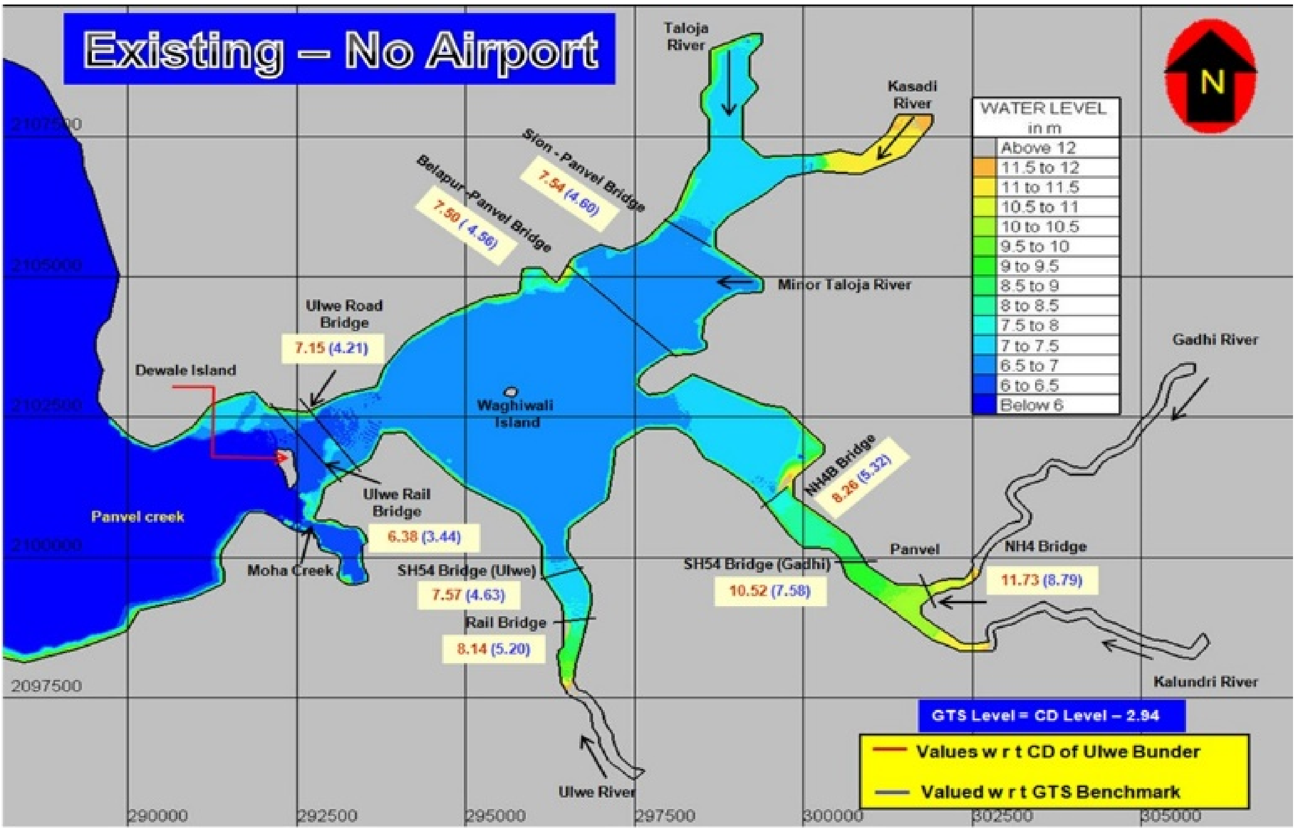
B. With Airport Condition

The model developed for the existing bathymetry conditions was modified by incorporating airport layout having an area of about 1160 hectares. The Ulwe River from the south passing beneath the airport was diverted along the southern boundary of the airport to Moha Creek, which subsequently meets Thane Creek. The diversion was initially considered to have a width of 120 m and water levels were predicted at various locations for the hydrodynamic conditions as it was considered for without airport (existing bathymetry conditions) conditions. The predicted water levels with the airport are given in Fig. 10.

