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Study of Wave Propagation by Comparing the Mathematical and Physical Model of Chennai Port

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Abstract:- The present study delves into the intricate dynamics of wave propagation and its consequential impacts on the harbor of the Chennai port. This research undertakes a comprehensive analysis employing two distinct yet complementary methodologies: a Mathematical approach and a Physical approach. The Mathematical aspect is meticulously simulated utilizing the cutting-edge MIKE 21 software, with a particular focus on Boussinesq wave equation (BW). This equation is renowned for its specialization in near shore conditions, thereby facilitating a profound investigation into the wave tranquility within the Chennai port harbor.

This study is distinctly geared towards attaining optimal tranquility conditions at the berths through a thorough examination of the efficiency of breakwaters. By juxtaposing the results obtained from both the Mathematical and Physical models, a nuanced understanding emerges regarding the disparities in tranquility achieved through each approach. Consequently, this comparative analysis enables the identification of the most suitable parameters that ought to be implemented for ensuring the utmost stability and tranquility within the harbor environment.

Keywords:- *Wave Propagation, MIKE 21 Software, Physical Modelling, Mathematical Modelling, Comparative Analysis, Wave Tranquility.*

I. INTRODUCTION

Waves are omnipresent in marine environments and can vary significantly in their characteristics, including amplitude, frequency, and tranquillity. This research paper embarks on a comprehensive exploration of wave propagation and its consequential impacts on harbor tranquility, with a specific emphasis on ensuring the maintenance of minimal wave height within permissible limits to foster calm waters within the harbor. Since its inception in 1881, the Chennai port has undergone significant evolution, marked by the addition of berths, introduction of new breakwaters, and numerous other minor and major modifications. This paper directs its attention towards a critical examination of the effectiveness of these breakwaters in preserving the calmness of the harbor waters. As the maritime landscape continues to evolve, it becomes imperative to evaluate the efficiency of existing infrastructure in mitigating the disruptive effects of waves. Should the breakwaters fail to deliver satisfactory outcomes, it prompts a crucial reassessment of their design and functionality.

II. APPROACH METHODOLOGIES

In coastal engineering there are two basic approaches to study any analyse the land water or coastal structure interaction. They are either by preparing Mathematical Modelling or constructing Physical Models.

➢ *Physical Models in Coastal Engineering*

A physical model is a tangible, scaled-down representation of a real-world object, system, or phenomenon. It is created to simulate and study the behaviour, characteristics, and interactions of the original object or system in a controlled environment. In coastal engineering, physical models are crucial for studying wave propagation, sediment transport, erosion, and the behaviour of coastal structures. These models are scaled-down representations of coastal areas, shorelines, beaches, or structures built in laboratory settings with controlled water flow, wave generators, and scaled environmental conditions. Researchers use these models to simulate and observe coastal processes, test the effectiveness of different coastal protection measures, and understand the impact of waves and currents on coastal environments.

Physical Models are used to simulate the behaviour of waves, currents, sediment transport, and other coastal processes in a controlled laboratory setting. These models are utilized in the study of wave propagation in coastal engineering:

- *Understanding Wave Behaviour:*

Physical models help in understanding how waves behave in various coastal conditions. By replicating wave characteristics such as height, period, and direction, researchers can observe how these waves interact with different coastal features like beaches, breakwaters, and structures.

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- *Design and Analysis of Coastal Structures:*

Engineers use physical models to test the effectiveness of different coastal structures in reducing wave energy and protecting coastlines. For example, they can simulate wave impacts on seawalls, breakwaters, jetties, and offshore structures to optimize their design for coastal protection.

- *Wave-Structure Interaction Studies:*

Physical models allow researchers to study how waves interact with different coastal structures. They can analyse wave forces on structures, wave run-up, wave reflection, transmission, and diffraction, providing valuable insights for designing resilient coastal infrastructure.

- *Prediction of Erosion and Sediment Transport:*

Coastal erosion is a significant concern. Physical models help in studying sediment transport due to wave action, currents, and tides. This understanding aids in predicting erosion patterns and developing strategies to mitigate coastal erosion.

- *Validation of Numerical Models:*

Physical models serve as benchmarks for validating numerical models used for simulating wave behaviour and coastal processes. Comparing the results obtained from physical models with computer simulations helps improve the accuracy of numerical models.

