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# DETRMINATION OF A PLUNGER TYPE WAVE MAKER CHARACTERISTICE IN A TOWING TANK

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## ABSTRACT
Regular and irregular waves are generated at small scales in laboratories using various wave makers. In the present work, characteristics of a plunger type wave maker in towing tank in Subsea Research and Development Center (SRDC) of Isfahan University of Technology (IUT) are obtained. Parameters of waves are measured using resistive wave probes after being calibrated. To calibrate wave probes, a relation between wave elevation and output voltage of probes is obtained. This is employed to develop a computer program to calculate the wave parameters such as wave height, wave period and wavelength. To verify the achieved results, video and still cameras were also used.

## INTRODUCTION
All coastal and offshore structures such as sea walls, break waters, oil platforms, etc, are directly or indirectly affected by waves. Also due to broad requirements of coastal engineering, knowledge of the magnitude and behavior of waves at site is an essential prerequisite for almost all activities in the ocean including planning, construction and operational harbor, offshore and coastal protection structure [1]. Instead of studying behavior of the marine structure prototypes in the presence of waves, it is usually preferable to use their small scale models in laboratories. One of the advantages of performing the model tests in the laboratories is that it provides necessary tools to study; wave energy effects near coastal structures, reflection and transmission phenomenon on break waters, hydrodynamic forces exerted on floating bodies, etc. It is therefore required that waves be generated with specific characteristics in laboratories. These waves are usually generated in towing tanks or wave basins, using a wave maker which is composed of an electro mechanical mechanism. Different types of wave makers include piston, flap, pneumatic, paddle, and plunger types. A plunger type wave maker is made of a solid submerged body which oscillates vertically into water surface. This vertical motion causes water displacement which in turn generates waves. The plunger cross section could be in different shapes. However, the most general shape is cylindrical or triangular ones [2]. The plunger type wave maker is easily

deployed in towing tanks for making high amplitude waves in deep waters. However, due to difficulties in its analytical solution, the theoretical studies on this type of wave maker have not been extensively explored. This paper is an effort made to obtain characteristics of a plunger type wave maker installed in the subsea research and development center (SRDC) of the Isfahan University of Technology (IUT). Detailed information about wave makers can be seen in reference number [3].

## EXPERIMENTAL SET UP

All tests were carried out in the towing tank of hydrodynamic laboratory of SRDC at IUT, with a length of 108 meters, width of 3 meters and a depth of 2.5 meter. The plunger type wave maker has a triangular section and can generate regular waves with different frequencies traveling along the tank. The specification of this wave maker is shown in table 1. The frequency of the generated waves is controlled by a driver which controls the motor speed via a potentiometer. The amplitude of plunger to be immersed in the water can also be adjusted. The wave maker is shown in Fig 1.

**Table1) Specification of Plunger type wave maker**

| Plunger frequency | Motor Power (*Kw*) | Plunger Length (*mm*) | Plunger width (*mm*) | Plunger height (*mm*) | Plunger amplitude |
|---|---|---|---|---|---|
| Variable | 5.5 | 3000 | 330 | 430 | 150 |

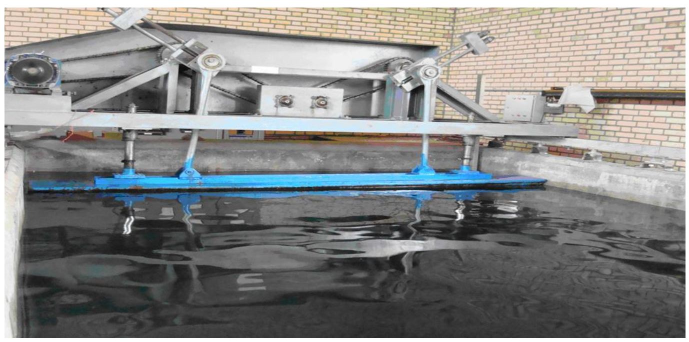
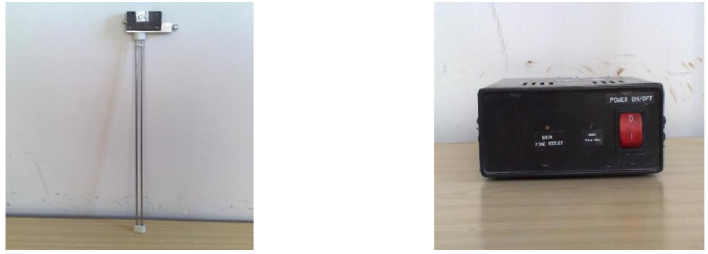