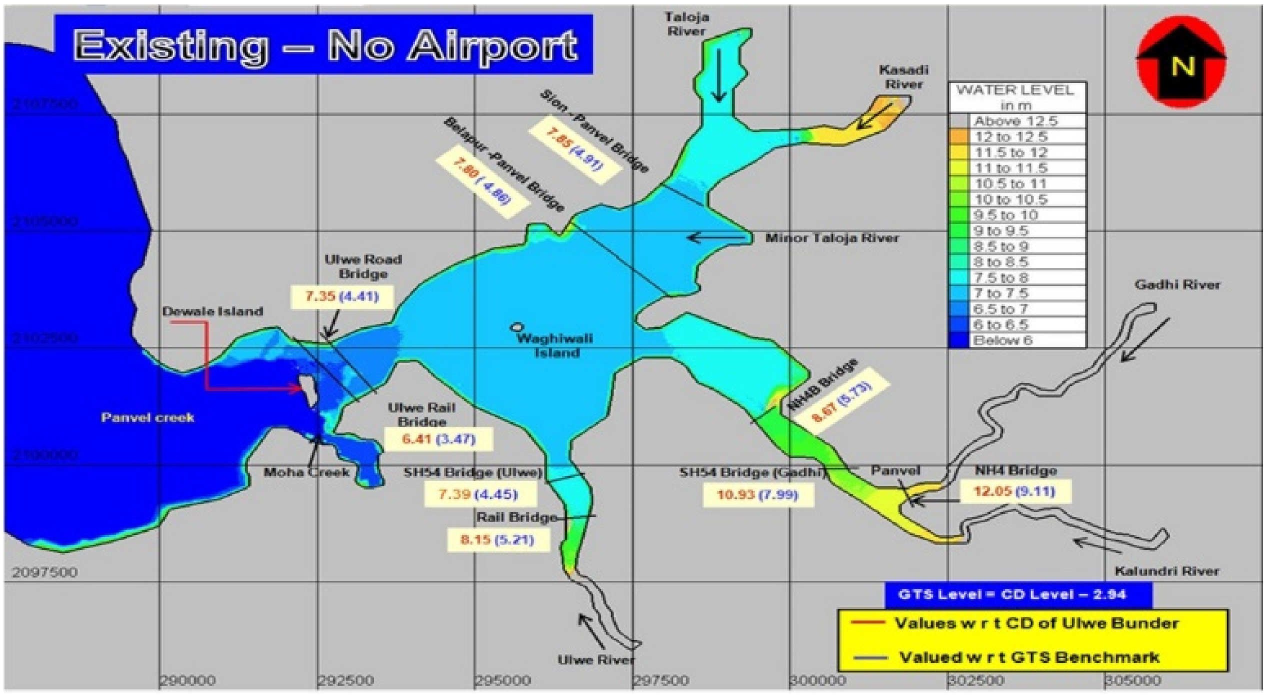
The comparison of water levels at important locations such as the mouth to Panvel Creek, the NH4 Bridge on Gadhi, the SH54 Bridge on the Gadhi and Ulwe rivers and the railway bridge on Ulwe River are made. The studies carried out reveal that the SH54 Road Bridge on Ulwe River governs the safe design level for the airport, as SH54/NH4 bridges on Gadhi are away from the airport area. The water level predicted at the SH54 Road Bridge on Ulwe River for a tide and PMP-6 hours flood hydrograph event with airport is maximum. The results are shown in Table IV. These levels are predicted for the existing clear opening of the bridge at Moha Creek as 60 m and the proposed Ulwe River diversion channel with a base width of 120 m. This diversion channel meets Moha Creek to let out flood waters to Thane creek.


Existing – No Airport
Taloja River
Kasadi River
WATER LEVEL in m
Above 6.5
6.4 to 6.5
6.3 to 6.4
6.2 to 6.3
6.1 to 6.2
6 to 6.1
5.9 to 6
5.8 to 5.9
5.7 to 5.8
5.6 to 5.7
Below 5.6
Sion - Panvel Bridge
6.26 (3.32)
Belapur-Panvel Bridge
6.24 (3.3)
Minor Taloja River
Ulwe Road Bridge
6.20 (3.26)
Dewale Island
Waghiwali Island
Gadhi River
NH4B Bridge
6.27 (3.32)
Ulwe Rail Bridge
6.20 (3.26)
Panvel creek
Moha Creek
SH54 Bridge (Ulwe)
6.27 (3.33)
SH54 Bridge (Gadhi)
6.29 (3.35)
Panvel
NH4 Bridge
6.32 (3.38)
Rail Bridge
6.40 (3.46)
Kalundri River
GTS Level = CD Level – 2.94
Values w r t CD of Ulwe Bunder
Valued w r t GTS Benchmark
Ulwe River
2107500
2105000
2102500
2100000
2097500
287500
290000
292500
295000
297500
300000
302500
305000

(a)

