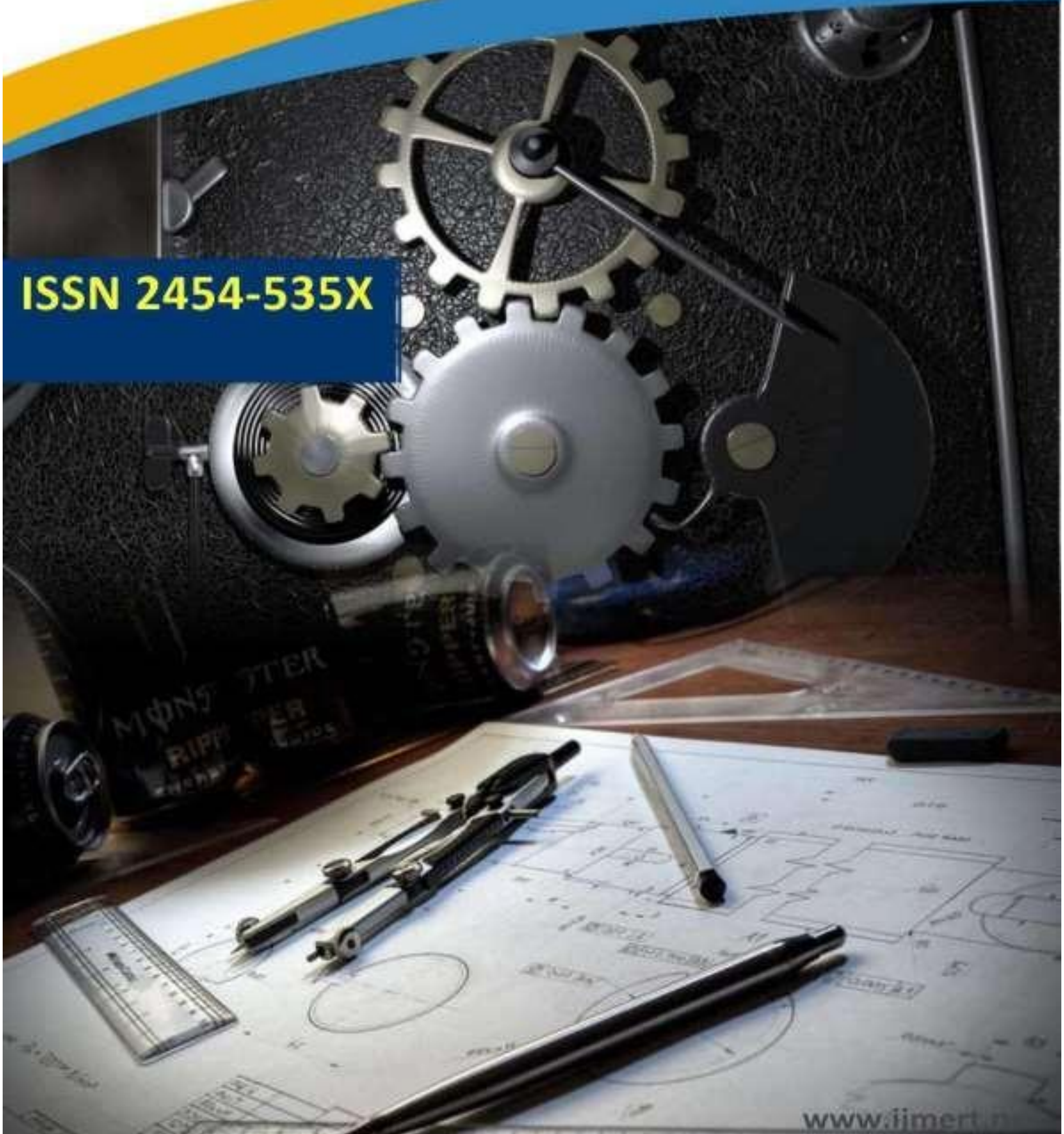
International Journal of
Mechanical Engineering Research and Technology

ISSN 2454-535X



Email ID: info.ijmert@gmail.com or editor@ijmert.net

Int. J. Mech. Eng. Res. & Tech 2017

International Journal of Mechanical Engineering Research and Technology

ISSN 2454 – 535X
www.ijmert.com
Vol. 15 Issue. 4, Nov 2023

Experimental Verification of Wave Height Predictions for Shallow Wave Basin in a Top Hinged Flap type wave Generator

V.Prabhakarachary[1], Scientist-C, R.S. Erande[2], Scientist-B, N. Sunil Naik[3], Scientist-B, S. Bagwan Jamir[4], Scientist-C, M. Phani Kumar[5], Scientist-D, R.S. Kankara[6], Director
[1, 2,3,4,5,6] Central Water and Power Research Station, Maharashtra state, Pune-411024, India
Corresponding Author
V.Prabhakarachary
Scientist-C
Email: prabhakarachary72@gmail.com
Phone: 8552076074