**Fig 1) Plunger type wave maker of the SRDC.**

Wave heights are measured using different types of wave probes such as resistive, capacitive, acoustic, and servo types [4,5]. The resistive type of wave probes are generally used in most laboratories, as is the case in this study. The wave probe and its transducer are shown in Fig 2.
Resistive wave probe is made of two stainless steel rods with standard length of 600 mm. Each probe comes with a transducer which incorporates the electronics for converting wave heights into electric signal with proportional voltage. The principle of probes lies on measuring conductivity of water between the two rods which changes as height of water surface elevates. The output voltage of the transducer is fed to an analogue to digital board in order to be employed by a computer. The probes are calibrated by applying specified water levels and measuring the corresponding induced voltages. The calibrated probes are then used to monitor the time series obtained by passing the generated waves through them. The wave parameters are calculated by developing a software, using the obtained time series.



(a) (b)

**Fig2) (a) Wave probe (b) transducer**

**WAVE PROBE CALIBRATION**

A set of wave probes, transducers, an analogue to digital board, a computer and the developed software for calculation of wave surface elevation, comprise the data acquisition system (DAS). Wave probe is installed on a scaled holder which in turn is placed over a standing configuration placed over the towing tank. Fig 3.

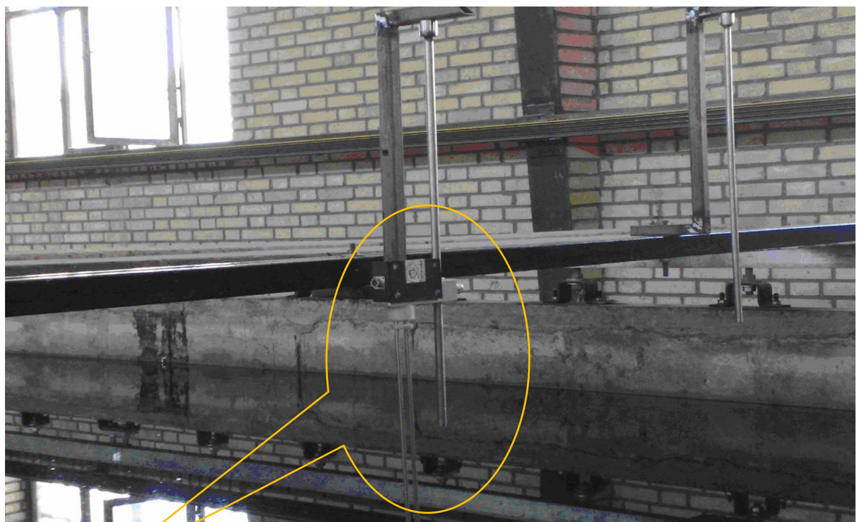


**Fig 3) The wave probe installed on a scaled holder located on standing frame.**

Wave probe calibration is carried out in still water using the DAS. It can be performed by measuring the changes in output voltages, when the probe is raised or lowered by a known amount in still water. Hence, the relation between water height and voltage is obtained. Considering characteristic of wave probe calibration and employing it by the software, the time history of water surface elevation and hence wave parameters (wave height, wave period, and wavelength) are obtained at the probe locations. It should be mentioned that accuracy of the probes is about ±1mm. Fig 4 shows calibration characteristic of a wave probe in which *H* indicates wave height in *mm*. As seen in fig 4 height variations over ±150 mm is quite linear.