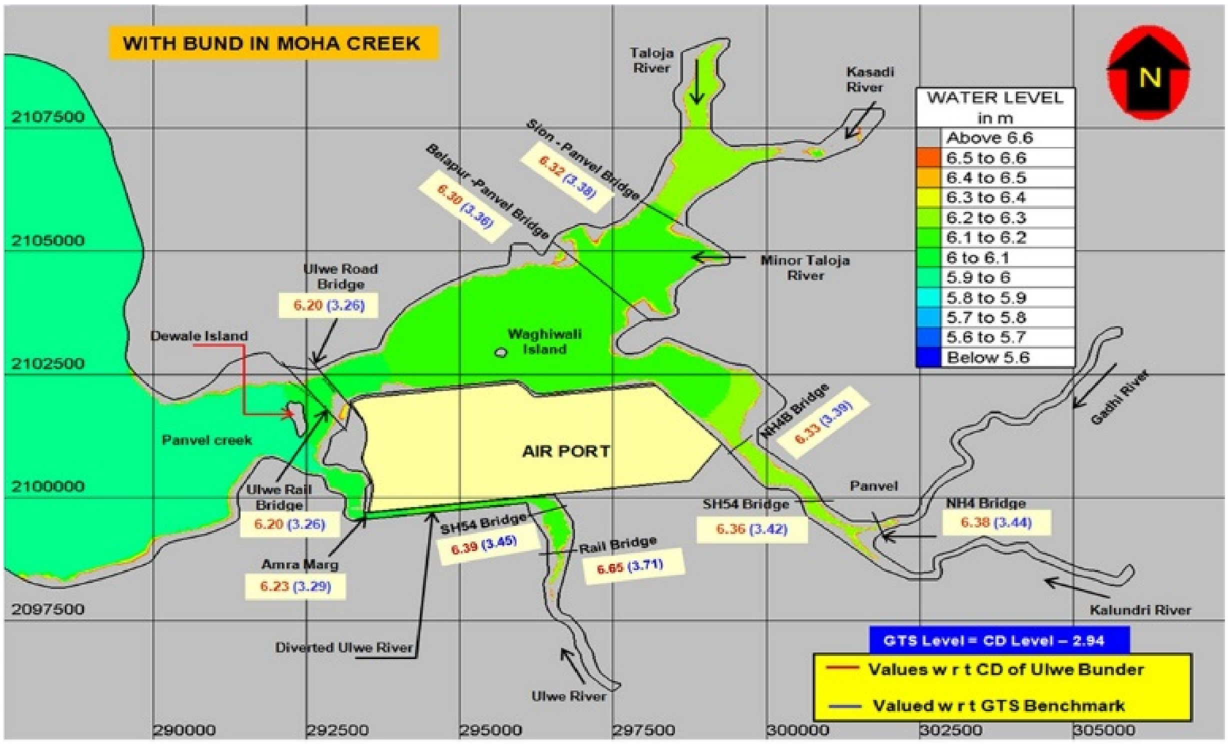

Existing – No Airport
Taloja River
Kasadi River
WATER LEVEL in m
Above 12
11.5 to 12
11 to 11.5
10.5 to 11
10 to 10.5
9.5 to 10
9 to 9.5
8.5 to 9
8 to 8.5
7.5 to 8
7 to 7.5
6.5 to 7
6 to 6.5
Below 6
Sion - Panvel Bridge
7.54 (4.60)
Belapur-Panvel Bridge
7.50 (4.56)
Minor Taloja River
Ulwe Road Bridge
7.15 (4.21)
Dewale Island
Waghiwali Island
Gadhi River
NH4B Bridge
8.26 (5.32)
Ulwe Rail Bridge
6.38 (3.44)
Panvel creek
Moha Creek
SH54 Bridge (Ulwe)
7.57 (4.63)
SH54 Bridge (Gadhi)
10.52 (7.58)
Panvel
NH4 Bridge
11.73 (8.79)
Rail Bridge
8.14 (5.20)
Kalundri River
GTS Level = CD Level – 2.94
Values w r t CD of Ulwe Bunder
Valued w r t GTS Benchmark
Ulwe River
2097500
290000
292500
295000
297500
300000
302500
305000

(b)

