Installation and Analysis of a New Wave Tank

From Theory to Signal Processing and Water Wave Generation

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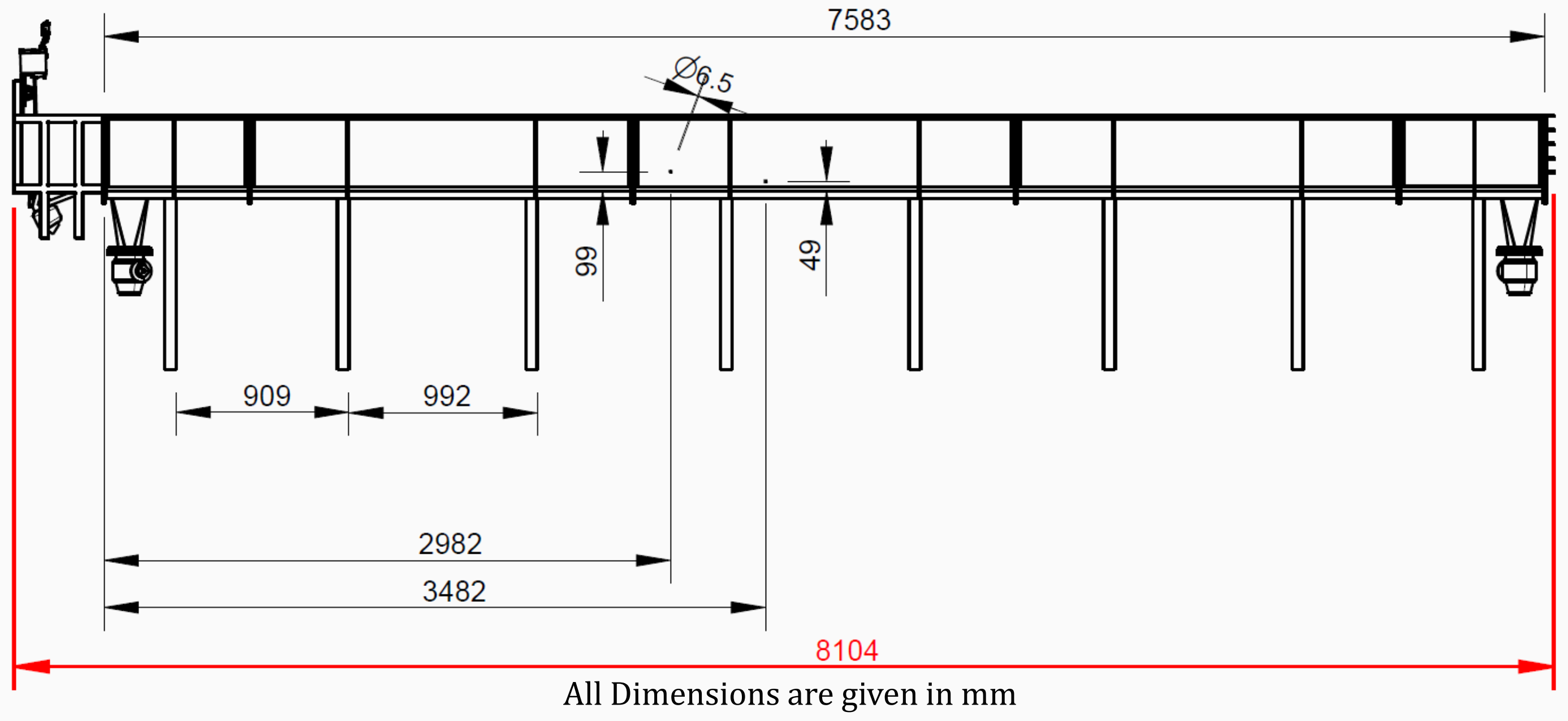
Abstract

With the Ocean Engineering Department's recent addition of an eight meter long, two-dimensional wave flume, there was a desire to analyze its capabilities and accuracy of generating linear and nonlinear waves of solitary and periodic type. This begins by the derivation of the stoke-voltage and wave height-stroke transfer functions that are used to generate the desired wave height and period as the volume of the displace fluid during a single stoke is directly proportional to the volume under the crest of the generated wave. To verify the efficiency of the wavemaker to produce the desired type of waves, real-time data of water surface elevation and pressure will be collected from a series of wave height gauges and pressure sensors. The measurements will then be compared with their theoretically generated time-series equivalent. Airy wave theory will be used for this examination.

