Laboratory Experiments on Water Wave Generation

University of Dundee

School of Science and Engineering

Honours Project

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Declaration

I hereby declare that this dissertation is my own work, unless stated, and references have been made for the projects of others.

Muhammad Yaseen Khalid

April 2020

Acknowledgements

After an exhausting, yet enjoyable eight months, this year has been the most challenging and I would not have been able to complete this year without the support from my family, friends and supervisor.

I would like to thank my parents and brothers for their prayers, support and words of encouragement while studying away from home.

I am sincerely grateful for the friendships that have been made over these past four years, your encouragement, support and memories will be treasured.

Finally, a huge thank you to my supervisor Dr Masoud Hayatdavoodi, who has helped overcome many obstacles and point me in the right direction. I have gained many skills and my interest in fluid mechanics continues to grow.

Abstract

Ocean waves are important for climate modelling as well as shipping routes, coastal communities and offshore structures. Water waves are studied within wave flumes, were one can replicate a wave within a narrow channel. The nature of these waves is complex, and many studies have been done to find easier methods and theories on the types various type wave.

The fluids laboratory at the University of Dundee has a wave flume for the purpose to study water waves. The wave flume is fitted with a piston wavemaker and an artificial coast, wave absorber on the other end. An insight into the different types of waves and various types of wavemakers used for studies shows the importance's on many theories when replicating waves.

This thesis indicates the current status of the wave flume in the hydrodynamics laboratory and the new addition of pressure gauges added and suggestions for further studies.

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1 Introduction

The ocean is always moving, whether you are observing on a ship or the coast. Waves are created from energy that passes through water and causing it to move in various motions. Most caused by wind and severe weather, causing hazardous waves that can affect sea structure from rigs to windmill platforms and ships, causing damages and decreasing their performance. From earthquakes to volcanic eruptions large amount of water can be displaced creating tsunamis and storm surges. These waves travel upon coasts and can reach far distances inland causing destruction. With the gravitational pull of the sun and moon on the earth this also causes the generation of waves, these are known as tidal waves.

To study the nature of waves, wave flumes are used. A narrow channel with a wave generator on one side and a wave absorber on the other. Since the flumes are relatively long and the width is much shorter than its length, the wave is taken as two-dimensional in the x-z plane, where z is the measure from the still water level and that the wave are progressive in the positive x direction and are propagated over a smooth horizontal surface in water that is at a constant undisturbed depth. It is also assumed that the wave maintains permanent form with no underlying current or water contamination. The fluid is incompressible and inviscid.

This thesis outlines the installation and experimental use of pressure sensors. Along with the creation of a mechanism to improve the calibration method of wave gauges. The important aspect of the project is the change of the transverse function that plays a major role in the generation of waves.

1.1 Aim

The aim of the project is changing the current transverse function, that is for a paddle type wavemaker, to a piston wavemaker transverse function. Tests will have to be conducted before the change to compare with the tests conducted with the correct function. Also, to install new additions of pressure sensors to the wave flume.

1.2 Objectives

- Analysis of existing wave flume set up.
- Learning how to generate waves using the software.
- Learning the use of wave gauge and how to operate.
- Conducting preliminary experiments on current set up.
- Installation of pressure sensors and software.
- Changing of transverse function.
- Conducting experiments with different wave cases on new function and comparing them with linear theory.
- comparing pressure sensor values to hydrostatic pressure.

1.3 Layout

Section 1 introduces the thesis with the outline of the aims and objective of this project. Section 2 contains a literature review of previous projects conducted before this thesis. Section 3 explains the experimental equipment used to generate waves. Section 4 explains the method to generate waves. Section 5 gives an overview of results and discussion. Finally, section 6 conclude this thesis and further studies that are suggested.

1.4 COVID-19 Impact Statement

Due to the unforeseen circumstances of campus lockdown during the COVID-19 pandemic. A few tasks were unable to be completed. The transverse function was not able to be reviewed or changed. Wave gauge data was obtained incorrectly, and retesting was not possible.

2 Literature Review

2.1 Types of Waves

2.1.1 Capillary waves

Capillary waves have the shortest period and are generally the first types of waves that are noticed on the ocean surface, with a wind speed of about 3 m/s (Alessandro Toffoli & Elzbieta M. Bitner-Gregersen, 2017). The developments of capillary waves are primarily due to surface tension, this forces the group velocity, the speed at which the energy of a wave travels, to be greater than the phase velocity by 1.5 times. Phase velocity is the rate at which the phase of a wave propagates in space. For wavelengths approximately 1.7cm gravity will cancel out the capillary effect and supresses dispersion (Lamb, 1994). As waves grow and wave groups and phases propagate at the same speed, gravity effects will dominate wave dynamics and surface tension becomes a secondary role. These oscillations of waves are known as ultragravity wave. Typical wave lengths for capillary waves are less than 0.025m (Alessandro Toffoli & Elzbieta M. Bitner-Gregersen, 2017).

2.1.2 Long-Period Waves

Wave that have period longer than 5 minutes are recorded in the ocean. Tsunamis, seiches and storm surges are known as long-period waves. There can be different mechanisms that can be responsible for these waves, but earthquakes and meteorological conditions are the main cause. Seiches and storm surges are generated due to atmospheric conditions, results of high winds and atmospheric pressure changes. Tsunamis have periods which vary from 1 minute to 20 minutes with wavelengths from a few kilometres to a few hundred kilometres, these are generated by movement from tectonic plates changing in the sea-bed (Alessandro Toffoli & Elzbieta M. Bitner-Gregersen, 2017). Seiches that occur in nature the period can be estimated as $T= 2L/(gh)^{0.5}$, where h is the average depth of the basin, L is the length of the basin and g is the acceleration due to gravity. (Proudman, 1953). Seiches usually have wavelengths of a few kilometres. Storm surges are normally known as a change in water level. In extreme cases this can cause floods near coastal areas and cause disruptions to coastal life (Alessandro Toffoli & Elzbieta M. Bitner-Gregersen, 2017).

2.1.3 Deep and Shallow Waves

Deep water waves have a depth in the ocean that is significantly large. There is no shoreline to provide any resistance to their motion. The depth of the water is more than half of the wavelength of the wave. Waves with longer wavelength travel at greater speeds than those with shorter wavelengths. Deep waves have enough energy to span a large distance compared to other waves like breaking waves. Breaking waves are when the wave collapses on itself. (Network, 2019)

Shallow water waves are seen when the depth of the water is less, usually have depth about 1/20th of the wavelength (Network, 2019). The speed of shallow waves does not have a relation to wavelength and the speed is a function of the depth of water. So shallow waves traverse fast than deep water waves. (Network, 2019).

2.1.4 Breaking Waves

Breaking waves are waves whose amplitude reach a critical level and start to produce large amounts of wave energy that transfers into turbulent kinetic energy. Breaking usually occurs reaches the point where the crest, top of a wave, and over-turns on itself. Surging and plunging are types of breaking waves. (Sarpkaya, T., & Isaacson, M., 1981). The experiments were not based on breaking waves.

2.2 Stokes Wave Theory

Stoke wave is a non-linear surface wave on an inviscid fluid of a constant undisturbed water depth. The theory is based upon wave on intermediate and deep water, see Figure 14. This theory is used in the design on coastal and offshore structures as the kinematics are needed in the design process to calculate wave loads on a structure.

(Schäffer, 1996) created a full second-order theory for the generation of waves. The wavemaker theory had no assumptions of shallow waters or a narrow-banded wave spectrum. He uses a flap type wavemaker and later uses this theory on a piston wavemaker and experiments with various waves and in all the experiments, including the flap type wavemaker experiment, the results support the theory.

2.3 Solitary and Cnoidal Theory

Since Stokes theory is based upon intermediate and deep waves, Solitary and Cnoidal theory is used instead for shallow waves. (Siamak Malek-Mohammadi and Firat Y. Testik, 2010) proposed a new method for generating solitary waves and compared the method proposed by (Goring, 1978). They generated solitary waves using their method and Goring's method and compared them to theory. Their new method was successful in producing more accurate solitary waves with a reduction of force as the wave propagated.

(Goring, 1978) work was based on nonlinear solitary and cnoidal theory using Boussineq, McCowan and Laitone theories. Goring was able to produce solitary waves that are predicted well for small wave heights (Goring, 1978). But for wave height that were relatively large the shape and celerity of the waves are much different from the theories he used. Goring also found that the wavemaker motion had to be precise when generating cnoidal waves, if not secondary waves are produced at different speed from the main wave. Goring is considered the starting point for solitary and cnoidal waves wavemaker theory.

(Wu, Hsiao, Chen, & Yang, 2016) uses a piston wavemaker to generate solitary was using a method by (Wu, Tsay, & Chen, 2014) which is a modification of Goring's method (Goring, 1978) and Goring's original method. They found that their wave heights generated were about 10% of from the target. The piston wavemaker was not fitted correctly and there was water leakage during experiment. They also conducted numerical simulation to show that the gap, 0.24% of the width of the flume, is quite visible to be reason for the results. They concluded that the modification of Goring's method works better than the original.

2.4 Wave Flumes

A wave flume is a tank where the width of the flume is much less than its length. It is a narrow channel setup in a laboratory to observe the nature of surface waves. The tank is open at the top and at one end there is a wavemaker and the other is some type of artificial beach or wave-absorbing surface. Wave flumes can be used to study water waves and even the effects they have on coastal structures and offshore structures.

Modern wave flumes are computer controlled and can generate periodic waves, solitary waves, wave groups and waves that have tsunami like wave motions, depending on the size of the wave flume. The waves are generated with a mechanical wavemaker, types like plunger, piston or paddle wavemakers. The wave absorber can be natural materials like sand or gravel. Artificial absorbers can be made from pol-ether foam or wire screens. These absorbers will break up the wave energy and then reduce the number of reflected waves. There will always be a certain percentage of waves reflected to the wavemaker and a wave flume can never be infinite long and the absorber is hardly be complete (Wang, 1974). In (Bidokhti, 2012) the aim was to build a wave flume on a limited budget. M.R. Khalilabadi and A.A. Bidokhti where able to construct a flume that was 14m long with a depth of 1.75m and a width of 1m (Bidokhti, 2012). The wave flume was small compared to other larger flumes, but it was well-suited for educational and basic research studies (Bidokhti, 2012). Larger flumes would require staff and funding for the maintenance and operations, therefore small-scaled experiments would be useless for larger flumes (Bidokhti, 2012). The wave flume consisted of a paddle type wavemaker and a gravel beach with a 1:4 slope, the sides where covered with glass for observation (Bidokhti, 2012).

2.4.1 Current Status of Fluids Laboratory

The wave flume is fitted with a piston wavemaker. This piston wavemaker runs of a transfer function that dictates its motion when creating waves. This function is currently set for a paddle type wavemaker. It was found by Christopher Wallis (Wallis, 2018), that the motion of the of the wavemaker would exert more than it needs to when generating waves. From his results he found that various waves would have much higher crests when compared to linear theory.

2.5 Types of Wavemakers

The three types of common wavemakers are paddle, piston and wedge type. Each type of piston type of wavemaker will be designed differently but operate in the same way. There are other ways of generating wave like dropping weights at certain heights. (Testik, 2010).

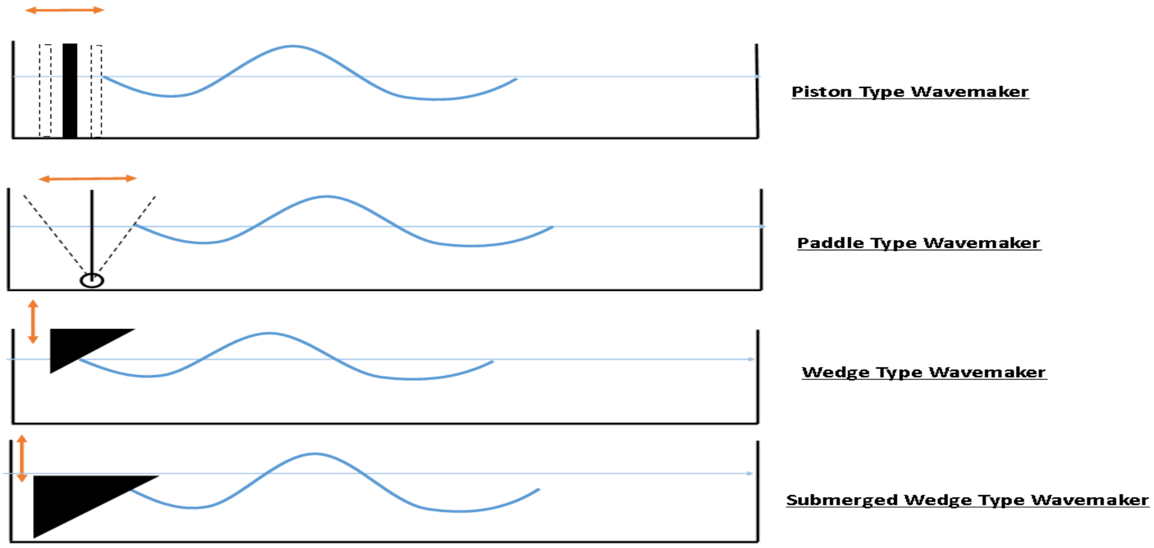


Figure 1 - Schematics of different types of wavemakers.