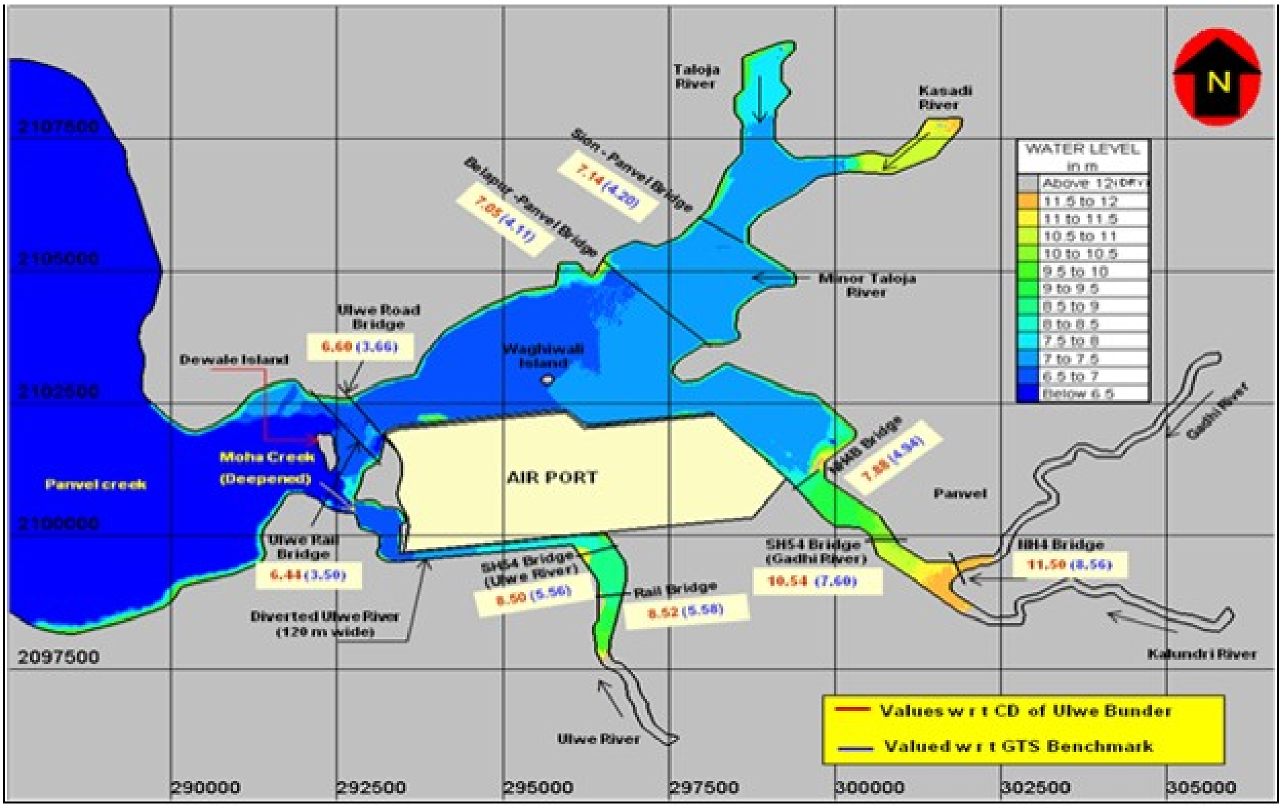


(c)

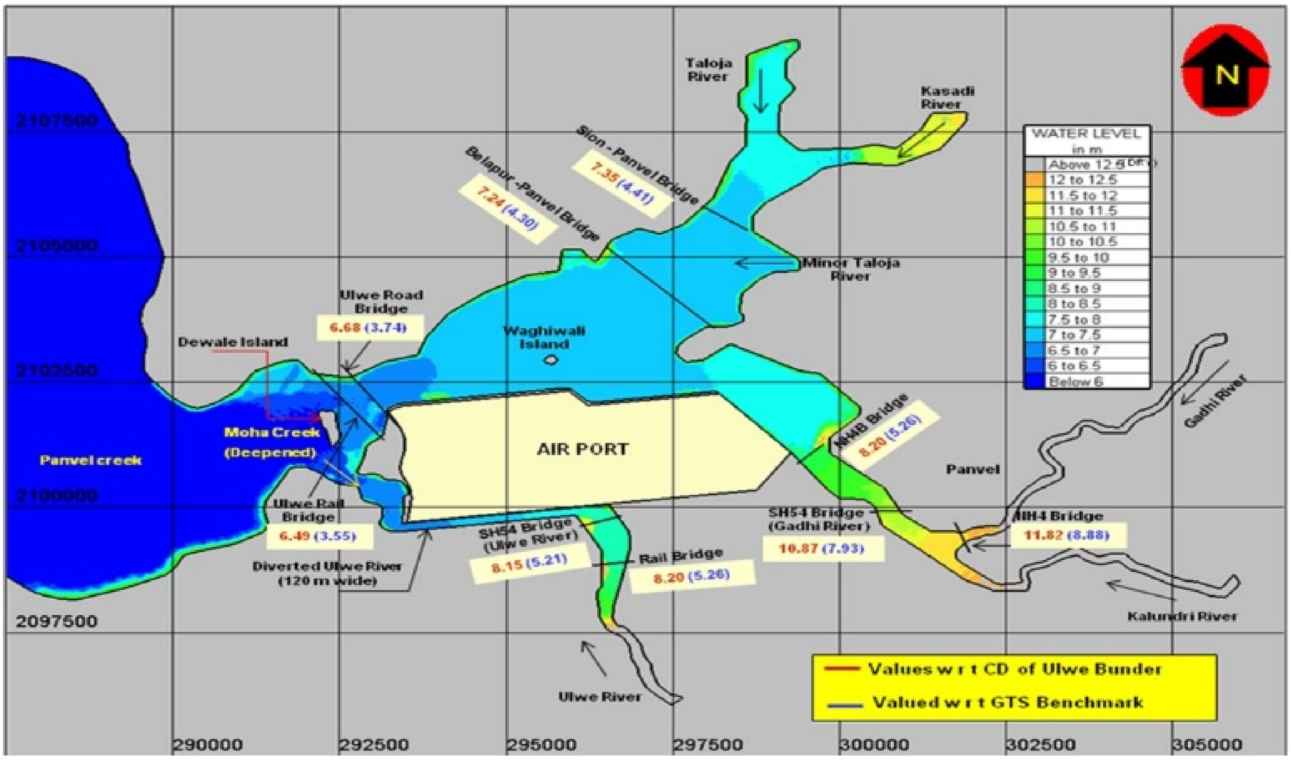
Fig. 9 Predicted Water Levels at Various Locations for existing bathymetry conditions (a) tide only (b) tide and PMP Hydrograph and (c) tide and 26th July 2005 Hydrograph



