SPEED POST

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Department of Water Resources, River Development and Ganga Rejuvenation
केन्द्रीय जल और विद्युत अनुसंधानशाला
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संख्या: TC/2023/612 दिनांक: 26 JUN 2023

To,
अधीक्षण अभियंता / The Superintending Engineer
नर्मदा जल संसाधन / Narmada Water Resources
जल आपूर्ति एवं कल्पसर विभाग / Water Supply and Kalpsar Department
गुजरात सरकार, ब्लॉक नंबर 8, 7वीं मंजिल / Government of Gujarat, Block No. 8, 7th Floor
नया सचिवालय, गांधीनगर / New Sachivalaya, Gandhinagar,
गुजरात -380026 / Gujarat-380026

विषय : "Mathematical Model Studies for Assessment of Wave Climate near Spillway Area for Proposed Kalpasar Dyke in Gujarat." से सम्बंधित तकनीकी रिपोर्ट।
महोदया,

Please find enclosed herewith two copies of the technical report on "Mathematical Model Studies for Assessment of Wave Climate near Spillway Area for Proposed Kalpasar Dyke in Gujarat." bearing No. 6142 of June 2023. For any clarification in the studies, you may contact Dr. Prabhat Chandra, Additional Director (Tel. 020-2410 3521).

Receipt of the same may please be acknowledged.

निदेशक, के. ज. और वि. अ. शाला के अनुमोदन से यह जारी किया जाता है।
धन्यवाद,

भवदीय,

26/6/2023

संलग्न : तकनीकी रिपोर्ट की दो प्रतियाँ।

(एस. जी. मंजुनाथ / S. G. Manjunatha)
वैज्ञानिक 'ई' (तकनीकी समन्वय)
Scientist 'E' (Technical Co-ordination)
For Director

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PORT AND HARBOUR – I DIVISION

TECHNICAL REPORT No.6142
JUNE, 2023

MATHEMATICAL MODEL STUDIES FOR ASSESSMENT OF WAVE CLIMATE NEAR SPILLWAY AREA FOR PROPOSED KALPASAR DYKE IN GUJARAT

Dr. R.S. KANKARA
DIRECTOR

REPORT DOCUMENTATION SHEET

Technical Report No. 6142 Date: June 2023

Title: Mathematical Model Studies for Assessment of Wave Climate near Spillway Area for Proposed Kalpasar Dyke in Gujarat.

Officers Responsible for Conducting the Studies :

These studies were conducted by Shri R. K. Chaudhari, Scientist 'B' and Shri Santosh Kumar Kori, Assistant Research Officer under supervision of Dr. Prabhat Chandra, Additional Director and overall guidance of Dr. R.S. Kankara, Director, CWPRS, Pune.

Initial studies were conducted by the Shri H.C. Patil Scientist -C and Shri Sagar Chandra, Research Assistant of PH-II division, under the supervision of Dr. J.D. Agrawal, Ex. Scientist -E

Name and Address of Organization Conducting the Studies :

Port and Horbour – I Division , Coastal and Offshore Engineering Laboratory, Central Water and Power Research Station, Khadakwasala Pune -411024, India

Name and Address of Authority Sponsoring the Studies

Superintending Engineer, Narmada Water Resources, Water Supply and Kalpsar Department, Government of Gujarat, Block No. 8, 7th Floor, New Sachivalaya, Gandhinagar, Gujarat-380026

Synopsis

To full fill the requirement of water in Saurashtra region of Gujarat, a huge multipurpose fresh water reservoir project is proposed by Gujarat Government by building a 30 km long Dyke across the Gulf of Khambhat connecting Bhavnagar and Bharuch districts. A road link will also be set up over the Dyke, greatly reducing the distance between Saurashtra and South Gujarat. For design of spillway gates and assessment of discharging capacity, the wave is a very important parameter to be assessed. The mathematical model studies were conducted at CWPRS, Pune to assess the wave conditions near the spillway of dyke under the extreme climate. The design significant wave height of 7.32 m as provided by the Project authorities, was adopted for the studies. Mathematical model studies for transformation of wave height and wave direction from deep water (at the distance of about 8.0 km from the approach channel) to mouth of the approach channel at depth of (-)15m using spectral wave model MIKE 21-SW indicated that the predominant directions are from 218^0 N to 225^0 N. The significant wave height at the approach channel mouth located at about 4km from Dyke axis was estimated to be about 4.0m. Wave propagation studies carried out with MIKE21-BW model to assess the wave tranquility for proposed approach channel dredged to (-)12m depth w.r.t MSL indicated that the significant wave heights near spillway would be upto 0.70m. The incident wave heights are attenuated while reaching the spillway gates mainly due to dissipation along slopes of dredged channel and around the turn provided in the approach channel. However, in absence of correct location of generation of design significant wave height of 7.32m, the most critical incident wave direction from 270 degrees at the mouth of channel with incident wave height of 4.0m at channel mouth was also considered and studied. The BW simulation results indicated that the significant wave height of 2.5m can reach upto the spillway under this condition. This may be considered as Design wave height for the spillways gates and for assessment of discharging capacity.

Keywords : Significant wave Height, spillway, Dyke axis, Numerical model, Channel

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MATHEMATICAL MODEL STUDIES FOR ASSESSMENT OF WAVE CLIMATE NEAR SPILLWAY AREA FOR PROPOSED KALPASAR DYKE IN GUJARAT

TECHNICAL REPORT No. 6142 **DATE: JUNE 2023**

1. INTRODUCTION

Gujarat is water deficient state since its surface water resource is only 2% of the country against 6.4% land area and 5% human population. However, including Sardar Sarovar Project (SSP), only 22000 Mm^3 water is possible to be stored. Gulf of Khambhat is the site in state, to construct Dyke which can store 10,000 million m^3 (25%) water inflows of the five rivers viz., Narmada, Dhadhar, Mahi, Sabarmati and Saurashtra rivers. The fresh water reservoir of this project is planned to require minimal land acquisition and rehabilitation of people. This project would serve as a lifeline of Saurashtra region as well as an accelerator for the growing economy of Gujarat State. The Kalpasar Project envisages building a 30 km long Dyke across the Gulf of Khambhat (Fig.1) connecting Bhavnagar and Bharuch districts, for establishing a huge reservoir for fresh water for irrigation, drinking and industrial purposes. A road link will also be set up over the Dyke, greatly reducing the distance between Saurashtra and South Gujarat.

The Gulf of Khambhat, is a bay on the Arabian Sea coast of India, bordering the state of Gujarat just north of Mumbai and Diu Island. The Gulf of Khambhat is about 200 km long, about 20 km wide in the north and up to 70 km wide in the south. The Gulf is not very deep and has abundant shoals and sandbanks. The high tide of the Gulf varies in terms of height and races with great speed. During the low tide, the bottom is completely dry for some distance below the town of Khambhat. The important characteristic feature of the gulf is its high tidal range and the tidal currents dominate the flow.

The various hydraulic studies have been carried out by various central agencies like IIT Delhi, IIT Roorkee, NIOT Chennai, CSIR-NGRI Hyderabad. NIO-CSIR Goa etc. pertaining to the following topics for the proposed development of Kalpsar dyke:

1. Bathymetric survey in Gulf of Khambhat
2. Hydrodynamics and sediment model studies and related measurement for Gulf of Khambaht
3. Estimation of PMF, Design flood and spillway capacities for Gulf of Khambhat Development project.
4. Geophysical survey for Revised Dam Corridor
5. Studies on sea –level rise along the Guajrat coast and regional climate over Gujarat.

