TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of civil engineering and architecture

ANALYTICAL AND EXPERIMENTAL MODELLING OF WAVE ATTENUATION PROPERTIES OF FLOATING WAVE BREAKER

UJUVKAI LAINETE SUMMUTUSVÕIME EKSPERIMENTAALNE JA ANALÜÜTILINE MUDELDAMINE

MASTER THESIS

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Tallinn 2021

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THESIS TASK

Student: Rasmus Paulus, 122390EAEI (name, student code)

Study programme, EAEI02/09 – Structural Engineering and Construction Management (code and title)

Supervisor(s): Docent, Kristjan Tabri, D.S.c, 5092585 (position, name, phone)

Thesis topic:

(in English) Analytical and experimental modelling of wave attenuation properties of floating wave breaker

(in Estonian) Ujuvkai lainete summutusvõime eksperimentaalne ja analüütiline mudeldamine

Thesis main objectives:

1. Determine wave transmission coefficient for Top Marine pontoons
2. Field-testing Top Marine pontoons and determine suitable method to analyse data from the field
3. Determine accurate formula(s) for predicting wave transmission coefficient for Top Marine pontoons

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Field-testing in Kihnu and Pärnu	31.12.2019
2.	Field data analysis	31.03.2020
3.	Kuressaare test pool data analysis	04.01.2021
4.	Completion of this thesis	11.01.2021

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PREFACE

This master's thesis has been written in collaboration with Top Marine OÜ. Silver Pütsep, from Top Marine, was helpful throughout the whole field-testing period. Top Marine provided transport to field-testing sites and helped to install the pressure gauges. The thesis topic was also proposed by Top Marine. The findings of the thesis are important for Top Marine to improve quality of floating solutions and would help them to expand to field that has few competitive firms. The author would like to thank Top Marine for the collaboration.

The author would like to thank his supervisor Kristjan Tabri, Tallinn University of Technology, School of Science, Department of Civil Engineering and Architecture Docent. Kristjan Tabri helped with MATLAB scripts, Kuressaare proof-testing and assisted in data analysis.

Also, the author would like to thank Rain Männikus, Tallinn University of Technology, School of Science, Department of Cybernetics, Junior Researcher. Rain Männikus assisted to develop the research problem and provided the necessary pressure gauges.

1. RESEARCH AREA

Breakwaters are widely used to provide shelter from wave action and are primarily designed for vessels in port and for port facilities. Breakwaters are also used to protect valuable habitats that are threatened by the sea. (d'Angremond, 2018)

Floating breakwater is good alternative solution for: (1) areas where foundation conditions are poor, (2) areas where water depth excesses 6 meters, (3) areas where water circulation and fish migration are important, (4) areas where ice formation is a problem, (5) areas with high tide ranges or (6) areas where breakwater layout has to change throughout the years (McCartney, 1985). Floating breakwaters are mainly used in small boat marinas that require protection from wave action (Christian, 2001). Wave heights and periods are restricted to 1.5 meters and 4 (s). Floating breakwaters are economically viable, easy to install and have a small ecological footprint (Christian, 2001; Cox & Beach, 2006).

Many different types of floating breakwater types have been developed from June 1944 (Koftis & Prinos, 2005). McCartney (1985) has described four main types of floating breakwaters: box, pontoon, mat and tethered float. Box type breakwater is box shaped and has been constructed of reinforced concrete modules. To make modules act as a single unit modules connection are flexible or pre- or post-tensioned. Modular and mooring connections are primary points of concern for box type breakwaters. Pontoon type breakwater consists of a deck and floating pontoons, usually has two pontoons for stability. Mat breakwaters modules are mostly made of tires and bound together with chains. Tethered float type consists of a float and a platform on seabed that is bond together with tether. (McCartney, 1985)

Floating structures use a pontoon structure that is anchored to the seabed through spud mooring lines or piles and connected to the shore by bridge or ramps. In small-craft marinas floating piers are most commonly used and include foam filled concrete floats, steel pontoons, or plastic encased foam filled pontoons joined and connected with a steel, aluminium, or timber frame and deck. Modular steel pontoon systems are also beneficial for marine construction. (Cairns, Carel, & Li, 2016)

The engineering and subsequent construction of the "Bombardon" floating breakwaters had an important impact in development of floating breakwater technology. The "Bombardon" floating breakwater was designed for a wave height of 3.3 meters and a wave period of 5.6 (s). "Bombardon" floating breakwater, were first built in early 1943 and theoretical analyses, hydraulic model testing, engineering design, construction, and field testing were completed in June 1944. "Bombardon" breakwater was destroyed by an unexpected storm with wave heights of 4.6 meters and wave periods of 8 (s). Conclusions drawn from "Bombardon" floating breakwater were important for future research and all subsequent floating breakwater development has reinforced these findings. (Headland, 2012)

Floating breakwaters remain to be a relevant topic. Interest in the study of the behaviour of floating breakwaters has increased due to the demand for new marinas and recreational harbours. The mobility of the structure and lower initial investment of floating breakwater is attractive to the designer. (Younes, Lafon, & Elchahal, 2008)

1.1. Research scope

The thesis focuses on two different products of Top Marine pontoons, HD 3.16x15m and HD 2.4x12 which are defined as pontoon type floating breakwaters. The main reason for the Top Marine floating breakwaters is to attenuate wave energy so destructive waves would not reach marina and cause any damage to vessels or marina. It is important that breakwaters match the marina requirements. Marina and vessels in it need to be protected from destructive forces of the sea. For economical and ecological reasons breakwaters can not be over designed, that can also affect water circulation and fish migration.

Predicting the wave transmission coefficient of floating breakwater is done by using different methods and formulas. In this thesis, it is determined through analytical and experimental modelling which of those methods is most accurate for the Top Marine products. The thesis focuses on Macagno's, Ruol's and Wiegel's wave transmission formula. The purpose of this thesis is to identify pontoons capability to attenuate wave energy by field testing two different Top Marine products.

