BEFORE THE NATIONAL GREEN TRIBUNAL WESTERN ZONE

BENCH PUNE

O.A. 6/2023

Mrs. Patricia Pinto and Ors ...Applicant

Vs.

State of Goa and Ors . ...Respondents

REPLY AFFIDAVIT OF RESPONDENT NO. 2.

I, DR SNEHA S GITTE, adult, being Member Secretary, Goa Coastal Zone Management Authority, having my office at 4th floor, Dempo Towers, Patto Panaji, Goa, do hereby beg to state on solemn affirmation as under:

1. I state that the proposal comprised of A) Miramar circle to Youth Hostel (0+00 to 0+634) 634m length of which 369m length completed (285m from Miramar circle to Marriott hotel and 84m from Marriott Hotel to Youth Hostel) and 265m length is not commenced (stretch in front of Marriott Hotel). B) Kala Academy to ESG (0+920 to 1+969) 1049m length is completed.

2. I state that of the Total length approved is 1,683m of which 1,418m is completed.

3. I state that the Land portion abutting the protection wall is CRZ II area in CRZ Notification 1991 as well as CRZ Notification 2011 I further states that the stretch from Marriott Hotel to Youth Hostel is located within zone 1B and from ch 0+420 to 0+634 the riprap is

Gitte

partly in water and the stretch from Kala Academy to Forest/ Children park is located within zone 1B and from ch 1+130 to 1+460 the riprap is partly in water.

4. I say and submit that the Project under challenge comprises of a steel bridge constructed at the confluence of river and St. Inez Nallah Mouth, which is marked as Waterbody in CRZ IVA as per CRZ Map. A sea Wall construction between chainage 1+540 and 1+920 is above HTL in the CRZ Map whereas high line marks are close to the river bank. The walkway and cycle track at the incomplete stretch near marriot hotel and small portion near Kala academy is in CRZ I B and iv rest of the cycle track and walkway is in CRZ II area.

5. I say that From Kala Academy to Children's park following chainages the footpath is partly in 1B
   ch 0+920 to ch 1+050 &
   ch 1+080 to ch 1+340 &
   ch 1+410 to ch 1+440

6. I state that the present Respondent has received an application from the Respondent No. 7 for Protection & Restoration of Mandovi River Coastline from Miramar Circle to Youth Hostel and from Kala Academy to ESG on 27.01.2022. The Respondent No. 7 has submitted the application in Form I along with following documents.

   a. Application letter no GSIDC/Engg/Works/1485/6054 dated 27/01/2022
   b. Form I

c.EIA Report

d.Project layout superimposed on CRZ map indicating HTL and LTL

e. Drawings indicating Pedestrian Bridge Details, typical section, and typical balcao details.

6. I state that in the drawings submitted by the Respondent No. 7; the proposed Bridge was included and the same is annexed as 'Annexure B' to the reply affidavit of the Respondent No. 7 in the preset Application. And Application along with the annexures were considered consolidated by the present Respondent.

7. I state that the proposal of the Respondent No. 7 was for Protection & restoration of Mandovi River Coastline from Miramar Circle to Youth Hostel and from Kala Academy to ESG.

NOTARY Goa CRPB Grade TP OF GOA No. 301 Date 24 GOA

8. I say and submit that the EIA report submitted by the Respondent No. 7 along with its Application was based on the study carried out by the Water Resources Department titled 'Mathematical Model studies on Hydrodynamics and sedimentation for demolition of Retaining Wall at Marriot Hotel Goa'. The copy of the said study is enclosed herewith and annexed as 'Annexure A' to the affidavit field by the Respondent No. 7 in the present Application. I state that the said study includes a study carried out by Shri Agarwal Director Department of Water Resources, River Development and Ganga Rejuvenation Central Water & Power Research Station Khadakwasla, Pune which is a study of the same stretch for which application was submitted by Respondent No 7 (GSIDC).

9. I state that in the said study the following works carried out by Water Resource Department are mentioned: The proposed construction of the protection was mere repair of the existing retaining wall constructed in 1978-1979 as per the Work Order.

1. Construction of protection wall at sea shore at Miramar up to changing room. (Work order no. HI/Accts/F.43/1945/78-79 dt.16/09/78.)
2. Construction of protection wall at sea shore at Miramar near Youth Hostel, Panaji. (Work order no. HI/Accts/F.43/3585/78-79 dt.20/11/1978.)
3. Anti Sea erosion work behind swimming pool campal, Panaji. (Work order No.7- 5/WD-I/Irrg/A/397 dt. 26.7.1991)
4. Temporary measures to safeguard the lighthouse behind Kala Academy at Campal, Panaji. (Work order No.7-5/WD-I/Irrg/Accts/499/91-92 dt. 10.3.1992)
5. Temporary anti-sea erosion protection measures behind Forest nursery to Punjab Upovan at Campal. (Work order No.7-5/WD-I/Irrg/Accts/267 dt. 14.7.1992).
6. Immediate temporary Anti sea erosion wall behind Indoor Stadium to Youth hostel at Campal, Panaji. (Work order No.7-5/WD-I/Irrg/Accts/302/92-93 dt. 5.9.1992).
7. Urgent temporary Anti sea erosion wall behind Indoor stadium to Football stadium, Campal. (Work order No.7-5/WD-I/Irrg/A/504/92-93 dt. 22.10.1992).
8. Temporary Anti sea erosion behind Kala Academy, Campal (Stretch I to V). (Work order No.7-5/WD-I/Irrg/Accts/95-9/22-23 dt. 24.7.1995).

9. Anti sea Erosion measures behind Children's park Campal, Panaji. (Work order No.7-5/WD-I/Irrg/Accts/96-97/760 dt. 1.1.1997).

10. Anti sea Erosion measures at Bhagwan Mahavir Balviharpark, Campal Panaji Tiswadi Goa. (Work order No. 7-5/WDI/Accts/07-08//09. Dt.19/06/2007)

10.I say and submit that on receipt of the application an Inspection was carried out by Expert Member of GCZMA Mr.Sujeetkumar Dongare and Surveyor Mr.Satishkumar Naik of the GCZMA and copy of the said inspection report is annexed as '**Annexure C**'.I state that in the said Report ;the expert member of the GCZMA and the surveyor at point no 5 have mentioned about the said EIA report. The said expert member was also present for the 299th meeting of the GCZMA when the application was considered for grant of permission. I state that as per para clause 3 (iv) (b) activities pertaining to measures for control of erosion are permitted in the CRZ Notification 2011.

NOTARY Adv. C.R.B. Gracias GOA

11. I further state that the present Respondent has considered the application of the Respondent No. 7 along with the EIA Study which includes the study conducted by Water Resources Department and which proposes to reconstruct the retaining walls constructed earlier by Water Resources Department in the year 1978-79 and mentioned in the EIA study conducted by LKS India Pvt Ltd study which also includes the bridge portion of 32.78mtrs length at the confluence of St Inez Nallah and Mandovi River with 2 number of piers with 4numbers of piles for each piers and the photograph of the same is annexed as '**Annexure D**'.

12. I state that the Respondent No. 7 has constructed 1418 meters of the retaining wall from chainage 0+285,0+550 to 1+969 along with the bridge. I state that the length from Miramar circle towards Youth hostel is shown as eroding coast as per the report prepared by Space Applications Centre, ISRO Ahmedabad and Central Water Commission, New Delhi.

13. I therefore say and submit that after due deliberation of the documents produced, Report and study material, the present Respondent has considered the grant of No Objection Certificate in accordance with law.

Hence this affidavit.

Solemnly affirmed on this the 30th day of November 2023.

DR SNEHA S GITTE
Member Secretary
Goa Coastal Zone Management Authority

VERIFICATION

I, the above named deponent, do hereby verify the contents stated herein above are true to the best of my knowledge. No part of it is false and nothing has been suppressed therefrom.

Verified at on 30th day of November 2023

DR SNEHA S GITTE
Member Secretary
Goa Coastal Zone Management Authority

Solemnly affirmed before me
Dr Sneha S. Gitte
Who is identified before me by
At Panjim - Goa
Sr. No. 326/11/2023
Date. 30/11/2023

Venefrada C.P.P.B Gracias
Advocate & Notary Goa State

Site inspection report of proposal with respect to protection and restoration of Mandovi river coastline from Miramar circle to youth hostel and from kala academy to ESG

Dated: 17/03/2022

Sujeetkumar Dongre and Satishkumar Naik

Ref: GSIDC vide its letter No. GSIDC/Engg/Works/1485/6054 dated 27/01/2022

Background:

In pursuance to the inspection notice issued by the Member Secretary vide Ref No. GCZMA /N/21-22/89/1913 dated 28/01/2022.

The undersigned have visited the site on 17/03/2022.

The observation and recommendations:

1. The GSIDC proposed to undertake protection and restoration of Mandovi river coast line staring from ESG to Miramar approximately covering a length of around 2 Kms

2. The proposed area falls within the Mandovi estuarine zone, which is an ecologically sensitive area.

3. At the time of undertaking protection and restoration activities, due care must be taken to avoid any irreversible damage to the estuarine zone by following all scientific protocols and materials (including construction and restoration), so that no ecological productivity of the area is hampered.

4. Free flow of any tidal influenced water be maintained wherever such streams/drains/nallah/creeks are connecting to the estuary, especially one near the indoor stadium and St. Inez mouth near ESG to avoid upstream flooding

5. The project proponent has submitted an EIA report undertaken by LKS INDIA PVT LTD, Pune titled 'Protection and restoration of Mandovi river coastline from Miramar Circle to Youth Hostel and Kala Academy to ESG' which the authority may like to study before any decision is made.

6. The Authority may deliberate and take appropriate decision as per the CRZ regulation in force.

Sujeetkumar Dongre
Expert Member
GCZMA

Satishkumar Naik
Field Surveyor
O/o. GCZMA

भारत सरकार
Government of India
जल शक्ती मंत्रालय
Ministry of Jal Shakti
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग
Department of Water Resources,
River Development and Ganga Rejuvenation
केन्द्रीय जल तथा विद्युत अनुसंधान शाला,
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No. PH-I/2020/374

Date: 10 / 09/2020

सेवा में,
Chief Engineer (WRD),
Sinchai Bhavan,
PORVORIM - BARDEZ,
Goa - 403 521.

विषय : MATHEMATICAL MODEL STUDIES ON HYDRODYNAMICS AND SEDIMENTATION FOR DEMOLITION OF RETAINING WALL AT MARRIOT HOTEL,GOA.