ABSTRACT

This paper describes an attempt to verify experimentally relative wave heights generated by flap-type wave generator against theory. The experiments are performed using Random Sea Wave Generators at CWPRS (Central Water Power Research Station), Pune. The experiments have been conducted in a shallow wave basin, and the wave-height envelope is measured with capacitance wave height recorders placed at various locations in wave basin. The ratio of the height of wave generated by displacement type wave generators in shallow water to the stroke of the flap is approximated as H/S= kd. 'S' is the stroke of the wave generator, 'k' is the wave number given by the small-amplitude theory, 'd' is depth of water in wave basin and H is the height of wave measured perpendicular to S. Agreement of this relation with the hydrodynamic theory for flap-type wave generators over the range of relative depths usually used in coastal engineering experiments are studied. Wave height-stroke transfer functions that are used to generate the desired wave height at selected period as the volume of the displaced fluid during a single stoke is directly proportional to the volume under the crest of the generated wave.

KEYWORDS -Wave height, Flap type wave generation, small amplitude wave theory, Random waves

INTRODUCTION

Ocean waves are being simulated in an experimental basin to study experimentally the characteristics of wave irregularity. The wind waves can be classified according to relative water depth (ratio of the water depth, d to wave length, L) and the characteristic behavior. The wind waves are classified as deep water ($d/L>0.5$), intermediate water ($0.05<d/L<0.5$) and shallow water ($d/L<0.05$) waves based on the water depth. Conidial and solitary waves fall in the shallow water wave category. The structures in the marine environment are designed for a designed wave height, period and direction, which are basically obtained from observing the ocean surface over a long period of time, say for one year at the particular location of interest. In the very shallow waters, the waves deform tremendously, that is, its length decreases, whereas, its height increases, finally resulting in breaking in the near shore zone . The dynamic behavior of wave motion is multifaceted with the interaction between offshore structures and/or sea bottom. The development of computing resources and the advent of super computers in the last two decades made it possible on the improvement in the numerical modeling

ISSN 2454 – 535X
www.ijmert.com
Vol. 15 Issue. 4, Nov 2023

techniques. However, due to the approximation of the dynamic physical processes in the representation of governing equation for the nonlinear wave propagation, still physical modeling in the laboratory plays a major role in the modelling process. The first major task in the physical modeling process is to generate the waves of interest with an exact scaled version of nature in the laboratory. It can be achieved by a random sea wave generation (RSWG) mechanism. In RSWG system hydraulic power pack is used to supply fluid with constant operating pressure and variable flow rate as per the demand generated by the wave generating system. Power of hydraulic system is a function of operating pressure and maximum flow rate. The flow rate depends on bore area and stroke of actuator. Maximum wave height determines the stroke of the actuator.

V.Prabhakarachary[1], Scientist-C, R.S. Erande[2], Scientist-B, N. Sunil Naik[3], Scientist-B, S. Bagwan Jamir[4], Scientist-C, M. Phani Kumar[5], Scientist-D, R.S. Kankara[6], Director
[1, 2,3,4,5,6] Central Water and Power Research Station, Maharashtra state, Pune-411024, India

II. PROBLEM DESCRIPTION

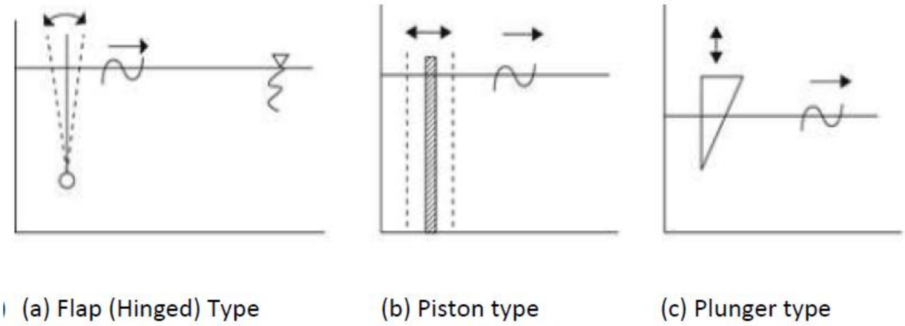
A physical model for simulation of Prototype Sea conditions in laboratory basin for the design and testing of port layouts and marine structures such as Breakwater, Seawalls, etc. under the wave spectrum is to be developed. Present studies were proposed for development of port layouts by modelling random waves approaching at 135 ° north directions with wave frontal length of 22m in order to cover a comprehensive wave length. Replication of sea wave spectra in laboratory to cover wide range of proto type sea conditions is needed for analysis of port lay out designs. Therefore, development of laboratory facility is being proposed by Kamarajar port Ltd, Chennai, India, under research and development scheme. A Random wave generating system for generation of random waves in physical models using servo-hydraulic system is considered. Sizing of actuator is needed for obtaining required wave height with given stroke. The system has been developed by assuming stroke as half of the wave height.