1.2. Thesis structure

This thesis is divided into three phases from these, conclusion can be drawn.

First phase concentrates on floating breakwaters and wave theory. From first phase important acknowledge is drawn and used in further phases. The first phase includes paragraph 2.

(s) phase focuses on collecting data from field and experimentally modelling it. To model data that is collected from the field, zero crossing method along with OCEANLYZ toolbox must be acknowledged. Through paragraphs 3 and 4, (s) phase points are explained.

Third phase concludes of different wave transmission formulas to predict floating breakwater wave transmission coefficient value. Third phase also concludes field data analysis and shows which formula is most accurate for Top Marine pontoons. Third phase is called analytical modelling and is represented in paragraph 5.

After experimental and analytical modelling, a conclusion can be reached. Conclusion includes results of Top Marine pontoons capability to attenuate wave energy and give them knowledge about their product’s efficiency in the field.

2. FLOATING STRUCTURES AND WAVE PARAMETERS

2.1. Floating breakwaters

The main purpose of breakwaters is to protect a part of shoreline, a structure, a harbour or moored vessels from extreme incident wave energy. Most fixed and floating breakwaters are passive systems. In other words, no energy is produced by the breakwater to achieve wave attenuation. Through breakwater, the incident wave energy is either transmitted, reflected, dissipated, or subjected to a combination of these systems. Fixed breakwaters provide a higher degree of protection than floating breakwaters, but fixed breakwaters are more expensive to construct. (Hales, 1981)

Floating breakwaters provide less protection, but on the other hand, are less expensive and the construction period is much shorter, compared to the fixed-type breakwater (Hales, 1981). The interference of a floating breakwater with shore processes, biological exchange and sea water circulation is minimal, and also has ecological advantages of sediment transport beneath the structure (Hales, 1981; Cho, 2016). Floating breakwaters are perceived to be lower cost structures that have great multiple-use potential (Reeve, Chadwick, & Fleming, 2018). The planform layout and location can be easily changed to accommodate changes in either seasonal or harbour long-term growth patterns (Hales, 1981). Floating breakwater can be easily placed on soft bottom ground (Cho, 2016), and their cost is not dependent on the depth of water or the tidal range (Reeve, et al,.2018).

The design of a floating breakwater system must be carefully matched to the site conditions, and also take account of infrequent storms that may appear (Hales, 1981). Usually, floating breakwater applications are for short-period wind waves, or boat wake protection at semi sheltered areas in estuaries, reservoirs, lakes and rivers (McCartney, 1985). A major disadvantage is that floating breakwaters move in response to wave action, and because of that, floating breakwaters are more prone to structural-fatigue problems (Hales, 1981). For these reasons, it is important for Top Marine that their products are efficiently designed.

2.1.1. Pontoon breakwaters

The most common type of floating breakwater is a single pontoon type. Pontoon type floating breakwater is generally made of composite material of reinforced concrete and plaster in cuboid shapes. In most cases, pontoon width is about 8 m and the draft ranges vary from 1.5 m to 4 m. (Ji, Chen, Cui, Yuan, & Incecik, 2015) Floating breakwaters based on pontoons are designed to reduce the wave transmission coefficient (He, Huang, & Law, 2012). In this thesis, measured data is converted to wave transmission coefficient and then it is compared to known formulas.

Unlike bottom-fixed breakwaters, the hydrodynamic interactions between the incoming waves and the floating breakwater are complex. The wave energy being partially reflected, partially transmitted beneath the floating breakwater and partially dissipated. At the same time, the incident waves energize the motion responses of the floating breakwater, which in turn acts as a wave generator, radiating waves away from floating breakwater to both its sides. Because of that, the total transmitted waves include two elements: the transmitted incident waves passing underneath, and the radiated waves propagating to the leeward side of the breakwater. The wave transmission characteristic has an important functional role of a breakwater towards the objective of wave protection. (He, et al,.2012)

2.2. Regular waves

Wave theories describe some phenomena well under certain conditions that satisfy the assumptions made in their derivation, but may fail to describe other phenomena that are in conflict with those assumptions. Theory has to be developed carefully to ensure that the wave phenomenon of interest is described reasonably well by the developed theory. Shore protection design depends on the ability to predict wave surface profiles and water motion, and on the accuracy of such predictions. (Demirbilek & Vincent, 2002)

According to Demirbilek & Vincent (2002) a progressive wave may be represented by the variables x (spatial) and t (temporal). Simple and compact way to represent them is by their combination (phase) that is defined as:

$$\theta = kx - \omega t \tag{2.1}$$

where

$\theta -$ phase

$k -$ wave number

$\omega -$ angular frequency, Rad/s

$t -$ time, s

$x -$ distance, m

Phase values vary between 0 and 2π. Figure 2.1 defines terms of elementary, sinusoidal and progressive wave, and also shows parameters that define progressive wave as it passes a fixed point in the ocean.