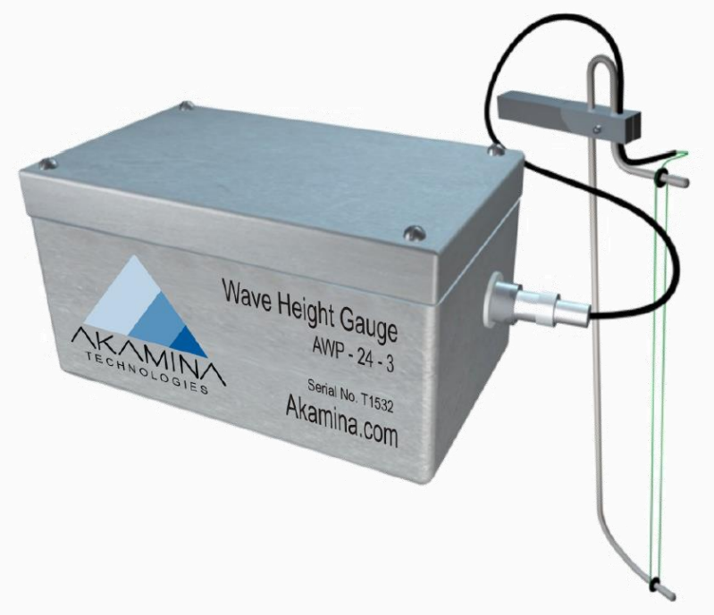
Wave Tank Installation and Specification

The wave tank, manufactured by OMEY Labs Ltd. based out of Kildare, Ireland, arrived at Texas A&M University, Galveston Campus on Monday, March 21st. With a team of five undergraduate student workers, the tank was structurally assembled by March 23rd and operating by March 26th. The tank, at a total length of just over eight meters, is equipped with three Akamina surface elevation gauges, three Honeywell pressure sensors, fittings for a recirculation system designed to simulate current, and a paddle type wavemaker driven by an Exlar Tritex III planetary gear linear actuator, and a passive wave absorber