(a)



(b)



(c)

Fig. 10 Predicted Water Levels at Various Locations for airport condition (a) tide only (b) tide and PMP Hydrograph and (c) tide and 26th July 2005 Hydrograph

TABLE IV
PREDICTED FLOOD LEVELS DURING PMP AND 26 JULY 2005 EXTREME RAINFALL EVENT AT IMPORTANT LOCATIONS

Location	Comparison of Flood Level in m			
	Without Airport		With Airport	
	PMP	26 July	PMP	26 July
Mouth of Panvel Creek	7.15	7.35	6.60	6.68
NH4 Gadhi Bridge	11.73	12.05	11.50	11.82
SH54 Road Gadhi Bridge	10.52	10.93	10.54	10.87
SH54 Road Ulwe Bridge	7.57	7.39	10.80	10.54
Rail Bridge on Ulwe	8.14	8.15	10.81	10.55

The values of water levels are considerably high and the existing bridges at SH54 on Ulwe and the bridge at mouth of Moha Creek will get submerged during such extreme events. The addition of free board as per IRC recommendations [6] will bring safe grade elevation of the airport to more than 13 m above CD of Ulwe Bundar and will have to be provided over the area of about 1160 hectares, which will result in uneconomic development. As such, to keep safe grade elevation (SGE) of the airport to a minimum, it is inevitable to optimize the cross section of the diversion channel of Ulwe to such a size that neither decks of the existing bridges will get submerged during extreme events, nor will the development be uneconomical.

C. Optimization of Ulwe Diversion Channel

The cross section of the diversion channel of Ulwe River from hydraulic consideration was optimized by varying the bottom width of the diversion channel at the diversion near the SH54 Bridge on Ulwe River from 120 m to width of 240 m for a distance of 500 m, and thereafter, with smooth transition to meet 120 m widths. In all cases, the width of the opening at the bridge near Moha creek was also kept as 120 m and existing bund in Moha Creek is removed to allow free passage of water during both flood and ebb tide. The typical cross section having a width of 200 m at SH54 Bridge on Ulwe River is shown in Fig. 11.