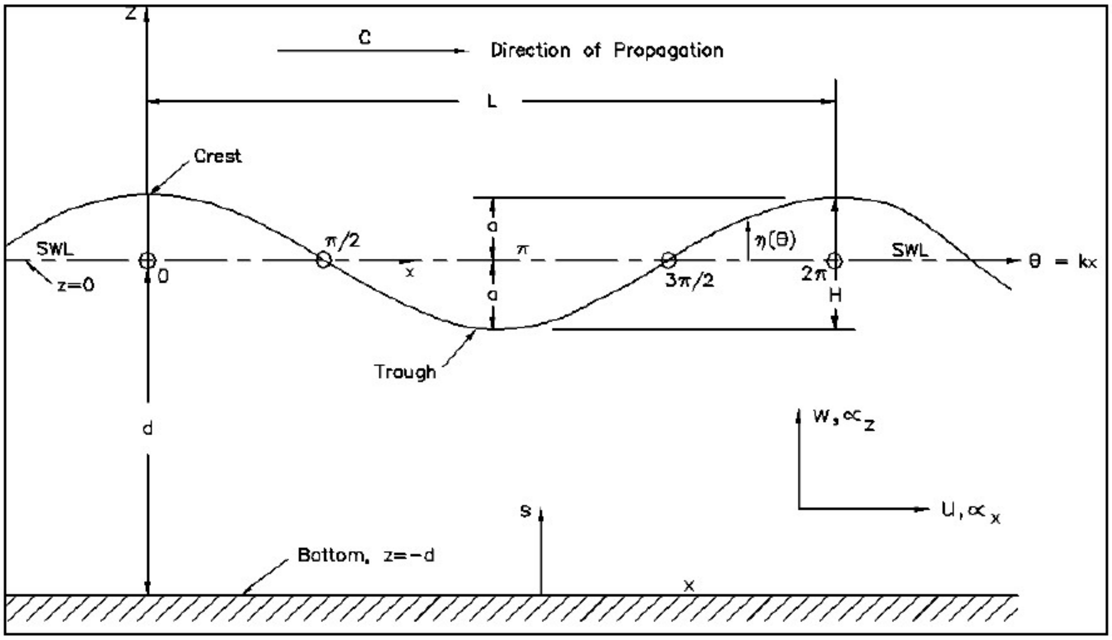

Figure 2.1 Definition of terms (Demirbilek & Vincent, 2002)

Periodic wave can be characterized by the wave height H, wavelength L and water depth d. The highest point of the wave is the crest and lowest point is the trough (Coastal Engineering Research Center, 1984). See Figure 2.1. Wave amplitude for linear or small-amplitude waves is equal to the height of the crest above the still-water (SWL) and the distance of the trough below the SWL (Demirbilek & Vincent, 2002):

$$a = \frac{H}{2} \tag{2.2}$$

2.3. Linear wave theory

The most elementary wave theory is the linear wave theory. In this thesis it is important to understand the basics of linear wave theory to convert our test results into wave heights. Linear wave theory is easy to apply, and gives approximation of wave characteristics for a wide range of wave parameters. (Demirbilek & Vincent, 2002; Holthuijsen, 2007)

Stated by Demirbilek and Vincent (2002), there were many assumptions made in developing a linear wave theory. Some assumptions that are important for this thesis are:

- The fluid is homogeneous and incompressible; the density ρ is a constant.
- Surface tension can be neglected.
- Coriolis effect due to the earth's rotation can be neglected.

- Pressure at the free surface is uniform and constant.
- The fluid is ideal or inviscid (lacks viscosity).
- Waves are plane or long-crested (two-dimensional).
- The bed is a horizontal, fixed, impermeable boundary, which implies that the vertical velocity at the bed is zero.

The pressure under water consists of two main components, first one is hydrostatic pressure (is independent of the presence of the wave) and the (s) one is pressure that is caused by waves. Using phase definition from equation 2.1, pressure under water can be described as:

$$p = -\rho g z + \rho g a \frac{cosh[k(d+z)]}{\cosh{(kd)}} \sin\theta \qquad (2.3)$$

where

$p -$	pressure, Pa
$\rho -$	Density of water, kg/m^3
$g -$	gravity acceleration, m/s^2
$z -$	depth of the logger under still water level, m
$d -$	water depth, m

In the equation (2.2) first part is hydrostatic pressure component and (s) part represents the wave-induced pressure. (Holthuijsen, 2007)

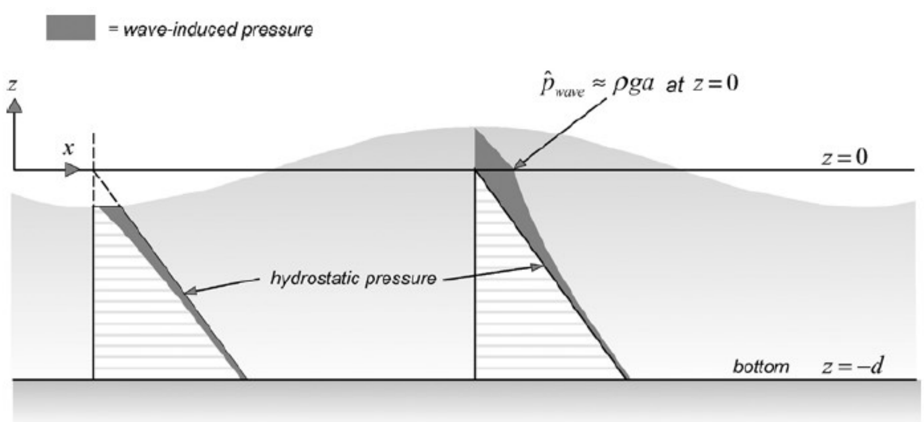

Figure 2.2 Hydrostatic pressure under wave (Holthuijsen, 2007)

Pressure sensors that were used for this thesis measurements sat on seabed. Because of that $z = -d$ and equation (2.1) can be written as:

$$p = -\rho g z + \rho g a \frac{cosh[k(d+z)]}{\cosh(kd)} \sin\theta \tag{2.4}$$

According to Kuo & Chiu (1994), relationship between the wave pressure and wave height allows us to transfer measured data to wave height. This relationship can be described as:

$$\frac{\eta_p}{\rho g} = K_p \eta \tag{2.5}$$

To prevent misunderstanding because of different symbols, equation 2.3 can be written as:

$$H = \frac{H_p}{K_p} \tag{2.6}$$

where

$$K_p = \frac{cosh[k(d+z)]}{cosh(kd)} \tag{2.7}$$

Because $z = -d$ equation 2.5 can be written as:

$$K_p = \frac{1}{cosh(kd)} \tag{2.8}$$

where

$H -$ wave height, m

$H_p -$ subsurface pressure head, m

$K_p -$ pressure response factor

According to Kuo & Chiu (1994), previous studies had shown that relationship between wave height and wave pressure can not be correctly predicted solely on the basis of linear theory and empirical coefficient N is introduced in effort to improve this deciation. In this thesis this coefficient is not used because of its complicity.