2.5.1 Plunger type

A plunger wavemaker or a wedged shape plunger can be used by being immersed in water or at a height that is just above the still water level and a plunger wavemaker oscillates vertically to generate waves. A previous study that was conducted by Shen Wang, where the aim was to conduct experiments using a triangular plunger type wavemaker and compare the wave height to the theoretical predictions (Wang, 1974). In the end Shen Wang was able to find a "good agreement between theory and experiment" as the average percentage deviation was 6.5% which was within the experimental error (Wang, 1974).

2.5.2 Piston Type

Piston wavemaker is an upright paddle that oscillates horizontally and is submerged by the depth of the working water level. Piston wavemakers are suited to shallow waters. Piston wavemakers are suited to shallow waters. A study conducted by (Nan-jing Wu, 2014) was based on how the motion of a piston wavemaker can generate solitary waves as pure as possible. A pure solitary wave has a stable amplitude and minimised trailing of waves during propagation (Nan-jing Wu, 2014). The results showed that applying Fenton's solution (Fenton, 1972) to the wavemaker motion that was proposed by Goring (Raichlen & Derek G. Goring and Fredric Raichlen, 1992) produced a purer form of waves than other paddle motions.

2.5.3 Paddle Type

A paddle type wave maker is a hinged paddle at the bottom. It oscillates around its axis horizontally. (Bidokhti, 2012) used a paddle type wavemaker for their construction of a wave flume, see 2.4 above. The wavemaker was able to generate waves that were approximately 3% lower than the predicted wavemaker theory. The ratios were the measurement of height to strokes. The wavemaker motion used an expression by (Madsen, 1971) and the theoretical approach for height to stroke ratios is given by (Hughes, 1993).

2.6 Wave Characteristics

2.6.1 Surface Elevation

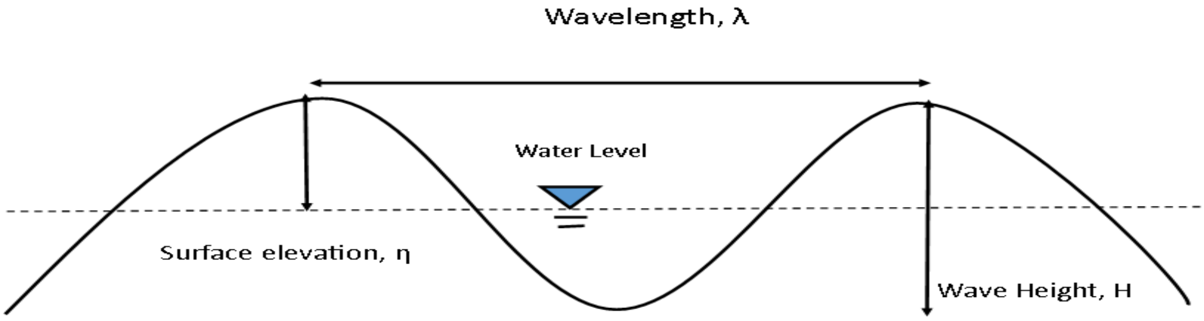


Figure 2 - Schematic of wave characteristics that are important in the studies of waves.

Airy wave theory is used mostly to describe the basic form of a two-dimensional wave. It is a linear theory for the propagation of waves from left to right. Figure 1 shows a two-dimensional wave, its wave height, wavelength and water depth are the most important when it comes to determining the surface elevation. The equation used to calculate surface elevation is:

$$\eta = \frac{H}{2} \times \cos\left(\kappa x_1 - \omega t\right)$$

Equation 1 - Surface elevation equation used throughout project.

Where: H = wave height; wave number, k = 2π / λ; space (constant), x_1; wave frequency, ω = 2π/T; Period, T; time, t (a range of time e.g. 0-60s).

2.6.2 Hydrostatic Pressure

Hydrostatic pressure is the pressure that is exerted, due to the force of gravity, by a fluid at equilibrium at a point within the fluid. Hydrostatic pressure is proportionate to depth and therefore increases when depth increases. This is due to the increasing of weight of fluid exerted downwards from above, the deeper an object is placed in a fluid the more pressure it experiences. The equation 2 gives hydrostatic pressure.

$$P = \rho \times g \times h$$

Equation 2 - Hydrostatic pressure

Where: ρ = density; g = acceleration of gravity; h = depth of the pressure sensor from the still water level.

2.6.3 Dispersion Relation

Dispersion of water waves means that waves which have different wavelengths travel at different phase speeds. Water waves propagating on the water surface, with gravity and surface tension as the restoring forces. This results in water with a free surface is generally considered to be a dispersive relation. The dispersion relation corresponds to waves travelling in the positive x-direction. Depending on several other parameter’s dispersion relation equation for the waves are:

$$\omega^2 = gk \times \tanh(kh)$$

Equation 3 - Dispersion relation

Where: ω = wave frequency; g = acceleration due to gravity; k = wave number; h = still water depth level.

3 Experimental Equipment

3.1 Wave Flume

The flume has a horizontal length of 12m, a depth and width of 0.6m with the internal working width of 0.4m. the flume is made up of 6 modules that are 2m long and is designed in a way where the tank can be expanded further. Each of the module sits on 4 legs that raise the tank at a height of 0.9m from the ground. The flume is made from mild steel welded frames and supports that are coated in marine grade epoxy (Omey Labs Ltd, 2017). The sides of the flume have toughened glass and the 3rd module sides are covered by polycarbonate sheeting, that has glass like clarity. The flume also has an additional module that was designed for the wavemaker. Previously the flume had an open end and a gusset was used on the wavemaker, it had to be replaced when using the tank repeatedly due to wear and tear. The gusset prevented water from leaking as the back end of the flume was open, this design prevents any spills and allows water to move more freely around the wavemaker.

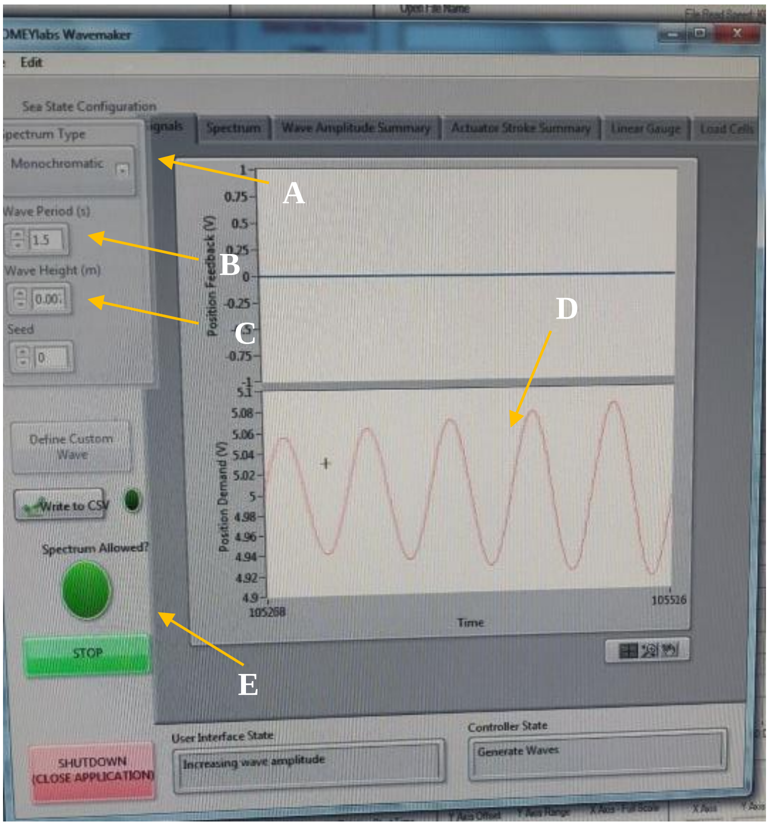
3.1.1 Maintenance

The flume should be checked daily for and dirt, leaks or cracks and any wear and tear. Dirt can lead to build up and could damage the flume or wavemaker. Leaks or cracks can put the tank out of use for a long period and therefore should be reported to the appropriate personnel immediately. Wear and tear will be experienced, when generating waves as it will lead to sealant along the bed of the flume to tear, which is easily replaceable.

3.2 Piston Wavemaker

Movement is provided to the piston wavemaker by the linear actuator. The dimensions are a depth of 0.6m and width of 0.4m (Omey Labs Ltd, 2017). The piston oscillates in a horizontal motion and there is no vertical movement. The wavemaker moves the entire depth of the water level.

3.2.1 Omey Labs Wavemaker Software



Spectrum Type: Monochromatic

Wave Period (s): 1.5

Wave Height (m): 0.00

Seed: 0

User Interface State: Increasing wave amplitude

Controller State: Generate Waves

Figure 3 - Software used to input wave height and period to generate waves.

Figure 3 show the show the software application window. A denotes the type of wave selection, this is left on monochromatic. Monochromatic waves are refer to one wavelength and a single frequency. B denotes the wave period, T, input, C denotes the wave height, H, input. D, shows the wavemaker output motion during wave generation. E is the start and stop button and also an indicator which goes green if the allowable wave height and period is selected. The wavemaker motion is set with a ramp up and ramp down when starting and stopping. This is to prevent any damages on the wavemaker because without out the ramp up and down sudden starts and stoppage can damage the wavemaker.

3.2.2 Maintenance

Daily checks before conducting experiments should be done to ensure the wavemaker is free to move and there is no debris or build up blocking any movement.

3.3 Linear actuator

An actuator provides the physical movement to the piston wavemaker to generate waves. There are two connections to the actuator, Power and signal that is connected to the control box, which is connected to a PC.

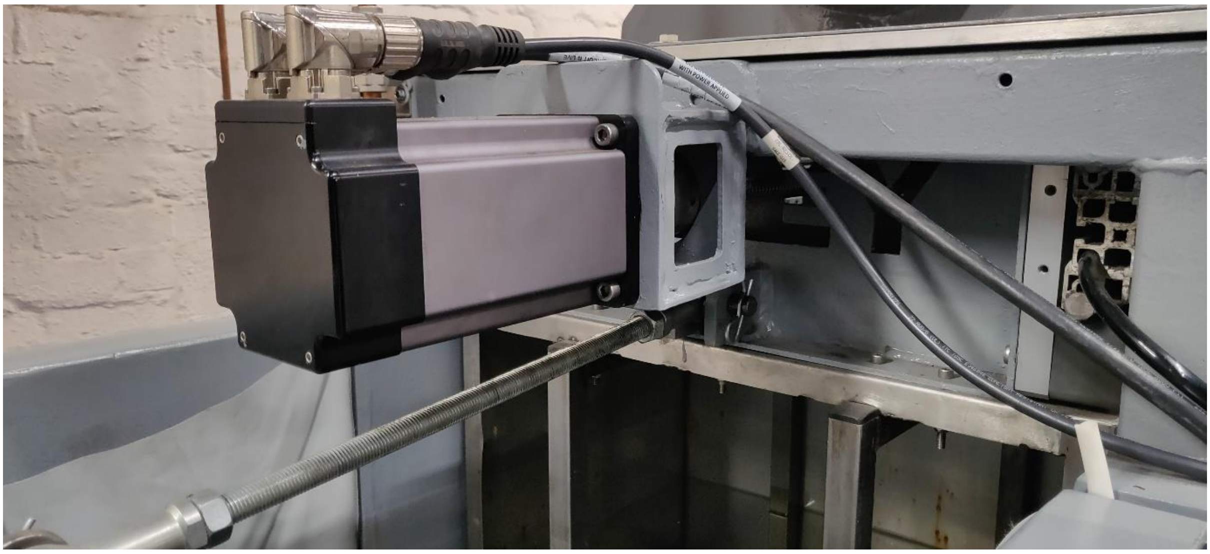


Figure 4 - Linear actuator that provides horizontal movement to the wavemaker.

3.3.1 Maintenance

Again, checks should be done before conducting experiments, no cables are constraining movements.