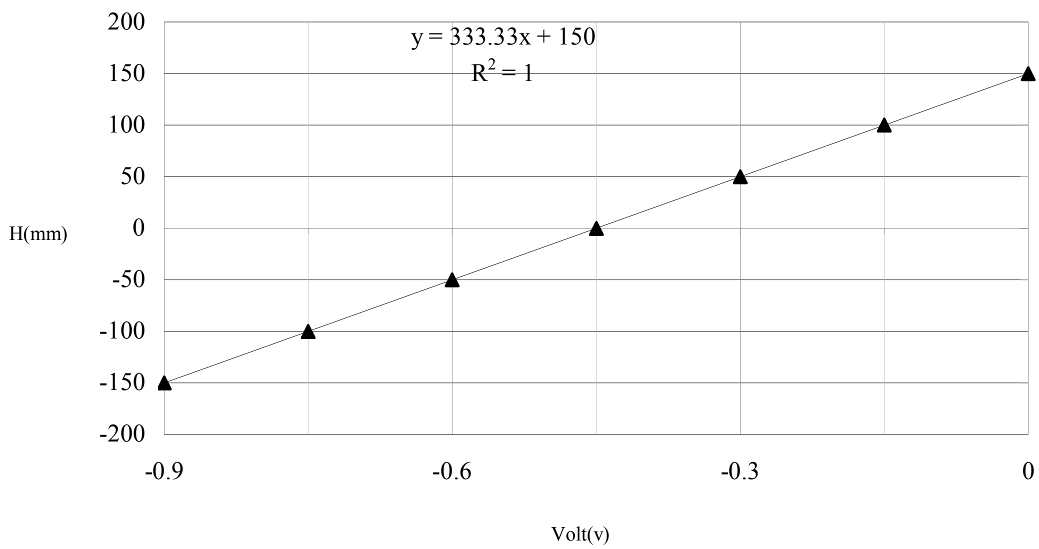



**Fig 4) Wave height versus voltage obtained during probe calibration.**

## WAVE PARAMETER DETERMINATION

Wave parameters are obtained at the middle of the cross channel, by locating the probe at a distance, 18 m from the wave maker. The water depth is 2.24 m. Data sampling were performed during periods which ensure that no reflection from the back wall reach the probe location. (The wave is purely incident).

Frequency of the plunger raising and lowering is obtained by counting the number of the vertically oscillations in a specific time. Fig 5 shows variation of plunger frequency, *f*, in *Hz* versus potentiometer scaling.