All Dimensions are given in mm

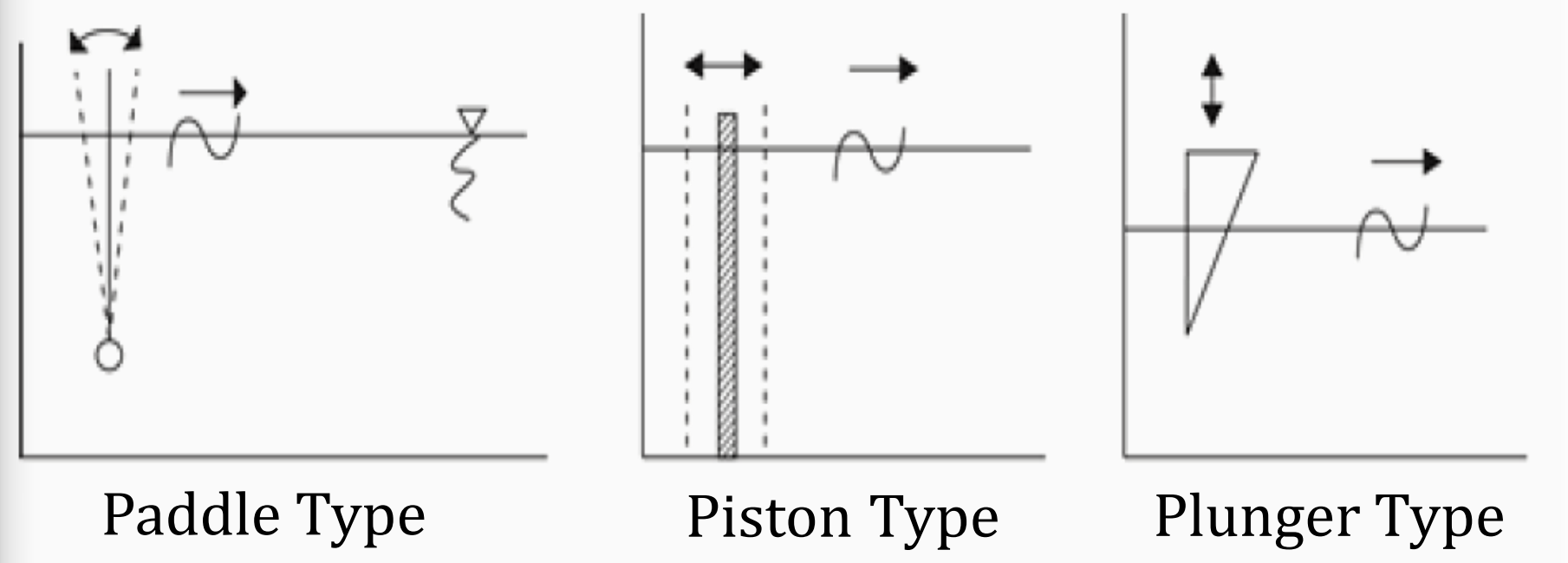
Honeywell Pressure Sensor



Akamina Surface Elevation Gauge

Types of Wavemakers

There are two basic types of wavemakers; shallow water wavemakers and deep water wavemakers. These general categories include various mechanisms and methods in order to generate the desired wave power profile, but the most commonly utilized configurations to generate waves are the piston type, plunger type, and the flap or hinged paddle type. (Sannasiraj) Shown in the figure below, our wave tank uses the paddle type wavemaker, that is what will be focused on for the derivation of the two main transfer functions between theory and wave generation.



Source: Sannasiraj, S. A. *Module II: Laboratory Wave Generation*

Airy Wave Theory

Prior to generating wave, it is important to first have a starting point to govern the mechanics behind the desired waveform. Here, the fundamentally aspects of Airy, or linear, wave theory are outlined which are applicable to two-dimensional (x, z) wavemaker theory.

The governing equation of Airy Wave Theory is Laplace's equation, given by,

$$\nabla^2\varphi = \frac{\partial^2\varphi}{\partial x^2} + \frac{\partial^2\varphi}{\partial z^2} = 0,$$

, where φ is the velocity potential. The boundary conditions used to solve Laplace's equation for two dimensional linear waves are the dynamic free surface boundary condition,

$$\eta = \frac{1}{g}\frac{\partial\varphi}{\partial t}, \qquad on\ z = 0$$

, the kinematic free surface boundary condition,

$$-\frac{\partial\varphi}{\partial z} = \frac{\partial\eta}{\partial t}, \qquad on\ z = 0$$

, and the impermeability boundary condition,

$$-\frac{\partial\varphi}{\partial z} = 0, \quad on\ z = -h$$

, where *h* is the water depth.