3.4 Control Box

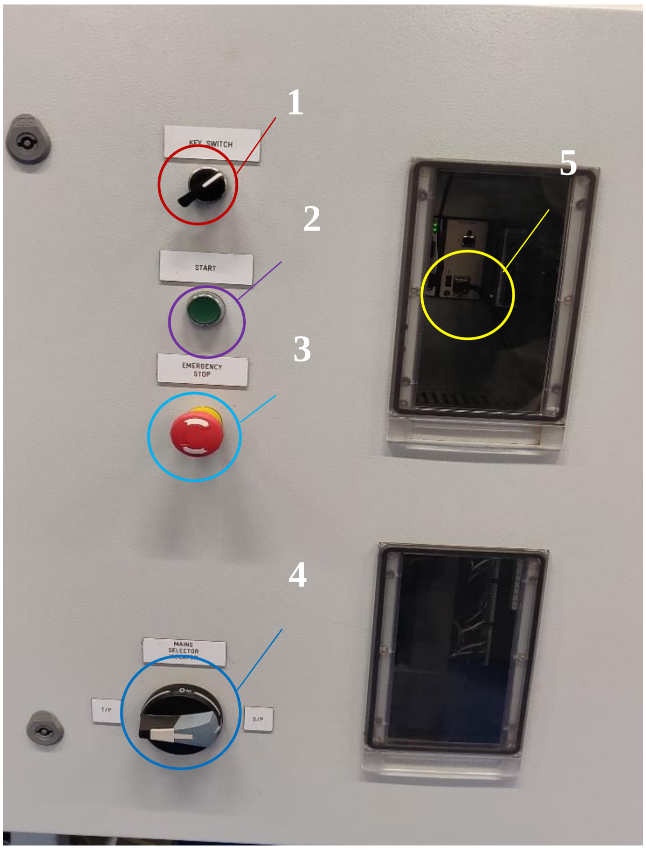


Figure 5 - Control box with operating switches and view windows to show connections.

Everything is connected by the control box. The control box is powered by a 240V mains plug. The switches are indicated is figure. Switch 1 is the ‘key switch’, this allows the computer to send signals to the wavemaker and cuts the signal when switched off. Switch 2 is the start button that resets the wavemaker to its starting position. Usually the wavemaker moves to its original starting position, if this does not happen press switch 2. Switch 3 is emergency shop. When pressed this will stop the wavemaker immediately. This should only be used in an emergency. Once safe, check the wavemaker and flume for any visible damages before continuing. Switch 4 is the on and off switch for all power to the wave flume. Turn the switch to S/P for power on and return the switch to the centre for power off. The view window denoted by 5 shows the compactRIO controller which allows signals to be sent to the actuator from the PC via an ethernet cable.

3.5 Wave Absorber

The wave absorber is situated at the end of the wave its purpose is to reduce the amount of wave energy being reflected from the end of the flume. This is to produce accurate results, reflected waves will produce unwanted characteristics, non-linear effects. The absorber is a lightweight foam and is weighted down by metal rods, this stops the absorber from risings when the tank is filled with water.

3.5.1 Maintenance

Check for debris or slime that may have built over time, this must be cleaned to avoid damages to the wave absorber or wave flume. The wave absorber can be cleaned in a tank filled with water and peroxide this is done to destroy any bacteria to prevent growth that may cause damages. But this is done by appropriate personnel and overall, the absorber does not require a lot of maintenance.

3.6 Wave Gauges

The surface elevation of the water is measured by using three wave gauges. The Wave Staff XB OSSI-010-025 is made by Ocean sensor Systems and are wireless, so the need for trails of wiring and multiple connections are removed and create ease within the laboratory. The gauges provide a data rate of 32 Hz, in other words it provides up to 32 readings a second giving a good amount of readings for accurate analysis (Ocean Sensor Systems, Inc). The gauges are powered using two C cell batteries.

The wave gauge works by measuring the capacitance between the water and sensor staff which is 0.5m long so any water depth that do not exceed the length of the measuring rod is suitable. As the water surface elevates the capacitance increases. The capacitance can be measured by the time it takes for the voltage to change with a given current. The equation for capacitance is shown in equation 1, where C = capacitance, V = Voltage, I = current and T = Time (Ocean Sensor Systems, Inc).

$$C = \frac{T \times V}{I}$$

Equation 4 - Capacitance Equation (Ocean Sensor Systems, Inc)

The gauges are wireless as stated and are connected to the PC and software using a Xstick USB Adapter. Once a connection is made between the software and gauges the data is then plotted on the software.

3.6.1 Staff and Sonic Products Interface Program

3.6.1.1 Plotting Data

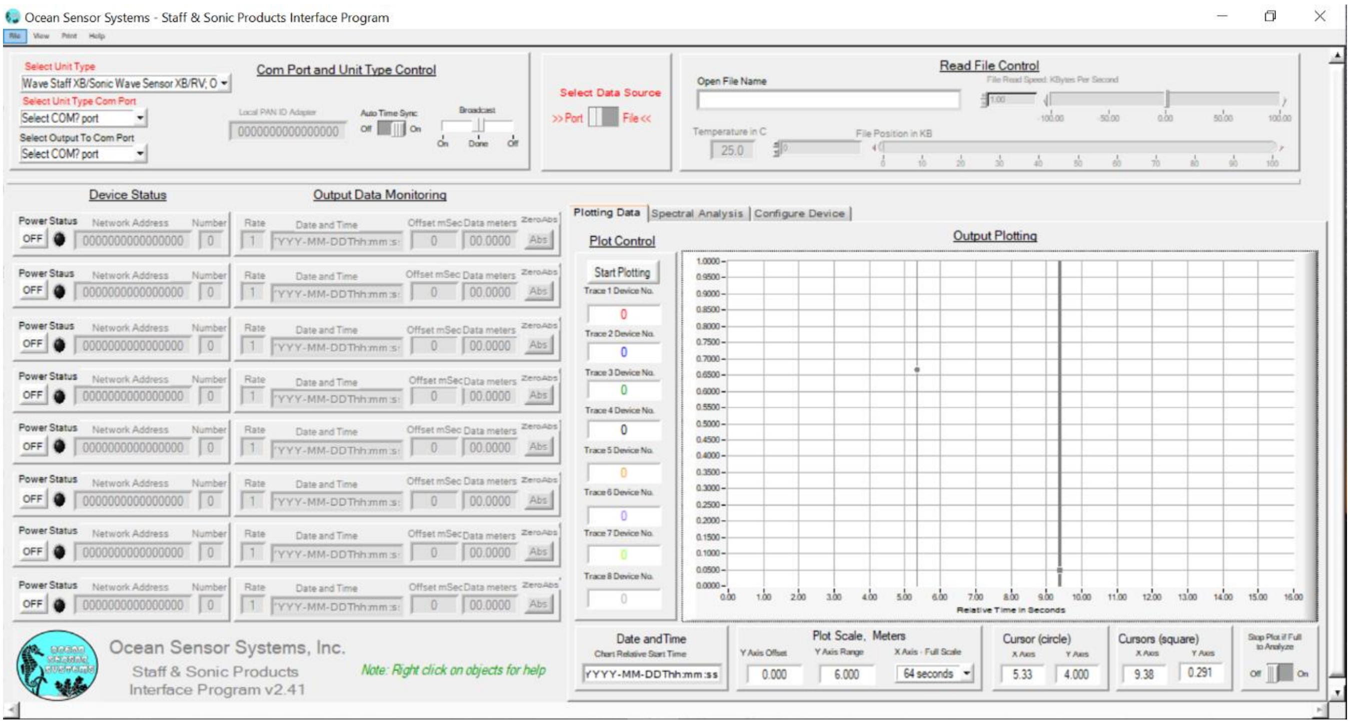
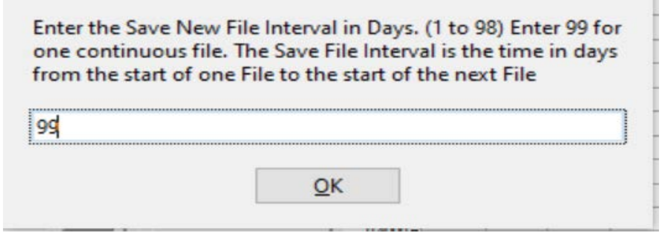


Figure 6 - Staff and Sonic Products Interface Program.

The program has been updated to version 2.41.

All the data that is sent by the wave gauges is time tagged and plotterd in real time (Ocean Sensor Systems, Inc). Before starting experiment make sure gauges are powered up and a connection is made. The device status and output data monitoring can be seen in figure on the left hand side, this indicates which gauges are powered and also shows real date and time. To plot enter the device number that is connected into trace device, then select start plotting. This allows the software to collect the data from the gauges and plot them on screen. The software also has a feature where right clicking on objects gives a help window.

To save the output data to a file, select ‘file’ and ‘save output data to file’. Once entering the ‘save new file intervals in days’, enter ‘99’ for one continous file, and then allow a few minutes for the the software to save the data to a file.



Enter the Save New File Interval in Days. (1 to 98) Enter 99 for one continuous file. The Save File Interval is the time in days from the start of one File to the start of the next File

99

Figure 7 - Save File Interval

3.6.1.2 Calibration

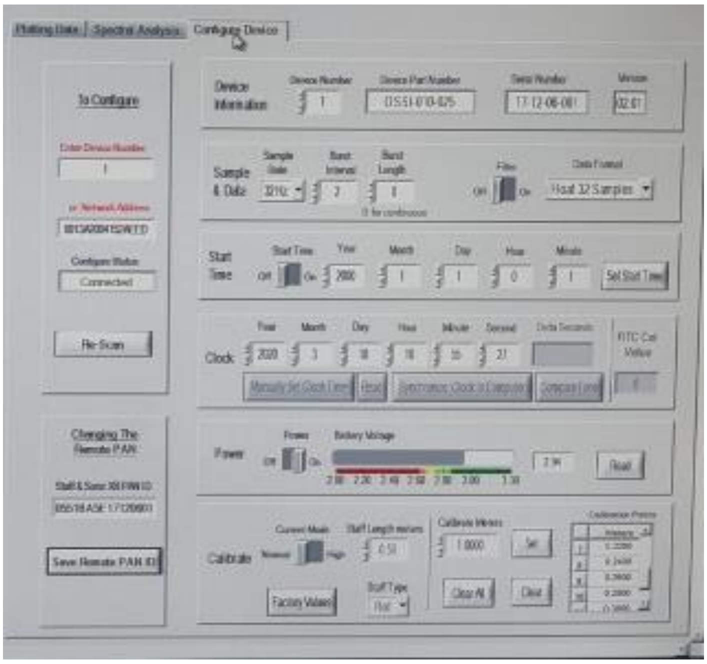


Figure 8 – Calibration section on program

The software comes with a calibration option for the wave gauges. This is so that every time experiments are conducted using the flume each gauge is calibrated to ensure the results are accurate. It is recommended that before conducting experiments the gauges are calibrated daily. The previous process to calibrate the gauges was performed by these steps (Wallis, 2018):

- Using the tap to fill the flume to a water level of 0.2m and wait for the water to become steady.
- Type 0.2m into the calibration section on the software for all three gauges.
- The water is then increased by 2cm.
- Type 0.22m into calibration section.
- Since the software allows 12 calibration points, the process is repeated until 0.4m.

This process became very time consuming to be carried out every day, so a mechanism was made to allow quick calibration of the gauges. The gauge is attached by two holders that are secured by screws; thumbs screws are located on the back which allows the gauge to move vertically. All screws to hold and move the gauge should not be fastened tight as this may cause damages, the gauges are also marked with green tape to indicated where the holders should be placed. Measurements are along the side in cm.

To calibrate the gauges the following process is performed:

- Fill the wave flume to the exact working level, in this case 0.3m
- Use the thumb screws located at the back and move the gauge to the exact working water level (0.3m) shown in figure.
- Again, using the thumb screws move the gauge down to 0.2m.
- By subtracting the working water level from the reading on the mechanism gives the first calibration point, 0.1m.
- Type 0.1m into calibration section on software.
- Move the gauge down by 2cm, new calibration point 0.12m
- Type 0.12m into the next calibration point in the software.
- Repeat this process until reached final calibration point of 0.3m.

- This process should give you 11 calibration points.

Figure 9 - Wave gauge attached to calibration mechanism.

3.6.2 Maintenance

The gauges may have dirt along the rod, simply use a paper towel to remove any build-up. If any build-up is ignored this could damage the gauge and the data may become inaccurate due to the gauge picking up the dirt as the working water level. The rods can easily bend so care should be taken when moving around and storing.

3.6.3 Errors

When calibrating, using up all 12 of the calibration points the gauges may begin to glitch and start reading the water level as ≈ 5m which is the factory calibrated level. This is a clear error as the water level is only 0.3m. If this problem is experienced use up to 11 calibration points and the gauge should read the correct water level.

3.7 Pressure Gauges

The wave flume fitted three pressure sensors. The PX409-USBH series are connected to a 4-port compact USB 2.0 hub, the hub is powered by the mains and is connected to the PC giving signals of all three gauges. The gauges are made from 316L stainless steel, weighing at 200g each (OMEGA Engineering). The PX409-015VUSBH gauges have a range of 0 to -15psi. This model is the vacuum range model which gives negative gauge pressure (OMEGA Engineering). The gauges come with a free downloadable software called “Digital Transducer Application”. The pressure sensors also provide 10 reading per second, giving a good amount of data to be analysed.

