Design of Cost Effective Wave Flume for Oil Spill Studies

R. Samuel Devadoss

Abstract— This paper describes the design, construction, and testing of a small wave flume and associated equipment. The wave flume is equipped with a Piston type wavemaker, capable of producing only regular waves. The wave-maker is controlled by a mini three phase digital transformer. The crank shaft has three pitches can produce three stroke length of 8 cm, 16 cm and 24 cm respectively. The passive wave absorber in the form of sandy beach is used with a slope of 1:10 for absorbing waves generated from the wave maker. The constructed wave flume was tested for leakages and enamel proof paints are quoted to reduce the effect of friction. Five distinct oil spill experiments are conducted in wave flume. The wave flume design is cost effective both in construction and operational phases.

Index Terms— Wave Flume, Piston Wave Maker, Oil Spill, Passive Absorbers.

I. INTRODUCTION

The primary idea of wave maker design is to match the motion of wave making mechanism with the natural wave's orbital velocity envelopes for deep, intermediate and shallow water waves defined by the wave length to water depth ratio. Since the testing and instrumentation of any experiments in real ocean becomes very expensive and most of the times impractical [1]. Obviously to generate perfectly matching deep, intermediate and shallow water waves in a single facility can be extremely expensive and hence most laboratories have different testing facilities. Wave flumes are a narrow long channel used to for the physical modelling of water waves to test the wave impacts on coastal structures, Wave run-up and overtopping, Wave reflection and absorption studies, Movement and forces for floating marina units, Water circulation and penetration, Wave energy device testing, etc. Wave flumes are constructed in such a way to reflect the real field conditions but restricted to two dimensional, since the width of the flume will be small, compared to its length [2].

The waves are most often generated with a mechanical wavemaker, although there is also wind–wave flumes with (additional) wave generation by an air flow over the water – with the flume closed above by a roof above the free surface. The wavemaker frequently consists of a translating or rotating rigid wave board. Modern wavemakers are computer controlled, and can generate besides periodic waves also random waves, solitary waves, wave groups or even tsunami-like wave motion [3]. Often, the side walls contain glass windows, or completely made of glass, allowing for a clear visual observation inside the water column, and the easy deployment of optical instruments such as Laser Doppler velocimetry or particle image velocimetry (PIV).

The wave flume dimensions are very much important; it should cater the need for the experiment and the nature of tests to be performed on the wave flume decides the nature of the flume. The chemical dispersion studies, oil spill dispersion in this case, needs an exclusive wave flume for so many reasons. Oil spill studies in wave flume has extensively studied by many researchers around the world for oil slick dispersion into a water column, dispersant efficiency under diverse wave conditions, effectiveness of booms and oil absorbers, oil mineral interactions and so on [4, 5&6]. Design of such specific wave flume should be economical, cost effective and more over it should serve the purpose. In this paper the design and construction of a small wave flume with required instrumentations to conduct oil spill studies, with a limited budget, is described.

II. MATERIALS AND METHODS

A compact wave flume was constructed in the Dept. of Ocean Engineering, Indian Institute of Technology Madras, Chennai, to study the oil spill behaviors. This wave flume design includes 12 m long, 0.5 m deep, and 0.35 m wide channel. The base of the flume is 0.2 m above the floor level and constructed with plain cement concrete (PCC). The sides of the flume are made of two layer brickwork. The plastered inner walls and the base of the flume are coated with enamel paint to reduce the friction between the side walls and water particles in movement. To make observations in the water column, the flume is fitted with, two glass panels of size 2 m x 0.5 m at 2 m and 8 m from the beach end of the flume, respectively. The flume is built-in with piston wave maker through which the regular waves are generated. The beach slope was maintained as 1 in 10. The flume was filled with water to its maximum capacity and checked for leakages if any, for a 24 hour period.