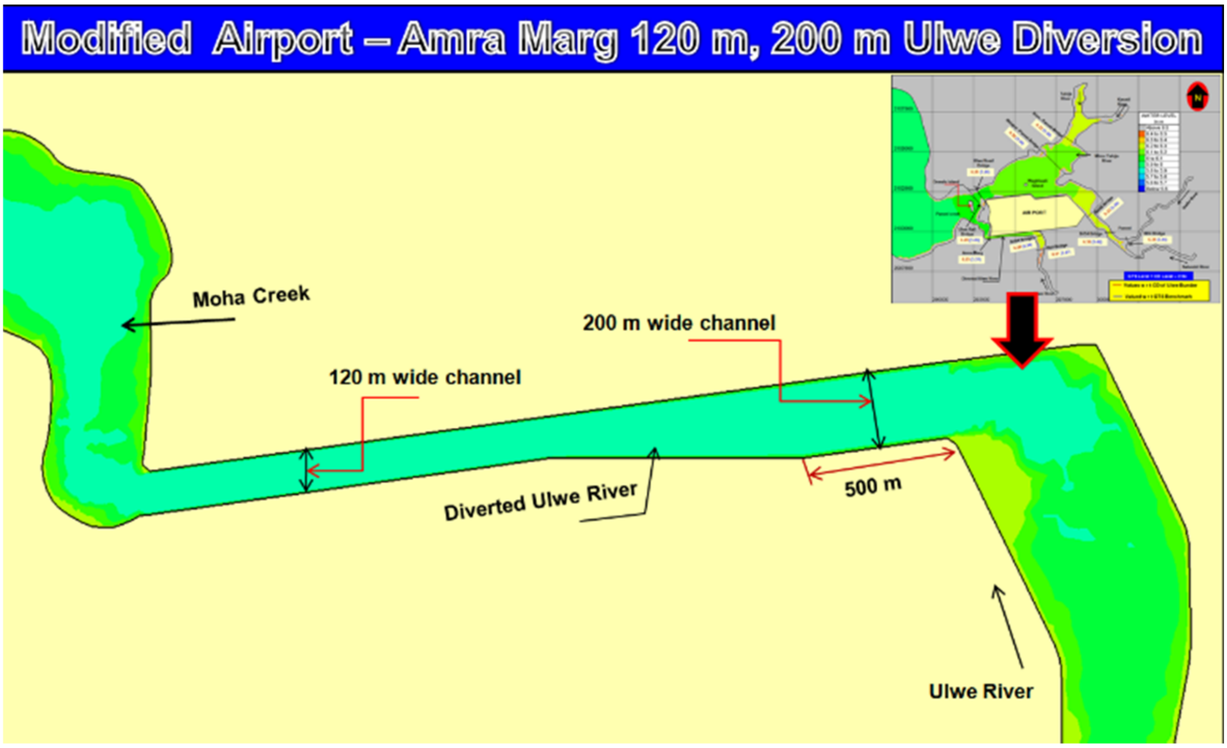


Fig. 11 Layout of diversion channel at Ulwe River 120m - 200m

TABLE V
PREDICTED FLOOD LEVELS FOR PMP – 6 HR EVENT AT IMPORTANT LOCATIONS TO OPTIMISE DIVERSION CHANNEL DIMENSIONS AT SH54 BRIDGE ON ULWE RIVER

Location	Comparison of Flood Level in m			
	Width at Ulwe Diversion Channel near SH-54 bridge on Ulwe River			
	120 m	180 m	200 m	240 m
Bridge at Mouth of Moha creek (Amra Marg)	7.49	7.46	7.44	7.50
SH54 Road Ulwe Bridge	9.20	8.60	8.50	9.11

The studies were carried out for the case of PMP, 6-hour storm duration event considering the fact that value of the peak estimated discharge for Ulwe River is a maximum for PMP (916 cum/sec) and not for 26th July 2005 event (722 cum/sec) as mentioned in Table II. This is due to the fact that the catchment for Ulwe River is less as compared to that for Gadhi/Kalundri and other two rivers from the north, namely Taloja and Kasadi. As such, to optimize the Ulwe diversion channel, studies with this event by keeping 120 m width as a common base width near the mouth of Moha Creek (Amra Marg Bridge), were carried out and the results on the water levels predicted are summarized in Table V. Thus, Table V indicates that the optimal dimensions of the Ulwe diversion channel is a width of 200 m near the SH-54 Bridge on Ulwe River. The water levels predicted for the 120 m X 200 m Ulwe diversion channel are for PMP, 6-hour storm event, and are given in Fig. 12.

