

Laboratory Wave Generation Techniques for Shallow Basin Harbour Modelling Studies

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ABSTRACT: It is important to understand the complexity of the wave propagation with different conditions like varied bathymetry, changes in the bathymetric condition due to incorporation of approach channel, port basin, breakwater and other pertinent port related structures. Physical model studies with shallow wave basin model having long crest wave generation facility have played a very vital role to support the harbour layout design and optimization. Wave basins are the traditional tools to study evolution of the wave field over a non-uniform bathymetry at specific project sites as waves undergo refraction, diffraction, shoaling, breaking, reflection, internal diffraction etc The results of physical model wave tranquillity studies carried out for the development of additional berths in a port by generating random waves from three directions are presented in this paper.

KEYWORDS: Random and regular waves, Hydraulic models, Statistical and spectral analysis, Wave generation

I. INTRODUCTION

Typical objectives of hydraulic wave modelling in harbour engineering studies are to determination of the best location and layout of protective structures with respect to acceptable wave conditions in the harbour entrance and at the berths, investigation of resonant wave which might lead to snapping of the mooring cables, and the determination of ship motion during manoeuvring or in the moored state. Model studies often show that a change in the functional design of the harbour basin or in the construction of the berths is required in order to avoid multiple reflections and locally excessive wave heights. The design of jetties and breakwater is also a typical study related to harbour engineering. The objectives of these experiments are to design these structures such that a minimum cost is achieved while maintaining sufficient structural stability in light of minor damage.

Coastal engineers mainly rely on three complimentary techniques in understanding complex hydrodynamic field in coastal engineering studies. They are field data, physical modelling and mathematical modelling. Field studies are often critical as they provide the best data in understanding complex hydrodynamic regime. These studies are much help in quantifying the flows, wave characteristics etc. for the verification of physical and mathematical modelling.

It is necessary to study the complex wave hydrodynamic near shallow water regions for the analysis and design of the harbour and other structures near the shore. This study is to understand the wave activity, wave tranquillity and the direction of the wave attack in the harbour and this will help in orienting the berthing structures for maximising operating comforts and finalising the port layout. Physical models are very economical and useful tool for this purpose.

II. MODEL STUDY

We shall address exclusively “hydraulic models”, which we defined as “any physical model for the simulation of flow processes, flow states and events, which concern problems of hydraulic engineering or technical hydromechanics.”

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 9, May 2016

Hydraulic model studies in basic and applied investigations of wave-induced phenomena have been conducted over approximately the past 50 years. The hydrodynamic similarity between model and prototype results has, on the contrary, not been definitively researched. Since inertia and gravitational forces are dominant, Froude similarity applies to the model studies. The Weber number "We" (ratio of inertia to surface tension forces) should also be considered for models with breaking wave

In general, wave models should be undistorted if the wave parameters are to be dynamically similar according to Froude scaling. Exceptions, in which distorted models are used, include investigations of long waves and particularly movable-bed wave models. Since the primary objectives of these models are the simulation of long-term morphological changes, it is not necessary to have exact dynamic similarity of each individual wave, but rather of the integral effects of the wave field. At any rate, the distortion should be kept small.

A statistical analysis of the sea state in the area to be investigated is the first step in the design of a hydraulic wave model. This implies a determination of the seasonal probability and spectral distribution of wave heights, periods and direction in relationship to the wind considered. Based on the analysis, the input or generated sea state in the model can be defined relative to acceptable risks. A decision, however, as to whether the model should be run using regular waves or a wave spectrum must be made on a case by case basis. Until recently hydraulic wave model studies were exclusively conducted with regular waves. The stochastic sea state was simplified in that characteristic parameter such as the significant wave height $H_{1/3}$ and its associated period $T_{H1/3}$ were determined and then generated as uniform waves in the model.

Through progress in hydraulics and experimental techniques, it is now possible to use models which allow the simulation of prototype wave trains or wave spectra. The generation of irregular waves is a significant advancement in experimental capabilities. Despite the tremendous experimental efforts already made, it is still necessary to conduct basic experiments in the future, using spectra determined from field observation, in order to improve quantitatively design technique. Further, experiments should also be conducted with wave spectra, when one is dealing with a final design phase of applied research, in order to verify that the results obtained from experiments using regular waves are conservative. This however requires input from extensive field studies.

In hydraulic modelling practice, wave in the model are produced mechanically. The flap or piston type wave generator is preferred today to the previously common plunger type wave generator. As compared with the pneumatic wave generator, mechanical generators have the advantage that the orbital velocity can be simulated more accurately. The relationship between paddle motion and wave characteristics must be known in order to control the wave generator. The theoretical relationship between paddle movement and wave parameters can, to a first approximation, be applied to the generation of the wave spectra, in that sine waves of different heights and frequencies are linearly superimposed into a spectrum. In order to simulate exactly a given spectrum measured in the field, it is necessary to correct the machine-generated spectrum based on a comparison between the field spectrum and that generated by the disk.