6. Impact of storm surges, wind wave and seiches on the design of proposed Kalpasar Dam.
7. Study of Tsunami Waves Impact on structures and Tsunami inundation modeling for the Kalpasar Project

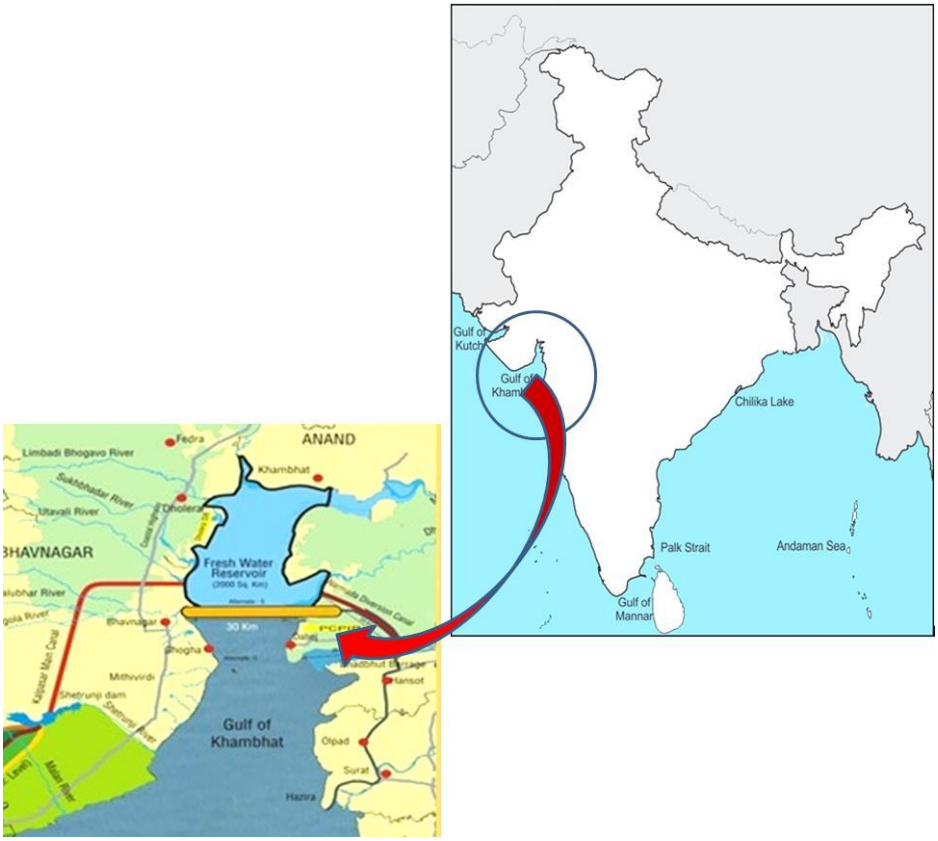


Fig.1: Location Map of Proposed Kalpsar Project Gujarat

The work of preparation of Detailed Project Report (DPR) for the Kalpasar Dyke project has been assigned to National Centre for Coastal Research (NCCR), Chennai by Kalpasar Project Authorities. A tentative design of spillway and energy dissipater was prepared earlier during 2013-14. The design was based on a provisional maximum outflow of 100,000 cum/sec to be passed through 105 spans, each 15m wide separated by 5m thick piers, at the highest flood level of El +5.0m, with the spillway crest at El -3.5m. The spillway (with embankment dam on both the flanks) was to be located on alignment L3, with its right end at a distance of 3600m from UTM coordinate 560,000E, which approximately corresponded to longitude 72° 32.77' E. Two alternative locations were proposed. Figure 2 shows details of the proposed alternative locations of the spillway.

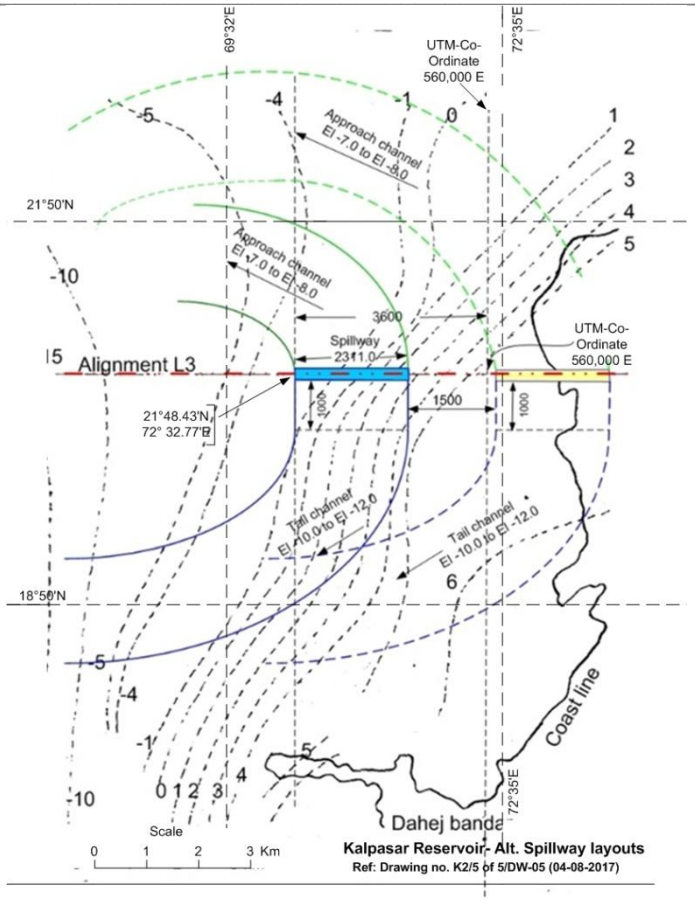


Fig.2: General layout and alternative locations of spillway (Plan)

Subsequently, while during preparation of DPR, the design parameters were revised. A layout of the spillway and other appurtenant structures (Figs.3&4) from the interim findings of the DPR was communicated to CWPRS in February 2023 for pertinent studies.

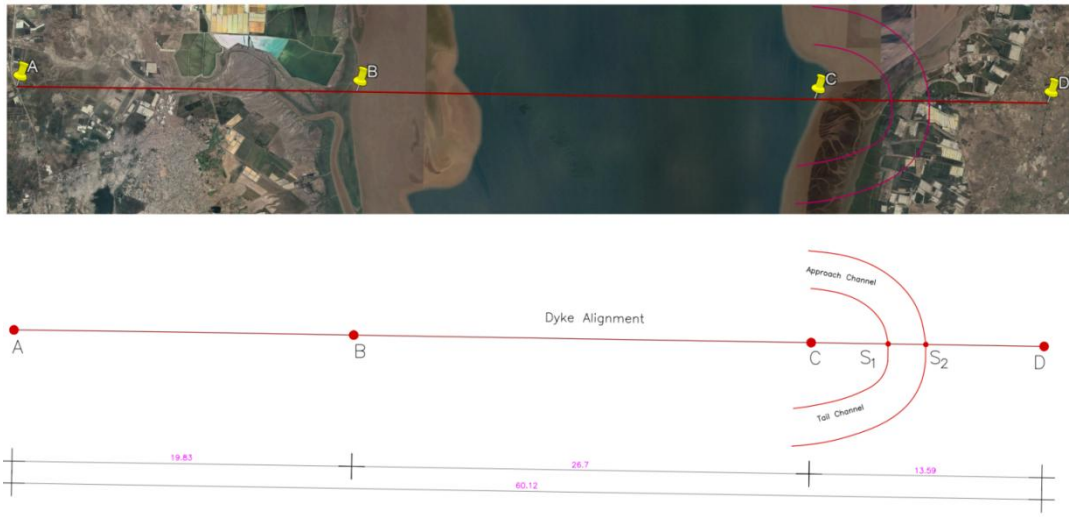
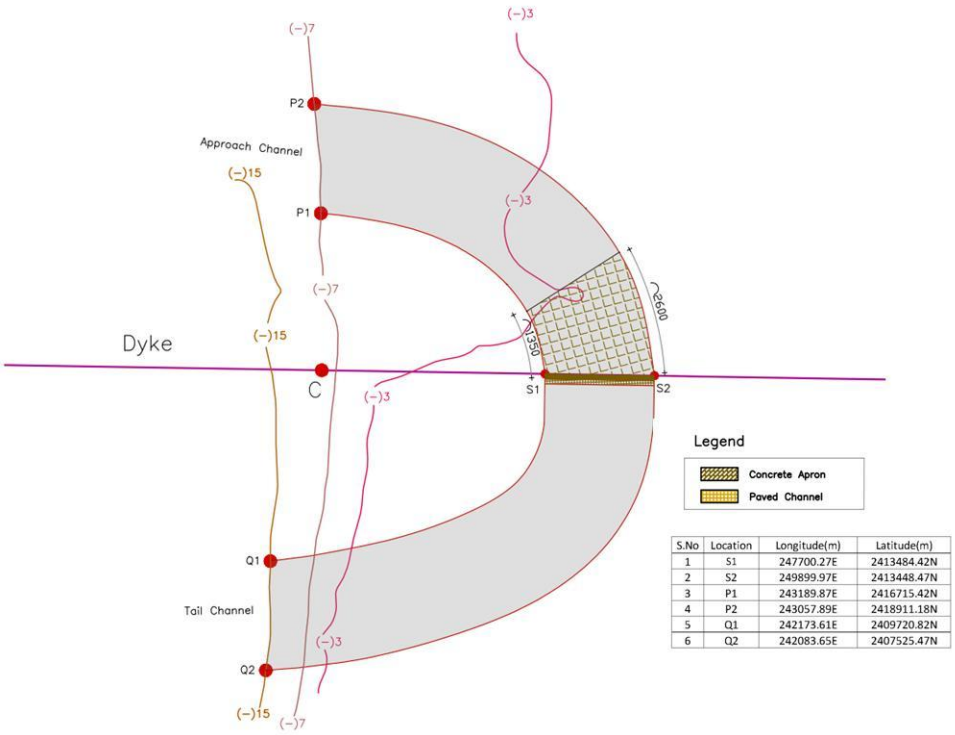