महोदय,

उपर्युक्त विषय के अनुसार, *DEMOLITION OF RETAINING WALL AT MARRIOT HOTEL, GOA* हेतु गणितीय प्रतिमान अध्ययन किया गया। उस गणितीय प्रतिमान अध्ययन की अंतिम तकनीकी प्रतिवेदन संख्या 5850 Septmber 2020 की, दो प्रतियां इस पत्र के साथ संलग्न है।

कृपया तकनीकी प्रतिवेदन प्राप्ति कि सूचना इस कार्यालय को अवगत करे।

धन्यवाद।

संलग्न : यथोक्त

भवदीय,

(डॉ. प्रभात चंद्र) 10/9/2020
वैज्ञानिक "ई"

भारत सरकार

Government of India

जल शक्ती मंत्रालय

Ministry of Jal Shakti

जल संसाधन, नदी विकास और गंगा संरक्षण विभाग

Department of Water Resources, River Development and Ganga Rejuvenation

केन्द्रीय जल एवं विद्युत अनुसंधान शाला पुणे- ४११०२४

Central Water & Power Research Station Khadakwasla, Pune - 411024

COASTAL AND OFFSHORE ENGINEERING LABORATORY

Technical Report No.:5850
September 2020

Mathematical Model studies on Hydrodynamics and sedimentation for demolition of Retaining Wall at Marriot Hotel, Goa

A. K. Agrawal
DIRECTOR

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REPORT DOCUMENTATION SHEET

Technical Report No.:5850 **Date: September 2020**

TITLE: **MATHEMATICAL MODEL STUDIES ON HYDRODYNAMICS AND SEDIMENTATION FOR DEMOLITION OF RETAINING WALL AT MARRIOT HOTEL,GOA.**

Officers Responsible for Conducting the Studies:
Shri V B Sharma, Scientist 'B' and Vaibhav Konde, Research Assistant carried out the studies under the guidance of Dr. Prabhat Chandra, Scientist 'E'.

Name and Address of the Organization Conducting the Studies
Ports and Harbour Division
Central Water and Power Research Station
Pune 411 024, India

Name and Address of the Authority Sponsoring the Studies
Chief Engineer (WRD),
Sinchai Bhavan,
PORVORIM - BARDEZ,
Goa - 403 521.

Key Words: Mathematical Model, MIKE-21 HD/MT, Bathymetry, Tide, Currents, River discharge, Mandovi river, Sedimentation

Synopsis

The Mandovi river in Goa state is facing severe problem of erosion at its left bank near Hotel Marriott and its upstream. In order to safe guard this bank, retaining wall was constructed in 1978. This wall got damaged in early nineties due to severe storms and discharges. In order to protect hotel property, the hotel management constructed retaining wall at about 10 m away from the damaged retaining wall in the year 1996. The length of this new wall is 242.85m and its top level varies between 3.78m to 4.38 m in different stretches of wall. It is proposed to dismantle the existing wall and part of hotel premise by about 10-12m.The mathematical model studies were carried out by using MIKE – 21 HD/MT to determine the impact of demolition of wall and adjacent properties in the vicinity of hotel Marriot on the left bank.

This area is highly influenced by tide, waves and high river discharge conditions. This stretch is prone to erosion. The studies show that the significant wave height in the region are of the order of 0.8 m during monsoon period. The peak currents near the Marriott hotel wall are of the order of 0.9 m/s. The studies strongly indicate that shifting of left bank would increase the curvature of river resulting in more erosion at left bank. The demolition of existing wall would result in shifting of channel towards left bank and this would further worsen the situation of erosion as angle of oblique current would further increase and the wave forces would be borne by bank alone.

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Technical Report No.:5850 **Month: SEPTEMBER 2020**

1.0 INTRODUCTION

The Marriot hotel is located at about 3.5 km from the entrance of Mandovi estuary on it's left bank on the west coast of India in Goa shown in the Fig. 1. The width of river at the entrance is about 3.3km while at Hotel Marriott, it is about 1.1 km. The existing retaining wall at Marriot Hotel and surrounding areas are influenced by tide, waves and high river discharge conditions. The combined impact of high river discharge and waves during monsoon period makes this area more vulnerable for erosion. During fair weather condition, a pretty beach appears along the left bank which disappears during monsoon. The bank is very dynamic in nature. During peak river discharge condition, the retraining wall is partially submerged under the increased water levels. During this period, non breaking waves attack the protection works while during low river discharge condition, breaking waves hit the vertical retaining wall which cause tremendous impact on the river bed as well as on the protection works. It appears that the old sea wall / protection works constructed in 1978 was beyond high water but due to severe river discharge conditions combined with wave condition, the protection work collapsed. The remains of this old retaining still persist as shown in Fig.2. In order to protect hotel property, the hotel management constructed retaining wall at about 10 m away from the prevailing damaged retaining wall in the year 1996 as shown in Fig. 2. The length of this new wall is 242.85m and its top level varies between 3.78m to 4.38 m in different stretches of wall.

Now, it is proposed to dismantle the existing wall and part of hotel premise as shown by imaginary line in Fig. 3. It could be seen from figure 3 that the pillar of Marriott hall is very close to the imaginary line and the footing may further be very close to the imaginary line. The figure also indicates high tide line and the retaining wall constructed in 1978.

Fig.1: Location Map

Fig.2: Damaged and Existing Retaining Wall

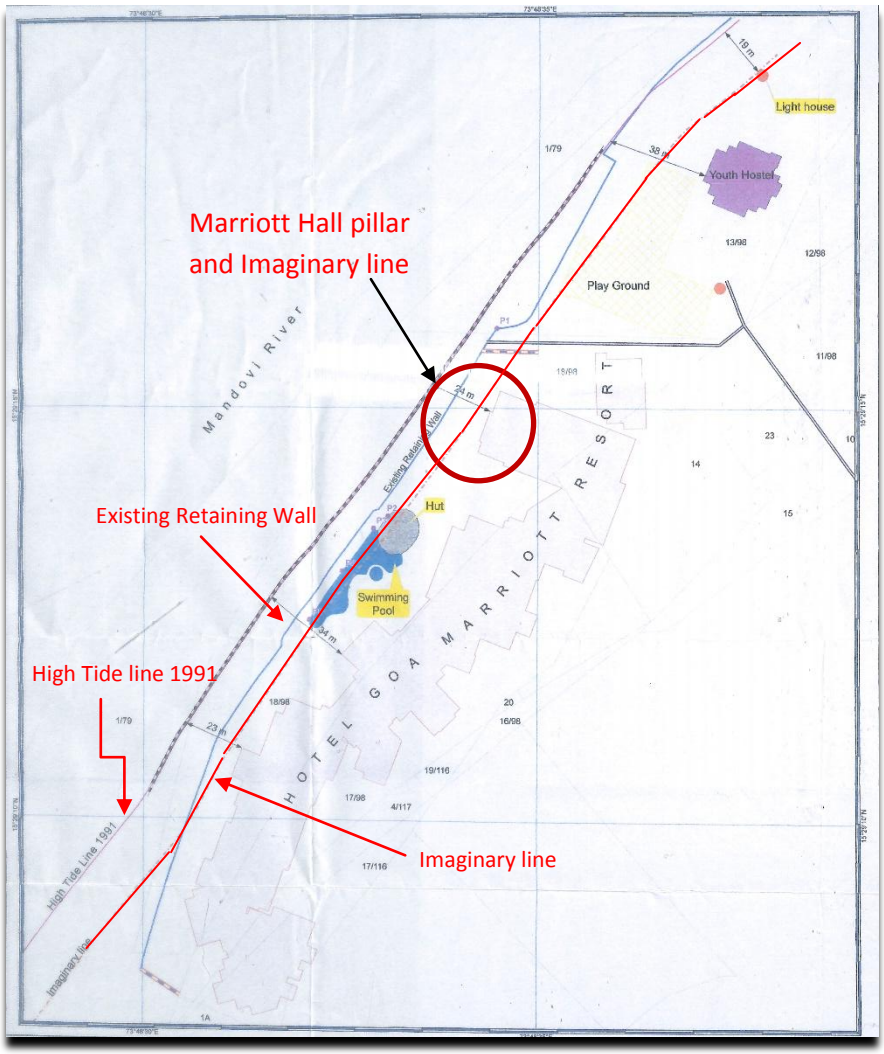

Fig. 3: Chart showing Damaged retaining wall, existing retaining wall and Imaginary line

Details of anti erosion protection works carried out by Government of Goa are listed below and locations are shown in Fig. 4 which are on the left bank of the river.

1. Construction of protection wall at sea shore at Miramar up to changing room. (Work order no. HI/Accts/F.43/1945/78-79 dt.16/09/78.)
2. Construction of protection wall at sea shore at Miramar near Youth Hostel, Panaji. (Work order no. HI/Accts/F.43/3585/78-79 dt.20/11/1978.)
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9. Anti sea Erosion measures behind Children's park Campal, Panaji. (Work order No.7-5/WD-I/Irrg/Accts/96-97/760 dt. 1.1.1997).

10. Anti sea Erosion measures at Bhagwan Mahavir Balviharpark, Campal Panaji Tiswadi Goa. (Work order No. 7-5/WDI/Accts/07-08//09. Dt.19/06/2007).

Fig. 4: Google images showing Mandovi River and locations of protection works

In the present interim report, the preliminary mathematical model studies have been carried out to assess the impact of demolition of retaining wall at Marriot Hotel, Goa on hydrodynamics and morphology of surrounding areas.

2.0 PHYSIOGRAPHIC AND HYDRAULIC CONDITIONS

The width of the Mandovi estuary at the entrance is 3300 m and natural depths are about 8 to 9 m below CD (Fig.5) which reduces to about 1km across Hotel Marriott and keeps on reducing to 600m width in a stretch of 1400 m. A sharp band can also be seen in the estuary 2000m upstream from Hotel Marriott. Estuary flow gets diverted towards left bank due to sharp band making left bank more vulnerable for erosion. It is also evident from the bathymetry of the area which shows that deep channel is very close to left bank. As the hydraulic conditions of the area were not available, a large area was modelled which comprises the Mormugao port area for which hydraulic parameters like velocities, hydrographs, wave, tide etc. Hydrographs of both the rivers namely Mandovi and Zuari are shown in Fig. 6. The peak discharge in Mandovi river is about 1600 m^3/s for those respective years. In general, the discharges in the Mandovi river are about 4-5 times more than those in Zuari river. The peak discharge in the Manodovi river has been estimated as about 5000 m^3/s. The same has been used for the model studies. The peak tidal currents in the offshore region are of the order of 0.25 m/s. Offshore wave data reported in Indian daily weather chart reports published by Indian Metrological Department (IMD) are shown in following rose diagrams (Fig.10) and the same have been used to simulate MIKE-21 SW module.

Fig. 5. Physiography of Mandovi estuary

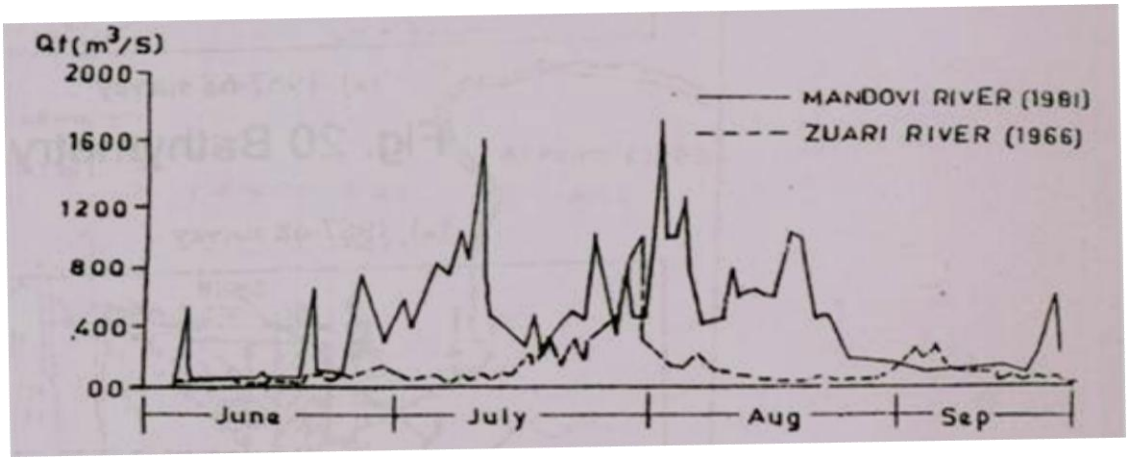

Fig. 6. Hydrographs of Mandovi and Zuari River

Bathymetry is one of the most important input for the model. Bathymetry was obtained from available hydrographic charts as supplied by the MPT and from MIKE-21 C map data. The bathymetry covers an area of 40kmX40km. The model area includes major stretch of Zuari and Mandovi rivers. Towards sea side, it covers soundings up to(-) 56 m depth contours below CD. Figure7(a) shows the 2-D view of the model area and bathymetry while Figure7(b)

indicates bathymetry in the vicinity of Hotel Marriott. A deep channel can be observed near the left bank of river. This is caused due to sharp bend of river 1.5 km upstream of river as flow gets deflected towards left bank. The flow velocity increases on the outer curvature of bend causing erosion which in turn creates deep channel near outer curvature bank. Thus, the flow attacks the left bank at an angle making it more vulnerable for erosion. On the other hand near the right bank (opposite to Marriott hotel), the depths are shallow. This can be seen in Fig. 7(c) which shows cross-section L1-L2 across River Mandovi near Marriott Hotel. It can be observed that deep channel is at a distance of about 900 m from right bank while from left bank it is just about 150 m.