For every trial of experiments, the used water in the flume needs to be changed and the surface wall of the flume need to be cleaned, the flume was constructed in such a way that, the above said actions are performed quickly. The cleaning and drying of the wave flume is highly important to quantify the oil concentration with good accuracy. Hence, extreme care was taken, while designing and constructing the wave flume.

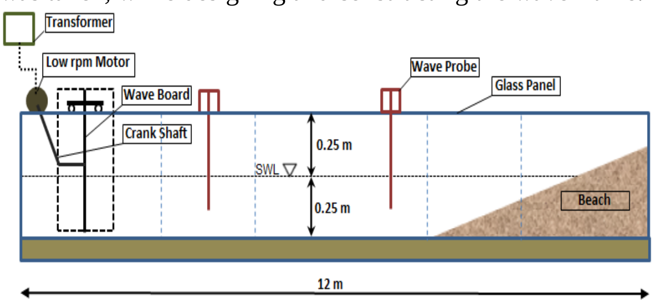

Figure 1. Wave Flume Details

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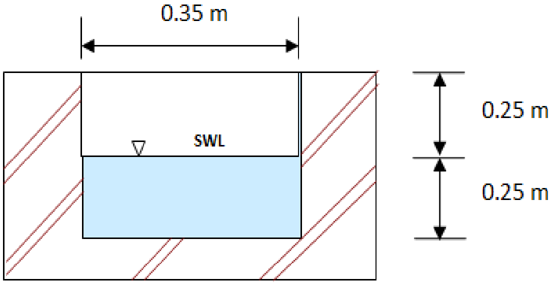

Figure 2. Cross-section of the Wave Flume

III. DESIGN AND CONSTRUCTION

3.1. Piston Wave Maker Design:

The basic idea of the Piston wave maker is to transfer the Oscillatory motion to a linear motion. The rotary motion of a low 120 rpm motor is transformed into linear translator through a crank shaft. The piston has three Pitch arrangements to generate three different wave stroke lengths, by changing the pitch length. Rigid connections are ensured in the crank shaft for the transfer the motions. The wave board is made up of poly vinyl chloride plate of 10 mm thickness. The wave board is supported on the sides of the flume walls by poly urethane wheels and hence the entire wave board load is distributed to the side walls. To reduce the friction between the wheels of the wave board and the surface of the wall, the wheels are positioned in an aluminum channels fixed on the surface wall. The power supplied to the wave maker is controlled by a three phase digital transformer.

Figure 3. Piston Wave Maker arranement

By controlling the speed of the wave maker through the digital transformer, different wave heights were generated in the wave flume. Such an arrangement allows one to generate waves of controlled geometry and frequency. Three pitch holes are designed and the distance from the central axis of rotation is 4 cm, 8 cm and 12 cm respectively. By changing the pitch length of the crank shaft different wave climates are generated. The pitch distances of 4 cm, 8 cm and 12 cm will generate a stroke length of 8 cm, 16 cm and 24 cm respectively. In this wave maker design the wave parameters can be changed by controlling the speed of the motor through transformer or by changing the pitch in the crank shaft. The moving paddle also generates waves on its back side of the wave board. This space was filled with a synthetic honeycomb that immediately dissipates unwanted waves.

Figure 4. Three Phase Digital Transformer

3.2. Dewatering and refilling the wave flume

The fresh water is directly discharged from the overhead tank to the wave flume and after required quantity (up to sufficient water depth) the inflow will be stopped through gate valve.

Suction Pump

The dewatering is an important action in the case of chemical dispersant studies in the wave flume. The mechanical way of dewatering using pumps will reduce manual work to a great extent. For dewatering, a suction pump was designed to expel the used water after each experiment from the wave flume. The model of the pump is high suction slurry type. Since the wave absorber used is of beach material with sufficient slope, the flume water will become turbid due to wave actions and hence a slurry type suction pump is must in this case. The suction pump was in operation after the completion of each run in the wave flume. The total time required to expel the water from the wave flume is approximately30 min.