- *Educational and Outreach Purposes:*

Physical models are valuable tools for educational purposes and public outreach. They can demonstrate the impact of coastal processes and the effectiveness of various coastal engineering solutions to policymakers, stakeholders, and the general public.

➢ *Mathematical Modelling*

The mathematical models can range from simple empirical equations to complex numerical simulations, often involving computational fluid dynamics (CFD) or finite element analysis (FEA) techniques. They require inputs such as bathymetric data, meteorological conditions, coastal topography, and characteristics of port structures to generate predictions and simulations for various scenarios. These models are essential tools for engineers, planners, and policymakers to make informed decisions about port design, management, and coastal protection strategies, ensuring efficient and sustainable port operations while mitigating potential risks to the environment and infrastructure.

They are used to simulate various physical processes such as wave propagation, sediment transport, coastal erosion, and shoreline changes. Here are some key types of mathematical models used in coastal engineering:

➢ *Wave Models:*

Wave models are used to predict wave characteristics such as height, period, and direction. They are crucial for designing coastal structures and understanding wave energy impacts.

➢ *Hydrodynamic Models:*

Hydrodynamic models simulate the movement of water due to tides, currents, and other forces.

➢ *Sediment Transport Models:*

These models predict the movement of sediment due to water motion, essential for understanding erosion and deposition patterns.

➢ *Morpho-dynamic Models:*

Morpho-dynamic models integrate hydrodynamics, sediment transport, and topographic changes to predict the evolution of coastal features.

➢ *Shoreline Change Models:*

These models predict changes in shoreline position due to factors like sea-level rise, wave action, and human interventions.

➢ *Storm Surge Models:*

These models predict the rise in sea level and coastal flooding due to atmospheric pressure changes and wind forces during storms.

➢ *Climate Impact Models:*

These models assess the impact of climate change on coastal environments, including sea-level rise, increased storm frequency, and changes in wave climate.

Mathematical models are highly flexible and can simulate large and complex environments. One of the primary advantages of mathematical modelling is its flexibility and scalability. Researchers can adjust model parameters and boundary conditions to simulate different wave scenarios and study their effects on tranquillity. Mathematical models also offer cost-effective alternatives to physical experiments, especially for large-scale or long-term simulations.

However, mathematical modelling also has limitations; they require significant computational resources and expertise in numerical methods. The mathematical modelling has limitations particularly in terms of model validation and computational complexity. Validating mathematical models requires comparison with experimental data, which may be limited in scope or accuracy. Additionally, simulating turbulent flows and nonlinear wave interactions can require significant computational resources, limiting the applicability of mathematical models to certain scenarios.

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III. WAVE PROPAGATION STUDIES

To study wave propagation from one end to the other, ocean data of that particular place is required, which was acquired from CWPRS (Central water power and research station). This involved gathering crucial information such as bathymetry, land contours, and water depth contours specific to the selected area within the Chennai port harbour. The bathymetry was meticulously designed to accurately represent the harbour's topography. Boundary conditions were established with sponge and porosity layers, essential for facilitating wave propagation and ensuring accurate simulation results. The simulation was conducted for **two predominant wave directions: ENE (65^{o}) and 145^{o}N** . Actual observed significant wave height and wave period data were input into the MIKE 21 software to generate realistic wave conditions. The output from the mathematical model provided insights into harbour tranquillity conditions and enabled the analysis of breakwater effectiveness.