Now, it is proposed to verify wave height predictions for shallow wave basin in a top hinged flap type wave Generator. In RSWG system hydraulic power pack is used to supply fluid with constant operating pressure and variable flow rate as per the demand generated by the wave generating system. Power of hydraulic pack is a function of operating pressure and maximum flow rate. The flow rate depends on bore area and stroke of actuator. Maximum wave height which can be obtained for a given stroke of the actuator is needed to decide the maximum stroke of actuator.

III.TYPES OF WAVE GENERATORS

Irregular waves in an experimental basin can be generated in the following methods

a) By introducing wind wave irregularly to sine waves. b) By summing up several sine waves with random phase. c). By giving irregular input signal to wave generator.



(a) Flap (Hinged) Type (b) Piston type (c) Plunger type

b)

Figure.1 ***Wave Generation Methods***

Matching of achieved wave spectrum with the desired is difficult by above methods mentioned in (a) and (b), but can be established using methods (b) and (c). Wave generation can be categorized into two basic types that are shallow water wave generator and deep-water wave generator. Within these two basic categories there are several various methods in which the power to generate waves can be produced; pneumatically, hydraulically, and electrically [6]. The primitive ways of the wave maker is either of a piston or flap or plunger type capable of generating regular waves [2]. Different types of wave generators are shown in Fig.1. The most commonly used wave generators are hinged and types [1]. The former is generally been used to generate deep-water waves and the latter for the generation of shallow water waves. Fig. 2 presents the water particle velocity profile in the immediate vicinity of wave makers. A close resemblance of water particle velocity profile generated by the paddles to its corresponding deep or shallow water wave conditions explains the use of wave makers [7]. If one is interested in obtaining the motion behaviour of structures subjected to waves of different frequencies, the tests have to be done several times in the laboratory covering the range of frequencies of interest. Due to the advancement in the computers, the present generation of wave makers can generate random waves of pre-defined spectral characteristics.

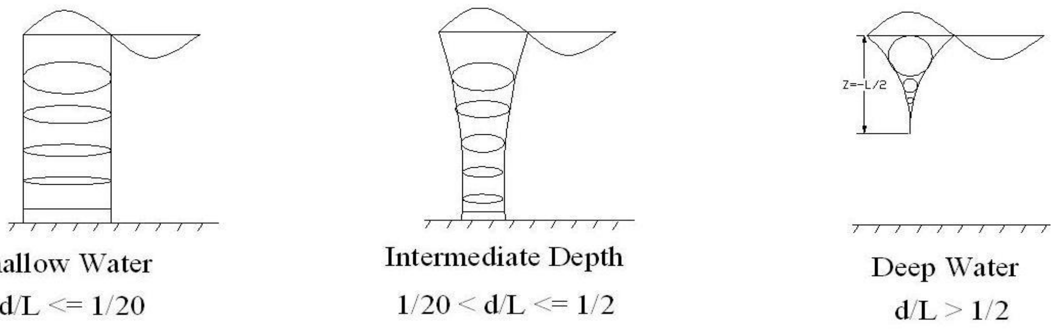


Figure.2 *water particle motion with respect to relative water depth*

ISSN 2454 – 535X
www.ijmert.com
Vol. 15 Issue. 4, Nov 2023

A. Working of Random Sea Wave Generating System (RSWG)

Simulation of ocean waves in laboratory flumes and basins, for hydro-dynamic study of maritime structures such as breakwater, sea walls and port layouts studies is being conducted using a Random Sea Wave Generating Systems (RSWG) [4]. A typical RSWG System is shown in figure.3, ram operated wave paddle which is driven by an electro-hydraulic servo system in which a servo-valve receives controlled signal. Pressurized oil is supplied to servo- actuator by a hydraulic power pack. The servo controller receives analog command signal from the micro-processor and generates error signal by comparing it with a feedback signal obtained from the displacement transducer [3]. The error signal from servo amplifier is converted into a current suitable for driving a servo-valve, which in turn controls oil flow to the actuator and hence the displacement.