Wave gauges have been designed in various hydrodynamic laboratories and industries. Instrumentation using the resistance principle is comparable with that based on capacitance. Wave heights are either directly recorded on analog charts or transmitted to appropriate data recorders. A manual reduction of data associated with wave spectra is not generally practical, so that electronic computers are required. A simultaneous analog recording then serves essentially the purpose of permitting the experimental results to be followed during the experiment

III. WAVE GENERATION

Wave generating techniques in laboratory have evolved from time when limited technology was available to the present, where capabilities of wave generation and computers have exceeded the current understanding of the wave hydrodynamic processes. In regular wave models waves are generated by moving the wave board with required amplitude and period. It generates a train of unidirectional waves with wave crests parallel to wave board. These waves conform well to linear wave theory, which is widely accepted and used in coastal engineering. But most physical

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 9, May 2016

models of coastal engineering involve forces resulting from gravity waves. In nature these waves are random and thus it is appropriate to simulate random waves with a close approximation to natural conditions with due care for minimising the laboratory effects that could influence the experimental outcome.

In the regular wave generation we can generate waves having a specific wave height and time period. In this all the wave generated would be of the same nature and they will break at the same location. These will give the critical conditions but not at the economic design optimisation. For the more optimised results we have to go for random wave generation techniques. In the actual sea condition will be random in nature and that will cause different magnitude of waves.

Hydraulic wave generators were used for generating random waves by establishing increased control over the movement of the wave board. Through these developments it was possible to generate 2-D random waves, cnoidal waves and solitary waves in wave tanks and directional random waves in shallow wave basins. While reproducing random waves in shallow water basin, to reproduce the 3-D sea state it is done in a 2-D process with random waves propagating from any one direction in the laboratory. Though it is fundamentally incorrect, 2-D regular waves are more acceptable to theoretical treatment and offer an intermediate solution in understanding complexities of 3-D sea state. The different equations used for the generation of the regular and random waves are included below.

Regular wave generation

Let H be the wave height and S be the wave paddle stroke, i.e., the maximum stroke distance at the free surface. The frequency of oscillation of the wave paddle should be the same as the frequency of the wave to be generated in the flume. The transfer function of two different types of wave paddle is given here. The detailed derivation can be obtained from Dean and Dalrymple (1969).

For flap motion,

$$\frac{H}{S} = 4 \left(\frac{\sinh kh}{kh} \right) \frac{kh \sinh kh - \cosh kh + 1}{\sinh 2kh + 2kh} = \text{transfer function for the wave paddle, } TF(f)$$

For piston type,

$$\frac{H}{S} = \frac{2(\cosh 2kh - 1)}{\sinh 2kh + 2kh} = \text{transfer function for the wave paddle, } TF(f)$$

Random wave generation

The wave paddle motion for the simulation of random waves is given by,

$$x_p(t) = \sum_1^n \frac{a_i}{TF(f)} \sin(\omega_i t + \varepsilon_i)$$

Where, $a_i = \sqrt{2S_{\eta}(\omega_i)\Delta\omega}$, n is the number of frequency components, $S_{\eta}(\omega)$ is any standard or measured spectrum.

A monochromatic wave is of uniform wave height H and frequency f can be successfully generated and could be validated by measuring the time series at various distances from the wave maker. However, if a long crested random wave were to be generated, it would be given as linear superposition of regular wave components summed up with a random phase. The measurement at various distances from the wave paddle would show that the time series would not match with the input as well as with the other locations. This is due to that the waves propagate according to its dispersive characters such that long waves travel faster than a shorter wave. This would lead to change the relative phase differences among different wave components. This would lead to different time series at various locations. However, the spectral energy at all locations would be same if there is no energy loss due to friction or wave breaking.

There are different programmes used to generate random waves like RWREP, RWPSU, RWRPH, and RWSIT, SPLSH etc in the wave flume and in the wave basin Random' wave in the laboratory by J.Pløeg in the report HY-209A^[5].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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Based on the measured spectra and theoretical results, several standard forms have been developed. This would provide a convenient platform for specifying the spectral representation to represent a particular sea-state. The major spectrums are *Bretschneider or ITTC spectrum, JONSWAP (Joint North Wave Project), DNV Spectrum etc.*

Before proceeding with an assumption of a particular form of a standard spectrum, one has to keep in mind the following limitations on empirical spectra: fetch limitation; state of development or decay; seafloor topography; local current and, effect of distant storms (swells). It has to be noted that a developing sea has a broader spectral peak and a decaying sea has a narrower peak.