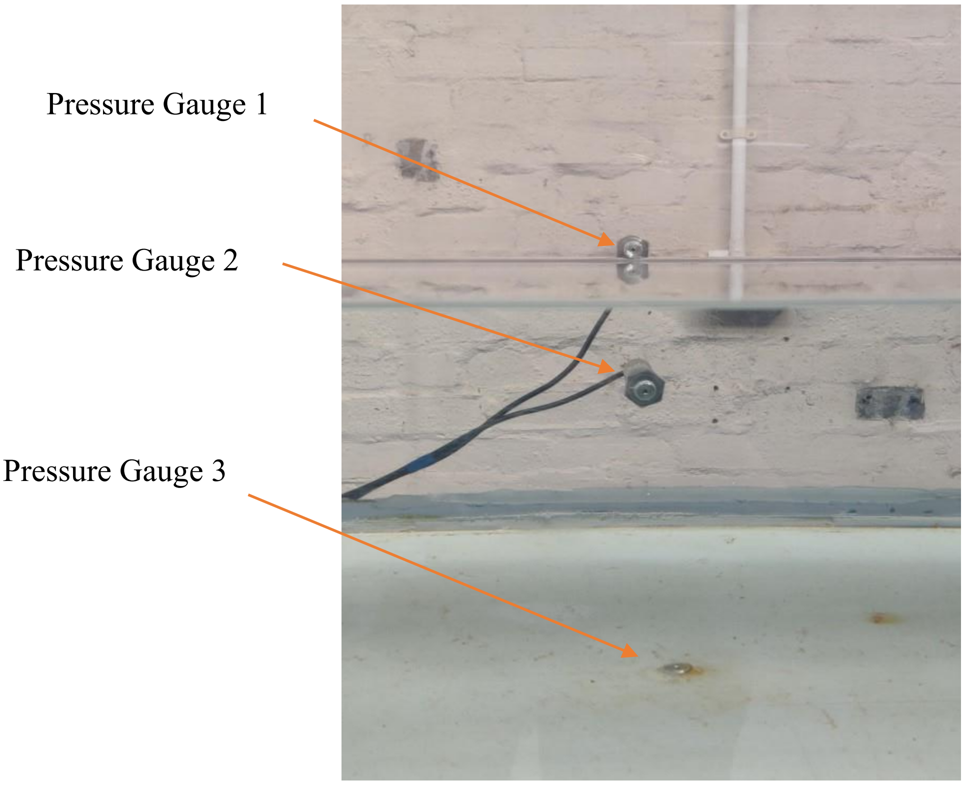


Figure 10 – Pressure gauges located in module 3 at the centre.

3.7.1 Digital Transducer Application

The software takes the data from the transducers and turns into a chart recorder or data logger.

3.7.1.1 Charting Window

The charting window shows the data graphed in real time. The Y axis is configured to allow graphing of multiple engineering units. The graph can be saved as an image with the data recorded. To charts data from gauges all three channels must be selected at the top of the window shown in figure 6.

3.7.1.2 Channels Window

The channels window displays all data values. All channels come with a user alarm, tare, three data filters and sample rates ranging from 1000HZ per second (OMEGA Engineering).

3.7.1.3 Logging Window

The data is saved via a excel file. The data is preformatted for readability which includes the start/stop time, pressure values, high/low readings, number of samples taken and the sensor information.

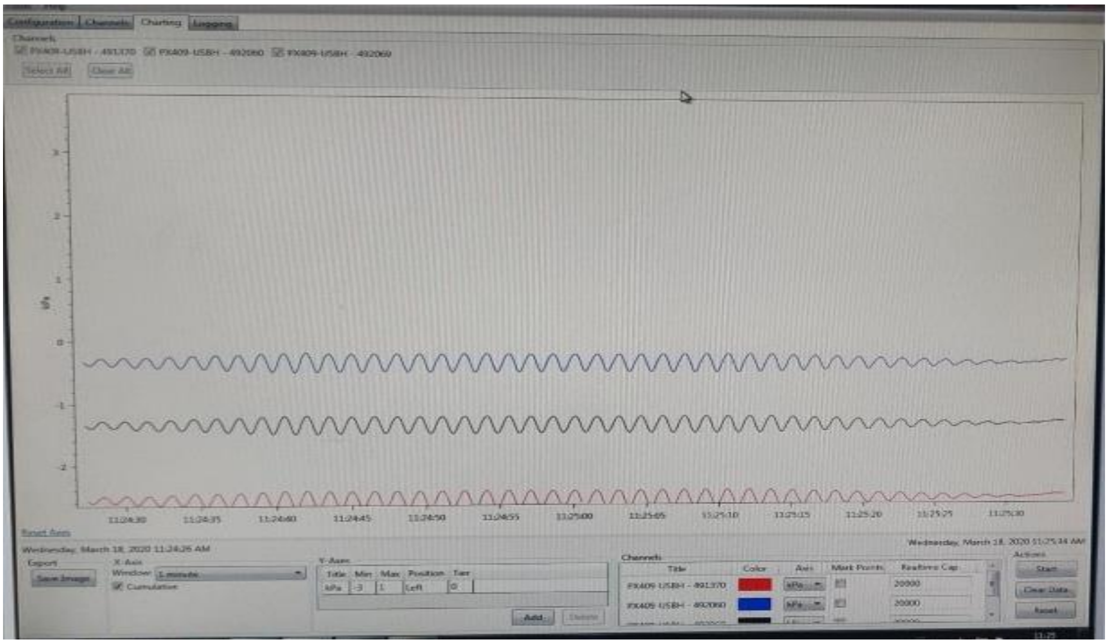
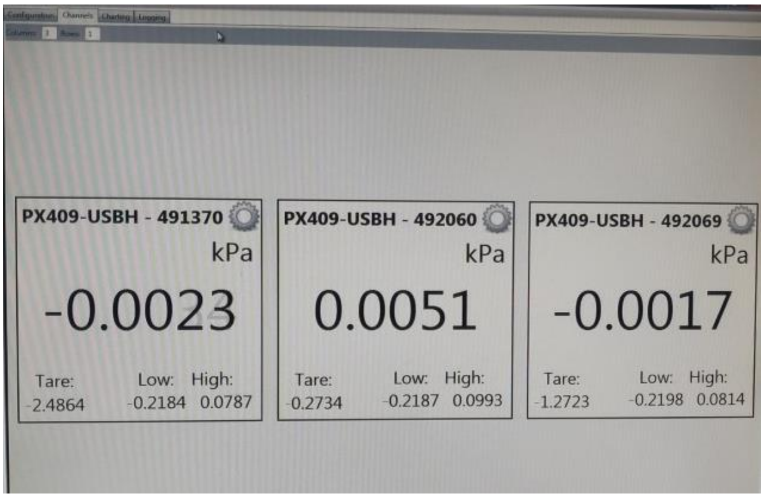


Figure 11 - Charting window with data recorded.



PX409-USBH - 491370
kPa
-0.0023
Tare: -2.4864 Low: -0.2184 High: 0.0787

PX409-USBH - 492060
kPa
0.0051
Tare: -0.2734 Low: -0.2187 High: 0.0993

PX409-USBH - 492069
kPa
-0.0017
Tare: -1.2723 Low: -0.2198 High: 0.0814

Figure 12 - Channels window with three gauges connected

3.7.2 Maintenance

Checks should be done around the gauge to see if there is any leaks or damages. The gauge has a hole in the centre, inside is the pressure sensor, this should be kept clear of any debris or build up as this will give inaccurate data if covered.

4 Methodology for Generating Waves

Using the equipment stated in section 3 above the software, “OMEYLabs Wavemaker”, requires a period and wave height in order to generate waves in the flume. The rod length of gauges is 0.5m long as stated in section 3.6 above, so the water depth must be below this to allow wave heights to be recorded. the water depth that were chosen were 0.3m and 0.2m.

4.1 Wave Gauge Location

Before conducting experiments, the wavelength of a case was calculated by using the dispersion relation. This was done to give a rough estimate on were the gauges should be placed. From case T = 1.5s H = 0.03m, the wavelength was equalled to 2.35m. The gauges were decided to be places 1.25m from the pressure sensors from both sides, gauge one being close the wavemaker and gauge 2 nearer the wave absorber. Gauge 2 should experience shorter wave heights than gauge 1 due to friction along the bottom and sides of the flume, but the difference would be very minimal. The distance between the wave absorber and gauge 2 is large, so reflected waves should not be an issue.

4.2 Wave Cases

The wave cases chosen to fall under different wave characteristics from cnoidal theory, linear theory, Stokes 2nd and 3rd order and 5th order stream function theory. The wavemaker was not pushed to its mechanical limits to generate waves as this could have caused damaged to the flume and wavemaker. The cases chosen are shown in table 1 and the cases are plotted on based on (Méhauté, 1976). The same periods and wave heights were used for both water depths.

Period, T (s)	**0.55**	**1.5**	**3.25**
h/gT^2	0.101	0.014	0.003
Height, H (m)	**H/gT^2**		
0.0055	0.0018	-	-
0.0075	-	0.0003	0.0001
0.01	0.0034	-	-
0.015	-	0.0007	
0.03	0.0101	0.0013	0.0003
0.05	-	-	-
0.06	-	-	0.0006
0.07	-	0.0032	-

Table 1 - Wave periods (T) and wave heights (H) chosen to run on wavemaker with water depth at 0.3m.

Period, T (s)	**0.55**	**1.5**	**3.25**
h/gT^2	0.067	0.009	0.002
Height, H (m)	**H/gT^2**		
0.0055	0.0018	-	-
0.0075	-	0.0003	-
0.01	0.0034	0.0004	0.0001
0.015	-	0.0007	-
0.035	-	-	0.0003
0.05	0.0168	-	-
0.06	-	-	0.0006
0.07	-	0.0032	-

Table 2 - Wave periods (T) and Wave heights (H)chosen to run on wavemaker with water depth at 0.2m

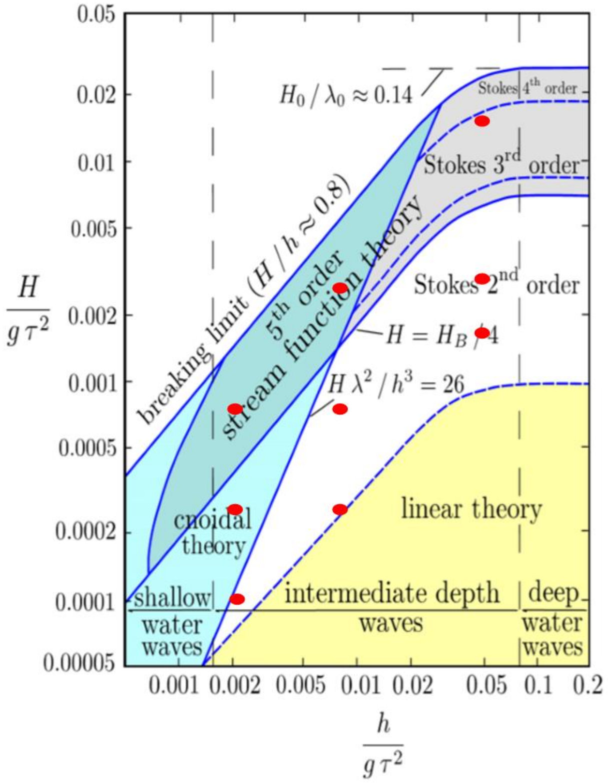


Figure 13 - Cases chosen in red for water depth 0.2m. (Méhauté, 1976)

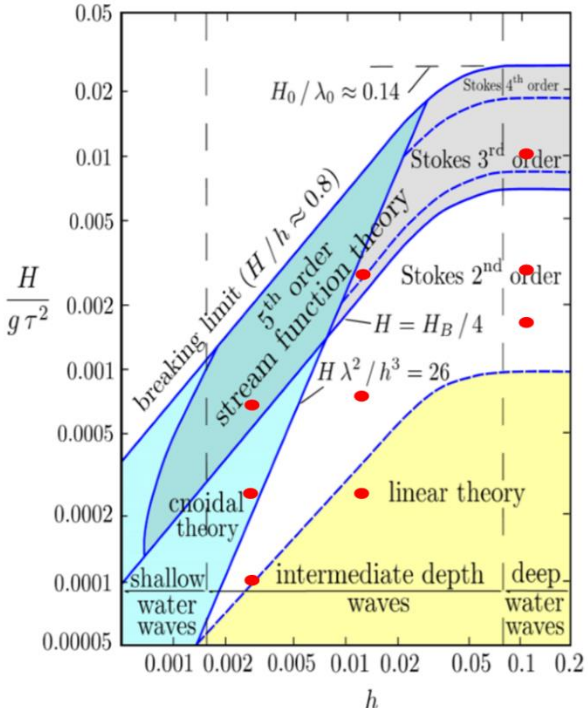


Figure 14 – Cases chosen in red for water depth 0.3m (Méhauté, 1976).

5 Results and Discussion

The results are based on the absolute values obtained from the pressure gauges compared to hydrostatic pressure. Wave gauge data compared to linear theory; the results will show the current status of the wavemaker and pressure gauge. Due to unforeseen circumstances, the results obtained from the wave gauges were incorrect, these graphs can be seen in …. The assumption was made that the wave gauges had been calibrated incorrectly and due to the circumstances, see section 7, the wave cases were not able to be repeated. The first few seconds the wavemaker has an incline ramp up to minimise damage when generating waves, see section 3.2 so during this period the sensors was not recording this period.