Figure 5. Installed Suction Pump

3.3. Wave Attenuator Design

Reflection of generated waves from boundaries of the flume and from model is not very desirable for any model tests except studies on wave reflection [7]. Unwanted reflection of waves can alter significantly the incident wave field which will result in error. It is therefore necessary to minimize the effect of reflection by placing absorbers at reflective boundaries. In general the absorbers are classified into, Passive and Active absorbers. The passive absorbers use the concept that damp the incident wave motion by a variety of techniques where the wave absorption at flume boundaries are traditionally achieved by placing gentle slopes (1:10) of porous material (Beach sediments in this case) or screens in front of the boundary to dissipate a large fraction of the incident wave energy. These absorbers can be designed to be effective over a specified range of wave conditions but require substantial length to reduce the reflection below 10 percent. Thus the passive absorbers use up valuable space in the flume.

Most popular passive absorber is constant slope beach constructed of gravel or stones. These are, though very effective, are not easily moved making them less practical, where frequent boundary changes are required [8]. And the concept of Active absorbers is that move in response to incident waves, thus absorbing them. The wave generated in the flume was synthesized by the beach formed in 1:10 slope. In the experimental study the beach material was varied for experiments on beach material, but the slope of the beach was kept constant. The three beach materials used were well graded sand, uniformly graded sand of size 120 µm, and uniformly graded sand of 75 µm. The particle size distribution for well graded sand is shown below. The wave breaks on the slope of the beach and rushed up further in the beach to spend the remaining energy.

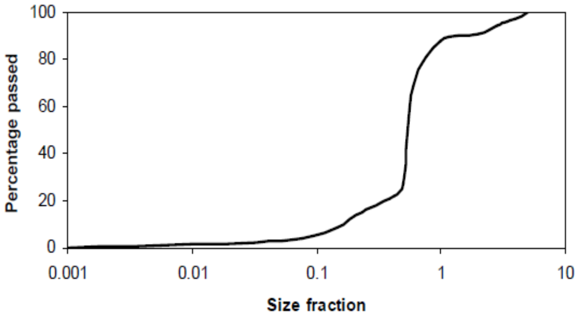

Figure 6. Sieve size analysis of well graded sand used

One of the main parameters to be considered is the ratio of the absorbers length to the water depth. Most absorbers have slopes lower than 1:5. In the present work, the slope of absorber was selected 1:10 because of dimensions of the wave flume. Passive wave absorbers are placed on the basin termination opposite to the wave maker. This beach absorbs wave energy both by causing the incident waves to break, and by allowing percolation of water through after breaking to minimize reflection.

Preparing the Wave Flume for new trail

After each experimental run, the wave flume was cleaned. This is because the spilled oil adheres to the inner walls of the flume and deposit inside the beach materials. To ensure virgin condition for all the experimental cases, the used water in flume was expelled and the inner walls of the wave flume cleaned with oil cleansers. The beach materials were completely removed and new beach is prepared. The normal time taken for cleaning, drying and making the flume to working condition takes 1 to 3 days.

IV. TESTING PROCEDURES

4.1. Wave Probes Calibration

The wave elevation is measured using wave probes. Wave probe comprises of two thin, parallel stainless steel electrodes. When immersed in water, the change in conductivity of the instantaneous water column between the two electrodes is measured. This change is proportional to the variation of the water surface elevation between the electrodes. In order to nullify the effects of temperature and salinity changes on the measured conductivity, the wave probe is equipped with a set of compensating electrodes, mounted at the bottom of the probe and electronically isolated from the main electrodes.

The calibration of an instrument is required to convert the acquired output voltage into physical quantities. It is carried out by knowing the output of the sensor, in terms of voltage, for known values of input physical quantity. The calibration coefficient is obtained from the slope of a best-fit line, drawn for the output on x-axis and input on y-axis. The calibration has been carried at for each set of experiments to minimize the calibration errors.