Large model area has been considered to incorporate Mormugao port where observed hydraulic data was available which has been used to calibrate hydraulic conditions in the model.

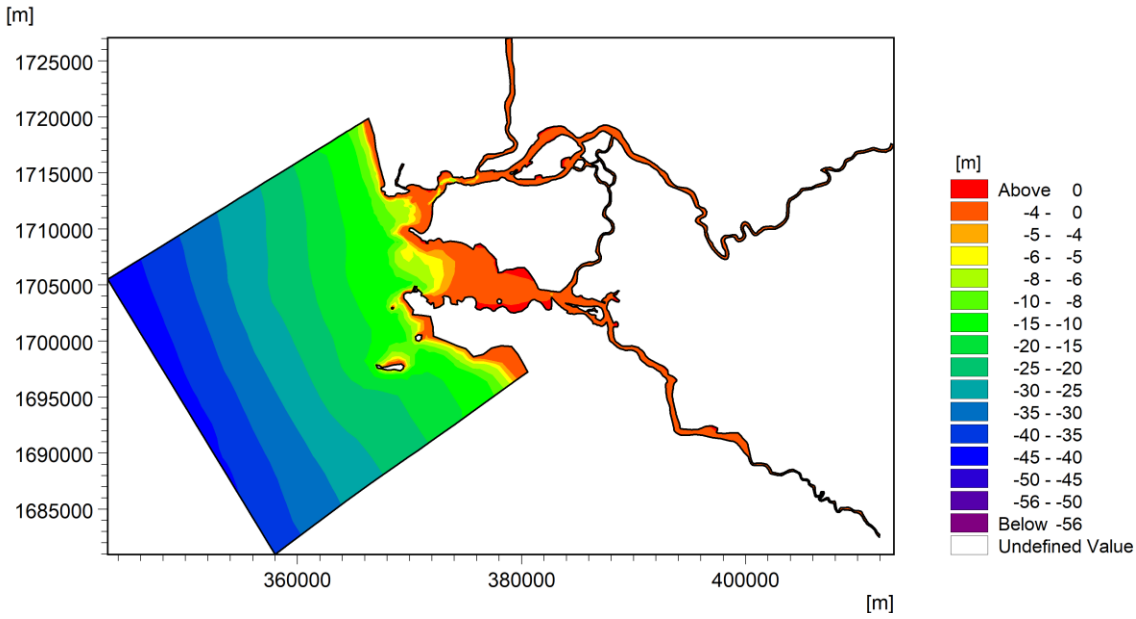

Fig. 7(a): 2-D View of Bathymetry in modelled area

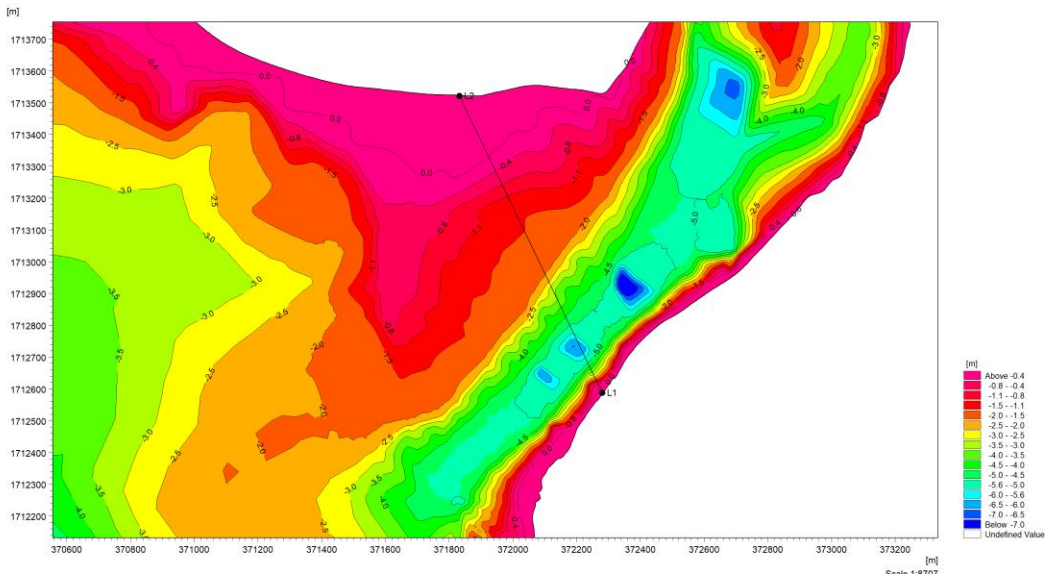

Fig. 7(b): 2-D View of Bathymetry in the vicinity of Marriot Hotel

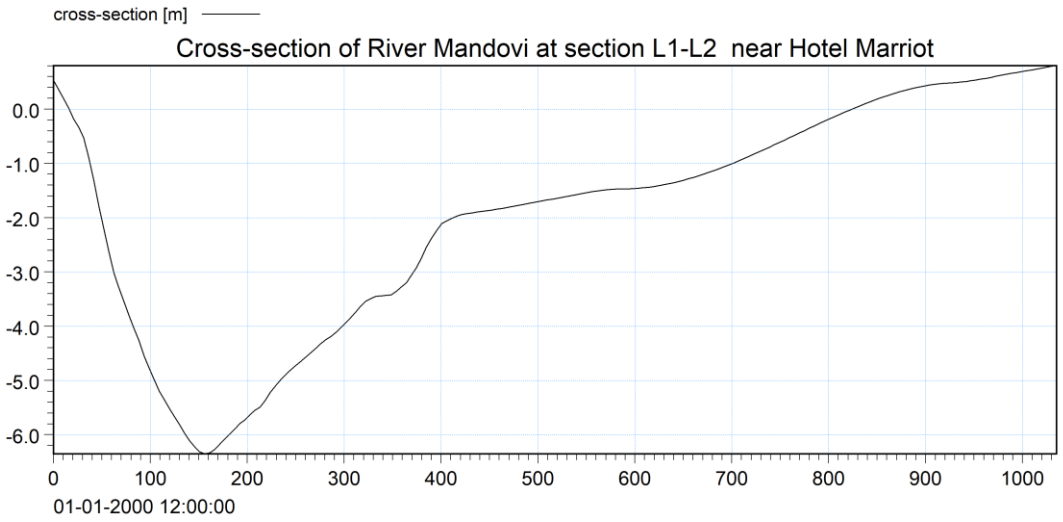

Fig. 7(C): Mandovi River Cross-section near Hotel Marriott

Offshore wave data reported in Indian daily weather chart reports published by Indian Metrological Department (IMD) are shown in following rose diagrams (Fig. 8) and the same have been used to simulate MIKE-21 SW module.

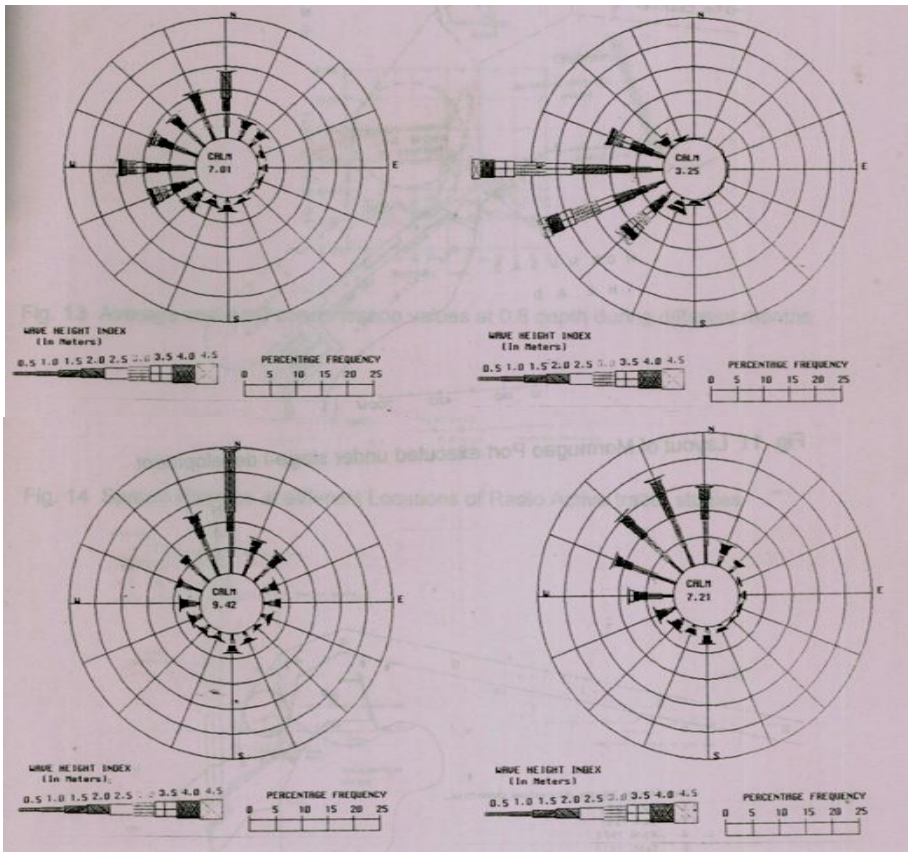

Fig. 8: Offshore Wave Data Rose Diagrams

The region is subjected to incident short period waves of significant height of 2.0m from the directions north to northwest during the non-monsoon season (October to May) and from the directions between southwest and west of significant height of about 4.0m during the southwest monsoon season i.e. from June to September.

3.0 Wave Transformation Studies

The computational model considered for wave transformation covered an area of 40 km x 40 km and the same has been used to for hydrodynamic and sedimentation studies. The model area covers the entire proposed port area upto (-) 56 m depth contour. Mesh and bathymetry files were generated using MIKE-21 tools. Model was simulated for both SW and NE monsoon period. The significant waves are shown in Fig. 9(a)-9(d). It could be seen from figure that significant wave height during monsoon period is 0.8m while during non-monsoon period it is only 0.15m.