5.1 Pressure Gauge

5.1.1 Water Depth 0.3m

	Pressure Sensor 1	**Pressure Sensor 2**	**Pressure Sensor 3**
Hydrostatic Pressure (kPa)	0.981	1.962	2.943

Table 3 - Hydrostatic Pressure values calculated for each sensor.

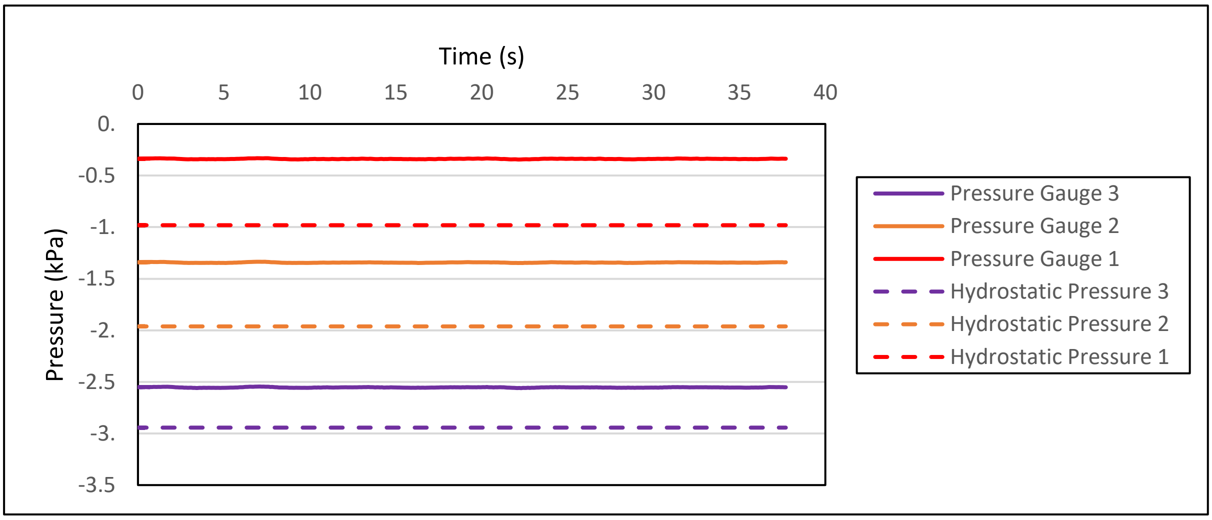


Figure 15 - Pressure values for T = 0.55s and H = 0.0055m, case 1.

Table 3 shows the hydrostatic pressure that are exerted at the locations of the gauge in theory. The values obtained were given as negatives this is due to the pressure being much less than on the free surface, at the top of the water level. Figure 8 shows the graph of the values obtained by the sensors. The hydrostatic pressure is plotted as a negative for comparison. From the graph, sensors one and two are off by 66% and 32 %. This is relatively large but sensor 3 is only 13% away from the hydrostatic pressure value. For cases 2 and 3 there was also not much difference these can be seen in section 7.

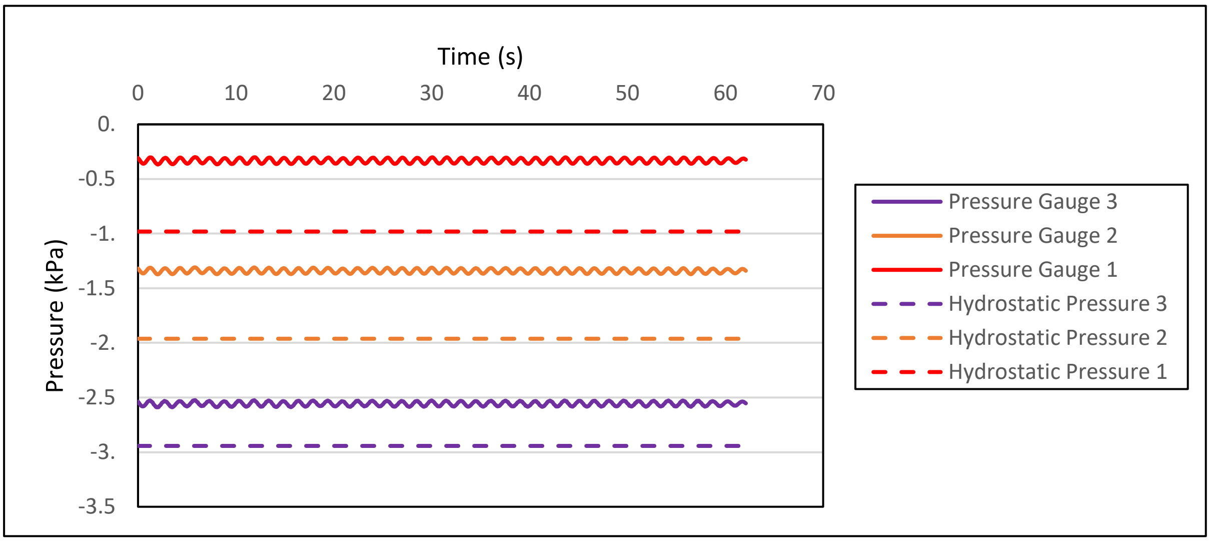


Figure 16 - Pressure values for T = 1.5s and H = 0.015m, case 5

The pressure magnitude begins to become more noticeable as the height of the wave begins to increase. The values are still quite far from the hydrostatic pressure, gauge 1 and 2 are now 62% and 30% and gauge 3 is 10% off from the hydrostatic pressure. Giving an indication that larger wave heights increases pressure. In figure 10 it is shown that the magnitude of pressure increases considerably and gauges 1 and 2 are still off by a large percentage though gauge 1 is now off by 7% from the largest pressure values recorded.

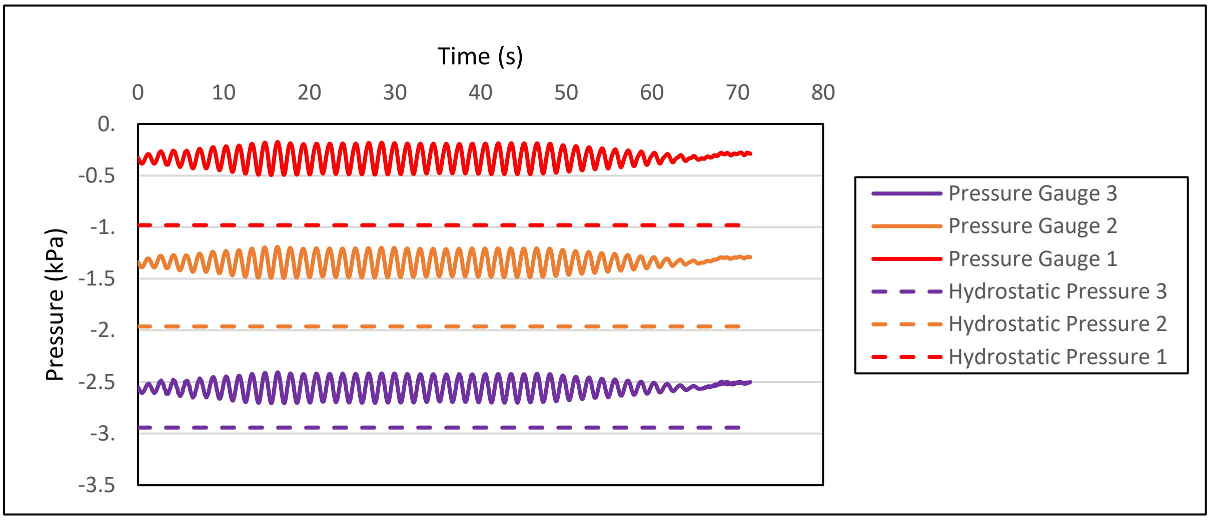


Figure 17 - Pressure values for T = 1.5s and H = 0.07m, case 7

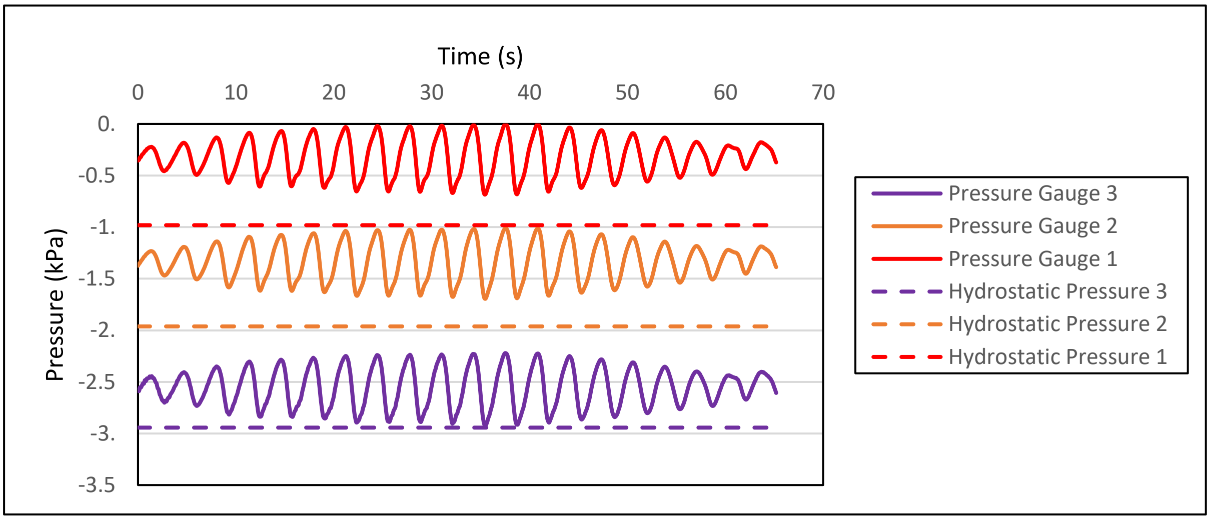


Figure 18 - Pressure values for T = 3.25s and H = 0.06m, Case 10

The gauge pressure values recorded are much closer their hydrostatic pressure, except for gauge 1 as it is still off by a large percentage. The highest value recorded of gauge 3 is very close to the hydrostatic pressure.

5.1.2 Water Depth 0.2m

Pressure gauge 1 becomes exposed to the free surface and therefore was not included for these results.

	Pressure Sensor 2	Pressure Sensor 3
Hydrostatic Pressure (kPa)	0.981	1.962

Table 4 - Hydrostatic Pressure for pressure sensors at water depth 0.2m

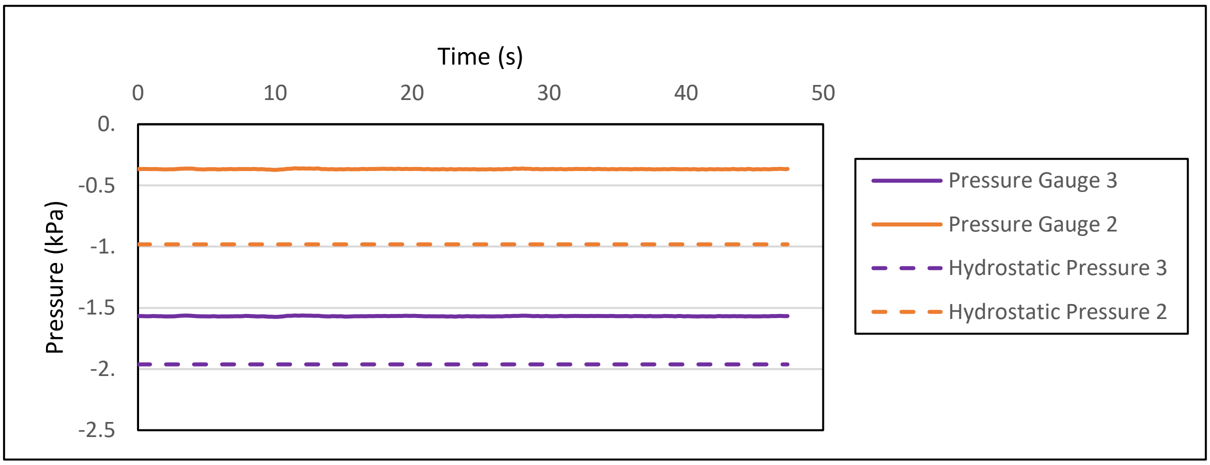


Figure 19 - Pressure values for T = 0.55s and H = 0.0055m at 0.2m water depth, case 1.