Wavemaker Theory for a Hinged Paddle Type Wavemaker Generating Linear Waves

In order to begin generating waves, it is first necessary to define a pair of functions which convert user defined wave parameters into the mechanical settings and voltage time series required to generate the desired wave. It was first proposed by Galvin (1964) that the water displaced during a single stroke (S) by a paddle over a water column is equal to the volume of water beneath the crest of a waveform. Taking these volumes and setting them equal to each other provides,

$$V_{paddle} = \frac{1}{2}\left(\frac{Sh}{2}\right) = \frac{Sh}{4}$$

$$V_{crest} = \int_0^{\lambda/2} \frac{H}{2}\cos(kx - \omega t)\,dx, at\ t = 0$$

$$V_{crest} = \frac{H}{2k}$$

$$V_{crest} = V_{paddle} \rightarrow \frac{Sh}{4} = \frac{H}{2k} \rightarrow \frac{H}{S} = \frac{kh}{2}$$

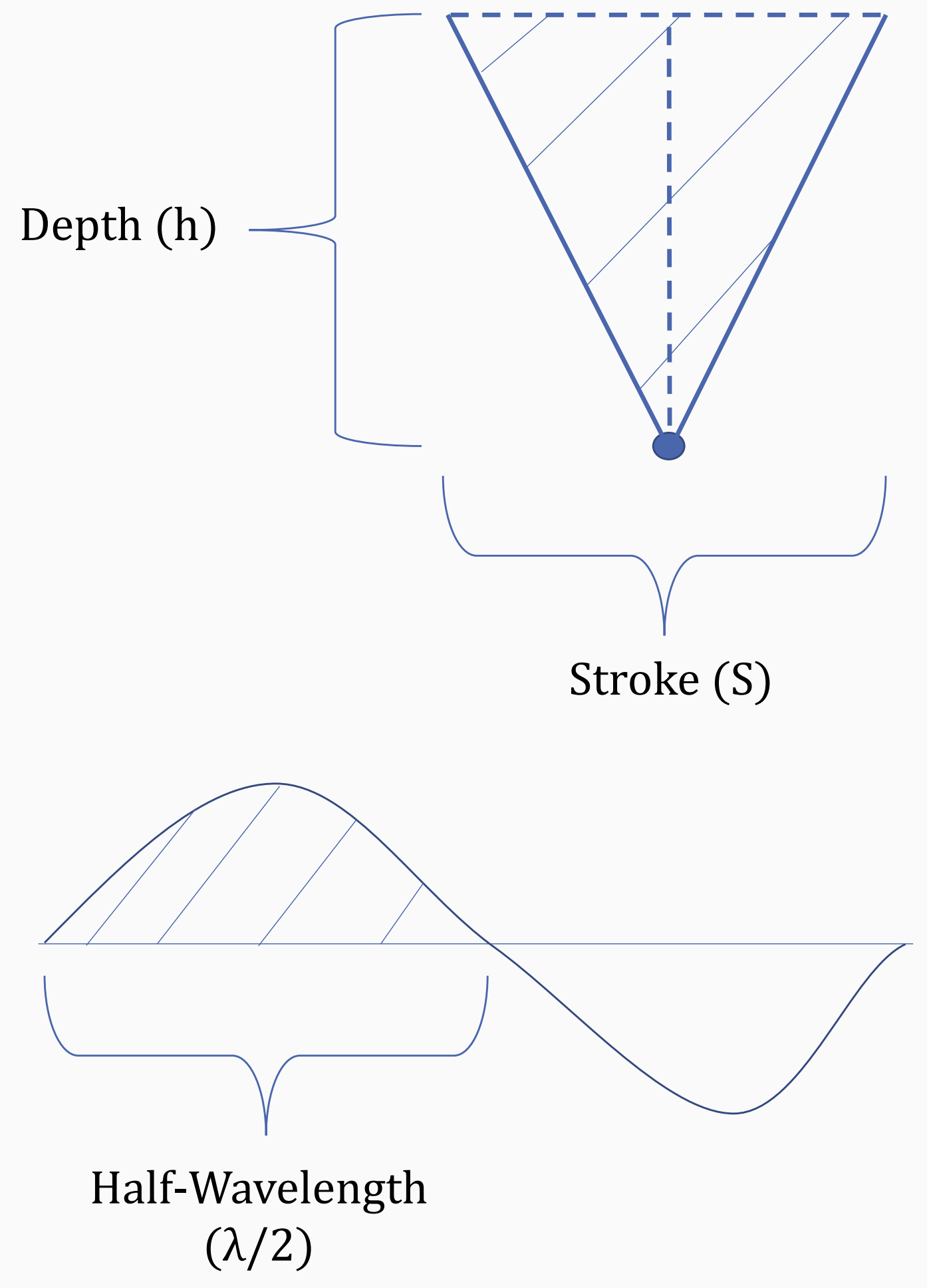
, where V_{paddle} is the volume displaced by the paddle over a single stroke and V_{crest} is the volume beneath the crest of a wave. Applying the Sommerfeld Radiation Condition for waves at a distance much farther from the wavemaker than the water depth yields the final form of the wave height to stroke transfer function,