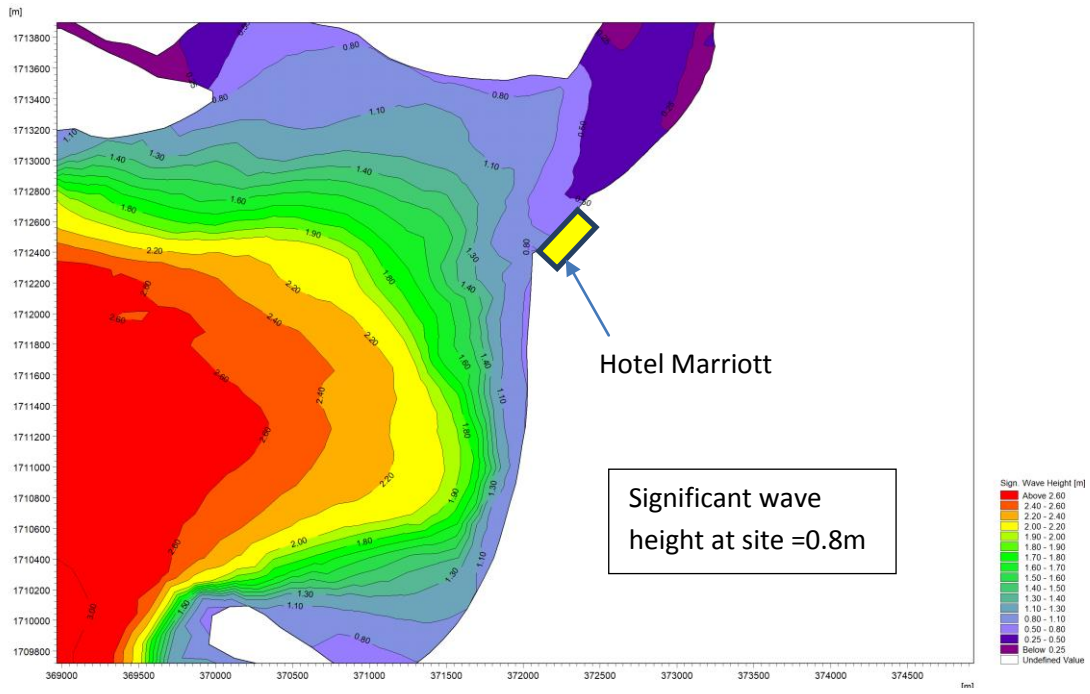

Fig.9(a):Significant wave Height at Hotel Marriott during SW Monsoon (Wave Direction 270^0)

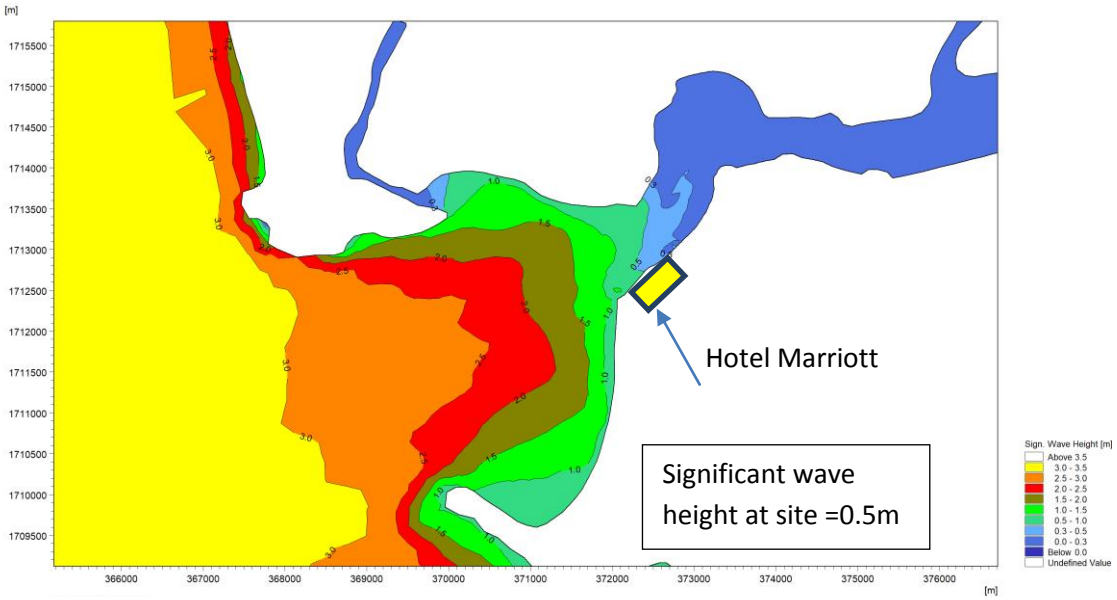

Fig. 9(b):Significant wave Height at Hotel Marriott during SW Monsoon (Wave Direction 250^0)

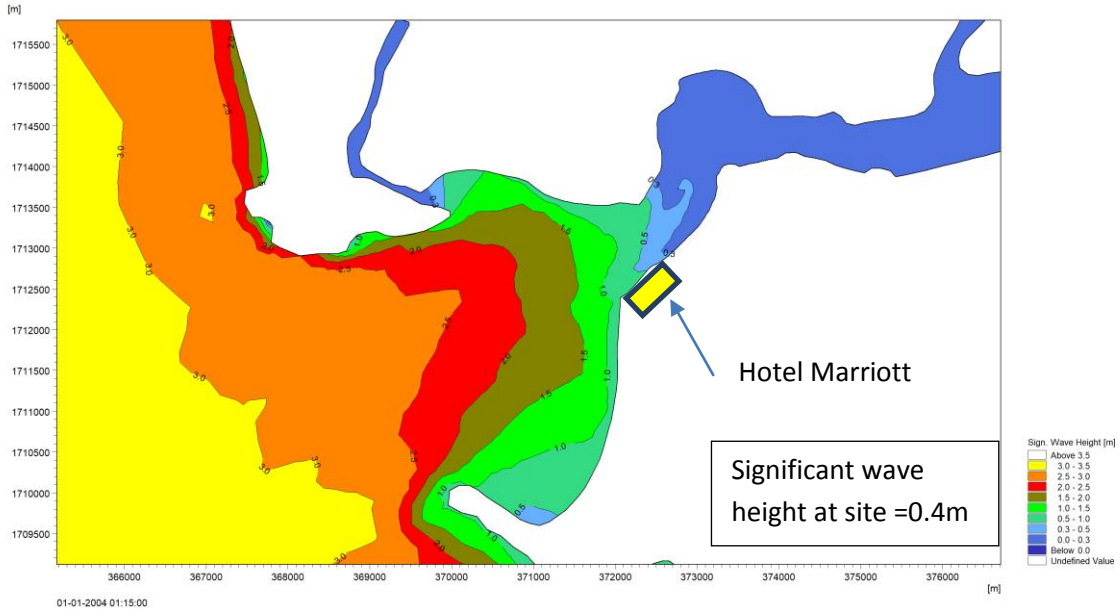

Fig. 9(c):Significant wave Height at Hotel Marriott during SW Monsoon (Wave Direction 225^0)

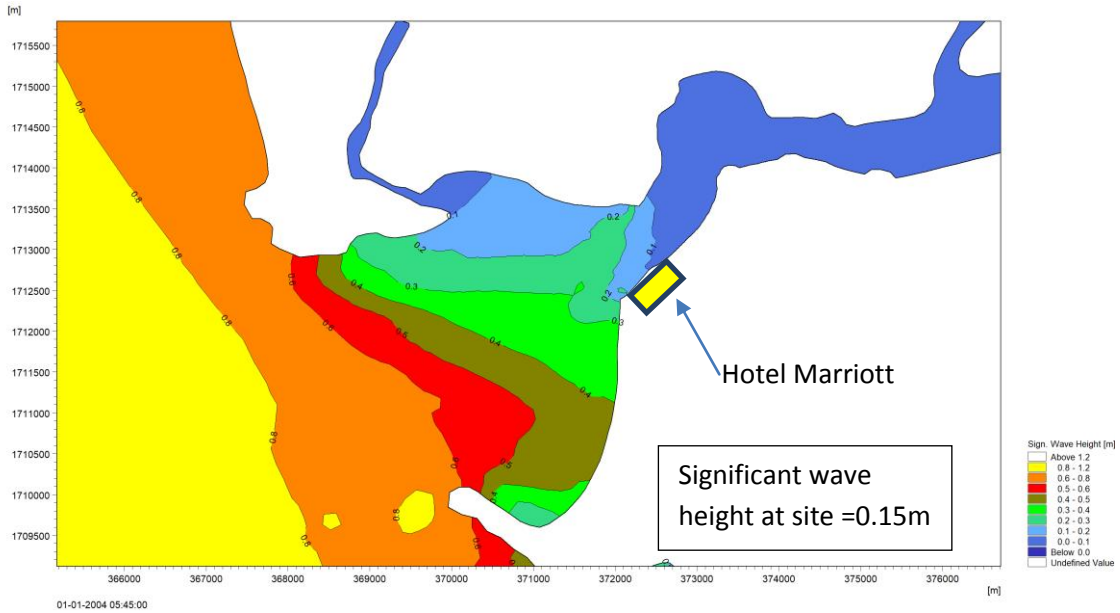

Fig. 9(d):Significant wave Height at Hotel Marriott during NE Monsoon (Wave Direction 315^0)

Details of retaining wall at six sections are shown in Fig. 10. The thickness of wall is 50 cm and its top levels are varying at different sections. The water levels at different tidal levels are marked in the figure. During peak river discharge, the retaining wall is partially submerged due to which this wave does not break and attacks the vertical wall causing huge force on the wall and also overtop it. During low river discharge condition, breaking waves hit the retaining wall.

These breaking waves have impact on both bed erosion and retaining wall trust. Depending upon type of waves; breaking or non breaking, the thrust varies.