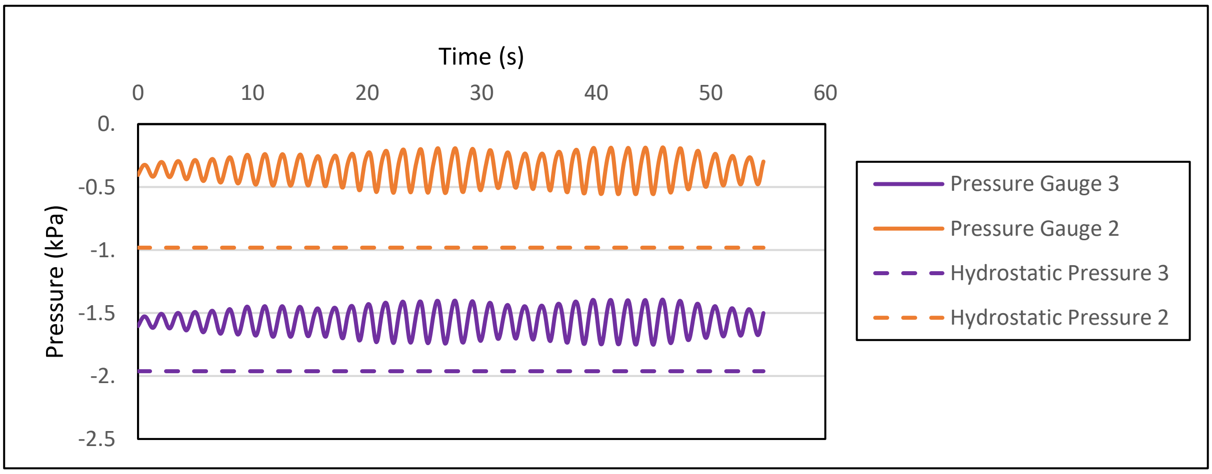


Figure 20 - Pressure values for T = 1.5s and H = 0.07m at water depth 0.2m, case 7.

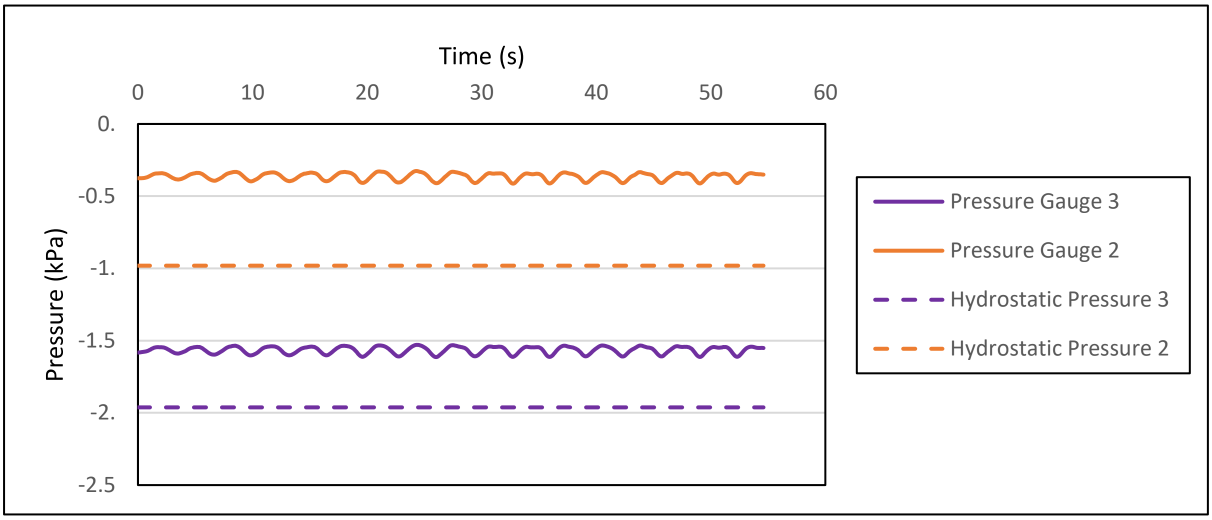


Figure 21 – Pressure values for T = 3.25s and H = 0.01m at water depth 0.2m, Case 8

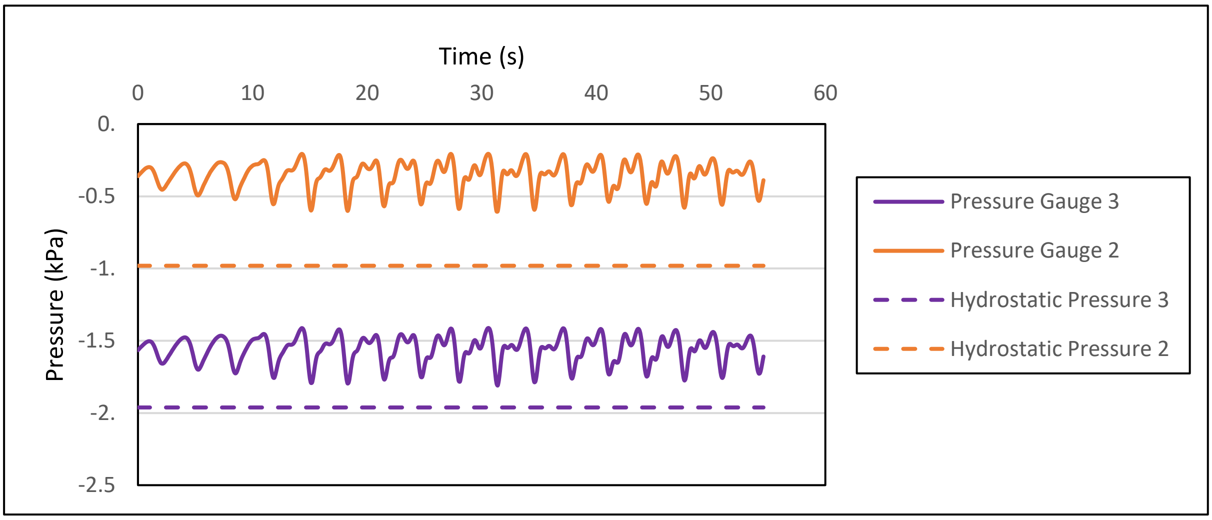


Figure 22 - Pressure values for T = 3.25m and H= 0.06m at water depth 0.2m, case 10.

For case one, the pressure values are off by a large percentage from the hydrostatic pressure. It is not until case 7 were the values recorded become close the hydrostatic pressure. However once the wave height is decreased to H = 0.01m the values are now off by a large percentage, around 30% for gauge 3 and 60% for gauge 2. As the wave height is increased to H = 0.06m the shape of the graph is not like figure 11. Even though they are at different depth they should roughly show the same shape.

5.2 Overall Discussion

The graphs in section 5.1.1 shows that as the wave height increased the values of pressure recorded are much closer to the hydrostatic pressure. Gauge 3 which is located at the bottom of the flume was the closest to its hydrostatic pressure. Gauge 1, for larger wave heights begins to record values that are quite off from its hydrostatic pressure. This is due to the surface elevation of the wave and at times would expose the gauge to the free surface when wave with higher wave heights are generated.

The graphs in section 5.1.2 there is only a slight change in pressure values at smaller waves heights. There is a noticeable change in values when the H = 0.07m, case 7. Again, the values record is not far from the hydrostatic pressure. For case 10 the shape of the graph is not the same as case 10 in section 5.1.1, it can be seen that the wave produced was experiencing non-linear effects as of the odd non-symmetric shapes. This was due to water oscillating behind the wavemaker as it was generating waves. Case 8 also shows small sign of non-symmetric shapes, the water was also oscillating for this case but not as aggressive as case 10.

The gauge values are off by a large percentage for some plots, but before generating any wave the values should be close to the hydrostatic pressure at their depths, though they do look reasonable. There may be other factors that are affecting the values, like not being totally flush against the bed and sides of the flume.

Due to unforeseen circumstances there was not any reliable wave gauge data to include within this section. See section for incorrect data obtained. what was supposed to be seen in the wave gauge data is the surface elevation recorded against the linear theory calculated for the period and wave height selected. Due to time the main aim was the changing of the current transverse function to the correct function was not complete. (Wallis, 2018) found that the wavemakers displacement would move further than it requires, generating greater waves.

The error that was found was possibly due to the calibration of the gauges as previous projects did not experience any issue with gathering data with the gauges. Since there was not a possibly way of retesting, it is possible to say that the current calibration process is to blame.

6 Conclusion

To conclude the outline of this thesis the studies reviewed showed that the methods and theory used within their experiments, they were able to replicate the waves they wanted. For (Bidokhti, 2012) used (Madsen, 1971) wavemaker motion and was able to replicate linear wavemaker theory. For stokes theory (Schäffer, 1996) was able to create a full second order theory for paddle and piston wavemakers that produced results which satisfied the theory. For solitary and cnoidal many theories were made and conducting to satisfy wavemaker theory for solitary and cnoidal waves. It is possible to say that (Goring, 1978) is the backbone for the modification in the other methods attempted.

Due to the unforeseen circumstances it is difficult to comment on the wavemaker motion at this current stage. Though from the review of previous project it showed that the wavemaker exerted to much than it needs to be due to the incorrect transverse function (Wallis, 2018).

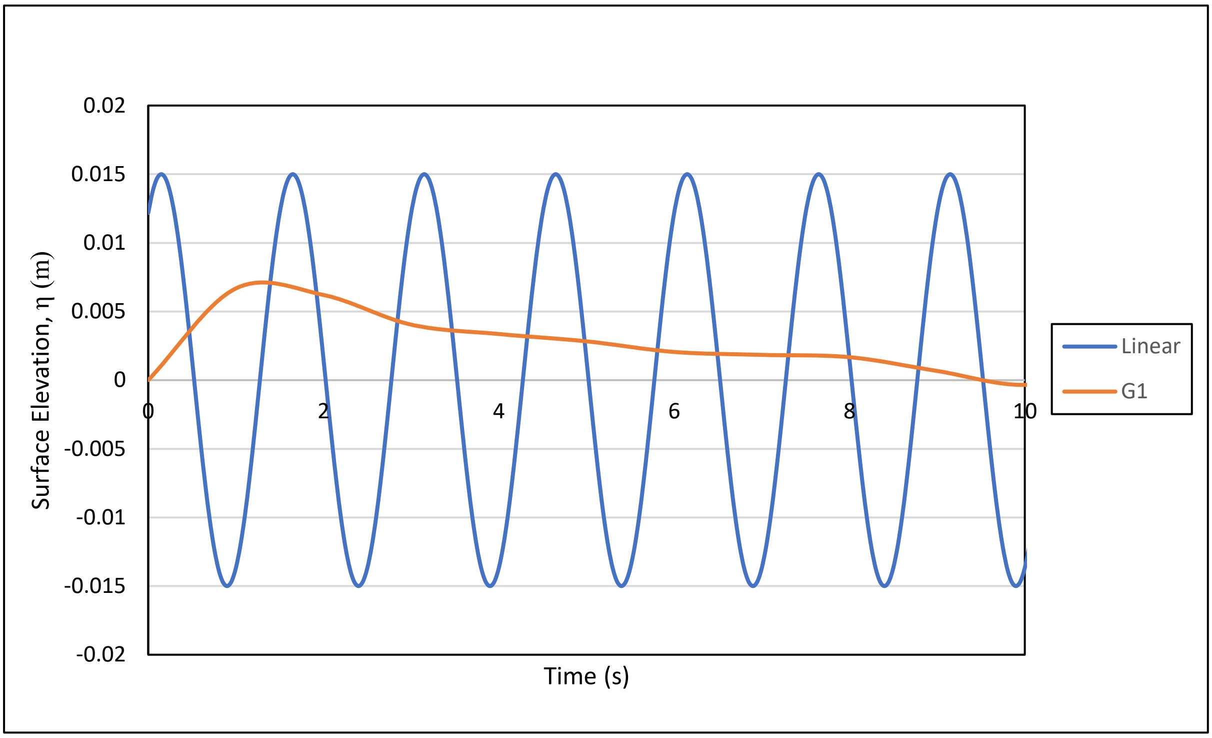
The pressure sensor values compared to the hydrostatic pressure value do make sense as they are not quite far from each other. From the results it shows that the pressure values increase as the wave height increases and become relatively close to the hydrostatic pressure value.