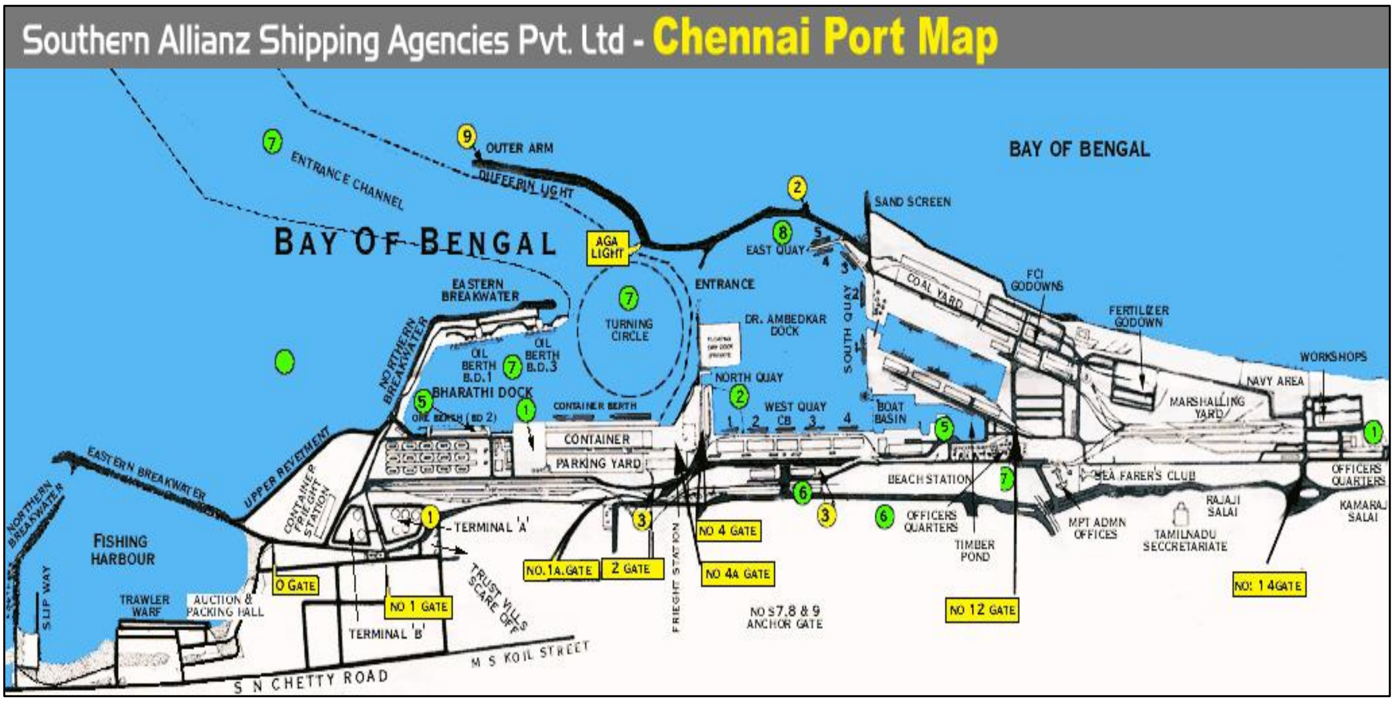

Fig 1 Chennai Port Layout [3]

Wave propagation studies were carried out by physical model studies as well as by using MIKE21 BW software for the layout shown in Fig 1.0 above

Chennai Port has observed the following current patterns in their area: In January the current sets South Westward or Northward at a rate of 1 to 1.5 knots. But it is irregular in February (Northward parallel with the coast 1.5 knots). During March, April and May the current sets Northward from 1 to 3 knots. In June variable but sometimes Southward and weak in July and in August southward or against the wind from 2 to 3 knots at times. In September the current sets South and South-westwards and in October Southerly along the coast. In November and December the current sets South Westerly or Southerly along the coast [1].

Waves ranging from 0.4 m to 2 m in the deep water around Chennai harbour have been experienced. The predominant wave directions during southwest and northeast monsoons are 145^0 from north and 65^0 from north respectively [2]. The wave height is around 2.5 – 3 m with a wave period of 10 s during northeast monsoon and 2 - 2.5 m with a wave period of 6 s during southwest monsoon [1]