Fig.3: Location of layout of finalized spillway



S.No	Location	Longitude(m)	Latitude(m)
1	S1	247700.27E	2413484.42N
2	S2	249899.97E	2413448.47N
3	P1	243189.87E	2416715.42N
4	P2	243057.89E	2418911.18N
5	Q1	242173.61E	2409720.82N
6	Q2	242083.65E	2407525.47N

Fig.4: Details of Final spillway channel

For design of spillway gates and assessment of discharging capacity, the wave is a very important parameter to be assessed. Generally, the waves in the gulf of Khambhat vary in the range of 1 to 3m throughout the year under normal conditions. But for the present studies, the data regarding the storm surge conditions is used. The Design water level and significant wave height under extreme conditions considering storm surges was provided by the NCCR by email dated March 10, 2023. The same data has been used in the present studies to find out the critical wave conditions near the spillway.

The present report describes the details of mathematical model studies carried out to assess the critical wave conditions near the spillway.

2. SCOPE OF STUDIES

The mathematical model studies were carried out in three stages to access the critical wave conditions near the spillway structure:

- Assessment of the wave condition at the Mouth of the tailrace channel and near the spillway through the MIKE 21 SW Module.
- Simulation of wave propagation in the proposed tailrace channel dredged with (-)12m depth through MIKE21- BW model.
- Simulation of wave propagation from the most critical direction for spillway.

The design wave height and water level conditions under extreme climate have been used as provided by the NCCR and Kalpasar Project.

3.0 SITE CONDITIONS

3.1 Data Regarding Kalpsar Dyke and Spillway

The length of the Kalpsar Dyke axis is about 30km in water having the spillway of length 2200m with 100 gates. The spillway is designed to pass the flood of the magnitude of 1,20,000 m^3/s (PMF). Total length of the tail race channel dredged to -12.0m is about 9.0km from spillway gate to offshore mouth at (-) 15m depth contour. All depths / contours are with respect to MSL. The shore channel point Q1 is about 4 km away from the Dyke axis.

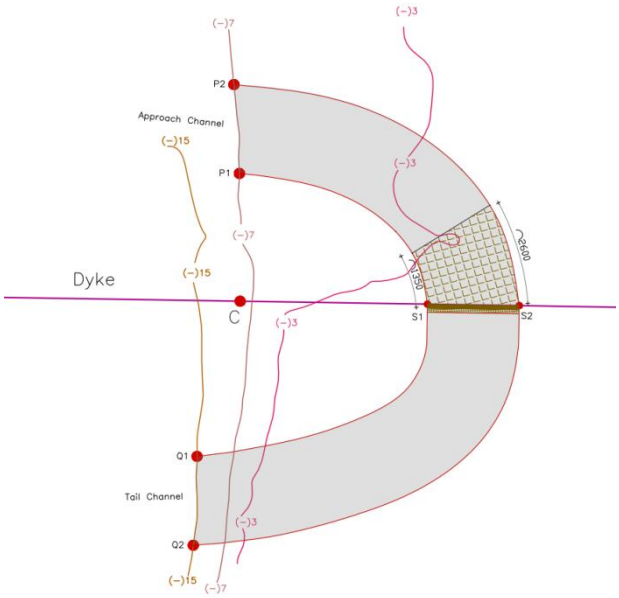


Fig. 5 Layout of approach and Tail race channel

3.2 Bathymetry Data :

Measured bathymetry data along the Gulf of Khambhat and near the Dyke axis and spillway area is provided by the Project Authority and the same is used for the preparation of bathymetry for the Mathematical wave model studies. Data is provided in form of XYZ and depths therein are w.r.t MSL. The boundary condition for the SW bathymetry is considered at 12 km away from the Dyke axis.

3.3 Data for Design Wave and Water level

The details of the design wave and water level data were received from the NCCR, Chennai in March 2023 as below:

Design Wave Height = 7.32 m

Time Period Tp = 8 to 10 sec

Sea Level Rise = 0.71 m

Storm Surge = 0.90m

Wave setup = 0.42 m

Design Water Level = 8.22 m

Highest High Tide = 6.20 m

Lowest Low Tide = (-)5.30m

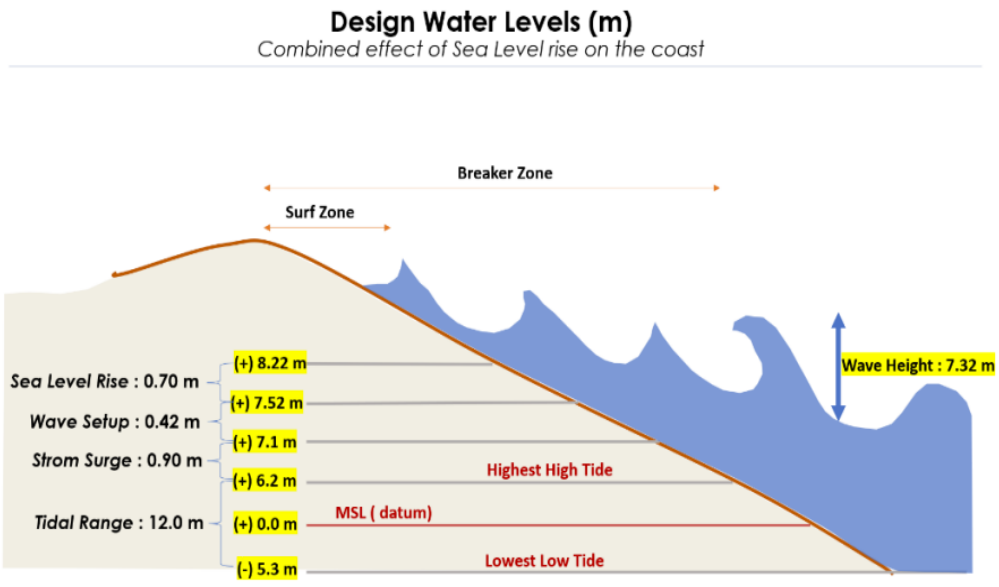


Fig .6: Diagram regarding the components of design water level selection

All levels are wrt MSL. The same design wave and water level data has been used for the present mathematical model studies at the SW model boundary.

4.0 MODELLING TECHNIQUES

Brief description of the mathematical models is given below.

4.1 MIKE21-SW MODEL

As waves travel from deep sea to shallow coastal waters, they undergo changes in direction and height due to the processes of refraction and shoaling. The computation of wave transformation from deep to shallow coastal waters was carried out using MIKE21-SW model.

MIKE21 Spectral Wave (SW) model is one of the state-of-the art third generation spectral wind wave models. The MIKE 21 - SW model simulates wave growth due to wind action, transformation due to refraction and shoaling resulting from depth variations, and decay due to white capping, bottom friction and wave breaking. The effects of wave-current interaction, non-linear wave-wave interaction, time-varying water depth and diffraction are also included within the model. The model is based on flexible mesh which allows for coarse spatial resolution for offshore area and high-resolution mesh in shallow water and at the coastline.

4.2 MIKE21-BW MODEL

Mathematical model MIKE21-BW is used for studying the wave disturbance in the harbour. The model is based on time dependant Boussinesq equations of conservation of mass and momentum obtained by integrating the three-dimensional flow equations without neglecting vertical acceleration. They operate in the time domain, so that irregular waves can be simulated. These equations include nonlinearity as well as frequency dispersion. The frequency dispersion is included in the flow equations by taking into account the effect of vertical acceleration or the curvature of stream lines on pressure distribution. The model simulates the processes of shoaling, refraction, diffraction from breakwater tips and bed friction. It also takes into account partial reflections from the boundaries, piers and breakwaters.