The relationship between the water surface elevation and the output voltage is established by carrying out the calibration of wave probes. The wave probe was mounted on a frame with half of its length immersed below still water level. The output reading on wave meter was adjusted to zero at this position. Then, the wave probe was raised by 50 mm and corresponding output voltage was noted. Similarly, it was raised up to 200 mm in steps of 50 mm and corresponding output readings were recorded. In addition, the wave probe was also lowered below still water level in steps of 50 mm up to 200 mm and corresponding voltage readings were recorded. The calibration chart for the wave gauges are shown in Fig.7 and 8. Calibrations were repeated few times to check for the repeatability.

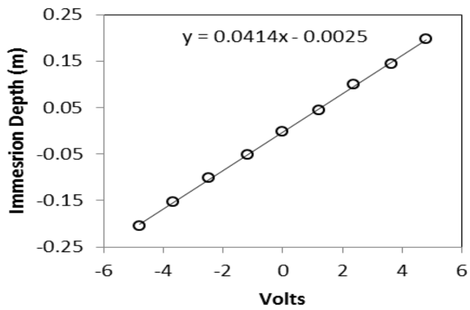

Figure 7. Calibration charts - Wave Probe 1

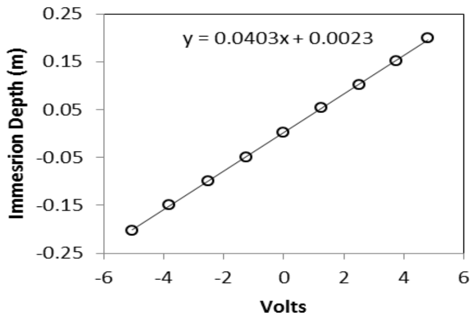

Figure 8. Calibration charts - Wave Probe 2

4.2. Wave Generation

For the entire experimental program, the water depth, was maintained as 0.25 m in the wave flume and the wave maker was operated in the piston mode. All the test conditions were subjected to the action of regular harmonic waves.

4.3. Data Acquisition

The signals acquired through the amplifier were filtered through a 20 Hz low pass filter to remove the sampling ripple. A personal computer was used for storing the wave data and for the simultaneous acquisition of signals from the sensor pick-ups. The physical quantity, i.e., the water surface elevation at different locations in the

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flume was acquired as electric signals from their corresponding transducers. The electric signals were acquired using quartz clock controlled sampling and converted to digital form using a 12bit A/D (Analog to Digital) converter. The A/D converter is supported by software, which controls the sampling frequency of the data acquisition, total time of data collection and data storage in a personal computer. Sufficient time gap was allowed between successive runs to restore calm water condition in the wave flume. The two main advantages of the single-wire capacitance wave probes are: The probes exhibits good linearity and dynamic response over a reasonable length so that it can be used for fairly large waves and The probe is stable over sufficiently long times (probe "drift" is not a significant problem). The other advantages are, minor obstruction to the wave front, no distortion of the wave shape and Low construction costs.

V. GENERATED WAVE HEIGHT AND PERIODS

The wave height produced by the piston-type wavemaker with three different stroke lengths and its corresponding wave period is shown below.

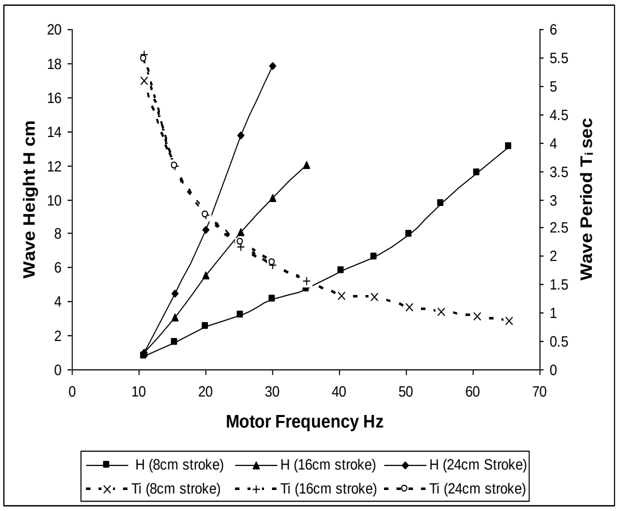

Figure 9. Wave Heights and Periods produced by the Piston-type Wavemaker (H- Wave Height and T_i- Wave Period)