One can understand this with the help of the Fig 2.0 below

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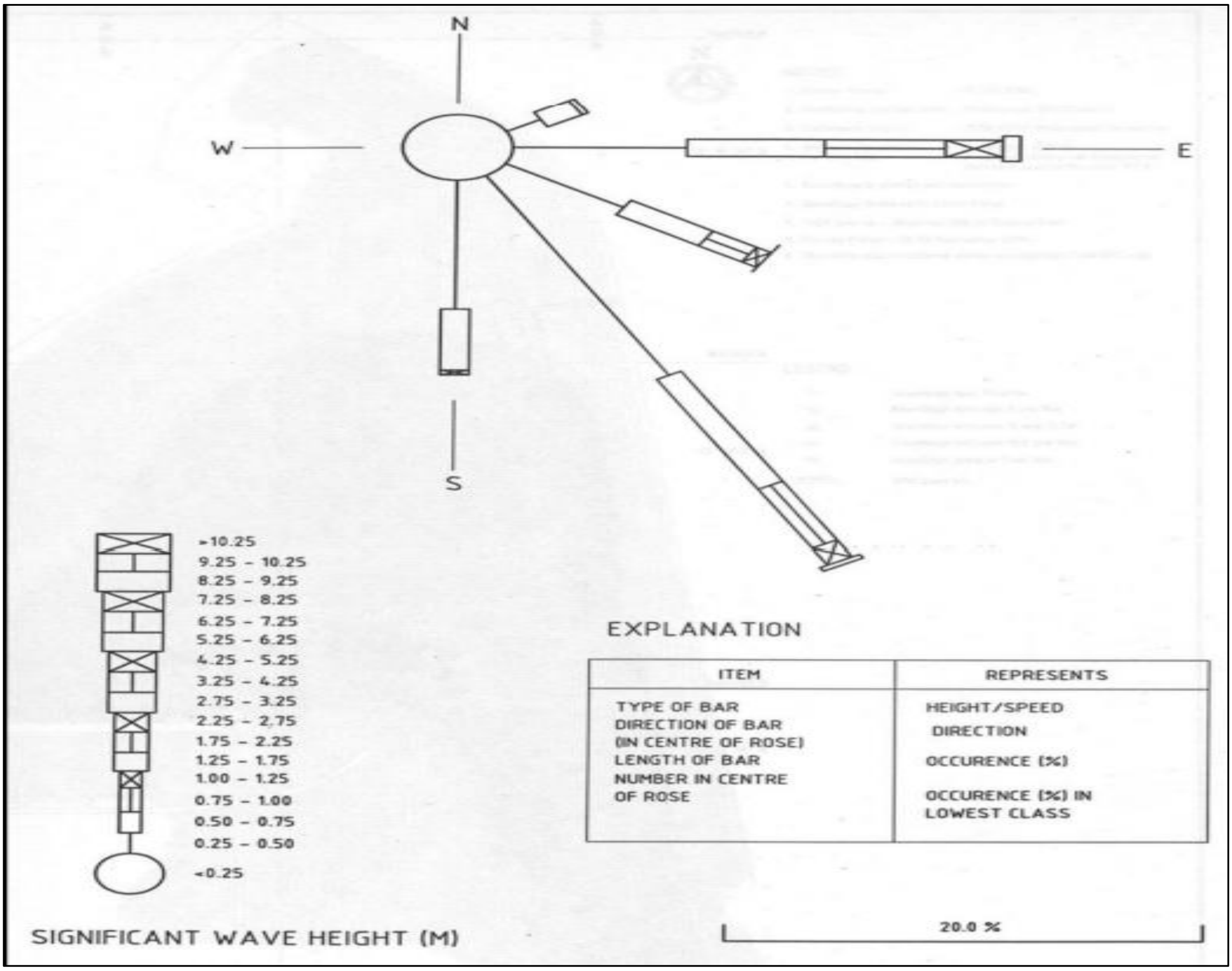

Fig 2 Wave-Rose Diagram [1]

The bathymetry and layout taken for wave propagation studies using MIKE21-BW is as shown in figure 3.0

The bathymetric layout consists of a 488m long northern breakwater and a 650m long eastern breakwater with an approach channel of depth -18.9 and a turning circle of depth -18.3.