6.1 Further Study

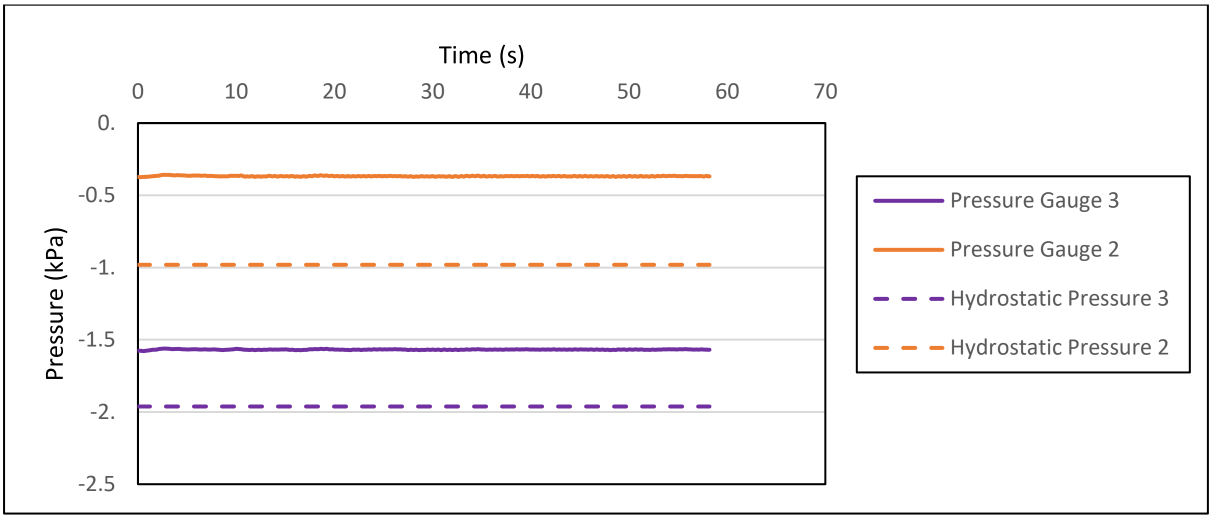
A few things that can be done to improve data from experience, when generating wave with high wave heights the water in the compartment behind the wavemaker begins to oscillate aggressively and this will produce non-linear effects and produce inaccurate data. It is recommended that a lightweight foam is attached to the back of the wavemaker as this will minimise the amount of water behind the wavemaker and stop water from oscillating when generating waves with larger heights. Calibrating the pressure gauges will produce more accurate data as the offset of the sensors gradually drift over time producing inaccurate readings, this can be done by contacting the manufacturer on their website. The current gauges are wired however, there are wireless gauges that were first installed but had to be removed due addition equipment required and the loss of time. The PC is fitted with the wireless gauge software and able to get a connection though there is no option to save to data recorded from the wireless pressure gauges on its software. The set up will require a data logger to save values from these gauges.

It is recommended to change the transfer function to change the wavemaker displacement and run different wave theories to see what theory is replicated the best. Also review the calibration process with the mechanism as this may have been the error for not obtaining accurate wave gauge data.

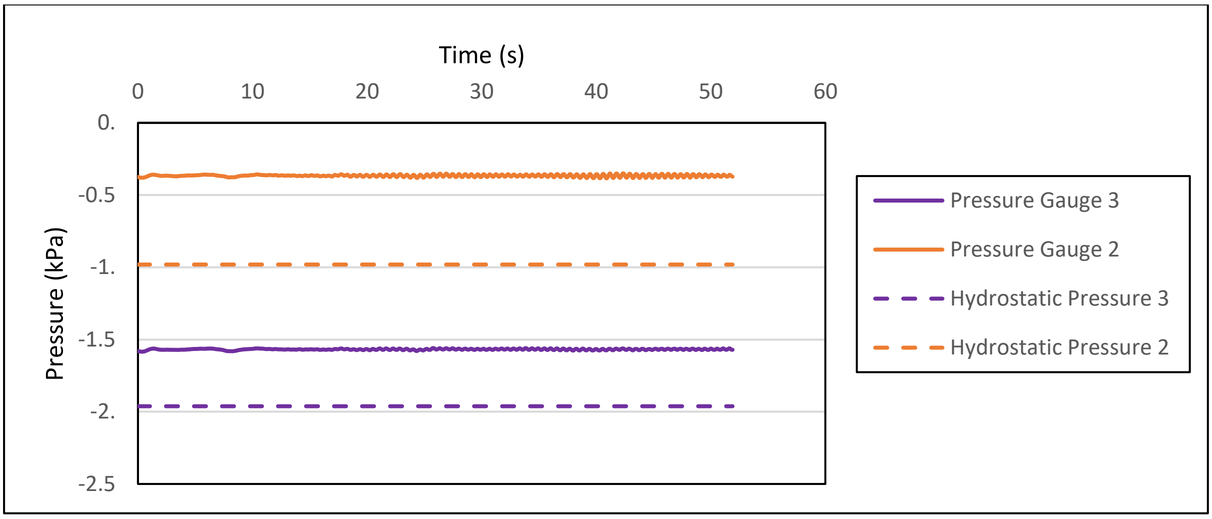
7 Appendix



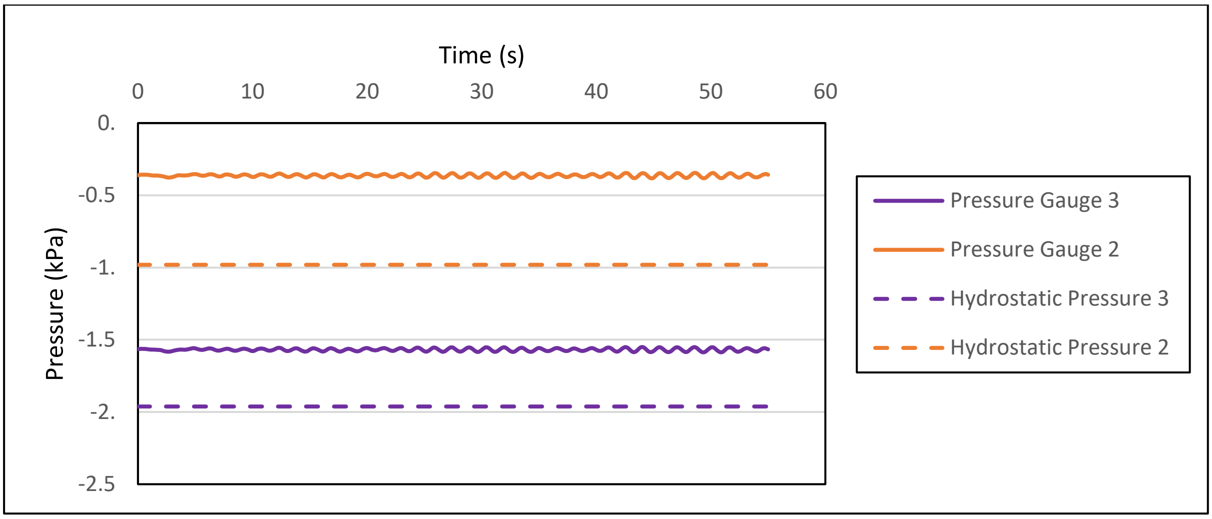
Appendix 1 - Wave gauge data against linear theory, inaccurate data obtained, T = 1.5s, H = 0.03m



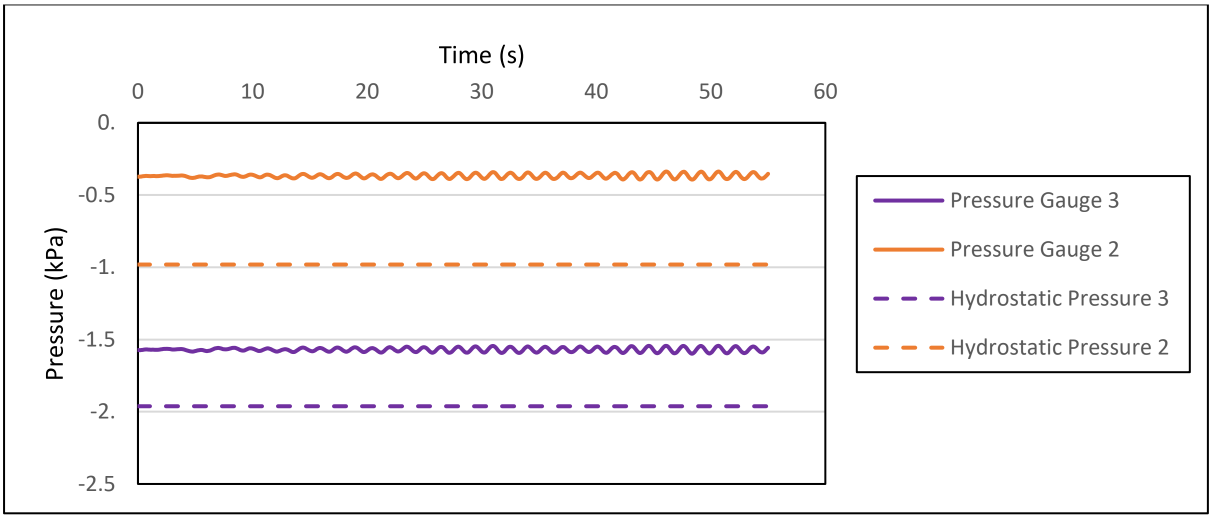
Appendix 2 - Pressure values, T = 0.55s H = 0.01m at water depth 0.2m. Case 2



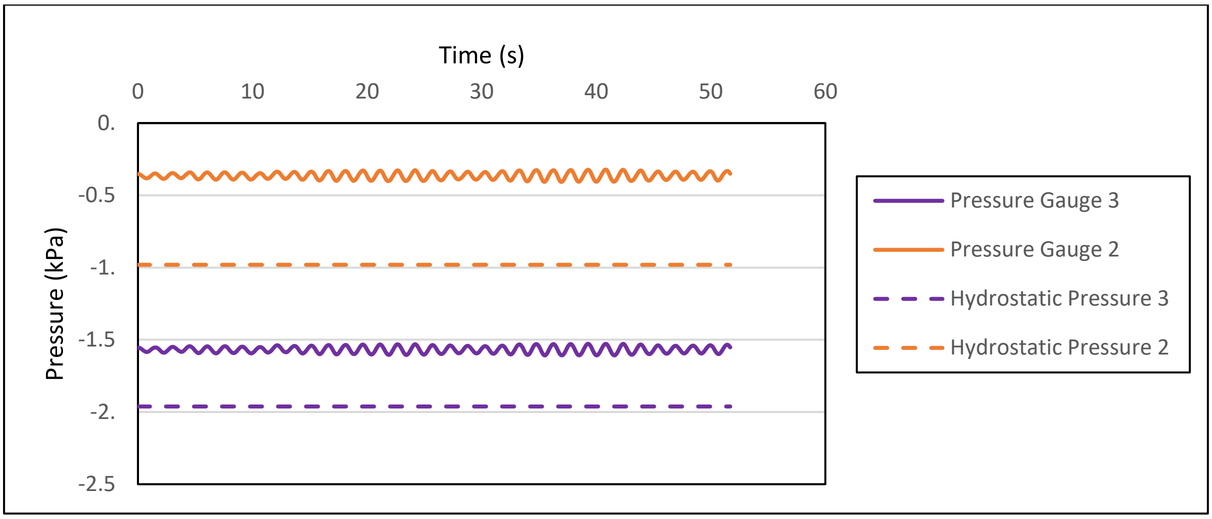
Appendix 3 - Pressure values, T = 0.55s H = 0.05m at water depth 0.2m. Case 3



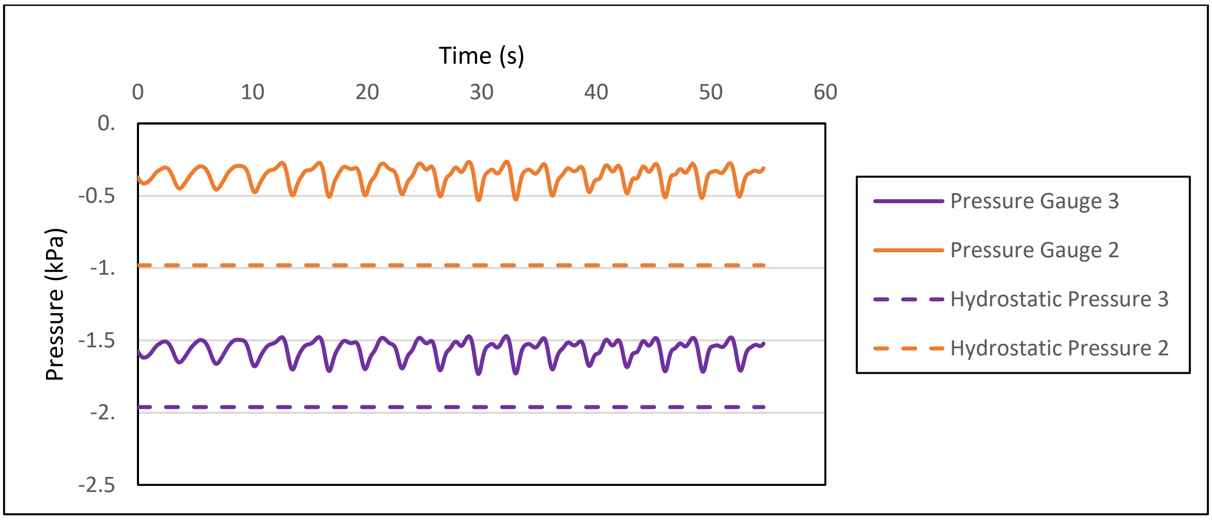
Appendix 4 - Pressure values, T = 1.5s H = 0.0075m at water depth 0.2m. Case 4