5.0 WAVE SIMULATION WITH MIKE21 SW / BW

Considering the size of Bathymetry of the project, the wave model studies were carried out in two stages. In the first stage, the simulation was done to get the wave condition and wave direction at the offshore mouth of the tailrace channel with the help of MIKE21 SW Model. Subsequently, the studies were carried out using the MIKE 21 BW. The bathymetry area of about 30km X 12km was considered for the model simulation (Fig.7).

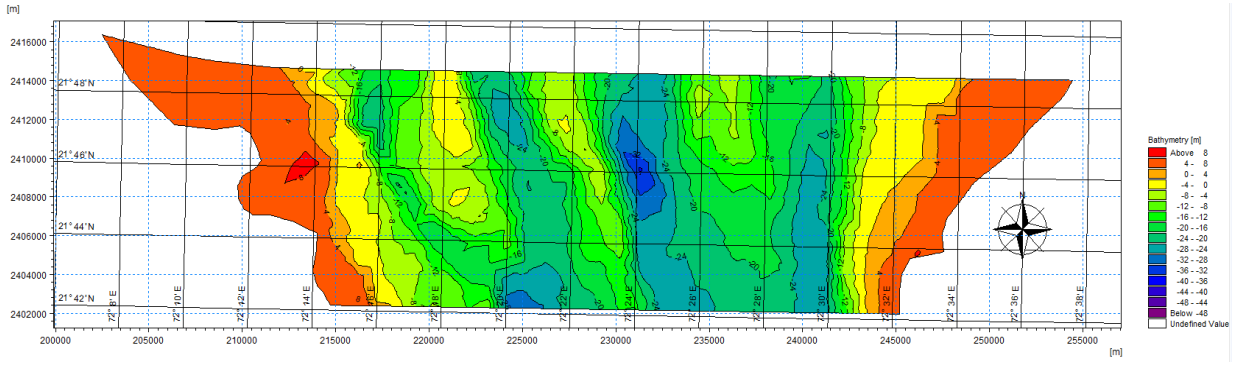


Fig.7: SW bathymetry used for existing condition

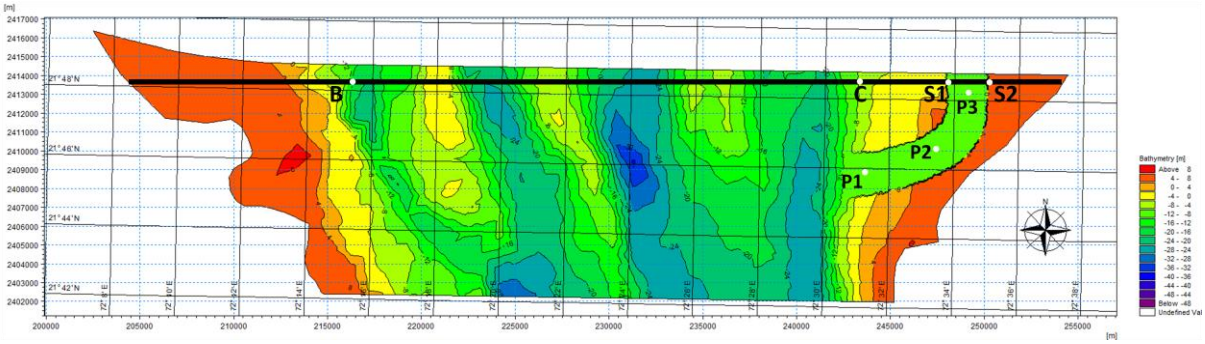


Fig.8: SW bathymetry with proposed Spillway Channel

As per the data supplied by the Project, an tailrace channel for spillway discharge was also reproduced dredged to (-) 12 m wrt MSL (Fig.8). The bathymetry was also superimposed on the Google earth as shown in Fig.9.

It is clear from the Fig. 9 that the spillway is situated on the land portion and the offshore end of the channel will be at about 9 km from spillway and 4km from the Dyke axis.

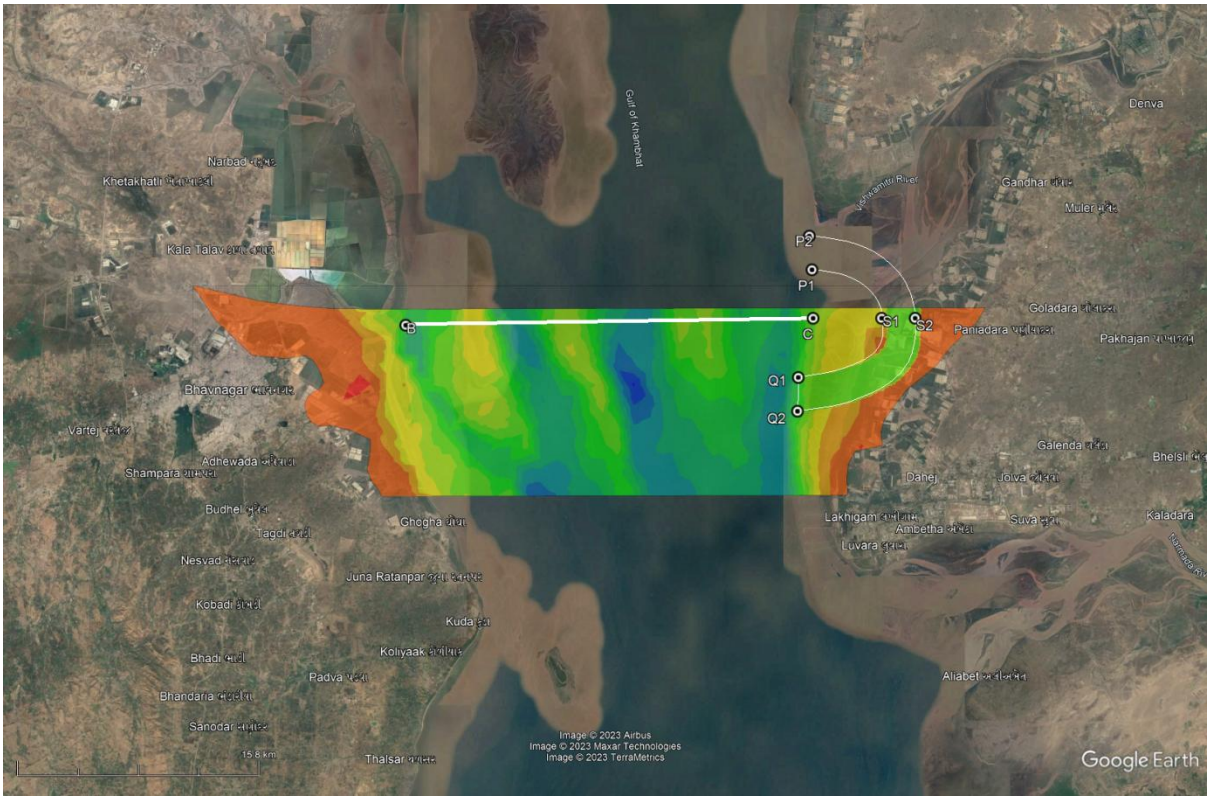


Fig.9 : Proposed bathymetry with spillway Channel superimposed on the Google earth

The model was simulated for the all possible incident predominant wave directions from South, SSW and SW for the design wave data as supplied by NCCR. The design wave of 7.32 m Hs is assumed to be generated at SW model boundary at 12 km from the Dyke axis (Fig.8) and from there on, it has been propagated in the tailrace channel and spillway area. The wave period is considered as 10 sec for the studies. All the simulations were carried out at design water level of 8.22m.

The simulation was carried out and the wave data was extracted from the model at P1 (midpoint of the offshore mouth of the tailrace channel), at P2 (midpoint of the tailrace channel) and P3 at 1.30 km before the spillway as per Fig. 10.