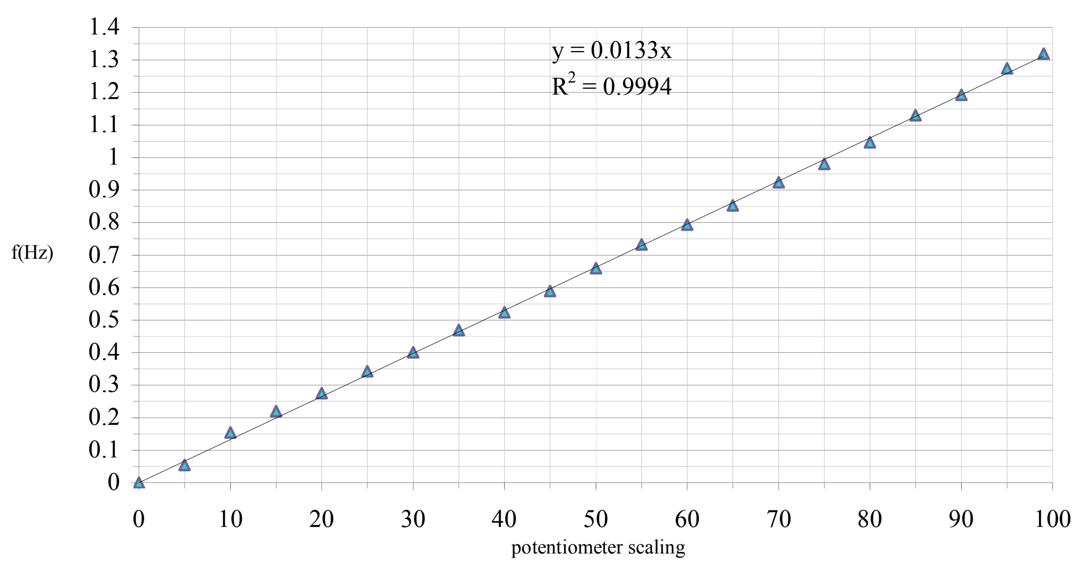



**Fig 5) Linear relation of wave maker with potentiometer scaling.**

## VALIDATION

To verify results obtained from DAS, a still camera, a video camera (25fps), horizontal and vertical rulers were also employed. The video camera and vertical ruler with 1m height were used to measure the wave parameters such as wave height, wave frequency and wave period. To obtain the wavelength, two horizontal rulers with 300mm height, 1m length and meshed in 10mm in vertical and horizontal directions accompanied with the still camera were used. The wave length was measured by still camera due to its good resolution.

By observing the frame by frame video image taken from wave motion, and counting the number of frames for two consecutive crests and then dividing that number by 25, the wave period is obtained. This gave us an accuracy of about one $25^{th}$ of a second. The wave frequency is then obtained using the below equation:

$$f = \frac{1}{T} \tag{1}$$

in which $T$ is wave period in seconds.

Also, by observing the frame by frame video image for wave crest and wave trough over the vertical ruler the wave height was obtained with an accuracy of about ±5mm.

Wavelength was obtained from photos taken from wave motion, in which two consecutive crests were observable on two horizontal rulers, shown in Fig 6.

The fixed distance between the two horizontal rulers is taken into account for measuring the wavelength for each wave frequency. The accuracy of this measurement was about ±50 mm.

Using this verification method, it was found out that the results obtained for wave amplitude by the wave probes and DAS slightly differ with that obtained by cameras. The cause was due to frequency response of the transducer. By comparing the two results a correction coefficient was obtained and introduced to the DAS. It was seen that introduction of this coefficient to DAS system, did not affect any other wave parameters. Fig 7 shows the time series of wave with particular frequency generated by the plunger wave maker obtained by DAS before and after implementation of the correction coefficient.

**Fig 6) Two horizontal rulers installed over side of the channel.**

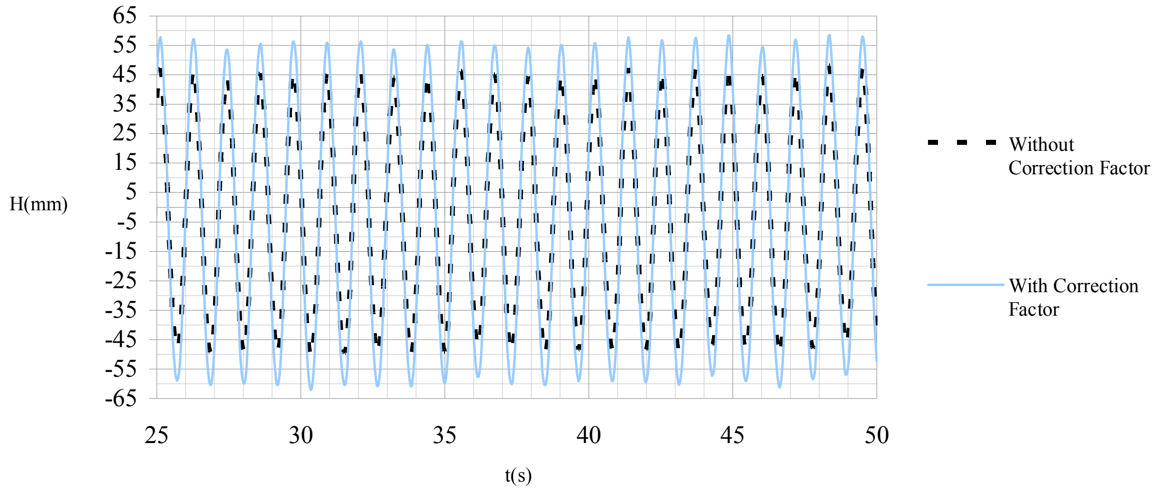



**Fig 7) Time series for wave with frequency of 0.86 Hz.**

The discrete Fourier transform of the above time series is as shown in Fig 8. From this figure, regularity of generated wave by the plunger wave maker is ensured.