3. METHODOLOGY

3.1. Research method

In this thesis, data is collected from field using loggers equipped with pressure sensor. Loggers collected pressure data from field for 1-1.5 months. Data was collected from two different places and both places had different pontoons. Idea was to get pressure data from leeward and seaward side of the pontoon and then transfer the results to wave height. Comparing measured wave height shows how much wave height decreases going through the pontoon. Thus, the wave transmission coefficient can be calculated.

3.1.1. Pressure gauge

The particular device was recommended by Rain Männikus, D.Sc., who has used the device for similar reasons. Pressure data was measured using pressure gauges described in Table 3.1 and Figure 3.1. The pressure is measured by a pressure sensor MS5837 at a frequency of five Hertz and saved on a Secure Digital (SD) memory card with a capacity of eight gigabyte. The power supply can be fixed in two ways, 6xD-cell battery back or CR1220 for real time clock. For this thesis 6xD-cell battery back is used.

For each hour, logger Adafruit Adalogger M0 creates a data file. In the file’s name is described logger’s name, date and time when pressure sensor started collecting data. There are 3 columns and 18000 rows in each file. For this thesis, (s) data column is required because it represents measured pressure in mbar. Rows represent measured pressure after every 0.2 (s).

Table 3.1. Description of pressure gauge

Long-term continuous pressure logger	
Logger	Adafruit Adalogger M0
Pressure sensor	MS5837
Maximum pressure	2 bar
Sampling rate	5 Hertz
Capacity	8 GB
Battery	6xD-cell battery back, CR1220 for real time clock
Working time	1 month
Weight	1.4kg (battery pack 0.85kg)
O rings	NBR9x1.8-1pc, NBR16x2-1pc, NBR70x2-4pc

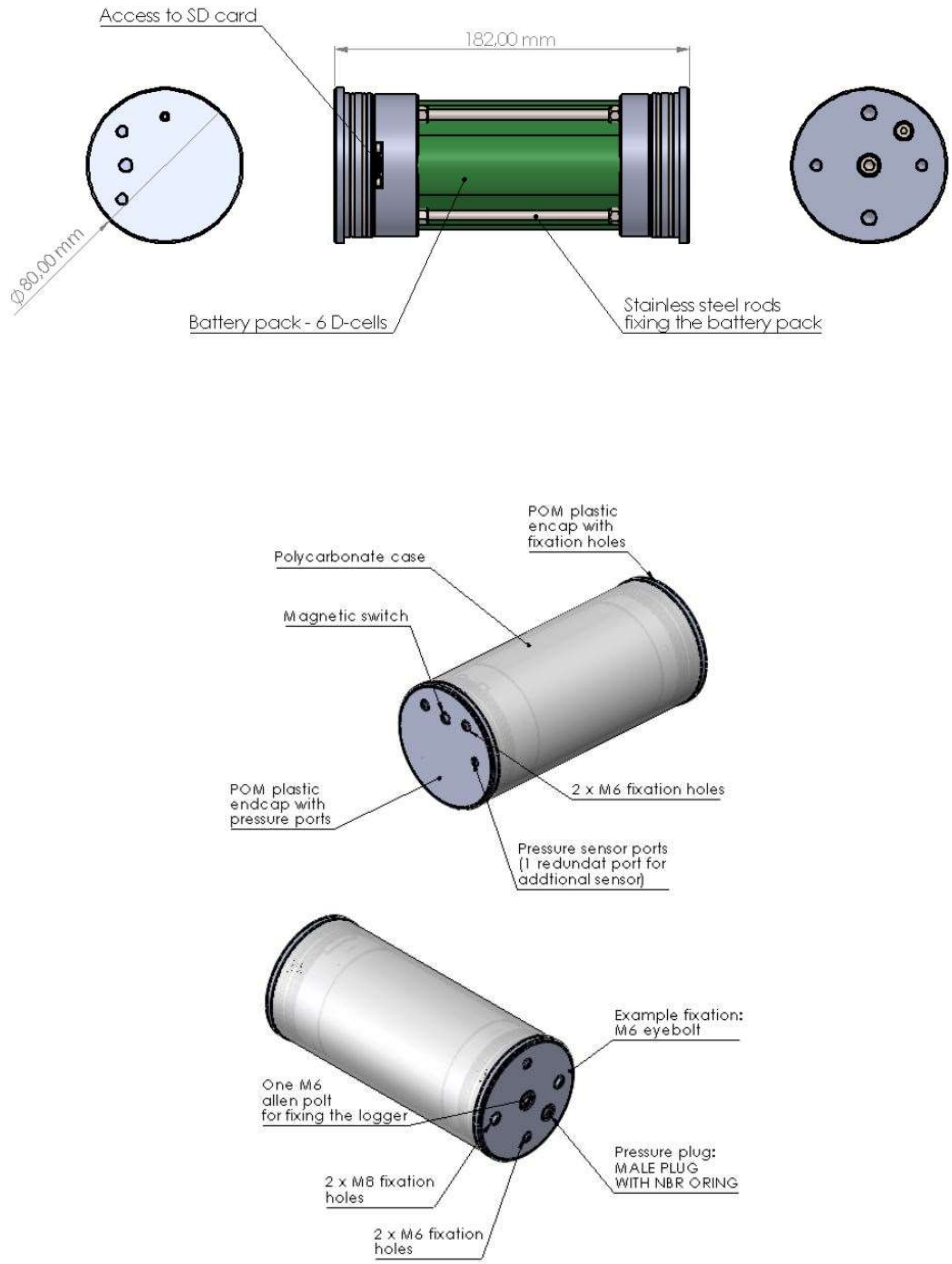

Figure 3.1. Logger schematics

Before using this device, some preparations had to be done. Due to the fact that the device is light, extra weight had to be added so it would sit on seabed. Devices were wrapped in bubble wrap and then mounted to concrete blocks. The purpose of wrapping devices in bubble wrap is to attenuation damage done to device by waves moving the device. Using bubble wrap was suggested by Rain Männikus, who had experience with this kind of field tests. See Figure 3.2.