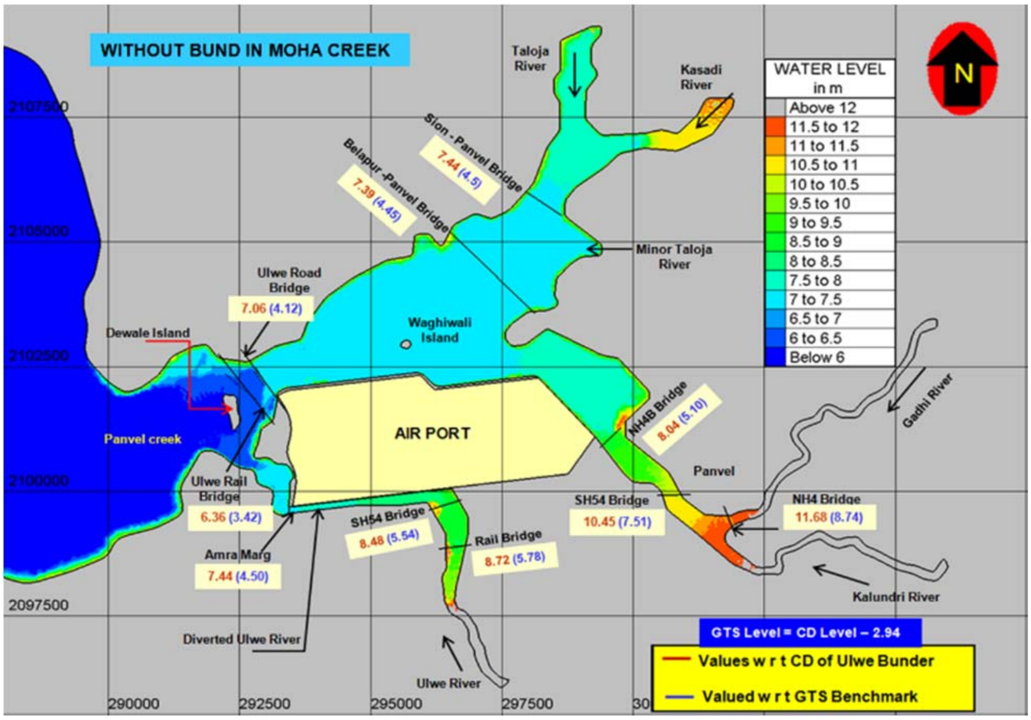


Fig. 12 Predicted water levels for optimal Ulwe diversion channel of size 120m - 200m for PMP-6 Hours storm duration

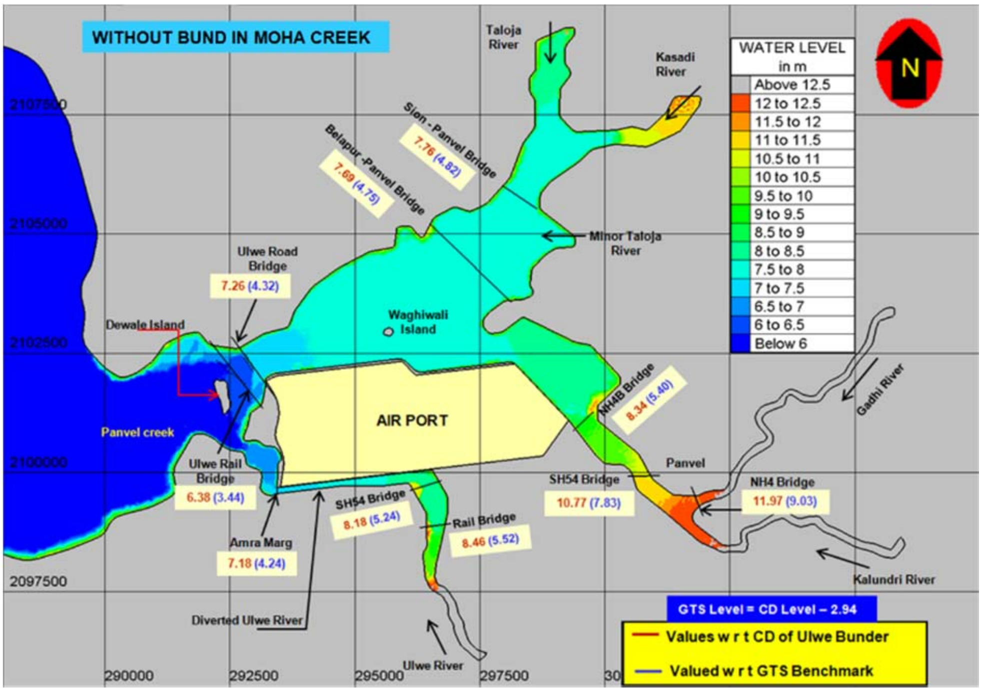


Fig. 13 Predicted water levels for optimal Ulwe diversion channel of size 120m - 200m for 26th July 2005 event

The water/flood levels predicted for the 26th July 2005 event for a 120 m X 200 m Ulwe diversion channel are given in Fig. 13. The analysis of water levels predicted reveals that on the southern side of the proposed international airport the PMP, 6-hour storm duration governs the maxima water level, while on the northern side of the airport the 26th July 2005 event governs the maxima water levels. As such, to determine safe grade elevation of the airport, maxima water levels around the airport were determined by model studies.

The water/flood levels were determined all along the airport boundary for the optimum dimensions of the Ulwe diversion channel at various locations and are shown in Fig. 14.