Oil Spill Experiments Conducted in the Wave Flume

The wave flume was used extensively to study the Natural spreading of oil, Non-breaking wave induced dispersion of oil spill, Breaking wave induced dispersion, Beach deposition of oil and oil spill mitigation using clay mineral fines. Under each objective, various parameters (effect of salinity, temperature, etc.) have been studied with two oil types. A total number of 174 trials have been conducted in the wave flume to accomplish the objectives.

VI. CONCLUSION

The wave flume described in this paper, designed for a specific study and built with a limited budget. Although this wave flume is small compared to most wave flumes, it is well-suited to educational and basic research studies particularly oil spill studies where fresh water conditions need to be ensured for each trial of experiments. Larger flumes require a staff and funding to operate and maintain them, and these overhead costs often prohibit their use in small-scale experiments. Instead of reserving a period of time well in advance to conduct experiments in large flumes, the researchers using this small flume only need to change it easily to investigate a physical behavior or try out an idea.

The designed wave flume has been extensively used for determining the natural spreading of oil, Non-breaking wave induced dispersion of oil spill, breaking wave induced dispersion, beach deposition of oil and oil spill mitigation using clay mineral fines. A total no of 174 trials has been performed in the wave flume with variable test conditions of temperature and salinity of water. Two oil types were used to for the entire analysis, one is medium and the other is a heavy type crude oil. The constructed wave flume served its purpose for oil spill research studies in the Dept. of Ocean Engineering, IIT Madras and the same can be used for such studies in future.

REFERENCES

1. Sorensen R.M., “Basic Coastal Engineering”, Springer Science Publications Ltd. (2010).
2. Dean R.G. and Darlymple R.A., “Coastal Process with Engineering Applications”, Cambridge University Press (2002).
3. Dean, R.G. and R.A. Dalrymple, “Water Wave Mechanics for Engineers and Scientists”, World Scientific Publishing Ltd., (1992).
4. Guyomarch, J., L.F. Stéphane, and F. Merlin, Effect of suspended mineral load, water salinity and oil Type on the Size of oil-mineral aggregates in the presence of chemical dispersant. Spill Science & Technology Bulletin, (2002), 8(1), pp 95-100.
5. Boufadel, C. M., D. R. Bechtel, and J., Weaver, The movement of oil under non-breaking waves. Marine Pollution Bulletin, (2006), 52, pp 1056–1065.
6. Li, Z., K. Lee, T. King, C. M. Boufadel, and D. A. Venosa, Evaluating crude oil chemical dispersion efficacy in a flow-through wave tank under regular non-breaking wave and breaking wave conditions. Marine Pollution Bulletin, (2009), 58, pp 735–744.
7. Hughes, S.A, “Physical Models and Laboratory Techniques in Coastal Engineering”, World Scientific Publishing Ltd., (1993).
8. Lu, X., J. Li, and S. Chen, Dynamic Model for Oil Slick Dispersion into a Water Column - A Wind Driven Wave Tank Experiment. Chinese Journal of Oceanology and Limnology, (1993), 11(2), pp 161-170.

AUTHORS PROFILE

Dr.R.Samuel Devadoss has received his doctoral degree from the Dept. of Ocean Engineering, Indian Institute of Technology Madras, India, for the thesis titled “Nearshore Oil Spill Dynamics and Mitigation using Clay Mineral Fines”, in 2013. Currently he is working with DHI (India) Water & Environment Pvt. Ltd, as Coastal Engineer. He is having more than six years of experience in the field of oil spill modeling, coastal engineering and shoreline management works.