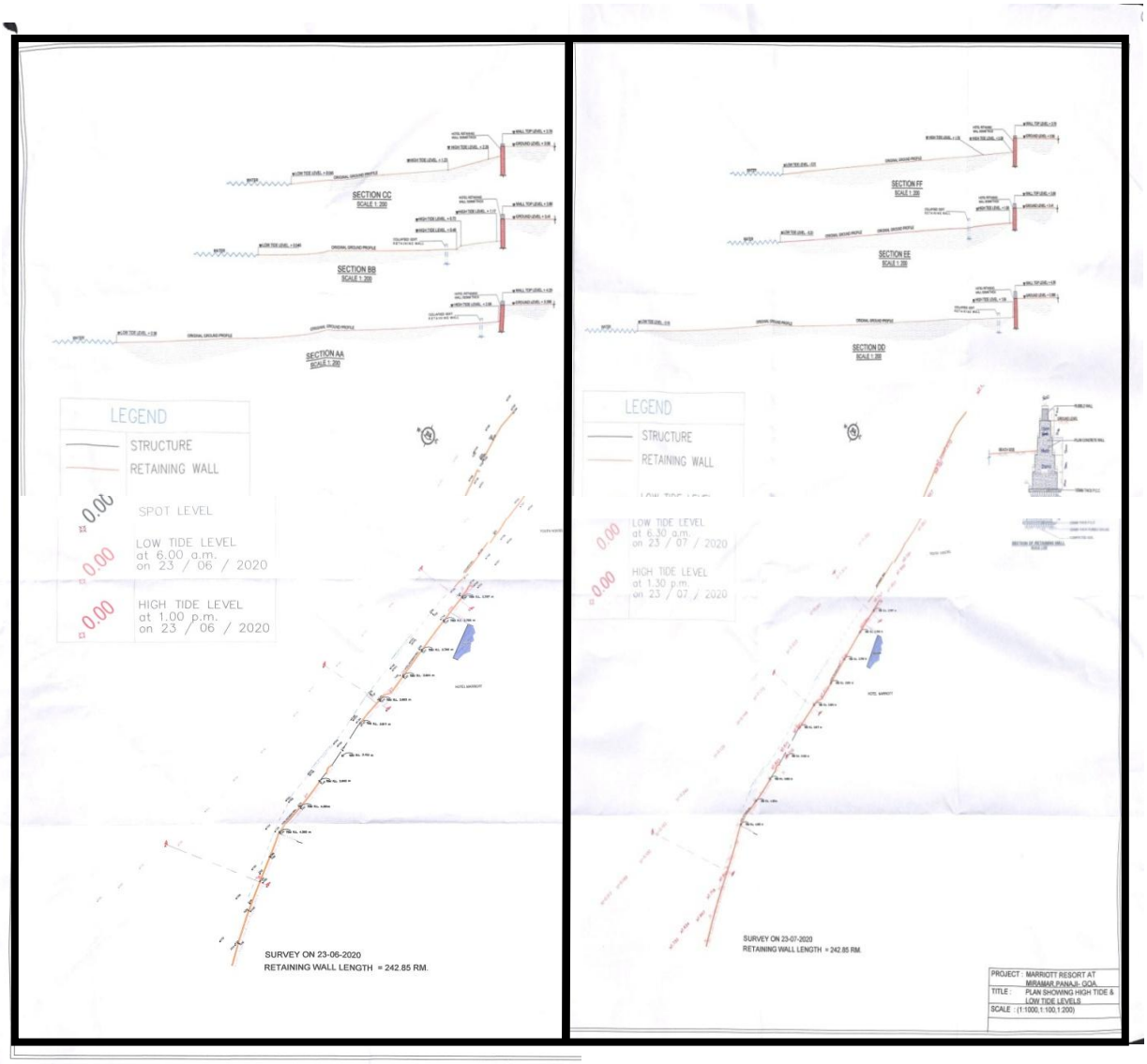

Fig. 10: Plan showing High, Low Tide Levels and Top Level of Wall

4.0 DESCRIPTION OF MODULES OF MODEL MIKE- 21

In the present study, 2-Dimensional hydrodynamic model MIKE 21 HD and mud transport Model, MIKE 21 MT have been used to simulate the flow field and sediment transport in the existing and the proposed scenario under prevailing tidal and wave conditions. Brief

description of scientific background of MIKE 21 HD model and MIKE 21 MT model is given in following paragraphs as below.

4.1 MIKE 21HD Module

In order to simulate dynamics of cohesive sediment, it is necessary to initially compute the hydrodynamics of water body in terms of velocity and water level fluctuations. Appropriate governing equations for hydrodynamics in tidal areas are given by the shallow water wave equations. These two dimensional shallow water equations are derived from Navier Stokes equations of motion with the simplified assumptions.

MIKE 21 Flow Model FM is based on a flexible mesh approach and it has been developed for applications within oceanographic, coastal and estuarine environments. The modelling system may also be applied for studies of overland flooding. The system is based on the numerical solution of the two- dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure. The spatial discretization of the primitive equations is performed using a cell-centred finite volume method. The spatial domain is discretized by subdivision of the continuum into non-overlapping elements/cells. In the horizontal plane an unstructured grid is used while in the vertical domain in the 3D model a structured mesh is used. In the 2D model, the elements can be triangles or quadrilateral elements. The spatial discretization of the primitive equations is performed using a cell-centered finite volume method.

The basic equations are derived from conservation equation for spectral wave action density, and are represented as under:

$$\frac{\partial(C_{gx}m_o)}{\partial x}+\frac{\partial(C_{gy}m_o)}{\partial y}+\frac{\partial(C_\theta m_o)}{\partial \theta}=S_o \qquad (4)$$

$$\frac{\partial(C_{gx}m_1)}{\partial x}+\frac{\partial(C_{gy}m_1)}{\partial y}+\frac{\partial(C_\theta m_1)}{\partial \theta}=S_1 \qquad (5)$$

Where,

$m_o(x,y,\theta)$: Zeroth moment of the action spectrum (m^2)

$m_1(x,y,\theta)$: First moment of the action spectrum (m^2/s)

C_{gy}, c_{gx} : Components in the x and y direction of the group velocity (c_g), (m/s)

c_θ : propagation speed representing the change of action in the θ dir. (m/s)

θ : direction of the wave propagation (degree)

S_0, S_1 : source terms (m^2, m^2/s)

The moments $m_n(\theta)$ are defined; $m_n(\theta) = \int_0^\infty \omega^n . A(\omega, \theta) d\omega$

where, ω is the absolute frequency (S^{-1}), and A is the spectral wave action density (m^2/s). The propagation speed c_{gx}, c_{gy} and c_θ are obtained using linear wave theory.

The left hand side of the basic equations takes into account the effect of refraction and shoaling. The source terms S_o and S_1 take into account the effect of local wind generation and energy dissipation due to bottom friction and wave breaking. The effects on current on these phenomena are included.

The spatial discretisation of the basic partial differential equations is performed using Eulerian finite difference technique. The zeroth and the first moment of the action spectrum are calculated on a rectangular grid for a number of discrete directions. In the X-direction, linear forward differencing is applied while in both the Y and θ directions it is possible to choose between linear up-winded differencing, central differencing and quadratic up-winded differencing. The best results are usually obtained using linear up-winded differencing in both the Y and θ directions. The non-linear algebraic equation system resulting from the spatial discretisation is solved using a once-through marching procedure in the X-direction (the predominant direction of wave propagation) restricting the angle between the direction of wave propagation and the X-axis to be less than 90^0.

The discretization in geographical and spectral space is performed using a cell-centred finite volume method. In the geographical domain, an unstructured mesh is used. The spatial domain is discretized by subdivision of the continuum into non-overlapping elements.

The sediment transport (MIKE-21 MT) formulations are built into the advection-dispersion module, MIKE 21 AD, which solves advection-dispersion equation:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = \frac{1}{h}\frac{\partial}{\partial x}\left(hD_x\frac{\partial c}{\partial x}\right) + \frac{1}{h}\frac{\partial}{\partial y}\left(hD_y\frac{\partial c}{\partial y}\right) + Q_L C_L \frac{1}{h} - S \qquad (6)$$

The following symbols are used in the equation:

c : compound concentration (arbitrary units)

u,v : horizontal velocity components in x, y directions (m/s)

h : water depth (m)

D_x,D_y : dispersion coefficients in the x,y directions (m^2/s)

S : accretion/erosion term ($kg/m^3/s$)

Q_L : source discharge per unit horizontal area ($m^2/s/m^2$)

C_L : concentration of source discharge (kg/m^3)

The advection-dispersion equation is solved using an explicit, third-order finite difference scheme, known as the ULTIMATE scheme.

4.2 MIKE 21 MT Module

The sediment transport studies were carried out using MIKE 21 MT model. This model simultaneously solves hydrodynamic and sediment transport equations. The calibration of sediment transport model is difficult because morphological changes are too slow and temporal bed changes are too variable to measure anything significant for comparison. The sediment fluxes at various locations may differ and the following factors contribute for these variations:

- Unsteadiness of flow,
- Mixtures of sediment in suspension,
- Variability of supply of mobile sediment on the bed,
- Presence of sandy (non-cohesive) sediment,
- Omission of depth variation,
- Effect of wave stirring.

The erosion, transport and deposition of silt, mud and clay particles under action of currents and waves can be best described by the multi-layers mode of the mud transport module of MIKE 21. The sediment transport module is dynamically coupled with the 2-dimensional hydrodynamic module, MIKE 21 HD. The module solves the primitive equations in two dimensions using finite difference methods by Alternating Direction Implicit technique and the Double Sweep algorithm. Following are the relationships used in the module.

The sediment transport formulations are built into the advection-dispersionmodule, MIKE 21 AD, which solves advection-dispersion equation:

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=\frac{1}{h}\frac{\partial}{\partial x}\left(hD_x\frac{\partial c}{\partial x}\right)+\frac{1}{h}\frac{\partial}{\partial y}\left(hD_y\frac{\partial c}{\partial y}\right)+Q_L C_L\frac{1}{h}-S \qquad (6)$$

The following symbols are used in the equation:

c	:	compound concentration (arbitrary units)
u,v	:	horizontal velocity components in x, y directions (m/s)
h	:	water depth (m)
D_x,D_y	:	dispersion coefficients in the x,y directions (m^2/s)
S	:	accretion/erosion term (kg/m^3/s)
Q_L	:	source discharge per unit horizontal area (m^2/s/m^2)
C_L	:	concentration of source discharge (kg/m^3)

The advection-dispersion equation is solved using an explicit, third-order finite difference scheme, known as the ULTIMATE scheme.

5.0 Hydrodynamic and sedimentation studies

5.1Existing Hydrodynamic Condition

The computational model considered for tidal flow simulation covered an area of 40 km x 40 km. The model area covers the entire proposed port area up to (-) 56 m depth contour. Mesh and bathymetry files were generated using MIKE-21 tools. In the vicinity of Marriott hotel, fine mesh was generated while in remaining model area, coarse mesh was generated to reduce the simulation time.

The model area consists of 5 open boundaries: two river boundaries and three sea boundaries. Predicted tidal levels obtained from C-map were supplied at north and south boundaries with appropriate level differences. As the flow is almost parallel to the contours along western boundary, no cross flow condition was provided at this boundary. At remaining two open boundaries, hydrographs of Mandovi and Zuari River were provided. The model parameter like bottom roughness coefficient, surface elevation etc. were adjusted to get the required prototype conditions in the model (available in vicinity Mormugao port). The model was simulated for peak river discharge condition. The simulations were repeated by changing model parameters until the computed values matched with the field observed data. The changes in flow fields were computed every time step of 30 sec and results are recorded at every 30 minutes time interval. The computed values of currents were compared with the field observed data. The studies were repeated by changing model parameters until the computed values matched well with the field observed data. Typical flow behavior is shown in Figs.11.The length of vector shows the magnitude of current and arrowhead of vector indicates the direction of flow.