IV. CASE STUDY: WAVE TRANQUILLITY ALONG THE EXTENDED BREAKWATER FOR NEW MANGALORE PORT

The Model:

The Model facilities comprised of 3-D hydraulic physical model to scale 1:120(G.S.) housed in a hangar of size 72m X 45m. It is a rigid bed model with latest bathymetry simulated and random wave generation from 3 directions namely West, South-West & North-West. (figure.1) The sea bed contours are almost parallel to the coast line in this region. The model is equipped with computerized wave generation and multi channel wave data acquisition system along with necessary software for data analysis. Electronic water level indicator is provided to monitor water level in the model during the course of experimentation. The approach channel was simulated to a length of about 4000m from the harbour basin entrance, up to sea bed contours of -11.00m in the adjacent natural depths. The model boundaries were simulated with proper wave absorption material like course and fine aggregates so that the undue reflection effects are avoided in the model. The region behind the wave flaps were suitably confined and provided with boulders of suitable sizes to eliminate the reflected waves from these regions which are generated by the backward movement of the wave flaps during the process of wave generation. The harbour basin was suitably simulated with the existing structures and spending beaches were also simulated at the locations as in the prototype for effecting proper absorption of wave energy thus reducing unwanted reflection effects of the waves within the harbour basin.

The lengths of each wave flaps were 11m each and care were taken to place the wave generators sufficiently far so the wave generated properly attains its shape by the time it reaches the points of interest in the model. The placement of the wave boards were made at the model boundary after suitably considering the wave refraction effects for the direction under study. Here the wave conditions near the model boundary were measured at the proposed boundary on the existing truncated model where the approach channel is simulated partially to a length of 4000m only instead of existing 7200m. This was also confirmed by mathematical modelling of the area.

By this it was noticed that wave heights of about $H= 3.66m/tp=10$ sec near the deep water conditions were reduced to about 2.5m near the model boundary, this may be attributed to wave transformation from deeper contours to shallower regions undergoes wave attenuation thus losing wave energy by bottom friction, refraction along the side slopes of the approach channel and reflection effects within the approach channel along its side slopes thus causing some complex wave conditions at few regions which still needs proper understandings. It is these type of complex situations where one can really feel the importance of physical modelling where in the visualisation of the phenomenon can really help in taking few important decisions which otherwise not possible through mathematical modelling.

Experiment details:

Studies were conducted for the development of outer harbour by extending the breakwaters by about 1100m each. The alternative were tested by keeping the breakwaters tips straight as shown in the figure.1. This proposal was to develop a LNG berth and a bulk cargo berth in the outer region of the existing lagoon port enclosed by the proposed breakwaters. Wave tranquillity due to this development was measured at various salient locations in the outer harbour and its effect on the inner harbour was also studied in the mode. The wave tranquillity at different locations is tabulated in Tables 1.

These studies show the wave disturbance in the outer region is higher comparatively and this may be attributed to reduced wave attenuation along the port approach channel caused due to the extension of the breakwaters there by reduction of the wave fronts moving out of the channel along the channel side slopes particularly in the shallow water

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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regions. These studies clearly show development of a harbour basin on a open coast is more beneficial by a lagoon type of land locked which naturally gets desired wave tranquillity and has better safety against wind effects on ship motions at berths and also against the extreme natural events like storms etc. Another important aspect is about losing the spending beaches which are naturally formed on the lee side of the roots of the two breakwaters. These spending beaches are very good wave absorbers; they absorb the wave energy passing out from the channel slopes within the breakwater enclose. This also contributes substantially in improving wave tranquillity in harbour basin. The studies conducted with spending beach for few developments inside the harbour have clearly indicated the positive effects of spending beaches in a harbour basin. In fact any absorptive surface in the basin like provision of mild slopes for wave runs ups underneath a berthing deck also contributes for achieving better tranquil conditions in the basin.

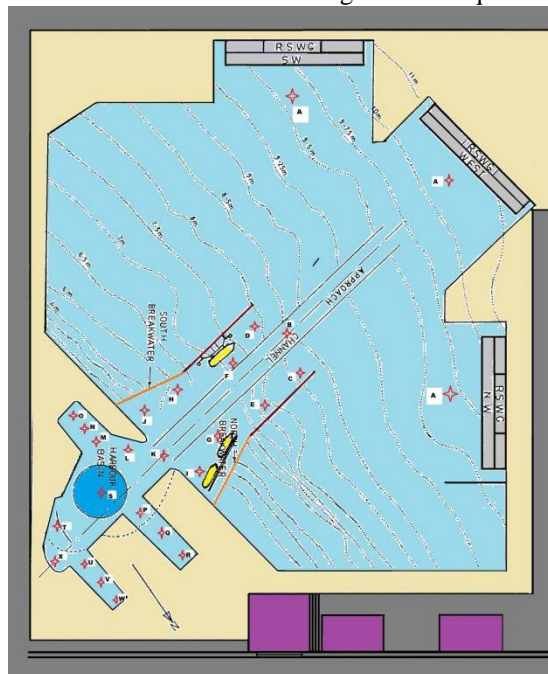


Figure 1 Location of Wave data acquisition points for breakwater extension with straight tips