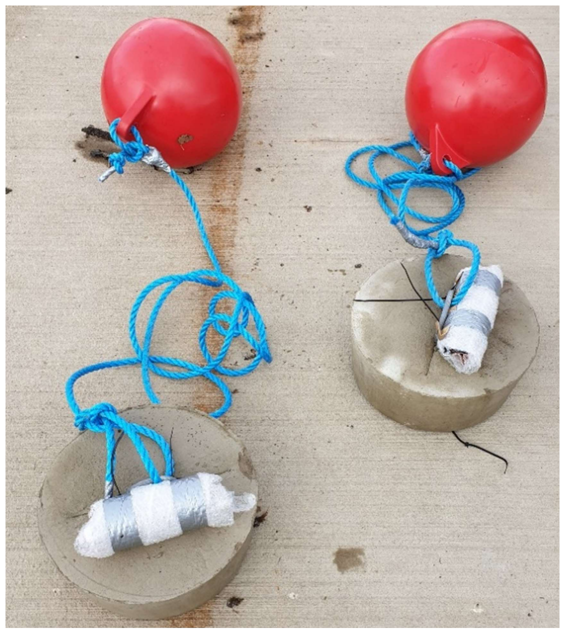

Figure 3.2. Pressure gauges

3.1.2. Location

For this thesis, the pressures were measured at two geographical locations close to Kihnu and Pärnu using four devices. Setup for both places was the same. The devices sat on the seabed and approximately 4 meters from breakwater landside and seaside, see Figure 3.3. Halfway through the testing period, divers went to check on the devices. According to the divers the seabed is muddy in both of the locations. In these locations, Top Marine pontoon HD 2.4x12m and HD 3.16x15m were used. These are both pontoon type breakwaters. Top Marine pontoons include concrete floats that are anchored to the seabed through mooring lines and are connected to the shore by ramp.

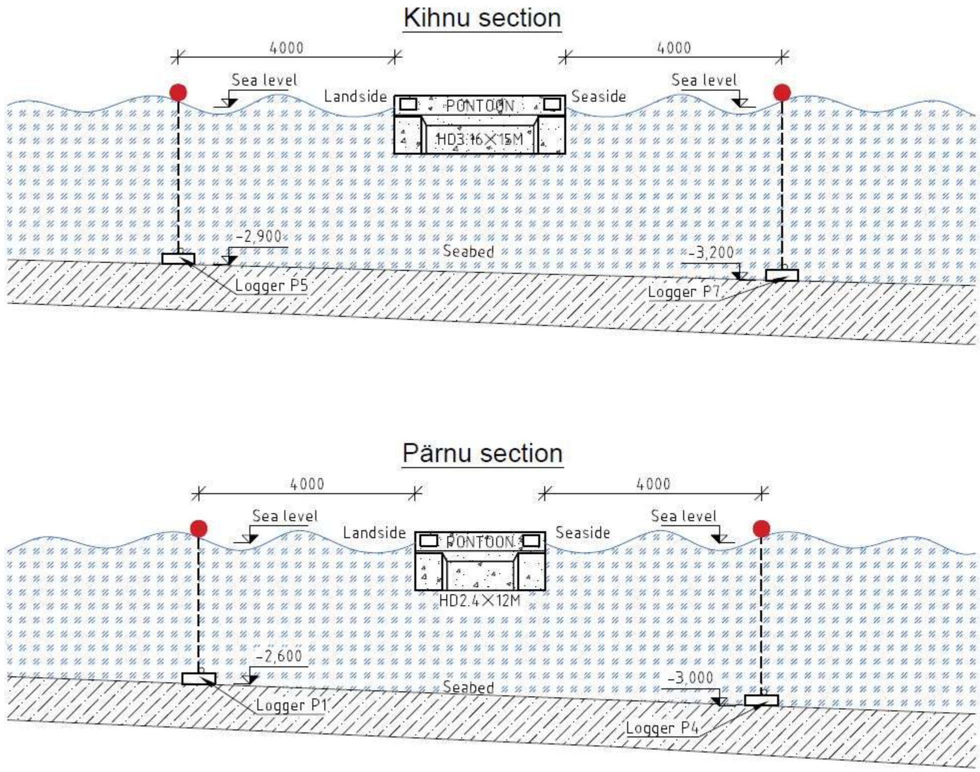

Figure 3.3. Cross section of measuring's.

Pärnu marina had Top Marine pontoon HD 2.4x12m that was the first test subject for this thesis. Field-testing period in Pärnu was 10.10-25.11.2019. Pärnu marina is located in the mouth of the river (see Figure 3.5) and water depth in testing site is 2.6-3.0 meters. Thus, it can be implied that the pressure measuring is done in shallow waters. Pärnu marina is not very open to waves. The only direction that has potential space for waves to grow is the southwest side of marina. During the field-testing period, it was navigation off season in Pärnu marina. Therefore, there were not many waves generated by vessels. In conclusion, the waves in that site had to be mainly wind generated.