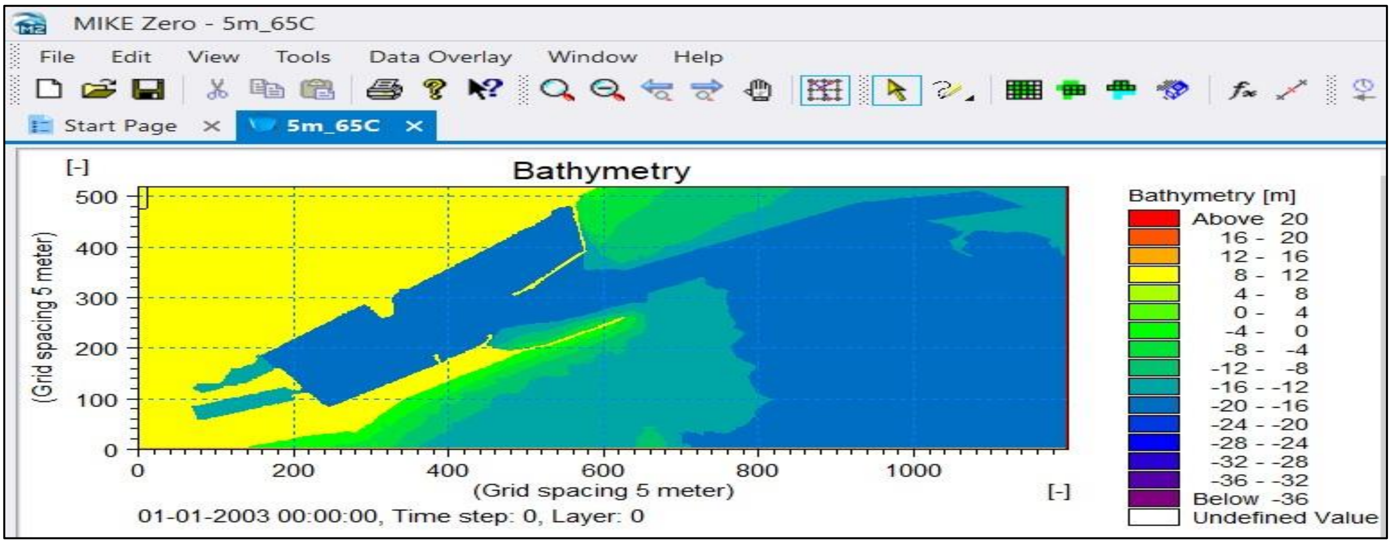

Fig 3 Bathymetry for MIKE21-BW Model

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➢ *Wave Conditions:*
The wave conditions considered for model studies are tabulated as below.

Table 1 Incident Waves Direction and Wave Heights

Wave direction	**Wave height (m)**
ENE	2.5m
North	2.5m

➢ *Wave Propagation and Wave Height Contours:*
Assessment of waves from ENE direction with the incident wave height 2.5m