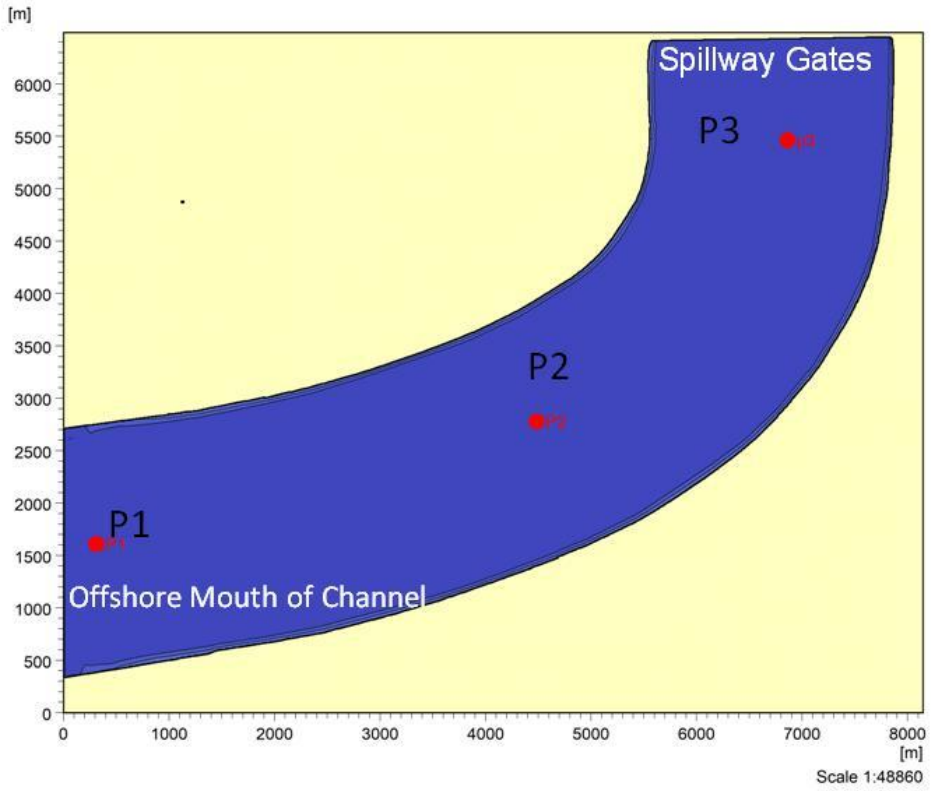


Fig.10: Image showing the location P1, P2, P3 points in the spillway channel

5.1 Wave propagation near Spillway using MIKE - SW Model

The SW simulations were carried out for predominant directions South, SSW and SW as described in succeeding paragraphs for assessment of wave conditions at the offshore end of the channel and near spillway.

(i) SW simulation with wave incident from the South Direction (180^0N)

The significant wave height and direction at points P1, P2 and P3 for waves incident from South direction are given below in Table 1.

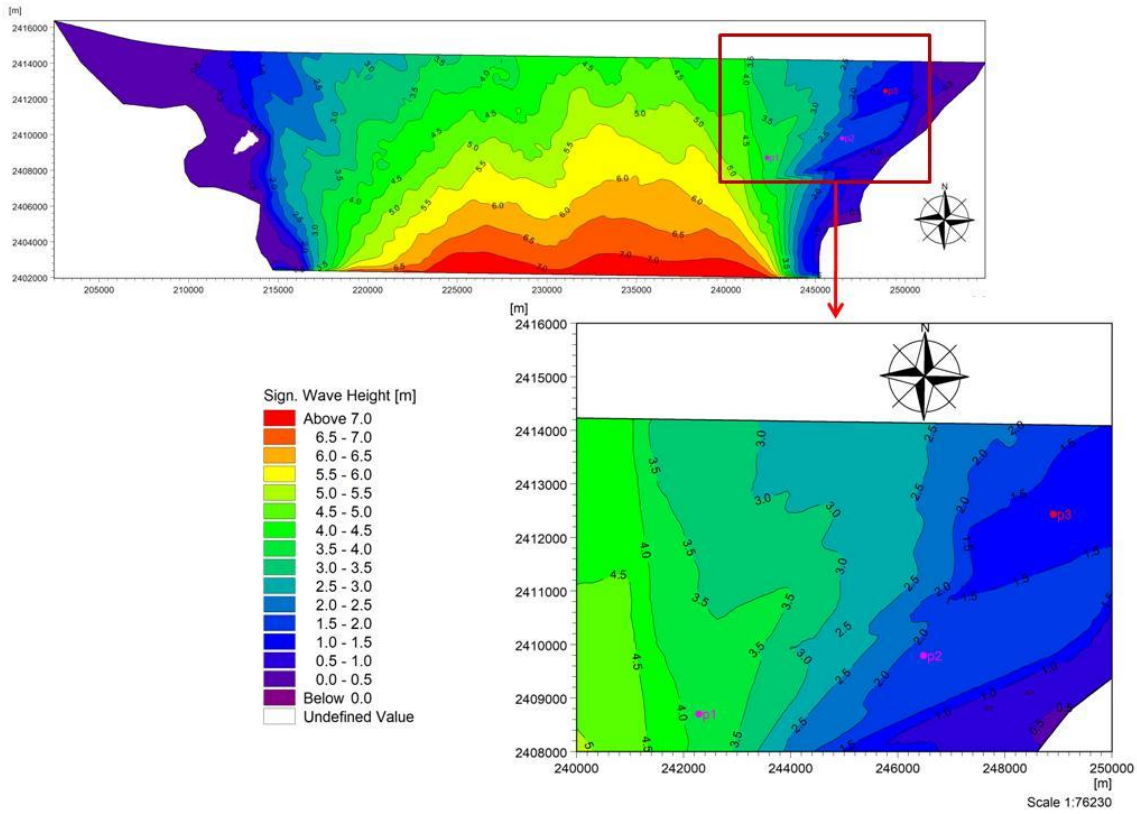


Fig .11: Wave distribution plot for wave incident from South direction

Table 1: SW Simulation results for wave incident from South Direction

Point	Significant Wave height (m)	Wave Direction (^{0}N)
P1	3.86	218
P2	1.85	243
P3	1.39	254

(ii) SW simulation with wave incident from the SSW Direction

The significant wave height and direction at points P1, P2 and P3 for waves incident from SSW direction are given below in Table 2.

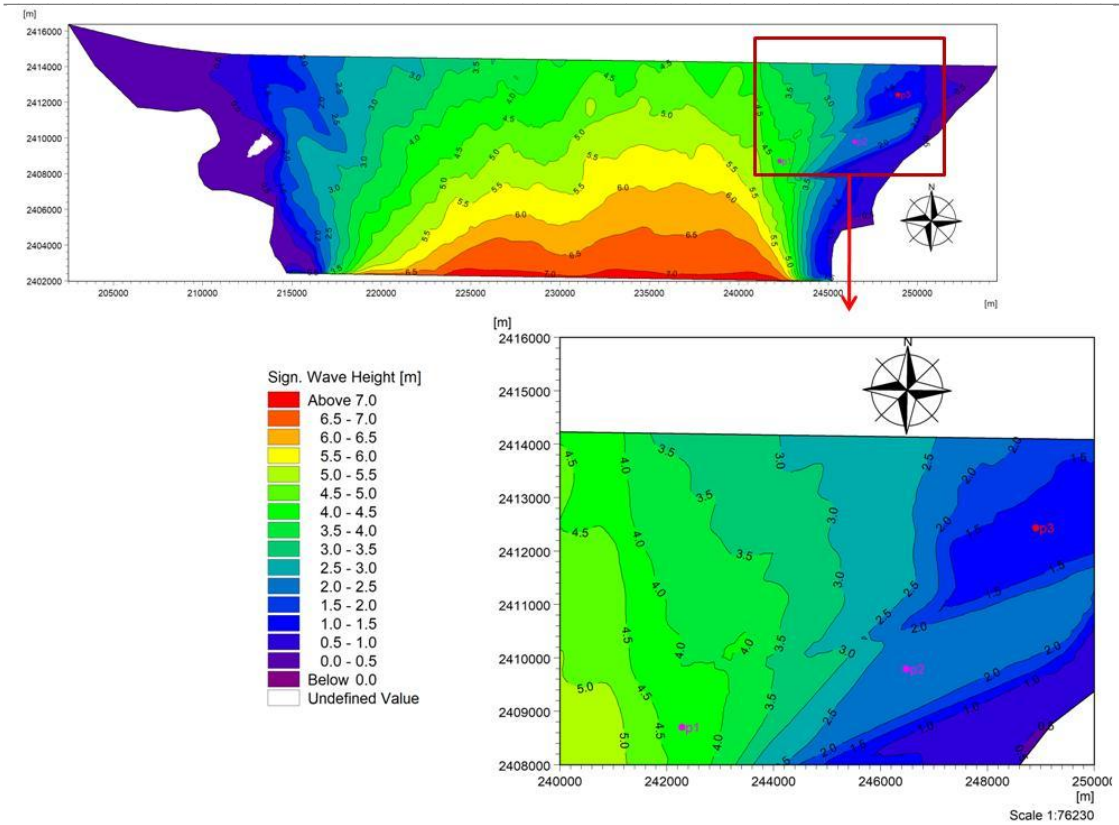


Fig.12 :Wave distribution plot for wave incident from SSW direction

Table 2: SW Simulation results for wave incident from SSW Direction

Point	Significant Wave height (m)	Wave Direction (^{0}N)
P1	4.27	222
P2	2.23	245
P3	1.37	257

(iii) SW simulation with wave incident from the SW Direction

The significant wave height and direction at points P1, P2 and P3 for waves incident from SW direction are given below in Table 3.