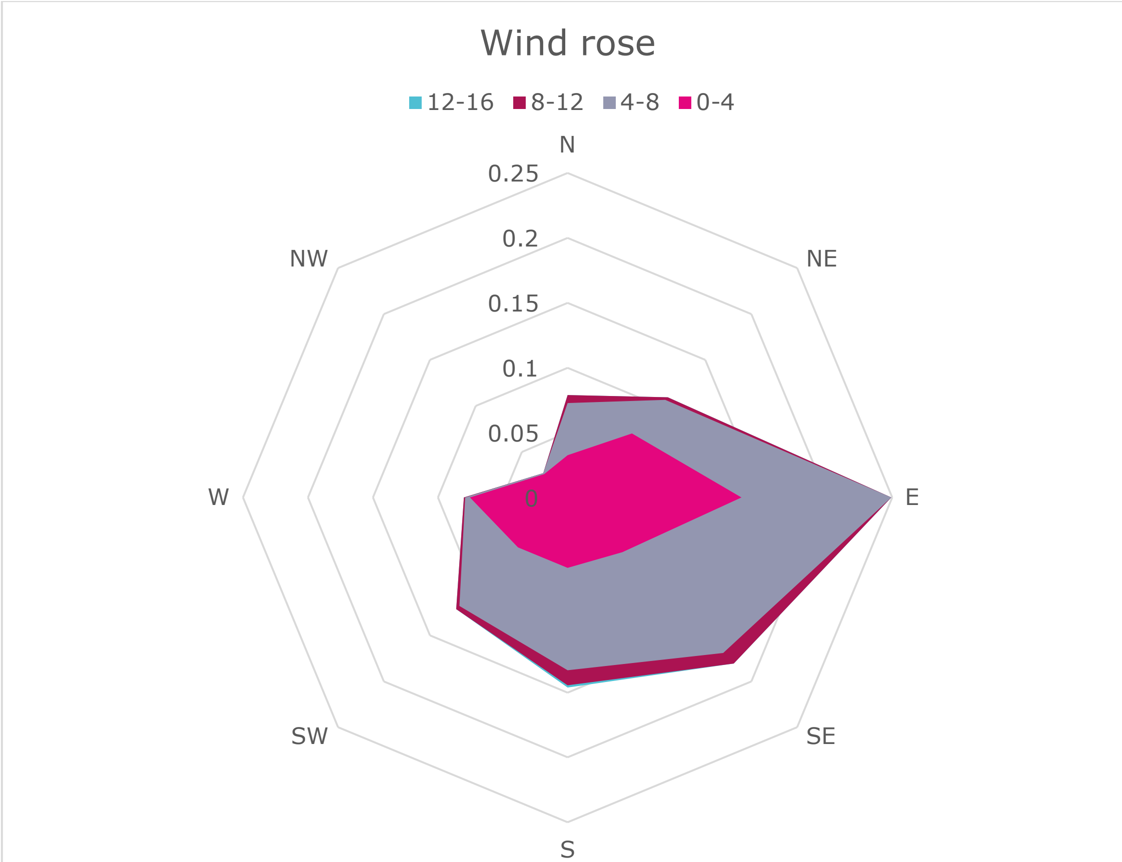

Figure 3.4. Pärnu's wind rose

To get a clear understanding of winds, the local observatory was asked for wind measurements that matched the field test period. The local observatory is near to the testing site and because of that, the wind parameters should be the same in both places. Based on the measurements, a wind rose was made (see Figure 3.4). Wind rose shows that main wind direction was east and wind speed was mainly between 4 m/s and 12 m/s. For best results, wave direction should be perpendicular with breakwater longitudinal side. For wave direction to be perpendicular with breakwater longitudinal side, wind direction should have been between north and northeast. Logger P4 was open to sea and logger P1 was protected by pontoon, see Figure 3.5.

Figure 3.5. Satellite image of Pärnu marina.

In Kihnu's port, Top Marine pontoon HD 3.16x15m was used and was the (s) measuring subject for this thesis. Field-testing period in Kihnu was 16.10-30.11.2019. Kihnu port is located at the east side of the Kihnu island (see Figure 3.7) and the water depth in testing site is 2.9-3.2 meters. Kihnu port is open to southwest and west direction waves. During field testing period, it was also navigation off season in Kihnu marina. However, a ferry docks two times a day near the test site that also generates waves. Since ferry does generate waves but only for a short period of time, in Kihnu waves are mainly generated by winds.