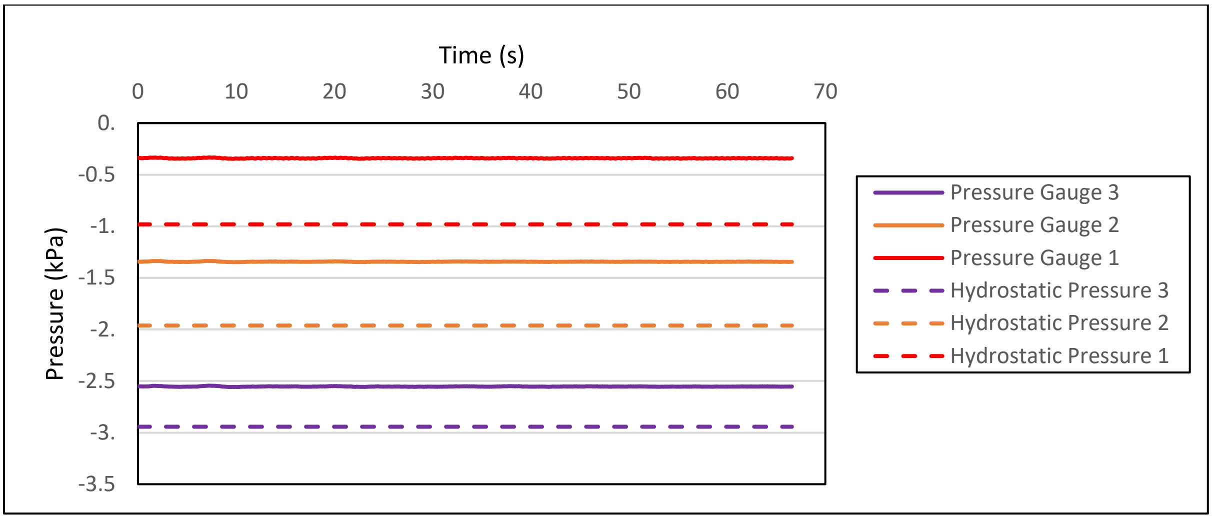
Appendix 5 - Pressure values, T = 1.5s H = 0.01m at water depth 0.2m. Case 5



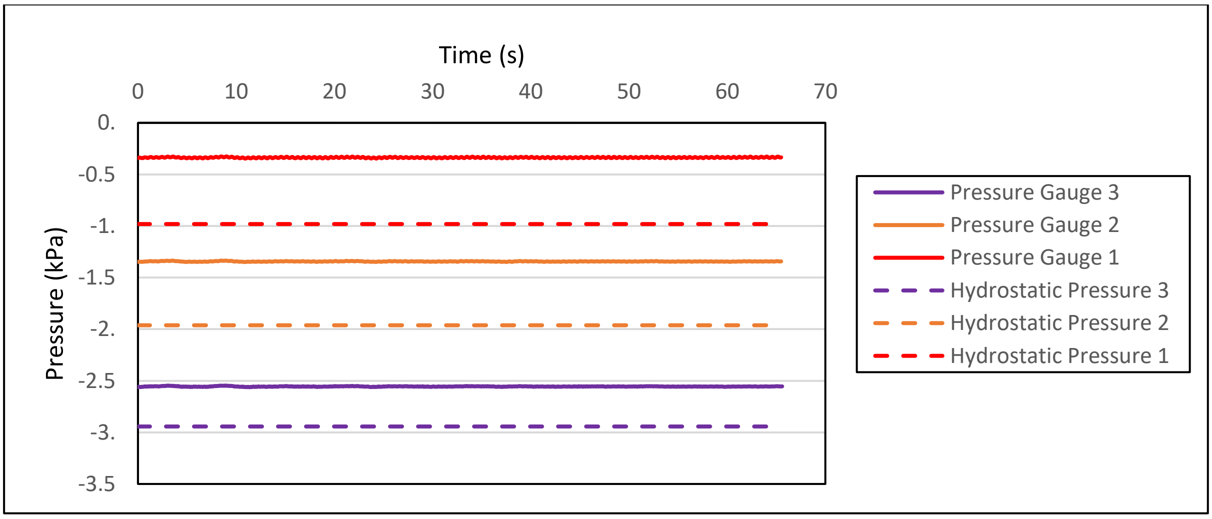
Appendix 6 - Pressure values, T = 1.5s H = 0.015m at water depth 0.2m. Case 6



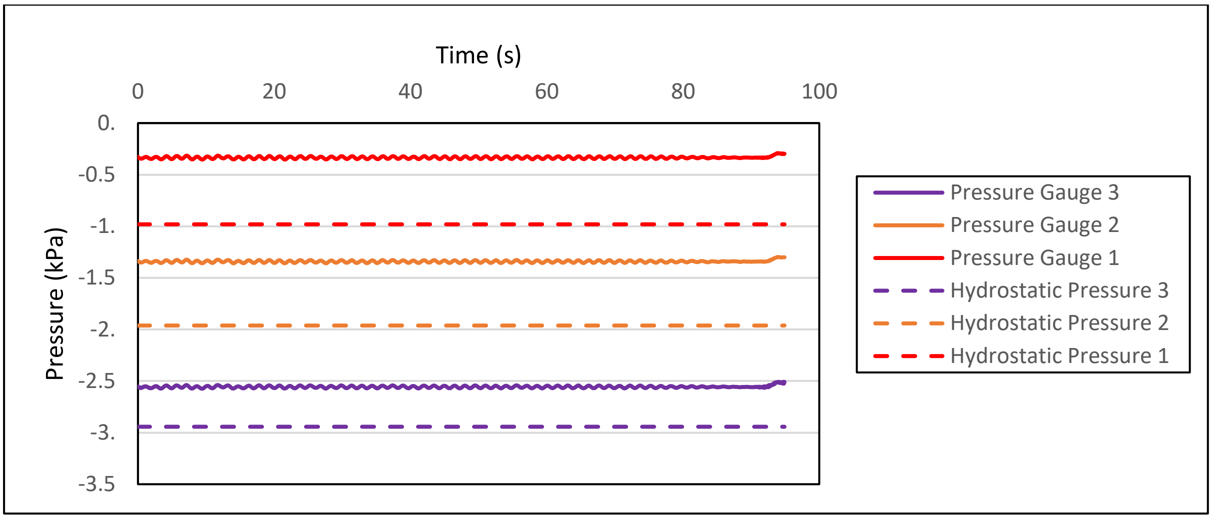
Appendix 7 - Pressure values, T = 3.25s H = 0.035m at water depth 0.2m. Case 9



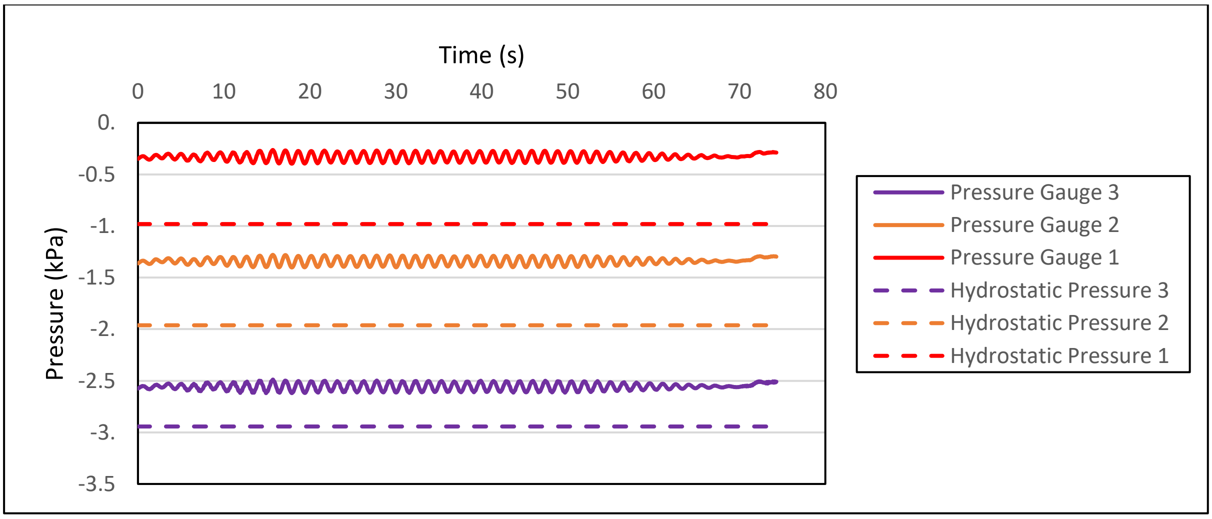
Appendix 8 - Pressure values, T = 0.55s H = 0.01m at water depth 0.3m. Case 2



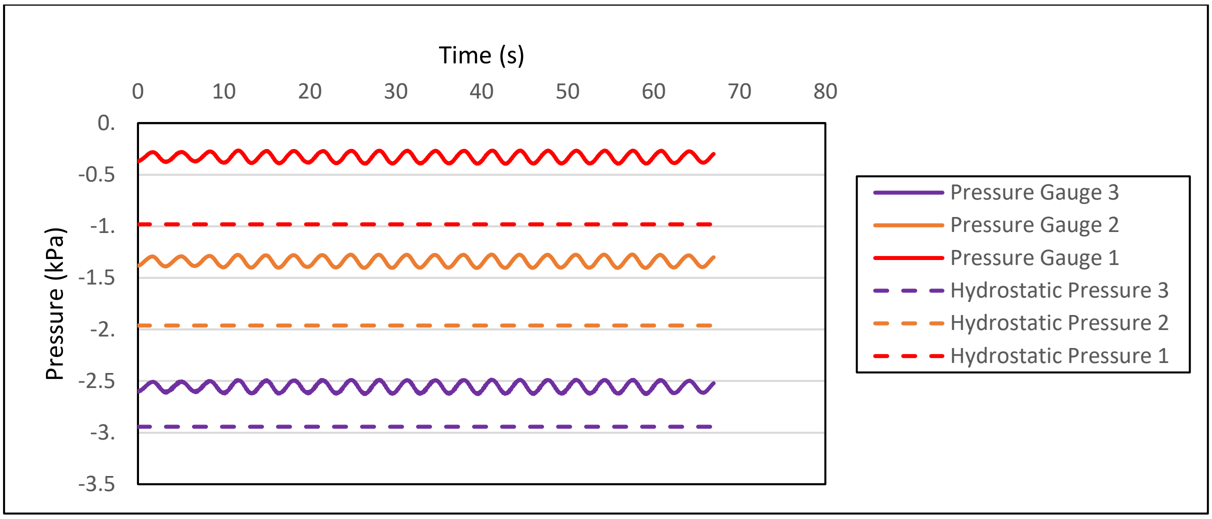
Appendix 9 - Pressure values, T = 0.55s H = 0.03m at water depth 0.3m. Case 3



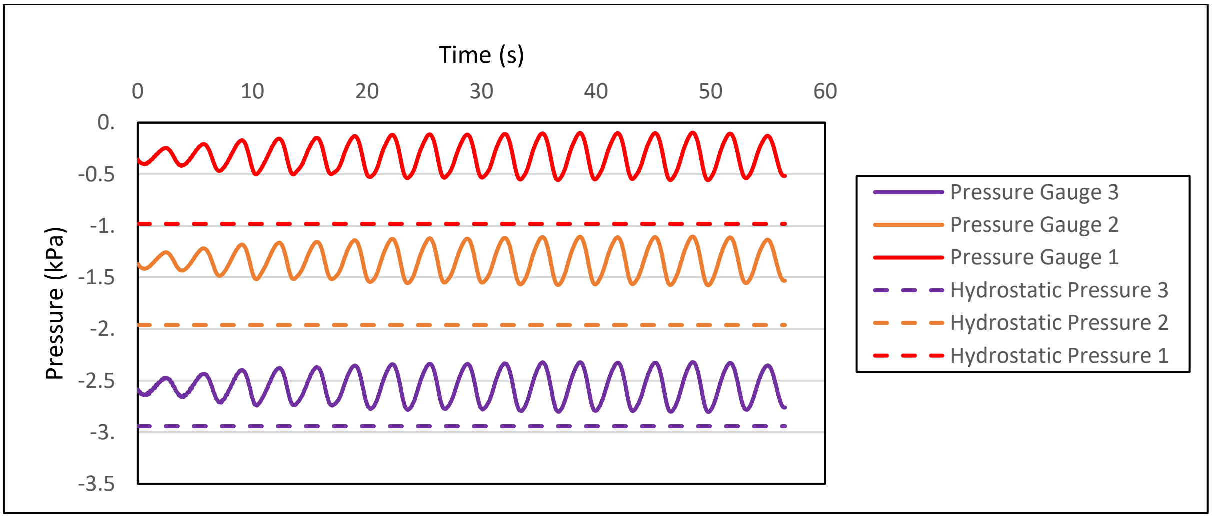
Appendix 10 - Pressure values, T = 1.5s H = 0.0075m at water depth 0.3m. Case 4



Appendix 11 - Pressure values, T = 1.5s H = 0.03m at water depth 0.3m. Case 6



Appendix 12 - Pressure values, T = 3.25s H = 0.0075m at water depth 0.3m. Case 8



Appendix 13 - Pressure values, T = 3.25s H = 0.035m at water depth 0.3m. Case 9

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