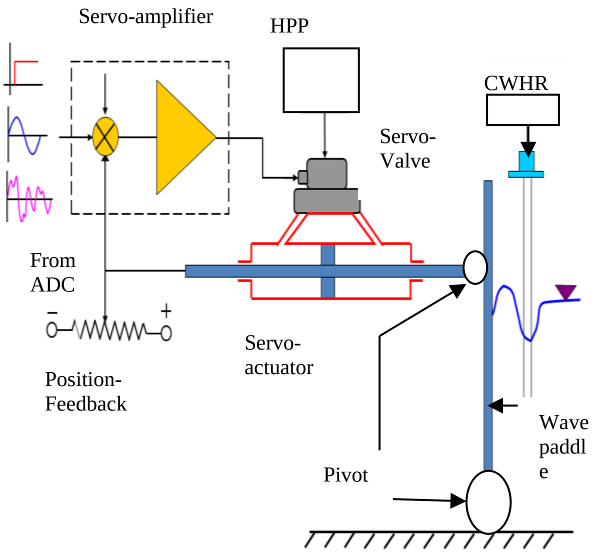


Figure.3.*Schematic diagram of RSWG system*

B. Ocean waves-Theoretical background

Ocean waves are represented by sinusoidal functions when amplitudes are small. This treatment of waves may be inadequate in some situations. In such situations, finite amplitude wave theories that deal with waves having peaked crest have to be used. In this article, selected features of a variety of such wave profiles are presented**.** Waves are the undulations of the sea surface. The most commonly observed waves on ocean surface are those generated by wind forcing. In the beginning, small ripples appear on the sea surface and these grow further by extracting energy from prevailing winds. There are different ways in which waves are classified and one of them is based on its relative amplitude, as small amplitude waves and finite amplitude waves [9]. This article provides a brief introduction to finite amplitude wave theories. Some of the general characteristics of waves as well as the importance of finite amplitude wave theories are touched upon. The topmost and the lowest levels of the waves are respectively called the crest and trough of the wave. The horizontal distance between successive identical points, say two crests, is the wavelength (*L*). Wave height (*H*) is the vertical distance between crest and position to crest or to trough is the amplitude (*a*), which in this case is half of wave height.The surface profile, is given by [9]

$$\eta = a \sin(kx - \sigma t) \quad (1)$$

Here η is the departure from undisturbed level, a is the amplitude, k is wave number, L is wavelength and σ is frequency. The wave speed is given by L/T. This is an example of a sinusoidal wave. In the context of waves on the surface of fluid, these waves (also known as airy waves) are based on Bernoulli's equation for irrotational fluid motion

$$-\partial\phi/\partial t + P/\rho + 1/2(u/2 + w/2) + gz = 0 \quad (2)$$

where ϕ is the potential function of flow, p is pressure, ρ is the density of fluid, u and w are the horizontal and vertical velocities, respectively, g is the acceleration due to gravity, and z is the depth. The higher order terms of velocities can be neglected for small amplitude waves and then the equation becomes

$$-\partial\phi/\partial t + P/\rho + gz = 0 \quad (3)$$

Hence, small amplitude waves are also called linear waves. Most of the aspects of the ocean waves can be explained by the small amplitude wave theory. Let us now see the water particle motion due to waves. While wave energy is carried by the wave as it progresses forward, the water particles oscillate up and down. However, it is not merely an up and down movement. It is either circular or elliptical movement. If the depth of the water column is more than half of wavelength, then waves are known as deep water waves. In the case of such waves, particle motion is circular. On the other hand, if the depth of the water column is less than half of wavelength and more than 1/20 of wave length, they are known as respectively. Waves in this region are called deep water waves and this condition is commonly denoted trough. The vertical distance from mean

intermediate or transitional water waves and if the depth of the water column is less than 1/20 of wavelength, they are called shallow water waves. In the case of both these waves, the particle motion is elliptical. Particle motions are shown in Figure 3. The velocity of waves is generally referred to as wave celerity. For small amplitude waves, celerity, C is given by [10]

$$C = [(g/k)(\tanh kd)]^{0.5} \quad (4)$$

k is the wave number and d is the depth of the water column. This equation gets simplified to $C = (g/k)^{0.5}$ k for deep water waves because tanh kd can be approximated as 1 for large d. For shallow water waves, celerity becomes $C = (gd)^{0.5}$ as the hyperbolic term tends to kd and for intermediate water waves, (3) is to be used. Deep and intermediate water waves are dispersive as the velocity of these depends on wavelength. This is not the case with shallow water waves and they are non-dispersive. An expression for wave length as a function of depth and period may obtained as [10]

$$L = (gT^2/2\pi)\ [\ (\tanh(2\pi d/L)\ ]^{0.5} \quad (5)$$

An important classification of surface waves is based on the relative depth (d/L). When a wave propagates from deep water into shallower water near shore the wave length decreases [see Eq. (2.14)], but at a slower rate than that at which the depth decreases. Thus, the relative depth decreases as a wave approaches the shore. When d/L is greater than approximately 0.5, tanh (2 π d/L) is essentially unity and Equations (3) to (4) reduce to [10] $Co = L_o/T$