$$\frac{H}{S} = 4\left(\frac{\sinh(kh)}{kh}\right)\frac{kh\sinh(kh) - \cosh(kh) + 1}{\sinh(2kh) + 2kh} = TF\left(\frac{H}{S}\right).$$

When utilizing a linear actuator, the voltage (v) required to obtain the desired stroke may be found by,

$$v_0 \pm (kS) = v$$

, where v_0 is the is the voltage correlating to the middle position of the wavemaker, k is the displacement-to-voltage conversion factor. An example of this process may be seen in the figure below.

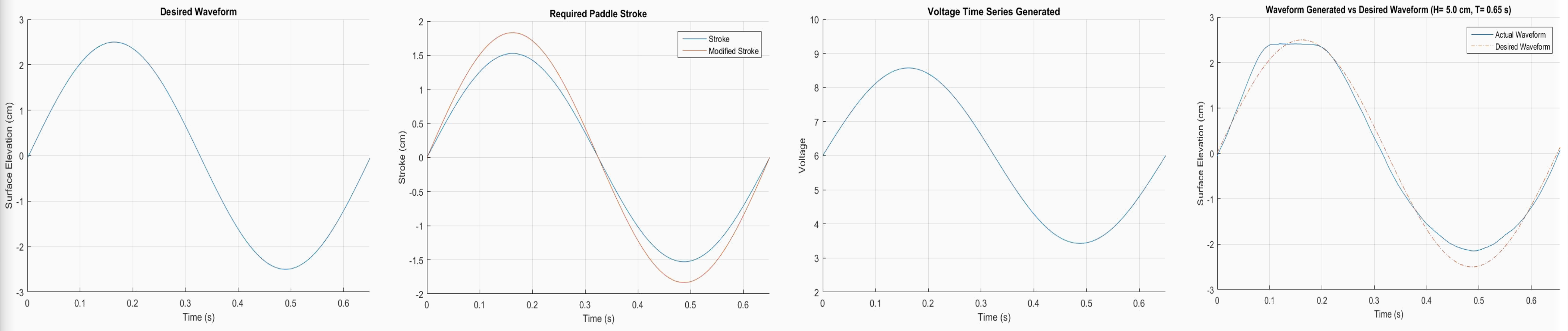


1) Define desired waveform
H = 0.25 m, T = 0.65 s

2) Calculate wavemaker stroke time series
$S(t) = (1.51\sin(9.7t))\ cm$

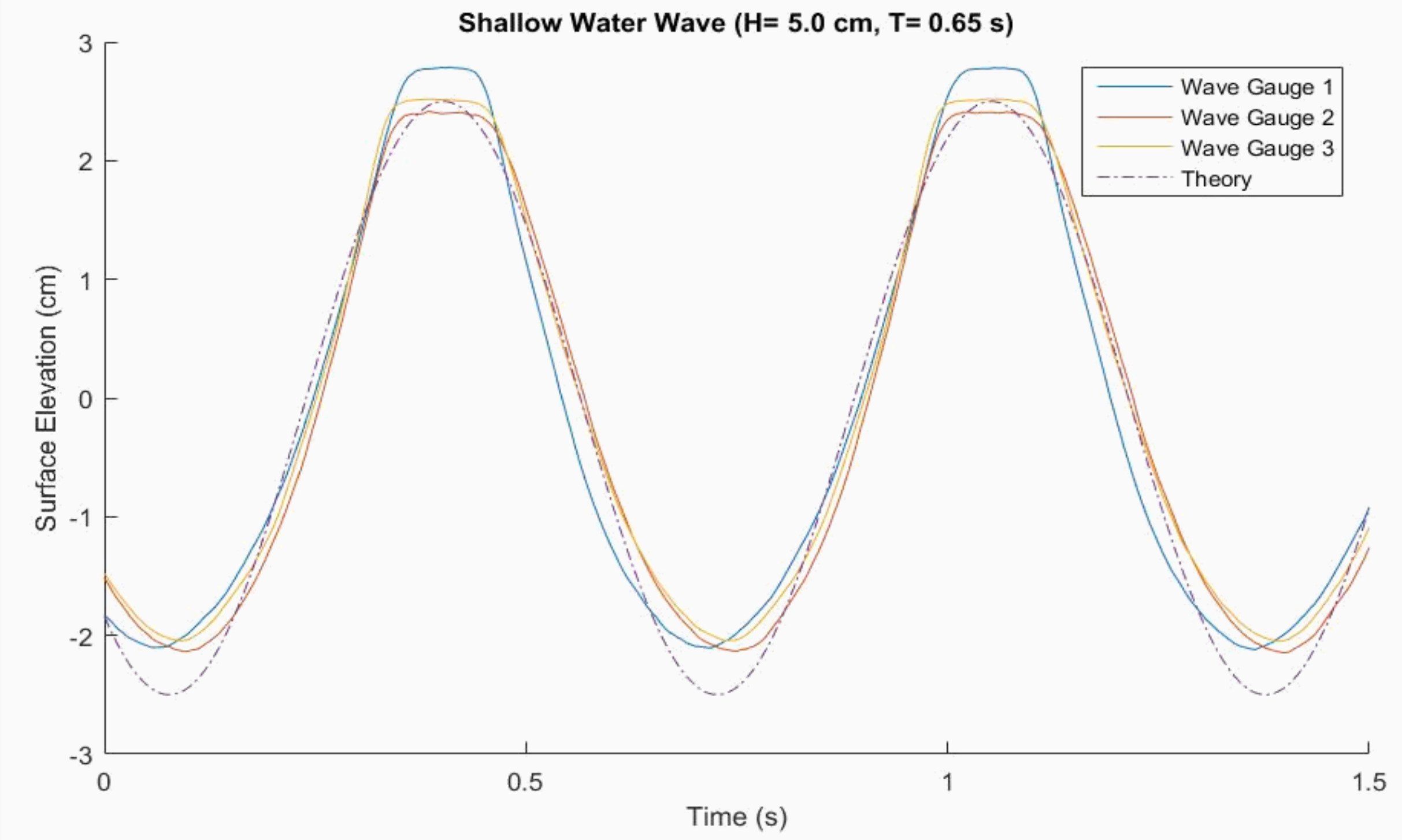
3) Generate required voltage
$v_{max} = 8.55$ V