Apart from measuring the wavelength by the still camera, the wavelength can be calculated using Eq. 2 which is valid for deep water conditions:

$$\boldsymbol{L} = 1.56\boldsymbol{T}^2 \qquad \left[\frac{\boldsymbol{d}}{\boldsymbol{L}} > 0.5\right] \qquad (2)$$

In this equation "$d$" is the water depth in m and "$L$" is the wavelength in m. Using this equation the wavelength is obtained by the wave period which was already calculated by DAS.

Results obtained by cameras and those calculated by DAS using equations (1) and (2) are shown in table 2.

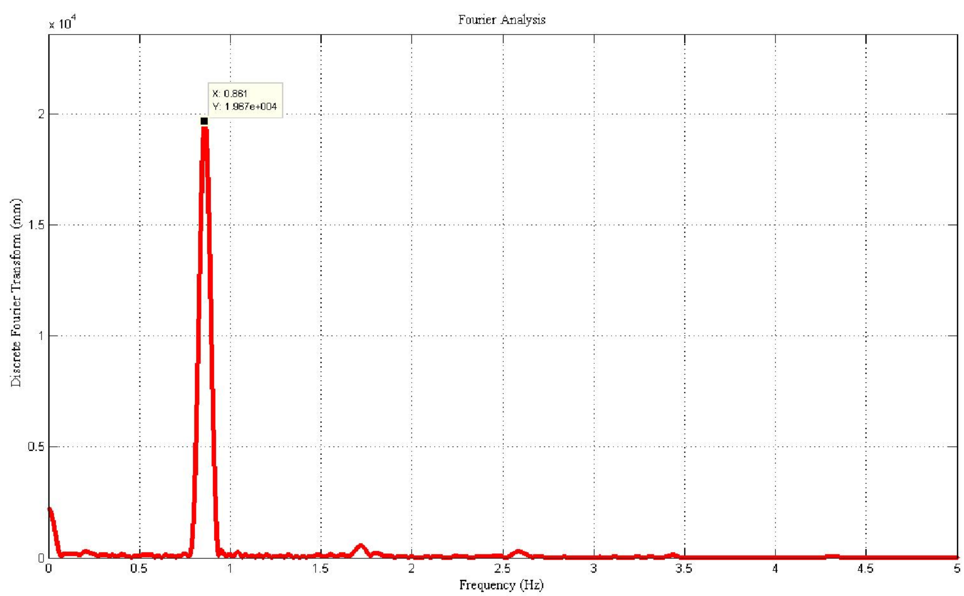



**Fig) 8 Fourier analysis of time series shown in figure 7**

**Table 2) Wave parameters resulted by DAS and cameras**

| Plunger frequency (*Hz*) | Wave period (*s*) | | Wave frequency (*Hz*) | | wavelength (*m*) | | Wave height (*mm*) | |
|---|---|---|---|---|---|---|---|---|
| --- | Video camera | DAS | Video camera | Eq. (1) using in DAS | Video camera | Eq. (2) using in DAS | Video camera | DAS |
| 0.66 | 1.52 | 1.5 | 0.66 | 0.66 | 3.65 | 3.53 | 50 | 50 |
| 0.73 | 1.36 | 1.36 | 0.73 | 0.73 | 2.9 | 2.91 | 70 | 70 |
| 0.79 | 1.28 | 1.26 | 0.78 | 0.79 | 2.45 | 2.49 | 95 | 95 |
| 0.85 | 1.16 | 1.16 | 0.86 | 0.86 | 2.05 | 2.1 | 115 | 115 |
| 0.92 | 1.04 | 1.06 | 0.96 | 0.94 | 1.85 | 1.77 | 130 | 130 |
| 1.05 | 0.92 | 0.93 | 1.08 | 1.07 | 1.4 | 1.36 | 135 | 135 |

Characteristic curves of the plunger wave maker, resulted from DAS are plotted in Fig 9 and Fig 10, which show the variation of wavelength and wave height with wave frequency, respectively, in which $H$ is the wave height in millimeters (*mm*), $f$, is the wave frequency in hertz (*Hz*) and $L$ is the wavelength in meter (*m*).