$$Co = gT/2\pi \quad (6)$$

$$Lo = gT^2/2\pi \quad (7)$$

by the subscript zero. Wave particle velocities and orbit dimensions decrease with increasing distance surface. In deep water at a depth of $-z/L > 0.5$ the particle velocities and orbit dimensions are close to zero. Since for $d/L > 0.5$ the waves do not interact with the bottom, wave characteristics are thus independent of the water depth. For deep water the particle orbits are circular having a diameter at the surface equal to the wave height. Since a particle completes one orbit in one wave period, the particle speed at the crest would be the orbit circumference divided by the period. Note that this is much less than Co. When the relative depth is less than 0.5 the waves interact with the bottom. Wave characteristics depend on both the water depth and the wave period, and continually change as the depth decreases. The full dispersion equations must be used to calculate wave celerity or length for any given water depth and wave period. Dividing Equation (4) by Equation (5) yields [10]

$$C/C_o = L/L_o = \tanh(2\pi d/L) \tag{8}$$

which is a useful relationship that will be employed in a later chapter. Waves propagating in the range of relative depths from 0.5 to 0.05 are called intermediate or transitional water waves. When the relative depth is less than approximately 0.05, tanh

IV. Wave height prediction

The horizontal water particle velocity u is constant over the depth of the fluid and vertical velocity particle v is small and varies directly as the particle elevation above the bottom because the small amplitude theory for shallow water waves assumes that the pressure beneath the wave form is hydrostatic. The theory predicts that the waves will propagate unchanged in shape through water of constant depth with the simplest periodic solution having wave shape is that of a pure sine wave [5].

disturbance given due to forward motion of a wave generator displaces or angular oscillation of

below the free

(2πd/L) approximately equals 2πd/L and the dispersion equation yields [10]

$$C=(gd)^{0.5} \tag{9}$$

$$L=(gd)^{0.5}T \tag{10}$$

Waves in this region of relative depths are called shallow water waves. In shallow water the small-amplitude wave theory gives a wave celerity that is independent of wave period and dependent only on the water depth (i.e., the waves are not period dispersive). The finite amplitude wave theories presented in the next chapter show that the shallow water wave celerity is a function of the water depth and the wave height so that in shallow water waves are amplitude dispersive. Remember that it is the relative depth, not the actual depth alone that defines deep, intermediate, and shallow water conditions. For example, the tide is a very long wave that behaves as a shallow water wave in the deepest parts of the ocean [10].

Wave length L_o can be calculated using equation (7) at different frequencies for a selected of 0.21m depth of water in wave basin. Knowing period T and depth d, the wave length L can be obtained from tables which contain the convenient factor 2πd/L.

The hydrodynamic theory of wave generators employing the same order of approximation as linear shallow water theory predicts that a rationally designed wave generator will produce smooth shape having sinusoidal motion within a short distance from the generator. Higher harmonic disturbances were lacking in these waves.

A simple theory for predicting the wave height produced by a wave generator in shallow water is possible based on these conceptions of wave motion. A volume of water is constrained to travel at known speed according to $C= [\ gd]^{0.5}$ by the wave flap. The volume displaced in small motion cannot instantly be disturbed over the entire wave basin. Instead, the volume is stored above the mean water level by the vertical elongation of the column of water in front of the flap. Because u is a constant over the depth in linear shallow- water theory, each vertical column of water remains a vertical throughout the entire wave motion. The volume displaced in half a period by the piston as it travels forward over the entire length of its stroke will be stored above mean water level in the positive half of a sine wave travelling away from the piston/flap with respect to shallow-water limit of d/L= 0.05. A relation can be obtained in which amplitude is the only un known by equating the volume displaced by the by the piston in half a period to the elevated volume in half a wave length.

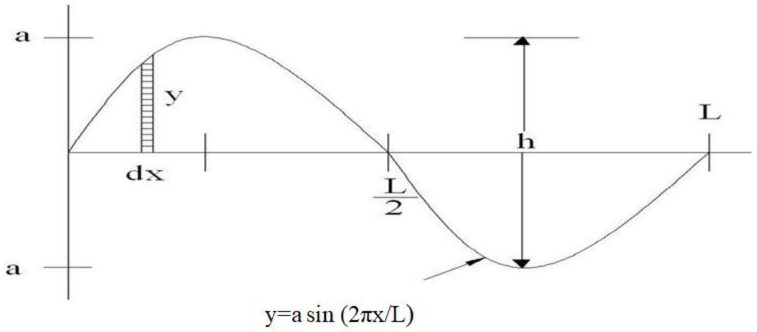


Figure.4 *Sine wave Curve*

Volume displaced by piston in half period =Sd (11)

Elevated volume in half wave length=$\int_0^{L/2}(H/2)\sin(2\pi x/L)d_x = HL/2\pi$ (12)

$H/S = 2\pi d/L$ piston and flap (13)

It is a common characteristic of these equations that H/S equals to 2π/L multiplied by an appropriate distance normal to S. S for flap type wave generators is the mean horizontal excursion of the flap. Similar relations can be obtained for other types of generators like bottom hinged/top hinged flap type wave generators. Top hinged flap type wave generator at CWPRS is shown in Fig.5

Flap Mid Position **Flap Forward Position**

Figure 5 *Suspended pendulum type wave board at CWPRS*

Since small amplitude wave theory is simplified by assuming waves generated as that of pure sine wave, the equation (13) gives an approximate value of H/S. Theoretical values of H/S are calculated using equations (13), in which wave number k is taken from wiegel tables given in shore protection manual [10] and few values are shown in table.2.