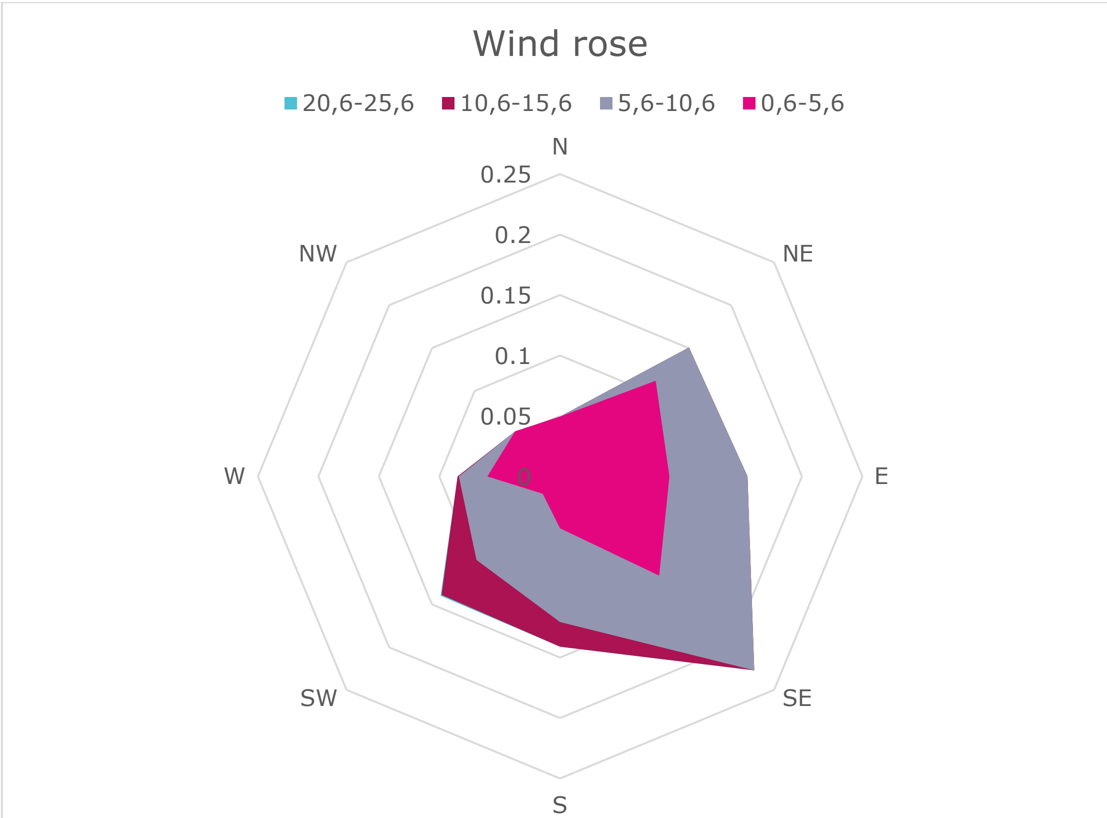

Figure 3.6. Kihnu's wind rose

To get a clear understanding of winds, the local observatory was also asked for wind measurements that matched the field test period. Based on the measurements a wind rose was made (see Figure 3.6). During measuring period main wind direction was southeast and wind speed was mainly between 5.6 m/s and 15.6 m/s. For wave direction to be perpendicular with breakwater longitudinal side wind direction should be between northeast and east. Kihnu observatory is located on the other side of the island. There is a large forest between the port and the observatory that may have lowered the measured wind speed. In Kihnu, loggers P5 and P7 were used. P5 was on landside and protected by breakwater and logger P7 was on open to the sea, see Figure 3.7.

Figure 3.7. Satellite image of Kihnu port.

3.1.3. Field-testing

Field-testing consist of 3 parts: first part is to install the devices; (s) part is to collect them, and lastly, to collect data from devices. In the first part, devices had to be installed approximately 4 meters from breakwater for the boat had to be used. After loading devices to the boat and using measuring tape to measure 4 meters from breakwater, devices were dropped into the water. Before collecting them, devices had to be under the water for 1-1.5 months. After that period was over, the devices were taken out. Last part was to get data from SD cards and start with experimental modelling.

4. EXPERIMENTAL MODELLING

4.1. Raw data analysis

MATLAB is used to transfer measured pressure data to wave height values and after that to other wave parameters. After 1-1.5 months of field-testing for each logger, there is about 1000 data files with extension.txt that needs to be converted. For data conversion MATLAB script is used. In this thesis, data that is converted directly from measured data is called raw data. Raw data had to be checked that it is logical and can be used for this thesis purpose. We determined that if pressure values are lower in protected side higher in seaside of the breakwater, then measured data is logical.

4.1.1. Raw data from Pärnu

Firstly, data from Pärnu was analysed, see Figure 4.1. Pressure values from both loggers, P1 and P4 are similar and almost the same. Logger P1 was located at the protected side of the breakwater, but the values are higher than values from logger P4 that was located at the sea side of the breakwater.

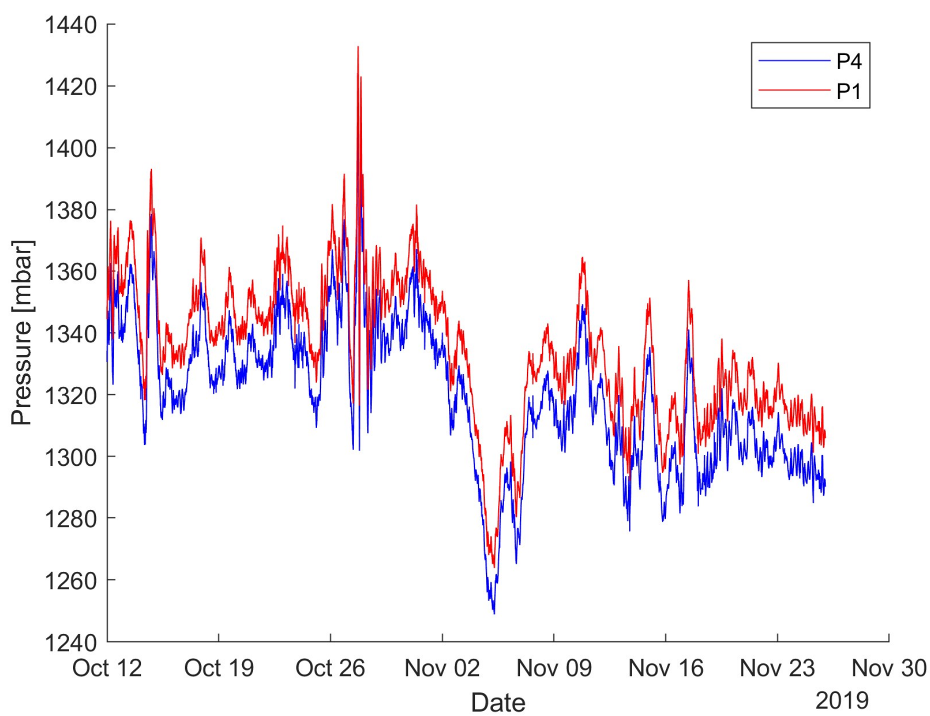

Figure 4.1 Raw data from Pärnu

Believing Figure 4.1, it can be said that the biggest waves were on 27th of October. That date also matched the windiest date in field-testing period. On that day, maximum measured wind speed was 25,1m/s and wind directions were between northwest and north. With that direction, wind would be blowing from land to river and there would not be enough space for wind to generate waves. The wind direction was the same as the breakwaters longitudinal side. Fortunately, Pärnu marina has video surveillance that covered the breakwater where field-testing was done. After looking at the surveillance video, conclusion was reached that assumptions made on wind direction were correct. Waves were low and waves direction was the same as breakwater longitudinal side. Pärnu marinas Captain said that waves heights were low on field-testing period. Measured data from Pärnu does not fulfil the purpose for this thesis and is used in thesis only for complementary information.