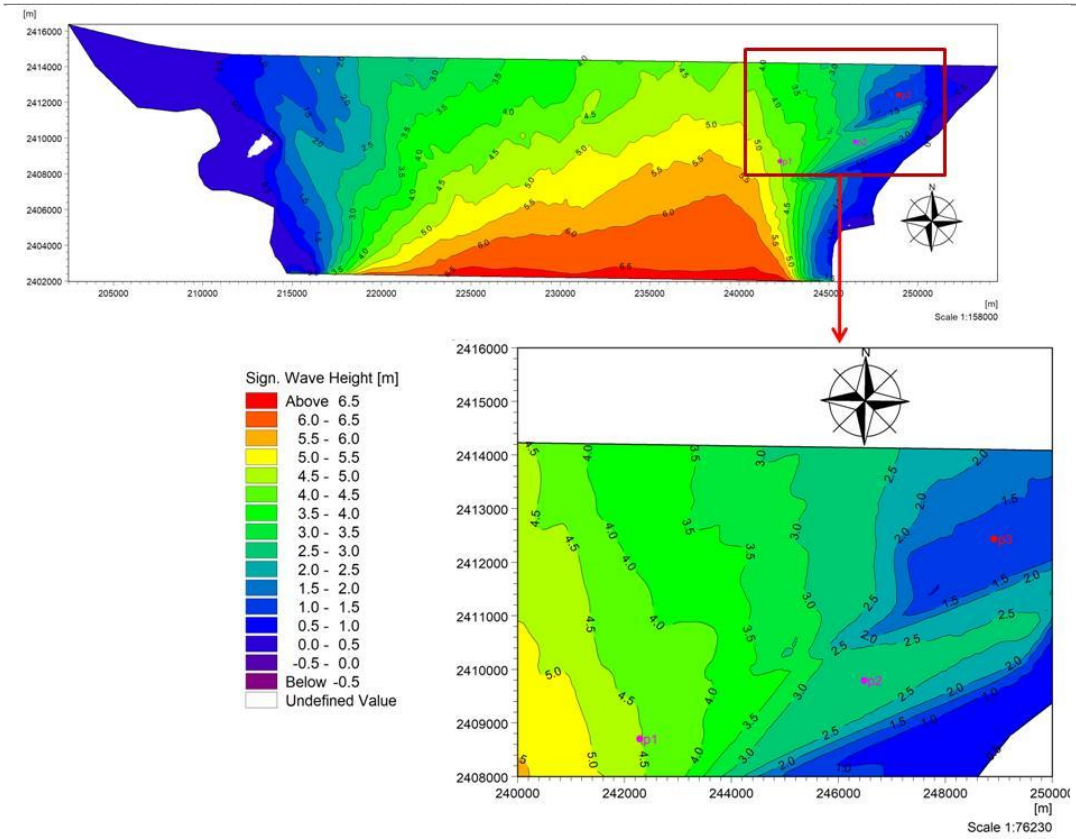


Fig.13 : Wave distribution plot for wave incident from SW direction

Table 3: SW Simulation results for wave incident from SW Direction

Point	Significant Wave height (m)	Wave Direction (^{0}N)
P1	4.52	225
P2	2.61	246
P3	1.35	260

The SW simulation plots from Figs. 11 to 13 indicate that the maximum significant wave height at point P3 near spillway is in range of 1.35m to 1.39m.

5.2 Wave Propagation near Spillway using MIKE - BW Model

The significant wave heights were again assessed with Mike 21 BW for Point P3 near the spillway. The boundary condition for MIKE21 BW simulations was considered from the SW simulations results at the offshore mouth of the tailrace channel Point P1. The significant wave height at Point P1 (at offshore channel end) is summarized in the Table 4 as below.

Table 4: Input wave conditions at Channel mouth P1 for MIKE 21 BW simulations

Wave Direction	Significant Wave Height	Wave Direction (^{0}N)	Wave period
South	3.86m	218	10 Sec
SSW	4.27m	222	10 sec
SW	4.52m	225	10 sec

The waves incident from South, SSW, SW direction reach the mouth of the tailrace channel at incident angles of 218^{0}N, 222^{0}N, 225^{0}N respectively. As seen, there are few degrees changes in the angles and marginal changes in the significant wave height at Point P1. These boundary conditions have been used for MIKE 21 –BW simulations to obtain wave condition near spillway area at Point P3.

Wave propagation inside the tailrace channel area was simulated using MIKE21-BW for the model area shown in Fig.14 for input wave conditions shown in Table 4. Area of 8.0 km by 7.0 km was discretized with a grid size of 5.0m by 5.0m as shown in Fig.15. Simulations were carried out for the design water level condition +8.22m corresponding to storm surge condition along with highest high tide. The wave propagation studies for all the input wave conditions as per Table 4 corresponding to predominant directions are described in detail as below:

Fig .14: Image showing the area covered for the BW studies.

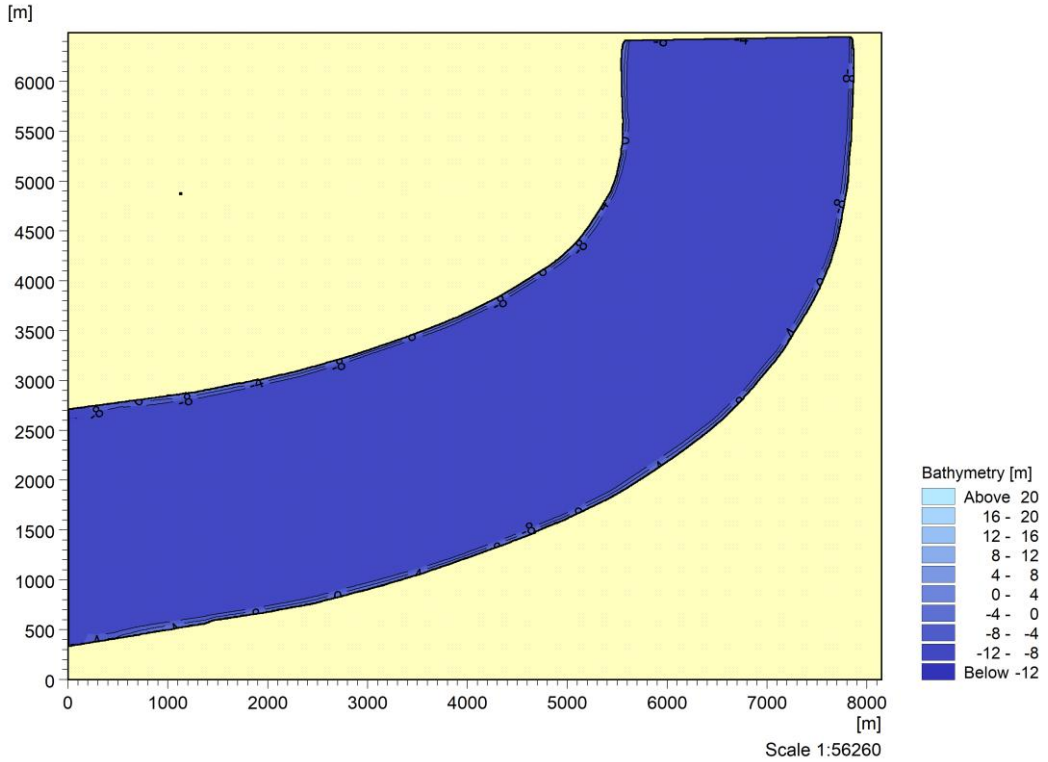


Fig.15: Bathymetry of the tailrace channel to the spillway

Tailrace channel length is about 9km and width is about 2400m. The depth along the channel has been considered as (-)12 m w.r.t MSL as per provided data by the Project.