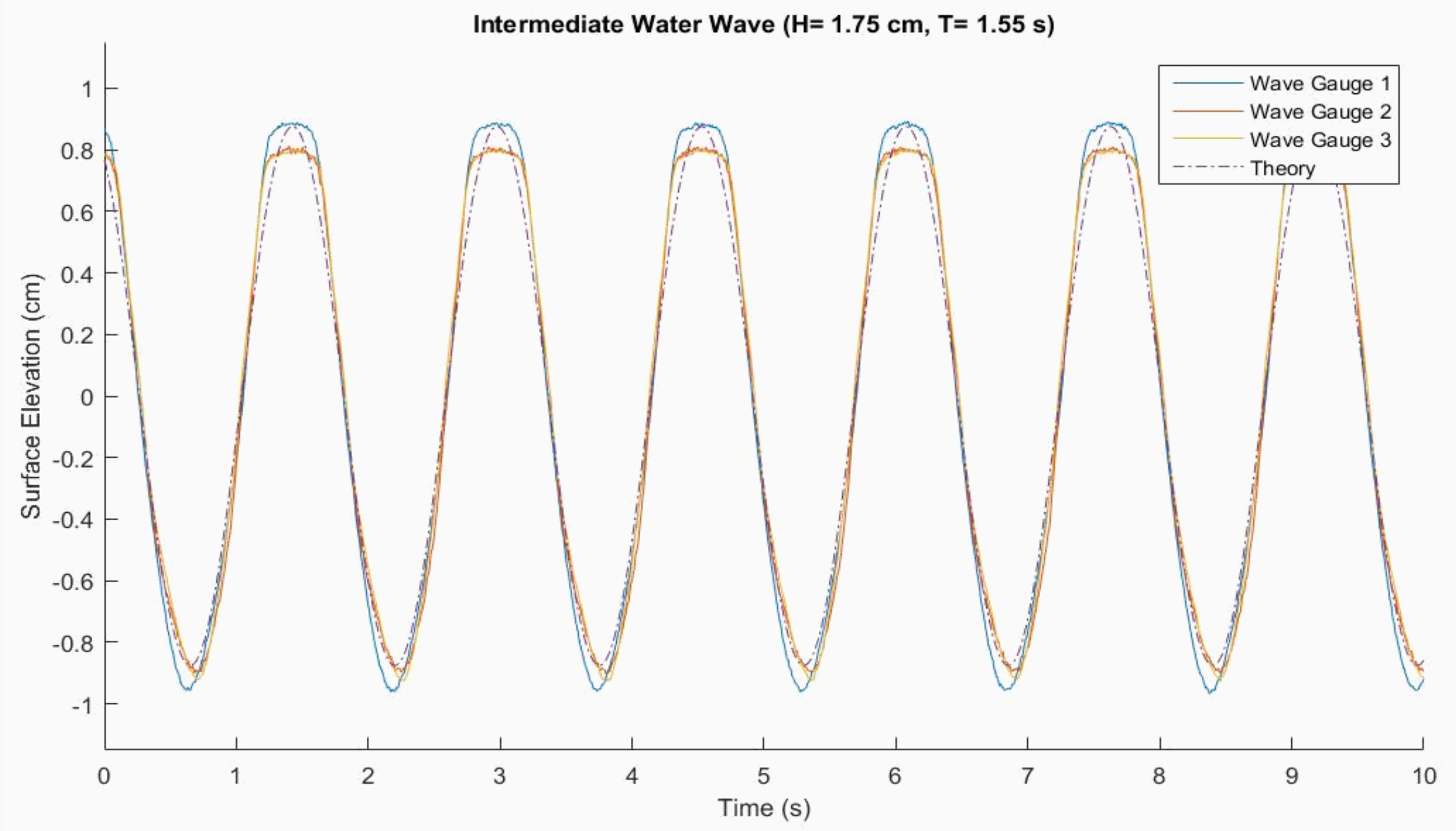
4) Output desired wave

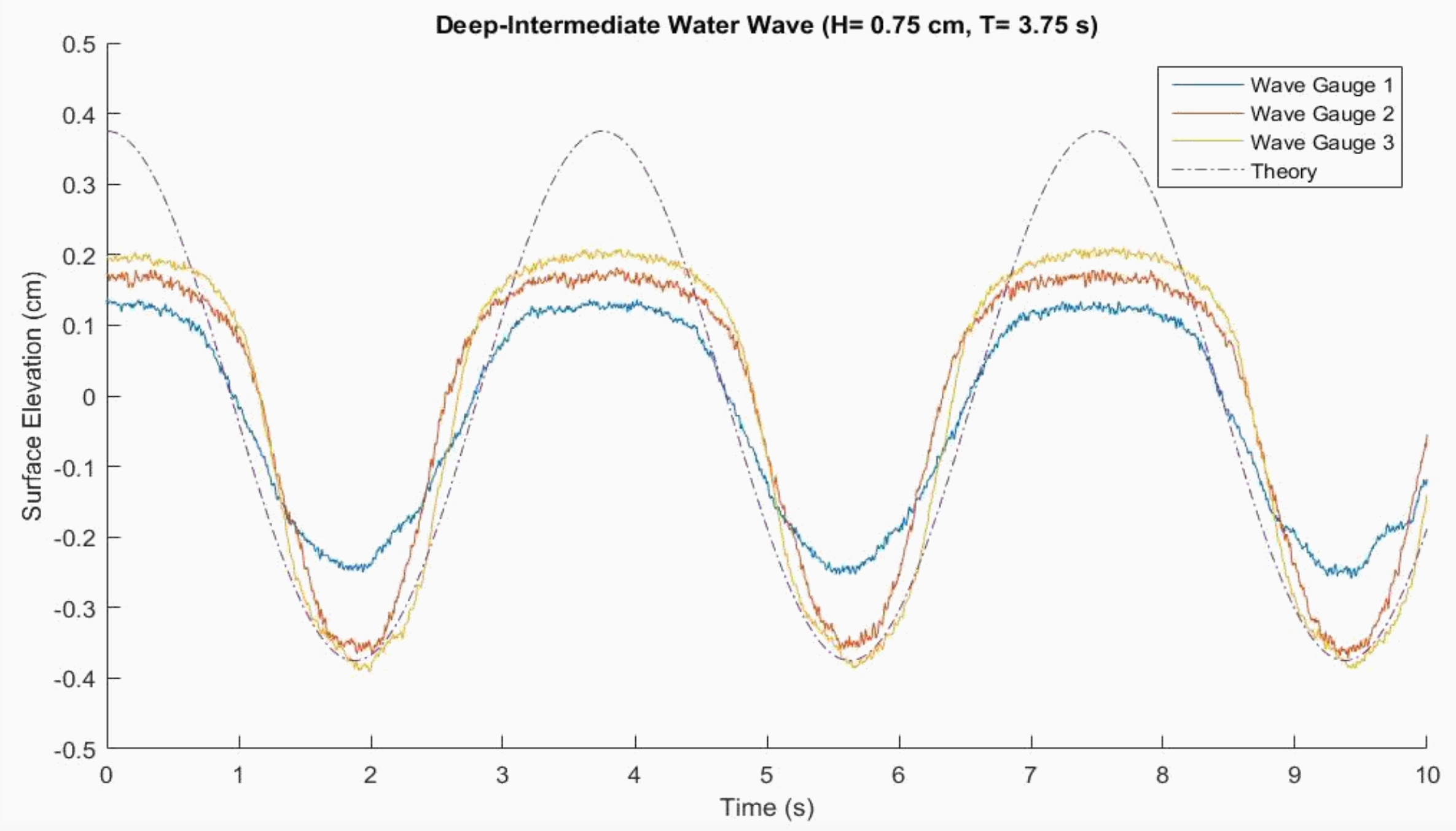


Examination of Wave Height Accuracy

The following is an analysis of three wave trials within the shallow, intermediate, and deep water categories . The profile of the wavemaker allows it to better produce shallow water waves. Overall, the preliminary results show a close agreement between measurement and the theory. Some differences are observed, particularly for deep water waves, which are likely due to the mechanical setting of the wavemaker and may be improved by further studying the wavemaker's stroke. For all examples shown below, a water depth of 25 cm was used.







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