Table.2 *Theoretical values of relative wave heights (H/S)*

S.No.	f	L_o	d/ L_o	d/ L	H/S Simplified Linear wave theory
1	0.3	17.35669	0.012675	0.029578	0.18575
2	0.8	2.440784	0.090135	0.114729	0.720495
3	1	1.562102	0.140836	0.160917	1.010562
4	1.4	0.796991	0.276038	0.283949	1.783198
5	1.5	0.694268	0.316881	0.32245	2.024989
6	1.8	0.48213	0.456308	0.457764	2.874755
7	2	0.390525	0.563344	0.563817	3.540772
8	2.3	0.295293	0.745022	0.745086	4.679141
9	2.6	0.23108	0.952051	0.952057	5.978916
10	2.9	0.185743	1.18443	1.18443	7.438222
11	3	0.173567	1.267523	1.267523	7.960045

V. EXPERIMENTAL SET UP

The experiments have been conducted in a physical model having Scale ratio1:120 using a RSWG system with top hinged wave flaps of two numbers each 11meter length, depth of water in the basin maintained at 0.21m, frequency: 0.3-3Hz.The experiments are conducted to investigate the response characteristic of wave production by the flap type wave generator. A Capacitance Wave Height Recorder (CWHR) unit and Analog to Digital Converter connected to USB port of the PC to acquire the wave data using sensors. The command signal is generated by wave generating software in a personal computer. The command signal in digital form is converted to Analog Voltage form by 'Digital to Analog Converter' (DAC). CWHR unit is placed at 30 meters far from wave flaps.The SCADA based Servo Controller receives the signal after smoothening by passing through active Low Pass filter. Position feedback signal is generated as the position transducer runs parallel to the actuator rod. Error voltage signal which is given to the servo valve are computed by comparing the command and feedback signals to ensure desired stroke of actuator. The acquired wave data is used for analysing simplified wave maker theory. The software comprises of modules for Simultaneous in turn controls oil flow to the actuator is given by a command signal generated by software. The command is given to the servo valve through servo controller, digital to analog convertor and low pass filter to obtain the displacement of wave board. Since wave board displaces volume of water in front of it, velocities are induced in water particles which results in generation of waves in wave basin. A Capacitance wave height sensor [3] is placed in front of wave board for recording generated waves. wave generation and data acquisition. A current suitable for driving a servo-valve which Software module for calibration of wave height sensors, Spectral Analysis, Data Plotting etc. developed in ‘C#’ language using Visual Studio 2010. The acquisition program has a special feature i.e. real time display of superimposed, acquired wave data plots signal from max 16 No. of sensors. This gives On-line instantaneous & simultaneous graphical picture of the wave pattern at various wave sensors installed in the wave basin.

Figure.6 *Generation of Regular waves in Physical model using Top hinged flap type wave generator*

In wave basin, control can be maintained over three parameters: the still water depth d, the period of oscillation ‘t’ of the wave generator and hence that of the water the wave and the length S of wave generator stroke.

At first, in order to investigate the response characteristic of regular wave generation, various sorts of regular waves are generated by varying the amplitude and period of flap motion and generated waves were recorded. From the amplitude of actuator motion detected by potentiometer, the amplitude of actuator motion at still water level has been noted. Thus, the relationship of f and H/S for regular wave obtained as shown in Fig.8, where f is the wave frequency and H wave height and S the full amplitude of the flap motion in still water level. The experiments are performed in wave basin with depth of 0.21m still water. Theoretical values of kd are calculated for various frequencies using wiggle tables given in shore protection manual in which linear wave theory is being used. The wave flap operated with known frequency, stroke of actuator and a still water depth of 0.21m. Frequency and wave heights of acquired waves are measured using CWHRS located at a distance of 30m from wave flap. Diamond beam of wave board moves in a circular path giving reciprocating motion to the wave paddle as depicted in a typical wave arrangement shown in following figure7. Wave heights of generated waves were measured for frequencies ranging between 0.3 to 3Hz and few of them are depicted in the following table no.3.