The simulation for MIKE21 BW was carried out with bathymetry in Fig.14. Input wave conditions were taken from Table 4. The simulations were carried out for the wave incident from the 218^0N, 222^0N, 225^0N respectively as shown in Figs.16(A&B) to Figs.18(A&B).

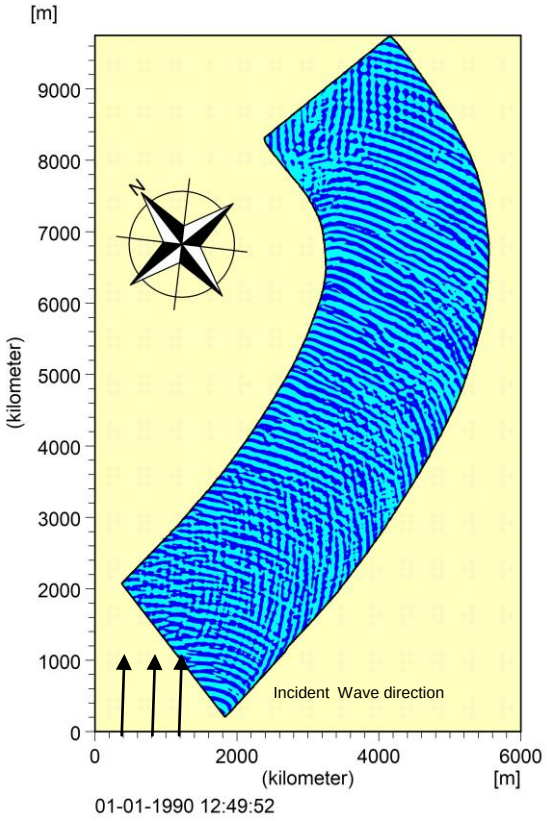


Fig.16A: Wave Propagation Plot for Waves Incident from 218^{0}N Direction

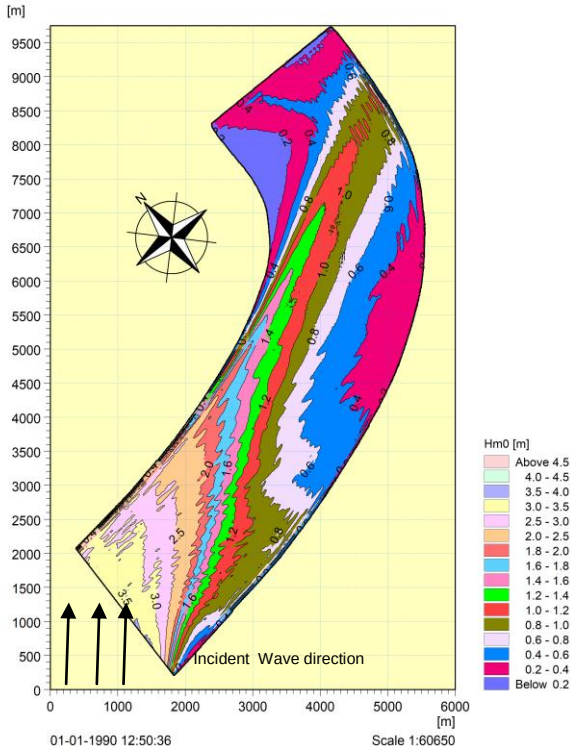


Fig. 16B: Wave Height Distribution Plot for Waves Incident from 218^0 N Direction (Incident Wave Height: 3.86m)

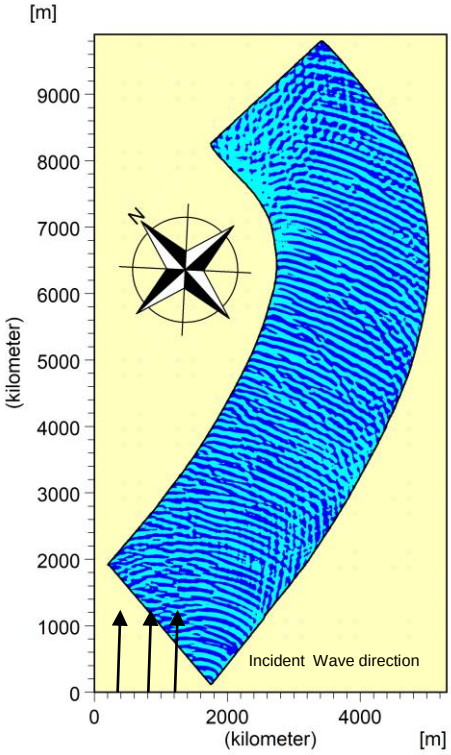


Fig.17A: Wave Propagation Plot for Waves Incident from 222^{0}N Direction

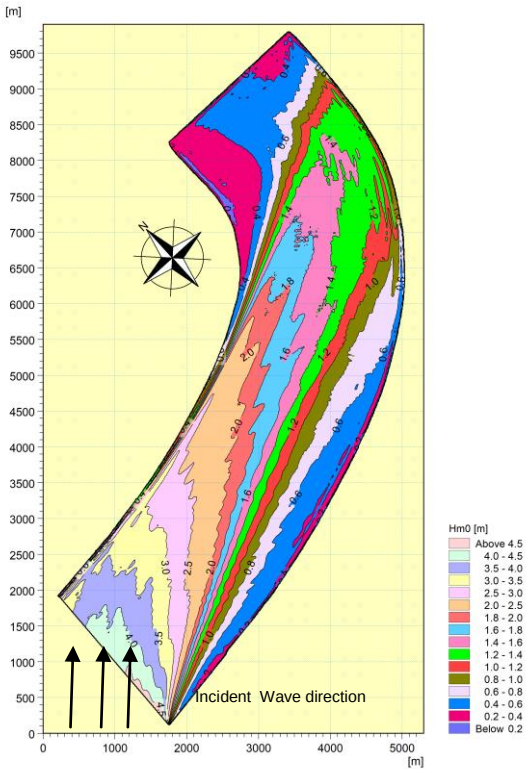


Fig. 17B: Wave Height Distribution Plot for Waves Incident from 222^0 N Direction (Incident Wave Height: 4.27m)

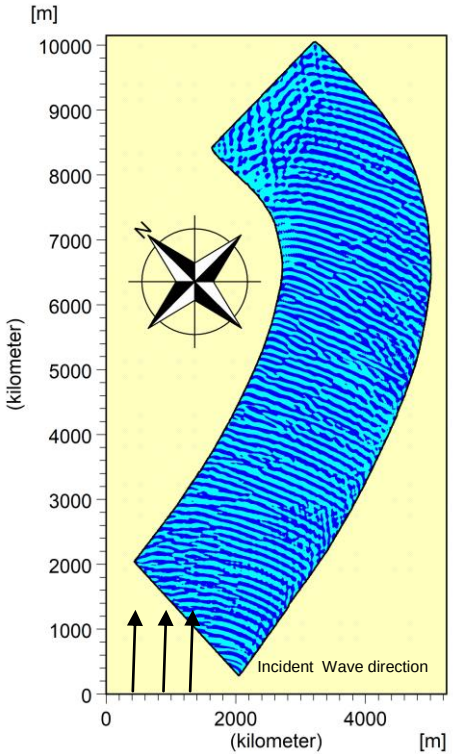


Fig.18A: Wave Propagation Plot for Waves Incident from 225^{0}N Direction

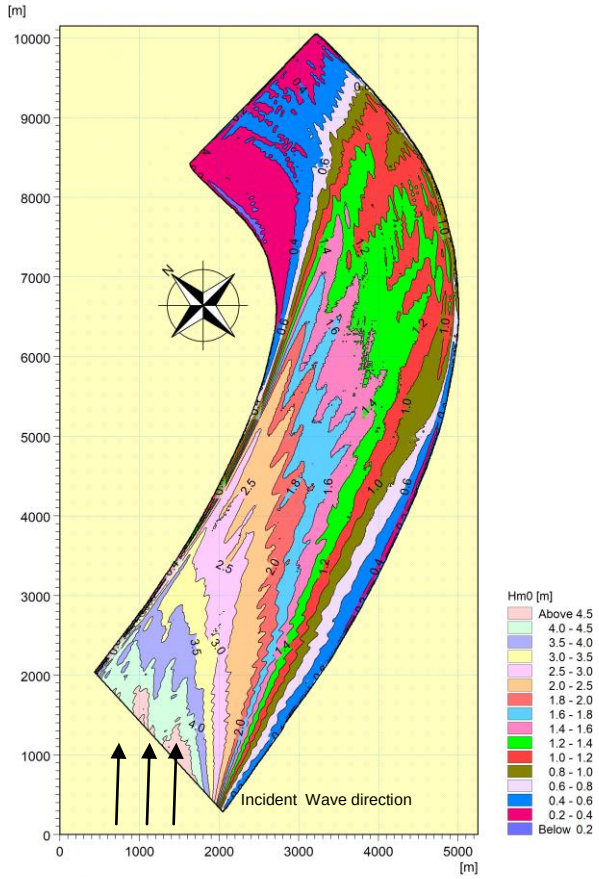


Fig.18B: Wave Height Distribution Plot for Waves Incident from 225^0 N Direction (Incident Wave Height: 4.52m)

From the above simulation plots as per Fig. 16B to 18B, it is seen that the wave conditions near the spillway at Point P3 are summarized in Table 5 for all predominant incident directions as per BW simulations.