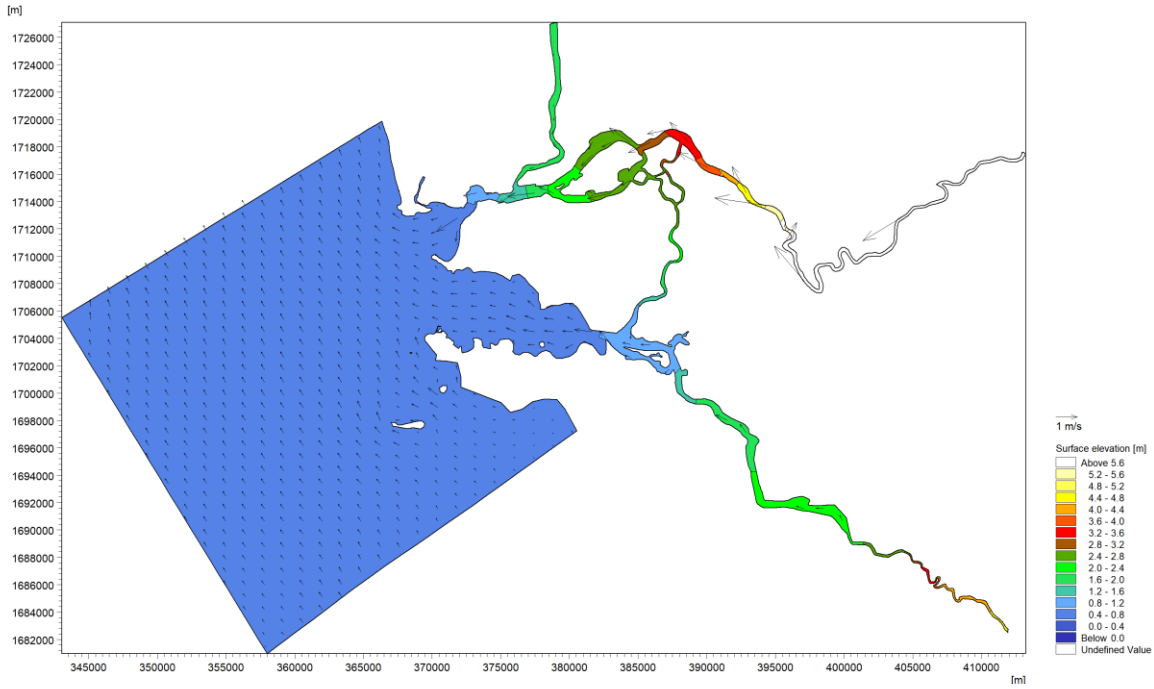

Fig.11: Flow Pattern in Model Area during peak river Discharge

In order to examine flow behavior in the vicinity Mandovi River, this river portion was model zoomed and flow behavior was studied in two conditions namely, high tide and low tide. The typical plots are shown in Fig. 12 (a) to 12(b). The length of vector shows the magnitude of current and arrowhead of vector indicates the direction of flow. It could be observed that during low tide magnitude of current is higher in river compared to during high tide. This is due to the fact that during low tide, level difference surface water is more.

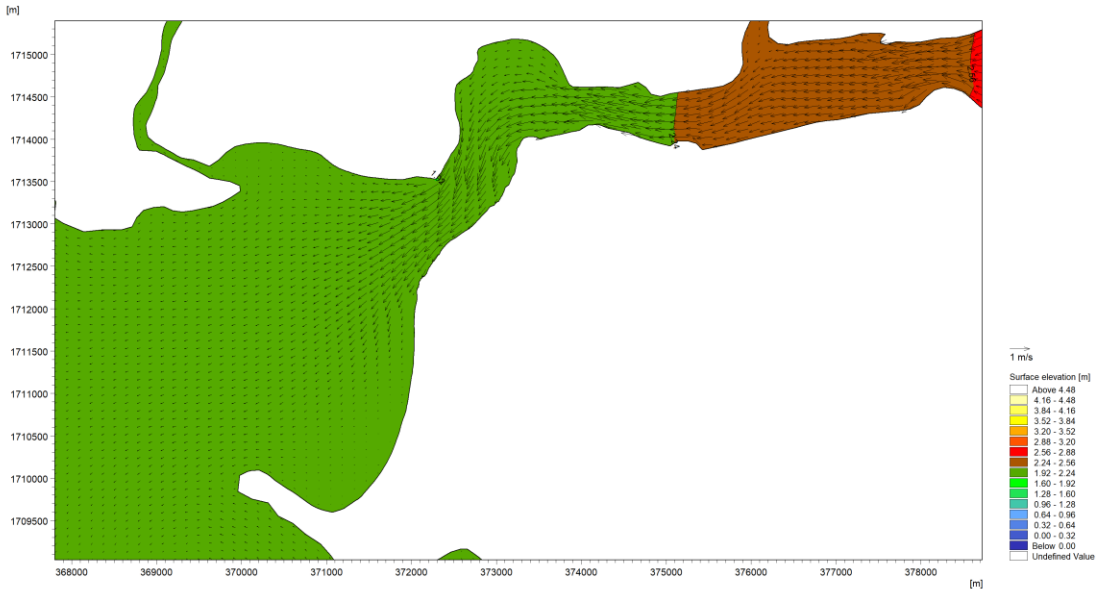

Fig.12 (a): Flow Pattern during High Water

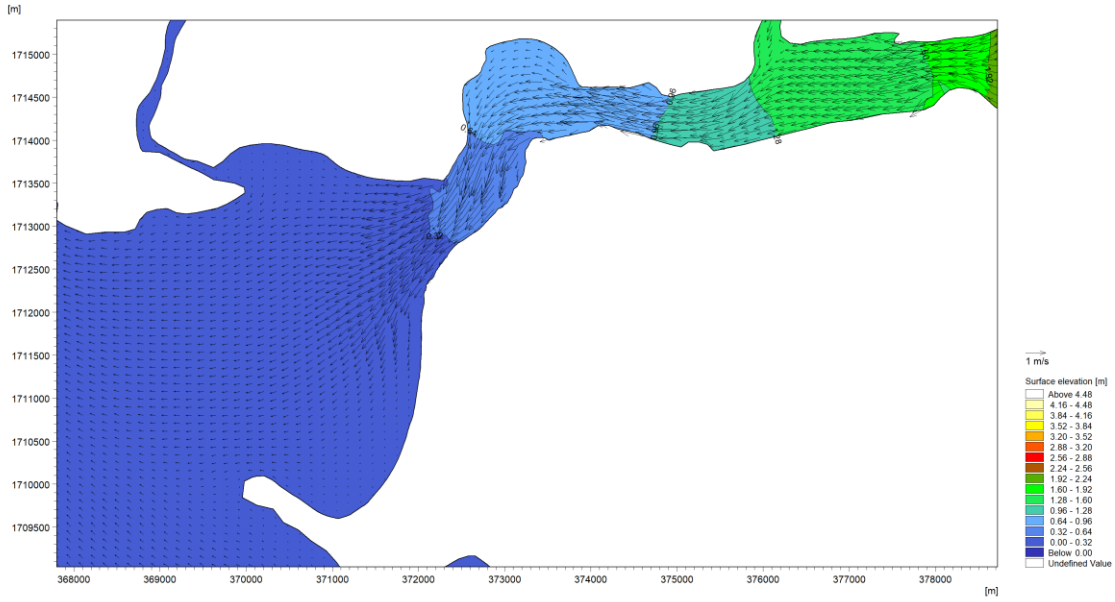

Fig.12 (b): Flow Pattern during Low Water

The typical plots during high tide and low tide are further zoomed to examine current pattern in the vicinity of hotel Marriott are shown in Fig. 13 (a) to 13(b). It can be observed that the flow is oblique to left bank upstream of Marriott hotel. It could cause addition impact on the bank and can cause more erosion in this area.

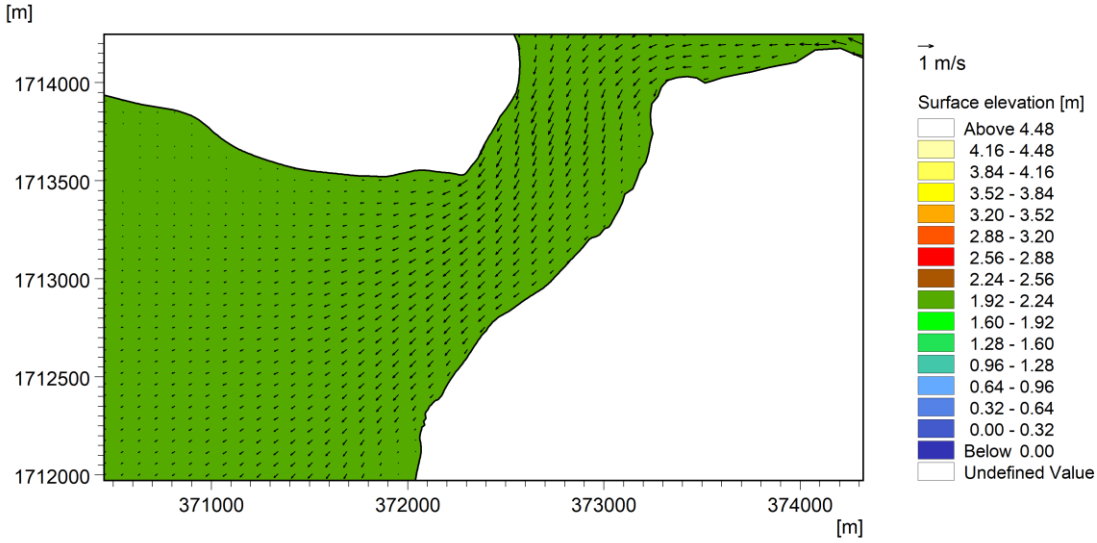

Fig.13 (a): Flow Pattern during High Water(in hotel vicinity)

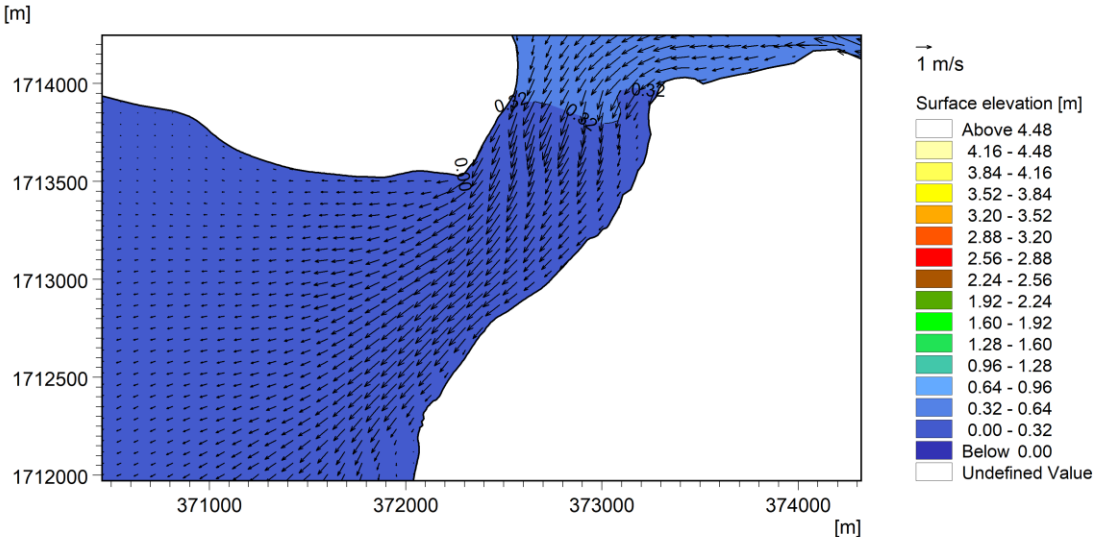

Fig.13 (a): Flow Pattern during Low Water (in hotel vicinity)

5.2 Existing Condition sedimentation

Model was simulated for the existing condition using MIKE 21 MT software for peak river discharge in the rivers. Model was simulated during monsoon period and suspended sediment concentration values were adopted as per the prototype data available with CWPRS. Typical plot of sedimentation is shown in Fig. 15. It could be seen from figure that during high river discharge condition erosion takes place in the vicinity of hotel along the retaining wall. The erosion varies from 0.5 m to 1.2 m in the region.