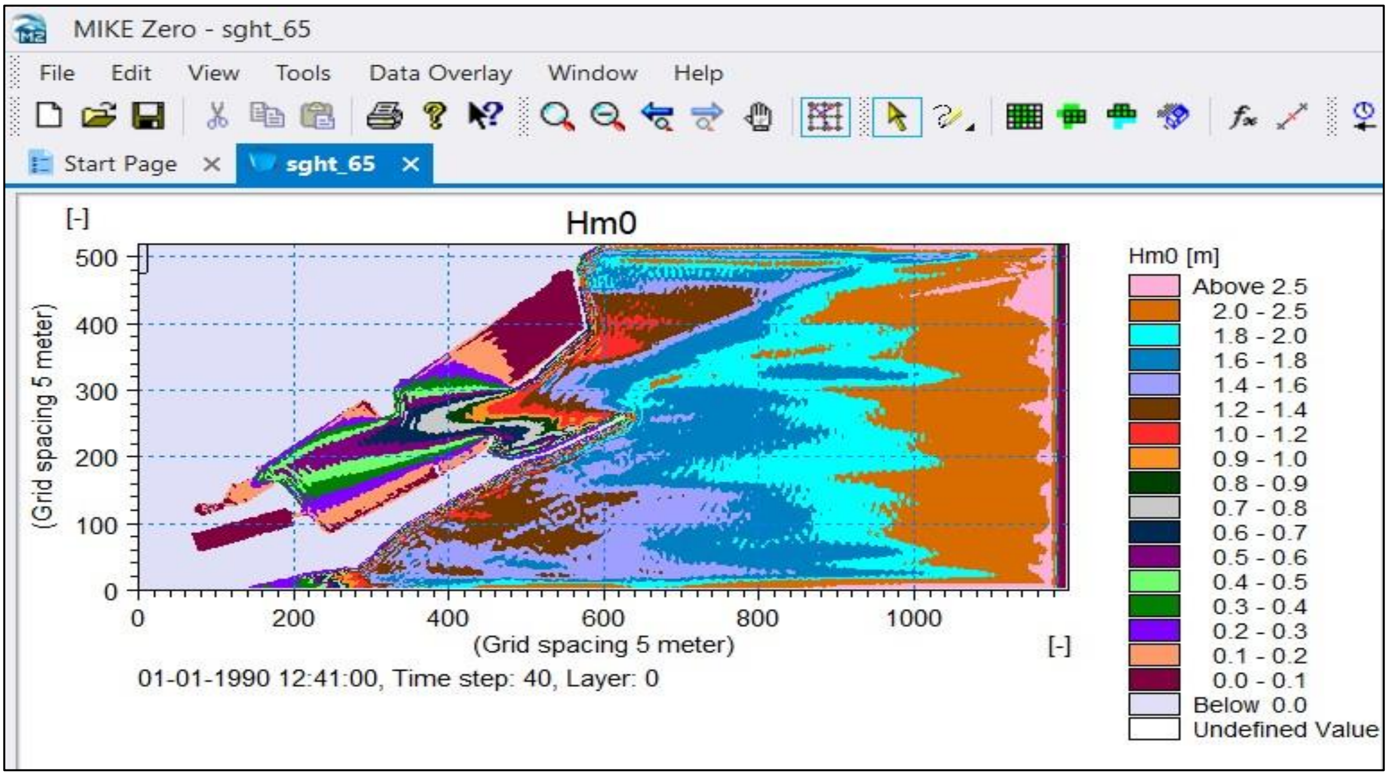

Fig 4 Significant Wave Height from Northeast Direction

The figure above shows that the waves entering the approach channel and turning circle is between 0.7 to 1.4.

IV. COMPARISON OF RESULTS WITH PHYSICAL MODEL STUDIES

The following results are for Significant wave height of 2.5m and wave period of 10 seconds provided as input for wave approaching from east of northeast (65°)

Table 2 For Wave Approach from ENE

Sr.no	**Location**	**Physical**	**Mathematical**
1)	Wave height at Approach channel	2 to 2.5m	1 to 2.3m
2)	Wave height at Turning circle	1.5 to 1.7m	0.7 to 1m
3)	Wave height Near the docks	0.8 to 1.1m	0.4 to 0.7m

The following results are for Significant wave height of 2.5m and wave period of 10 seconds provided as input for wave approaching from 145° N

Table 3 For Wave Approach from North

Sr.no	Location	Physical	Mathematical
1)	Wave height at Approach channel	2 to 2.5m	1 to 2.5m
2)	Wave height at Turning circle	1.5 to 1.7m	0.8 to 1.2m
3)	Wave height Near the docks	0.9 to 1.2m	0.5 to 0.8m

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The following results were observed for Physical model considering both predominant wave direction i.e. East of northeast (ENE) and North direction

- The average wave height that is observed at the approach channel is 2.5m
- The average wave height that is observed at the turning circle is 1.7m
- The average wave height that is observed near the docks is 1.15m

The following results were observed for mathematical model considering both predominant wave direction i.e. East of northeast (ENE) and North direction

- The average wave height that is observed at the approach channel is 2.4m
- The average wave height that is observed at the turning circle is 1.1m
- The average wave height that is observed near the docks is 0.75m

➢ *Comparative Analysis:*

To compare the effectiveness of physical and mathematical models in studying wave propagation, several factors must be considered, including accuracy, applicability, cost, and scalability. Physical models excel in providing direct observations of wave behaviour and testing engineering interventions, making them valuable tools for practical applications in coastal engineering and design. However, their scalability and cost constraints limit their utility for large-scale or long-term studies.

Both physical and numerical modelling techniques have distinct advantages and limitations in coastal engineering applications.

Physical modelling provides tangible representations of wave processes and allows for direct testing of coastal structures under controlled conditions. However, its scalability and cost constraints limit its utility for large-scale or long-term studies.

Numerical modelling, on the other hand, offers scalability and versatility for simulating complex coastal processes over large spatial and temporal scales. While numerical models may lack the direct observational capabilities of physical models, they provide valuable insights into underlying wave mechanics and coastal dynamics. Additionally, numerical models offer cost-effective alternatives for exploring a wide range of coastal scenarios and assessing the long-term impacts of climate change and sea level rise.

Mathematical models, also offer high accuracy and scalability, making them suitable for simulating complex wave phenomena over large spatial and temporal scales. Additionally, mathematical models offer cost-effective alternatives for exploring a wide range of wave scenarios.

V. CONCLUSION

Wave tranquility studies for the Chennai Port were done for two predominant wave directions i.e. 65° N and 145° N. Studies were done using Physical and Mathematical models at CWPRS on comparison of results both the model studies provided comparable results in approach channel, turning circle and dock area. Although tranquility limits for incoming vessels are in range of 0.6 to 1m the wave heights obtained are greater than these limits.

During the monsoon conditions, high wave activities prevail in open sea regions and during these times it may be difficult to operate the port. However, when the sea is calm or wave disturbances are less outside it should be possible to operate the port. This study has given the exposure to us as to how such complex waves phenomenon can be studied through physical and mathematical model effectively.

ACKNOWLEGDEMENT

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