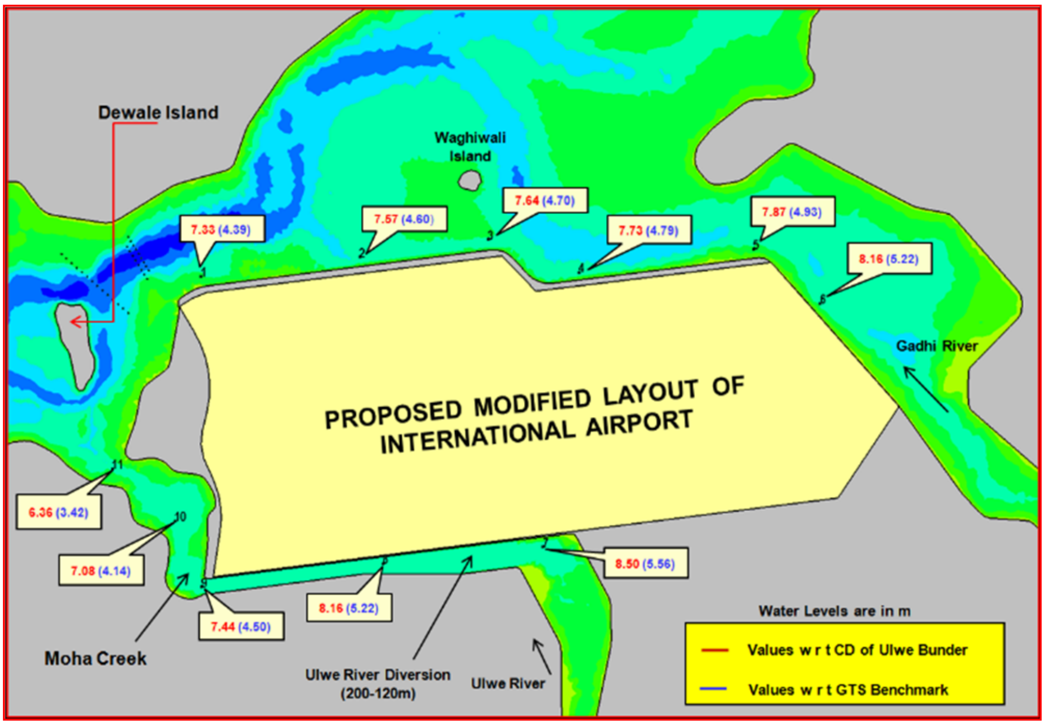


Fig. 14 Predicted maxima water levels around Airport boundary

Considering the factors for wind setup, storm surge, free board of about 1.8 m from flooding consideration and the estimated maximum water levels along the boundary area to be reclaimed for the airport, as well as 0.2 m for sea level rise and 0.5 m for all other remaining factors such as embankment settlement and subsidence, the Safe Grade Elevation of 11 m above CD of Ulwe Bundar [7] is the optimal level which can be adopted over all areas of the airport or with slope for terracing as per maxima water levels at different regions of the airport.

VI. Conclusion

Mumbai, being the epicentre of India's trade and commerce, has seen an exponential growth of population over the past few decades and due spatial constraints, there are traffic jams on existing road/rail networks and the existing airport facilities are not an exception. The domestic and international airports servicing Mumbai are inadequate to handle future air traffic needs, and due to heavy rainfall of 1000 mm/day on 26th July 2005, they were shut down due to the inundation caused by heavy floods and highest tide in the Arabian Sea. The government, to relive pressure on the existing airports, proposes the construction of a new airport at the confluence of five rivers namely the Gadhi, Kalundri, Taloja, Kasadi and Ulwe, meeting at the Panvel estuary near Navi Mumbai. Considering the precedence of extreme rainfall, due to which the existing airports built on Mithi River got inundated, and the nearby township being in low lying area of new airport being at the confluence of five rivers, hydraulic model studies using numerical techniques are essential to determine the SGE of the new airport to avoid inundation under extreme events.

The studies for estimation of hydrographs for extreme events (PMP and 26th July 2005 rainfall) and simultaneous simulation of highest tide from the Arabian Sea and discharges from all the rivers, governs the SGE of the airport proposed by the reclamation over 1160 hectares. Also, the Ulwe River flowing beneath the proposed airport needs to be diverted and the diversion being at a right angle to its natural flow direction, there is significant rise in the water level at the diversion compared to the existing condition, and hence, the optimization of Ulwe diversion channel from a hydraulic consideration is important to keep the SGE of the airport to a minimum.

The main findings of the studies are:

The diversion of Ulwe River, having width of diversion channel of 120 m near Moha Creek mouth, should have a 200 m base width near the SH-54 Bridge on the Ulwe River with removal of the existing bund in Moha Creek optimizes maxima water level to 8.5 m with respect to the CD of Ulwe Bundar, and thus, the SGE of the airport to a minimum of 11 m.

The bridges at SH-54 (Ulwe River) and Amra Marg at the mouth of Moha Creek should have a clear waterway of 80 m and 120 m, respectively.

The right bank of Gadhi River between the NH-4B and SH-54 bridges, being a low-lying area and upstream of the Ulwe

River diversion channel, is likely to get inundated after development of the airport, and therefore, river bank protection works are essential to avoid inundation of these areas

Application of unstructured mesh modelling is an extremely useful tool to simulate complex extreme hydrodynamic events and to provide reliable water level prediction to determine optimal SGE of the proposed airport.

ACKNOWLEDGMENT

The authors would like to thank to Dr. M. K. Sinha, Director, Central Water and Power Research Station, Pune (India) for his continuous encouragement and motivation for carrying out the research work.

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