Table 5: Significant wave heights at point P3 near Spillway

Wave height at P3	Direction		
	218^0N	**222^0N**	**225^0N**
	0.45m	0.62m	0.70m

It is also seen that the significant wave heights are attenuated while reaching the spillway gates through dredged channel and due to the turn provided in the tailrace channel and dissipation along channel slopes. This is almost half of the wave conditions obtained near spillway by using the SW simulations.

5.3 Wave propagation near Spillway under worst condition of incident wave using MIKE - BW Model

The most possible worst wave incidence situation at the mouth of the tailrace channel under extreme wave conditions was studied with the MIKE 21 BW wherein the wave is incident from the West direction (270^0N) considering the geometrical location of tailrace channel. In this condition, the wave will propagate along the channel with minimum losses as compared to other directions. The significant wave height as boundary condition at channel mouth for this situation is considered as 4.0m with 10 second wave period. The results are shown in Fig. 19A and Fig. 19B.

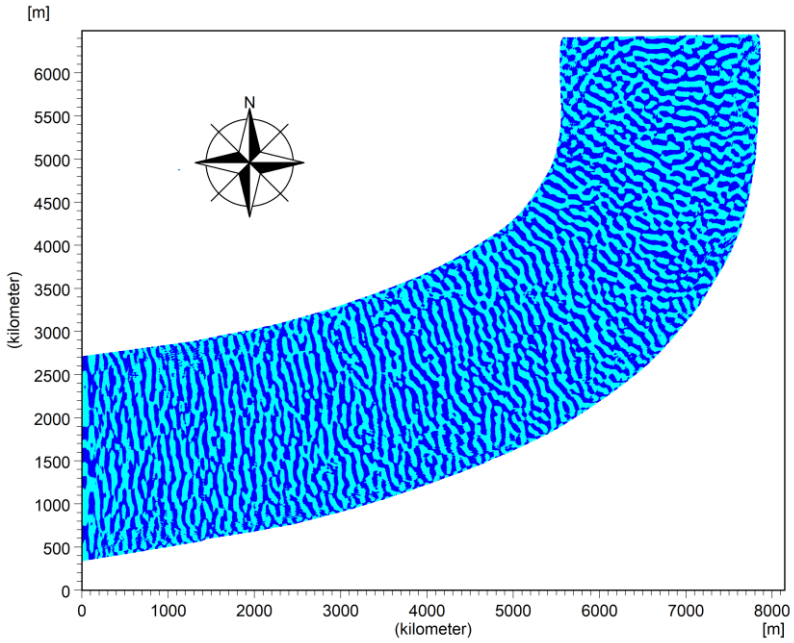


Fig.19A: Wave Propagation Plot for Waves Incident from 270^0N Direction

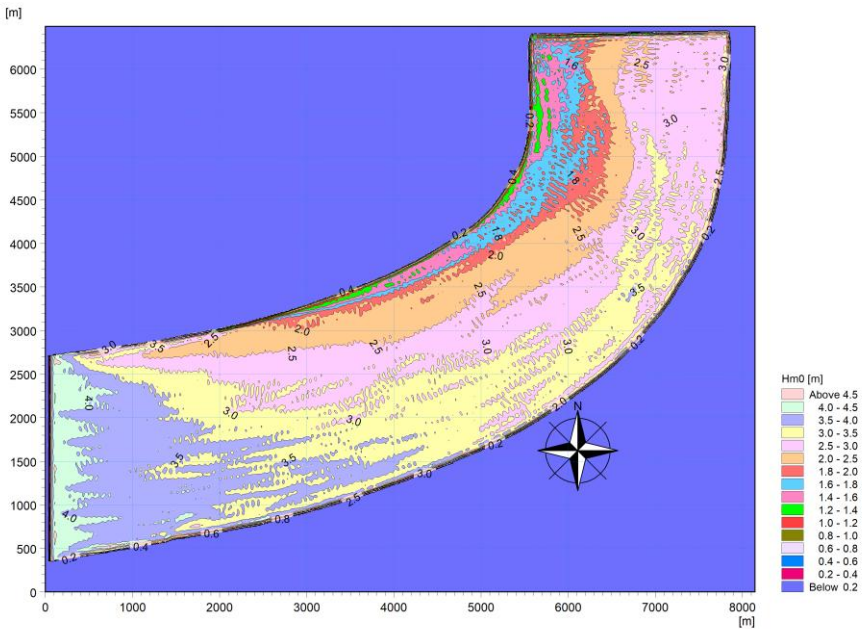


Fig.19B: Wave Height Distribution Plot for Waves Incident from 270^0 N Direction (Incident Wave Height: 4.0m)

As per this most critical wave incident direction from West, the significant wave height of the order of 2.5m would be present near the spillway gates and wave direction would be almost perpendicular to the spillway axis. This is more realistic and critical significant wave height near the spillway gates.

6.0 DISCUSSION ON RESULTS

In order to assess the wave condition near the spillway especially with the storm surge condition, the wave assessment has been carried out in two stages keeping in view of the size of the area. The generation point of the design significant wave height of 7.32m is not mentioned by the Project. During the SW model studies, the design wave height has been assumed to be generated at the model boundary which is located at about 12 km from the Dyke axis. In the first step, the wave condition assessment at the offshore mouth of the tailrace channel was carried out using MIKE21 –SW. The SW model boundary has been taken at about 8.0 km from the tailrace channel mouth. For the transformation of waves from the offshore boundary to tailrace channel, the simulation was carried out with Spectral wave Model. Model simulation was carried out with the three possible predominant incident wave directions South, SSW and SW. As per the MIKE 21 SW simulations, the wave conditions at the entrance of tailrace channel are summarized in the Table below:

Wave Direction	Significant Wave Height	Wave Direction (^{0}N)
South	**3.86m**	**218**
SSW	**4.27m**	**222**
SW	**4.52m**	**225**

It is observed from the further BW simulation inside the tailrace channel that at the Dyke spillway gates, the maximum significant wave height will be up to 0.70m. The significant wave heights are attenuated while reaching the spillway gates because the dredged depths, slopes and also due to the turn provided in the tailrace channel.

However, in absence of correct location of generation of design significant wave height of 7.32m, a critical incident wave direction from 270 degrees at the mouth of channel with incident wave height of 4.0m at channel mouth (as per SW results) was also considered and studied. The BW results indicated that the significant wave height of 2.5m would reach upto the spillway and this may be considered to be accepted as Design wave height for the spillways gates and for assessment of discharging capacity.

7.0 CONCLUSIONS

The preliminary findings of the Mathematical wave model studies for assessment of critical wave condition near spillway are as below.

- Mathematical model studies for transformation of wave height and wave direction from deep water (at the distance of about 8.0 km from the tailrace channel) to mouth of the tailrace channel at depth of (-)15m using spectral wave model MIKE 21-SW indicated that predominant directions are from 218^0 N to 225^0 N.
- Wave propagation studies carried out with MIKE21-BW model to assess the wave tranquility for proposed tailrace channel dredged to (-)12m depth w.r.t MSL indicate that the significant wave heights near spillway would be upto 0.70m.
- It is observed from the results that the significant wave heights are attenuated while reaching the spillway gates mainly due to dissipation along slopes of dredged channel and the turn provided in the tailrace channel.
- However, in absence of correct location of generation of design significant wave height of 7.32m, a critical incident wave direction from 270 degrees at the mouth of channel with incident wave height of 4.0m at channel mouth (as per SW results) was also considered and studied. The BW simulation results indicated that the significant wave height of **2.5m** would reach upto the spillway and this may be considered to be accepted as Design wave height for the spillways gates and for assessment of discharging capacity.