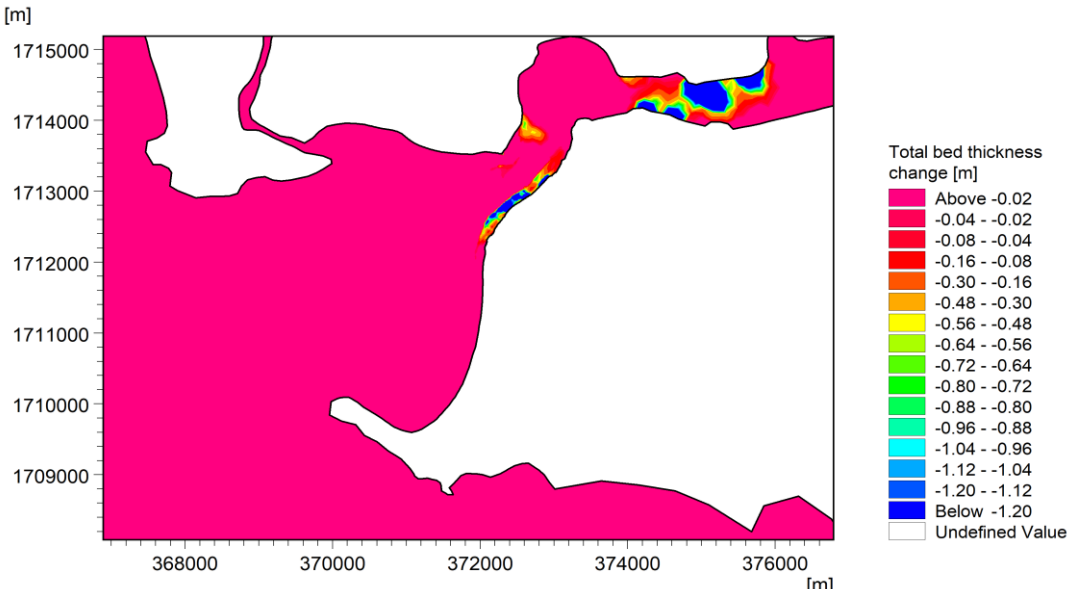

Fig. 15: sedimentation in the vicinity of Hotel

5.3 Proposed Condition Hydrodynamic

Once the model was calibrated for the observed currents, the proposed layout of having bank at imaginary line was incorporated in the bathymetry as shown in Figure 15 (a) and 16(b). Figure 16(a) shows imposition of layout on C- map data available from Danish Hydraulic Institute. Proposed bathymetry after incorporating shift in bank of river is indicated in Fig. 15(b).

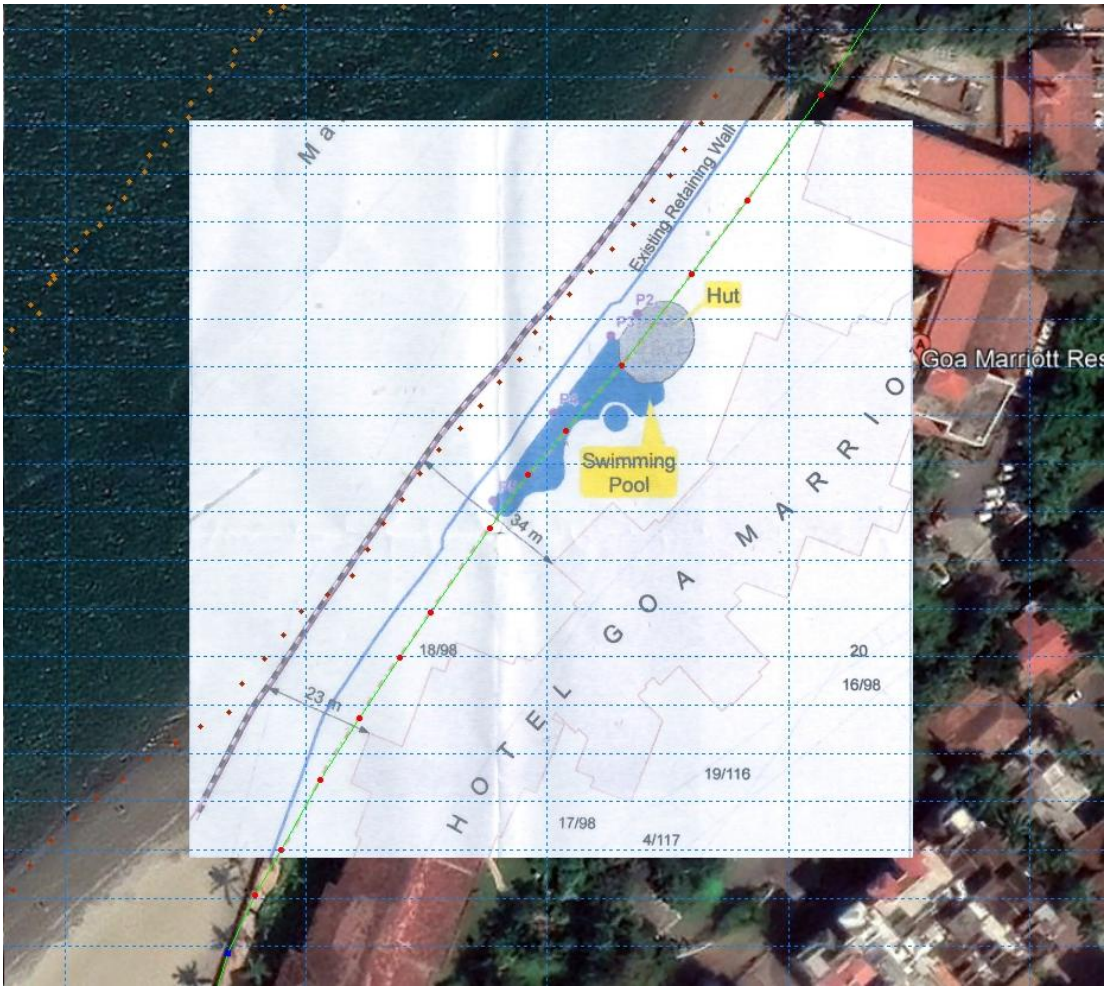

Fig.15 (a): Layout imposed on C- Map data

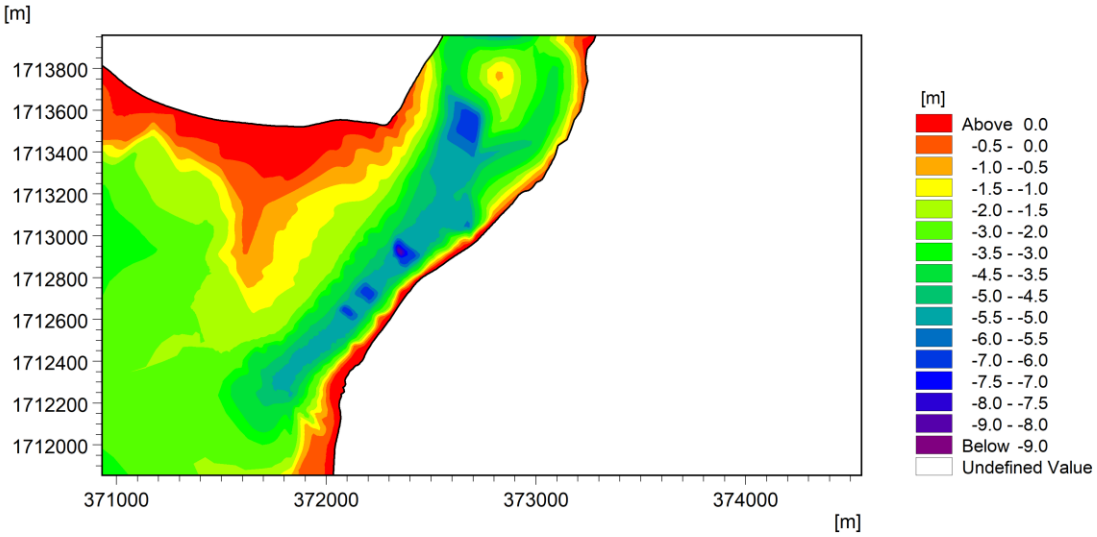

Fig.15 (b): Bathymetry in Proposed condition

Hydrodynamic model was simulated for this proposed bathymetry without changing the hydraulic parameters of Calibrated model. Typical plots of flow fields in the vicinity of Marriott hotel are shown in Figs. 16(a) and 16 (b) during high water and low water respectively.

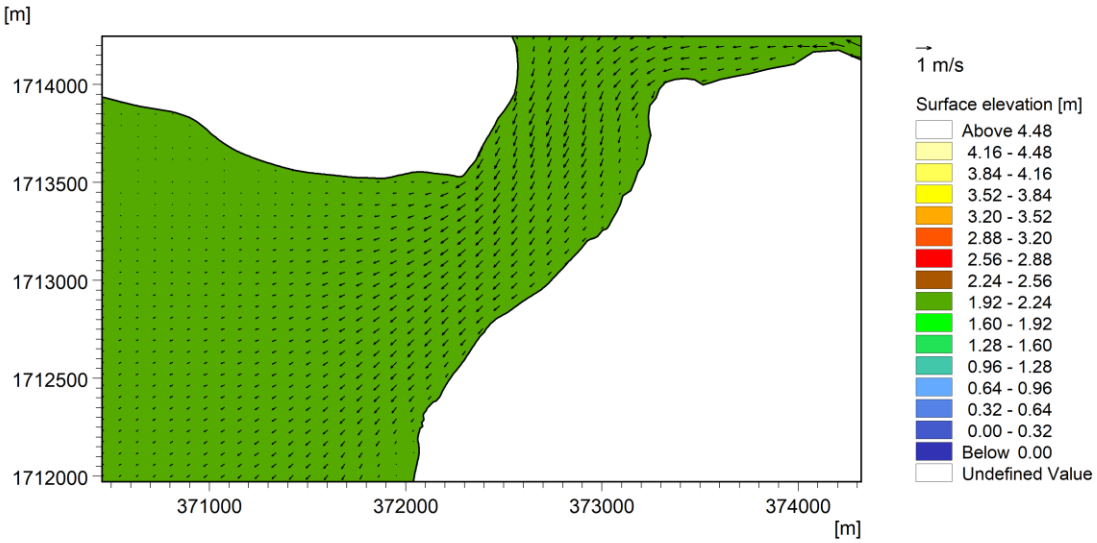

Fig.16 (a): Flow Pattern in Proposed condition during High Water (in hotel vicinity)