## CONCLUSION

In this paper characteristic curves for plunger type wave maker of SRDC are obtained by two methods, one with using DAS and the other by using rulers and cameras. Correction factors are introduced into DAS in order to compensate frequency response of the transducers. Results obtained by both methods are quite closed.

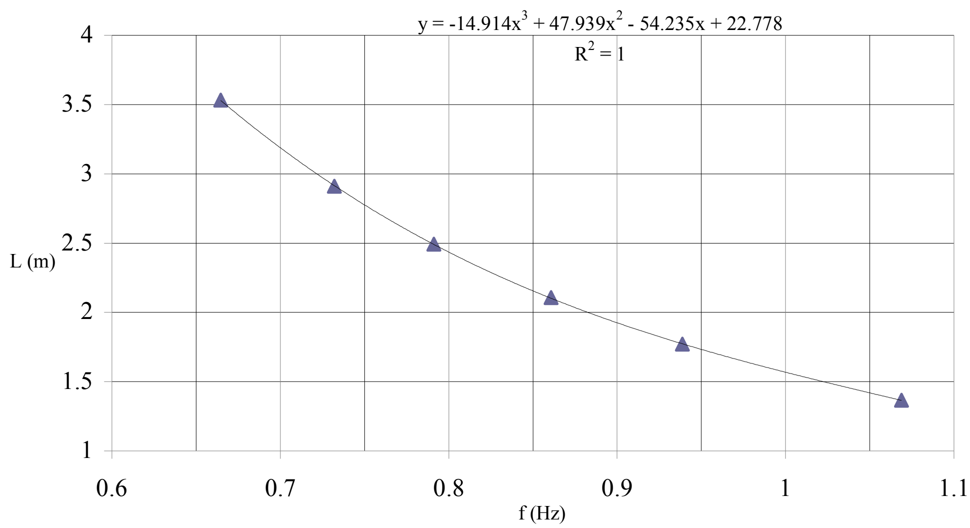



**Fig.9) Wavelength versus wave frequency**

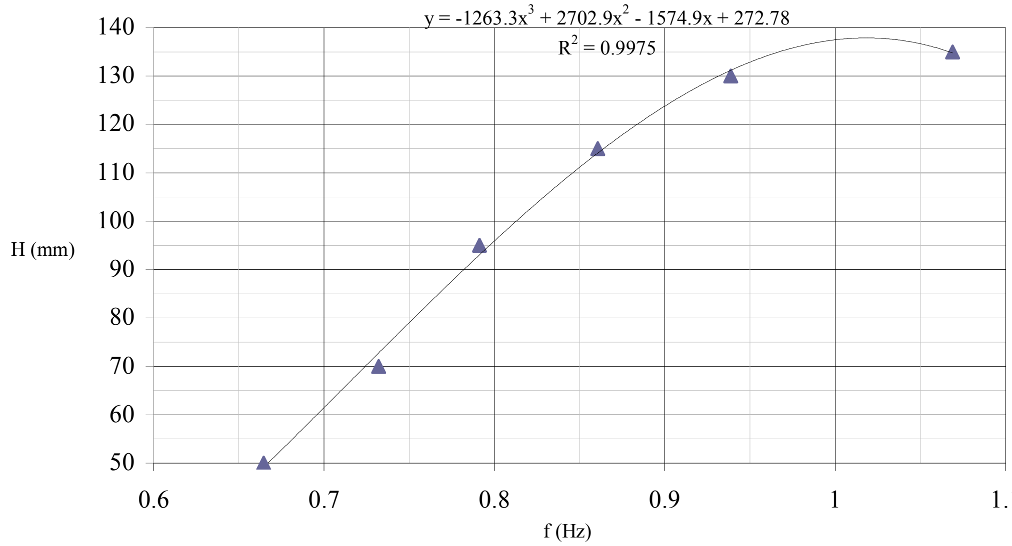



**Fig.10) wave height versus wave frequency**

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