Table 1 Wave Tranquillity for Waves from Different Directions on Breakwater Extension with Straight Tips

Sl.No	LOCATION	WAVE HEIGHT IN METERS		
		SW	W	NW
1	A (Wave generation point)	2.50	2.50	2.50
2	B (In the approach channel at the beginning of break water)	1.90	1.80	1.60
3	C (Leeward side of north breakwater)	1.75	1.70	1.40
4	D (Leeward side of south breakwater)	1.75	1.70	1.75
5	E (Lee side of extended North breakwater)	1.60	1.50	1.20
6	F (Proposed LNG berth at leeward side of south breakwater)	1.40	1.50	1.50
7	G (Proposed bulk cargo at leeward side of north breakwater)	0.55	0.50	0.45

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8	H (Leeward side of existing breakwater)	0.45	0.50	0.65
9	I (Proposed bulk cargo at leeward side of north breakwater)	0.75	0.70	0.55
10	J (At the end of south breakwater(leeward side))	0.60	0.70	0.75
11	K (In the entrance of lagoon area)	0.70	0.65	0.85
12	L (Proposed LPG berth)	0.60	0.55	0.70
13	M (Entrance of southern dock arm)	0.35	0.30	0.40
14	N (Middle of southern dock arm)	0.30	0.25	0.30
15	O (Rear end of southern dock arm)	0.20	0.20	0.20
16	P (Entrance of western dock arm)	0.55	0.50	0.60
17	Q (Middle of western dock arm)	0.45	0.40	0.45
18	R (Rear end of western dock arm)	0.30	0.20	0.25
19	S (In the turning circle)	0.75	0.65	0.75
20	T (Kudremukh iron ore berth)	0.55	0.50	0.50
21	U (Entrance of eastern dock arm)	0.30	0.25	0.25
22	V (Middle of eastern dock arm)	0.20	0.15	0.15
23	W (Rear end of eastern dock arm)	0.10	0.10	0.10
24	X (Spending beach on the eastern side)	0.45	0.40	0.45

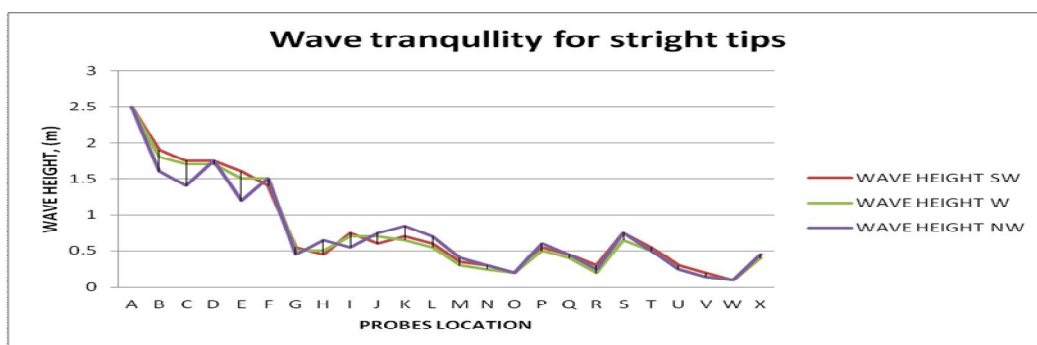


Figure 2 Variation of wave heights at salient locations-straight tips

V. CONCLUSION

Physical wave models are the one of the economical tool for wave propagation studies in shallow basin harbor. This is due to various complex wave transformation phenomena's in these regions. To get accurate results we have to design and construct the model with extreme care. For the physical model study we have to select suitable spectrum. This would provide a convenient platform for specifying the spectral representation to represent a particular sea-state.

A study on the model tested indicates the wave disturbances in the outer regions are higher even with large extensions of the breakwaters. These are not viable from economic point of view also and also loosing the naturally formed spending beaches processes negative effects on the harbour wave tranquillity. From practical point of view it is always beneficial to develop a harbour in a land locked lagoon type basin from which the following merits can be achieved

- Attaining wave tranquillity with minimum lengths of the breakwater.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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- Taking benefits of the wave attenuation effects along long approach channel with mild side slopes.
- Benefits of minimised wind effects on the land region effecting maximum berthing comforts for the port operations.
- Better security in case of extreme events, berths in open sea is more susceptible storms as compared to land locked berths.

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