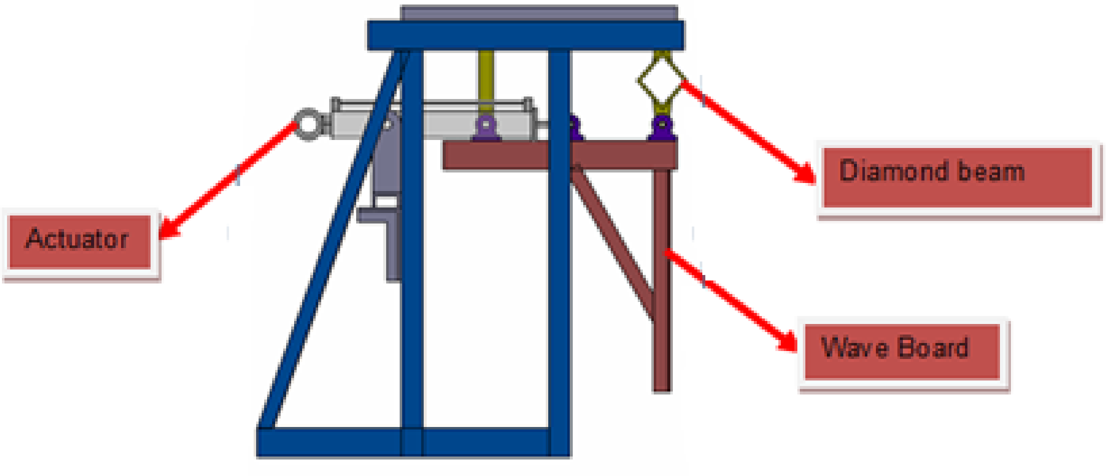


Figure.7. A typical top hinged pendulum type wave board

A. TEST RESULTS

The tests are concerned with verifying the wave-maker theory for waves generated with frequencies ranging between 0.3 to3 Hz. Frequency and acquired wave heights corresponding to the given actuator strokes have recorded in SCADA screen. These values shown in the Table.3 and Frequency versus H/S graph was plotted as below in Fig.8.

Table.3 *Acquired relative Wave heights in test basin*

S.No.	Frequency (f)Hz	wave height (H) m (Measured value)	Stroke of Actuator (x)m (Measured value)	H/S
1	0.3	2.6	6.9	0.38
2	0.7	11.3	6.5	1.74
3	0.8	11.9	6.2	1.92
4	0.9	12.3	6.1	2.02
5	1	12	5.9	2
6	1.4	7.8	5.3	1.47
7	1.5	6.9	5	1.4
8	1.6	6.5	4	1.6
9	1.7	4.5	1.6	2.81
10	1.8	3.2	1.1	2.91
11	1.9	2.1	0.8	2.63
12	2.3	1.7	0.5	4.5
13	2.6	2.3	0.4	5.8
14	3	3.75	0.5	7.5

ISSN 2454 – 535X
www.ijmert.com
Vol. 15 Issue. 4, Nov 2023

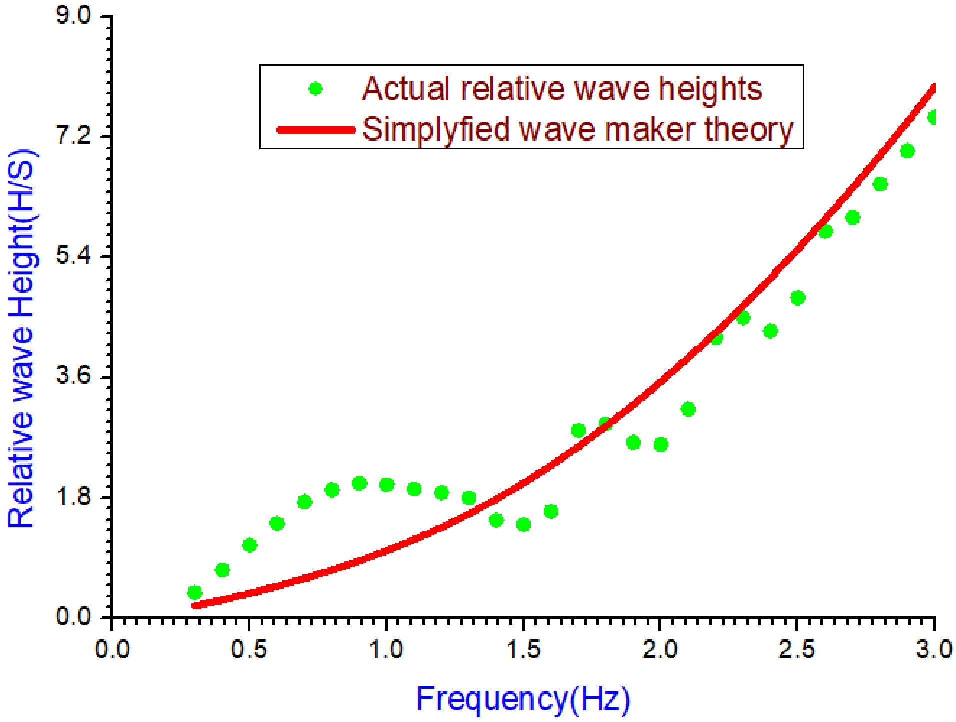
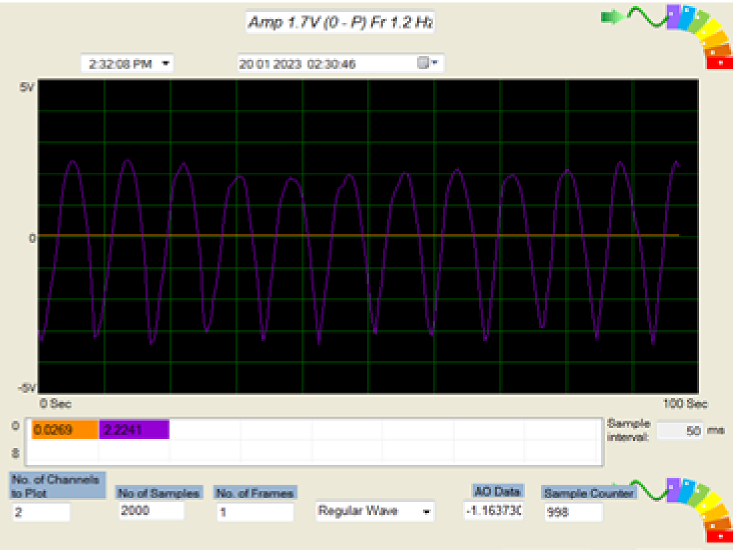