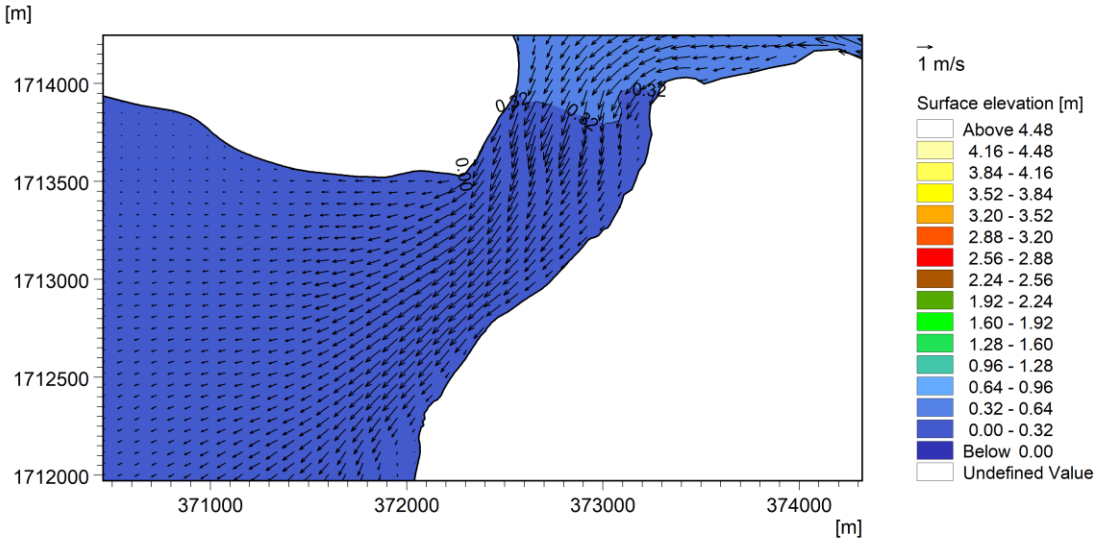

Fig.16 (b): Flow Pattern in Proposed condition during Low Water (in hotel vicinity)

Velocity rose diagram near the Marriott wall is shown in Figure 17. It shows direction of flow and magnitude of flow with respect to North. It indicates that for some duration flow is oblique to the bank. Simulated currents were also monitored at location P1 (Fig. 7) are shown in Figure 18(a). It could be seen that currents near the wall varies from 0.25 m/s to 0.9 m/s. It is observed that at high tide currents are low (0.25 m/s) while at low tide currents are high (0.9 m/s). The Figure 18(b) shows the current speed across the profile L1-L2 where high currents of up to 1.6 m/s could be seen in the main channel. It can also be seen from figure that magnitude of currents are low near the right bank while near the left bank, the currents are high. This pattern is observed in case of meandering of rivers. It appears that the river has tendency of meandering in this region. Thus further increase in the curvature of bend may result in acute problem of erosion on the left bank.

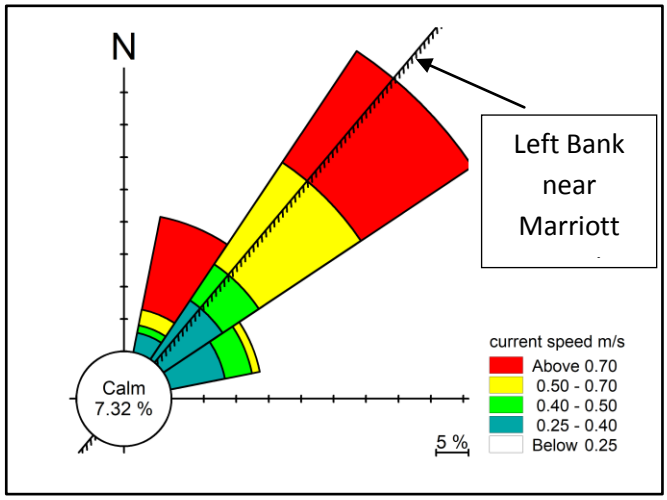

Fig. 17: Velocity rose diagram near Marriott hotel wall

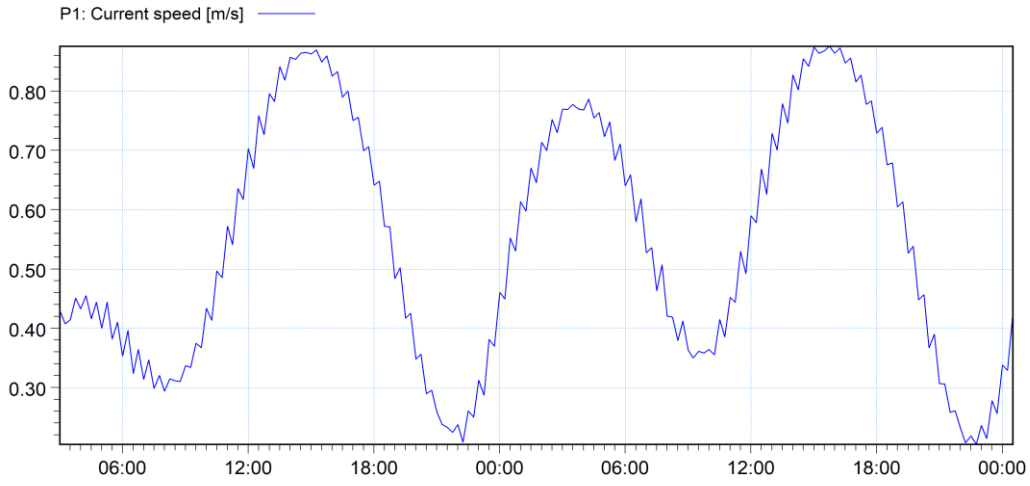

Fig. 18 (a): Currents at location P1 near the Marriott Hotel (Fig. 7)

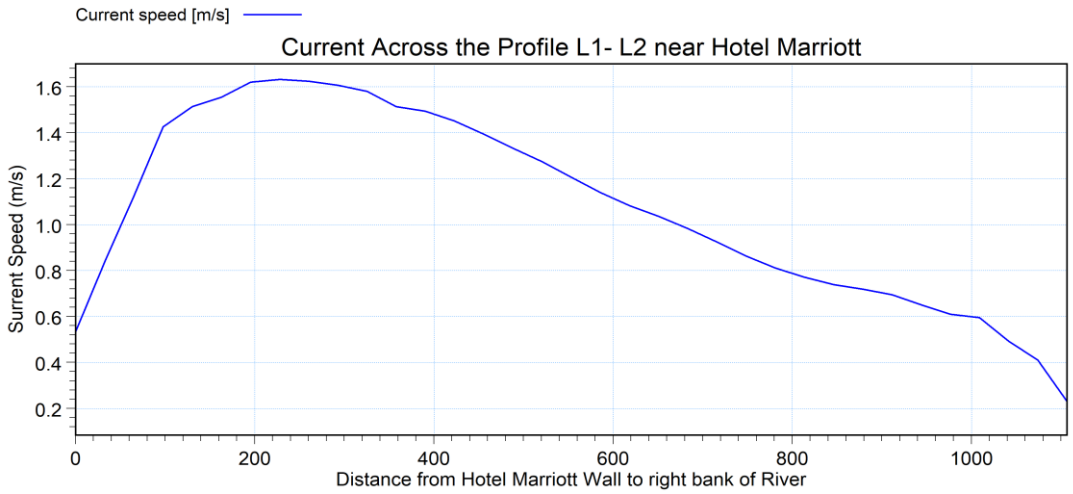

Fig. 18(b): Currents Across Cross-section L1-L2 (Fig. 7(b))

5.4 Sedimentation with Proposed Condition

Sediment Transport model was simulated for the proposed condition using MIKE 21 MT software for peak river discharge condition in the rivers without changing the model parameters used of existing condition. Model was simulated during monsoon period. Typical plot of sedimentation is shown in Fig. 19. It could be seen from figure that during high river discharge condition erosion takes place in the vicinity of hotel along the retaining wall. The trend of sedimentation almost remains same but in the long run channel may shift towards the left bank. Sedimentation in the stretch varies between 0.5 m to 1.2m.

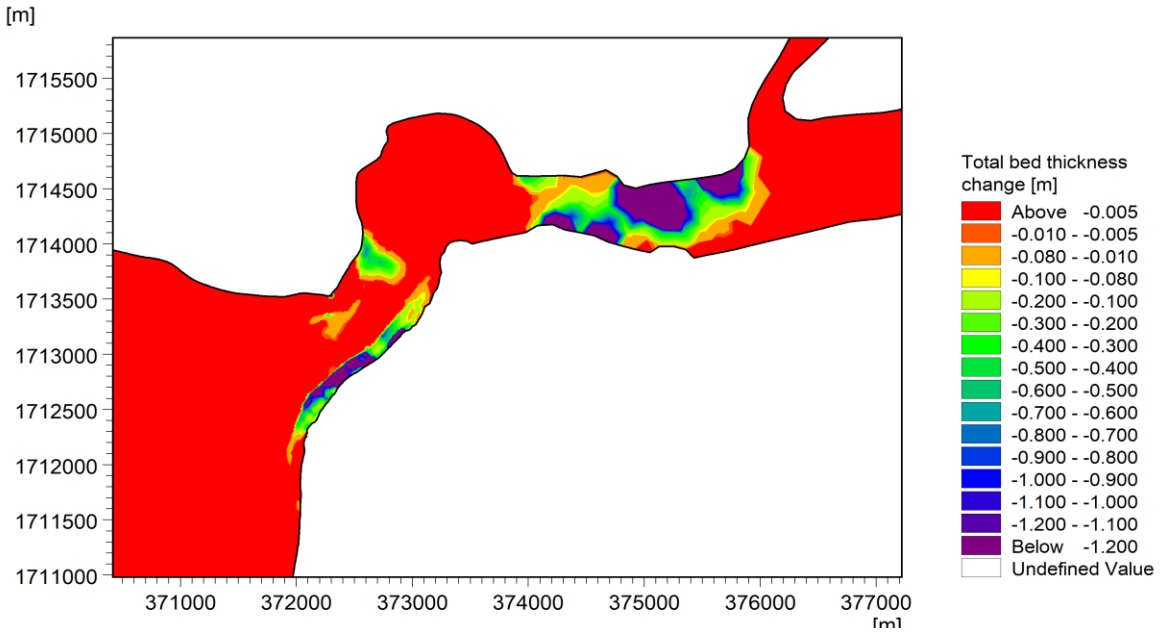

Fig. 19: Sedimentation in the vicinity of Hotel

6.0 RESULTS AND DISCUSSION

The site is influenced by waves, tide and large river discharge conditions. River discharges and waves play an important role in erosion of bank in the vicinity of Marriott hotel. This stretch is prone to erosion. Other major cause of erosion at the left bank is bending of river which is result of a large land outcrop towards Reis Magos fort site (right bank site) and flow gets deviated towards the left bank, which can also be correlated with the number of protective/anti-erosion works implemented by the state since 1978 all along the left bank. The river has the tendency to move towards left bank due to sharp bend in the upstream. This oblique flow along with high

river discharge combined with severe wave condition is the worst scenario for the bank near Marriot hotel. The demolition of wall would result in shifting of channel towards left bank and this would further worsen the situation as angle of oblique current would further increase. The peak currents near the Marriott hotel wall are of the order of 0.9 m/s. In addition to this, breaking and non breaking waves exert huge thrust on the wall. After shifting the wall, the whole force would be borne by the bank resulting into further erosion. The distance of pillar of Marriott hall hardly remains at about 5m. The distance between imaginary line and wall footing would further be less. Shifting of left bank would not help in improving the hydraulic conditions in the river instead it may further worsen the situation as it will increase the curvature of bend in this region.

7.0 CONCLUSIONS

- The high river discharges and waves and oblique flow towards left bank due to land outcrop at Reis Magos fort site (right bank site) play major important roles in erosion of bank in the vicinity of Marriott hotel.
- Shifting of left bank would increase the curvature of river resulting in more erosion at left bank.
- The demolition of existing wall would result in shifting of channel towards left bank and this would further worsen the situation of erosion as angle of oblique current would further increase and the wave forces would be borne by bank alone.