Figure.8.*Simplified wave maker theory versus actual relative heights*



Amp 1.7V (0 - P) Fr 1.2 Hz

2:32:08 PM

20 01 2023 02:30:46

0.0269 2.2241

Sample interval: 50 ms

No. of Channels to Plot: 2

No of Samples: 2000

No. of Frames: 1

Regular Wave

AO Data: -1.16373C

Sample Counter: 998

Figure.9.*Aquired regular wave pattern at frequency 1.2Hz*

VI. CONCLUSIONS

The theory is based upon the usual assumptions of classical hydrodynamics, i.e. that the fluid is in-viscid, of uniform density, that motion starts from rest, and that non-linear terms are neglected. If the water depth, wavelength, wave period, and wave-maker stroke (of a harmonically oscillating wave-maker) are known, then the wave-maker theory predicts the wave motion everywhere and in particular the wave height a few depths away from the wave-maker. In this paper, H/S curves developed are useful for predicting wave heights that can be obtained in a top hinged flap type wave generator. H/S curve is drawn with experimental data using Origin software. Experiments were conducted using wave generator with frequencies ranging between 0.3 to 3 Hz. It is observed that for frequencies ranging between 0.3 to 1.5 Hz, the actual relative wave heights are above theoretical curve whereas for frequencies ranging between 1.6 to 3 Hz is below the curve. The ratio of the height of wave generated by displacement type wave generators in shallow water to the stroke of the flap can be approximated as H/S= kd, S is the stroke of the wave generator, k is the wave number given by the small-amplitude theory, d is depth of water in wave basin. However, further investigation is needed to study relative wave height with respect to complete wave maker theory.

Acknowledgements

The authors are thankful to Kamarajar Port authorities for having sponsored RSWG facility at CWPRS.

References

[1] Hudspeth, R.T., Jones, D.F. and Nath, J.H., (1978) "Analyses of Hinged Wavemakers for Random Waves. In *Coastal Engineering"*, (pp. 372-387).

[2] Madsen, O.S., (1970), "Waves generated by a piston-type wavemaker. In *Coastal Engineering"* (pp. 589-607).

[3] V.Prabhakarachary, R.S.Erande, S.D.Ranade, M.D.Kudale (2017), "Design of Hydraulic Power Pack System for Servo-Hydraulic Random Sea Wave Generators for Design of Port Layouts", Vol. 7, Issue 1, Nov 2016 - April 2017, pp80-88.

[4] S.R.Swami, R.S.Erande, S.J.Ghule, P.K.Goel (2011), "Multi-purpose sea wave simulation facility for design of coastal structures", HYDRO 2011.pp.84

[5] Galvin, C.J. (1964). Wave-height prediction for wave generators in shallow water, Research Division, Coastal Engineering Research Center, 5201 Little Falls Road, Washington DC, USA, U.S. Army, Corps of Engineers, Technical Memorandum No. 4

[6] Nohara, B.T., (2000). "A survey of the generation of ocean waves a test basin. Journal of the Brazilian Society of Mechanical Sciences", 22, pp.303-315.

[7] Biesel, F., (1951). "Les apparails generateurs de houle en laboratoire. La Houille Blanche", 6, p.4.

[8] Ole Secher Modsen, (1970) "Wave generated by a piston-type wave maker", September, Coastal engineering Research Center, U.S.

[9] Hughes, S.A. and Mansard, E., (1996) "Physical models and laboratory techniques in coastal engineering". Coastal Engineering, 27(1), pp.124-125.

Shore Protection Manual- Volume II, 4th Edition