4.1.2. Raw data from Kihnu

(s)ly, data from Kihnu was analysed, see Figure 4.2. Unlike Pärnu's data, pressure values from loggers P5 and P7 are different. Logger P5 was located at the protected side of the breakwater and the values are lower than values from logger P7, that was located at the sea side of the breakwater.

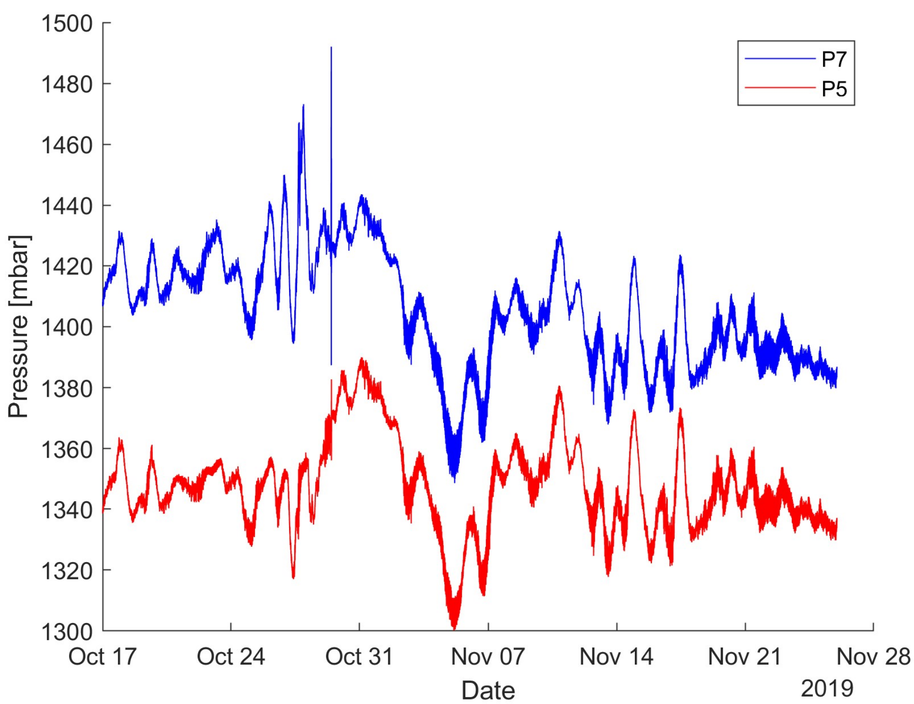

Figure 4.2. Raw data from Kihnu

Based on Figure 4.2, it can be said that breakwater did attenuate waves because of the pressure drop that happens when wave travels trough breakwater. P5 and P7 graphs are the same shape throughout the whole field-testing period and it gives confidence that, the raw data is correct. Measured data from Kihnu fulfils the purpose for this thesis, and wave parameters can be calculated.

4.2. Ocean Wave Analysing Toolbox

Ocean Wave Analysing toolbox, shortly OCEANLYZ, is a toolbox for analysing the wave time series data collected by sensors in open body of water such as ocean, sea, and lake or in a laboratory. In this thesis, MATLAB is used to run this toolbox. This toolbox contains different functions and each one of these functions is suitable for a particular purpose. In this toolbox, both spectral and zero-crossing methods are offered for wave analysis, and in thesis, zero-crossing method is used. Using this toolbox, many different wave parameters can be calculated, such as zero-moment wave height, significant wave height, mean wave height, peak wave period and mean period. This toolbox is very suitable for this thesis because it corrects and takes into account for the pressure loss in the water column for data collected by a pressure sensor. This toolbox can also separate wind sea and swell energies and reports their properties, but in this thesis, it has not been used.

4.2.1. Zero-crossing method

In zero-crossing method, time series data needs to be quality controlled, and then be split into a series data bursts before it can be analysed. Measured wave data must be of sufficient length to contain several hundred waves for the calculated statistics to be reliable (Demirbilek & Vincent, 2002). In order to evaluate the wave heights, the measured data has to be quality controlled and discretized into so-called bursts of equal durations. In this particular case getting the most eligible data. The duration of single burst is 10 minutes and consists of 3000 data points (10x60x5=3000). After, the wave data is evaluated, split into a series of bursts, de-trended and verified to be stationary, then it becomes ready for wave analysis. One method to explore a wave data is to analyse a time series in the time domain. For that purpose, wave data in each de-trended burst is separated into a series of single waves. To separate waves from each other, each wave is defined by two successive points, where at both points, a water surface elevation crosses a zero line in the same direction. (Karimpour, 2018)

Zero-crossing technique consists of two methods, zero-upcrossing method and zero downcrossing method. In zero-upcrossing method, a wave is defined when the surface elevation crosses the mean water level (MWL) upward and continues until the next crossing point. It means that, each wave is defined between two successive points where both are crossing a horizontal zero level upward. In zero-downcrossing method, a wave is defined by the downward crossing of the zero-line by the surface elevation. It means that, each wave is defined between two successive points where both are crossing a horizontal zero level downward. See Figure 4.3. (Demirbilek & Vincent, 2002; Karimpour, 2018)

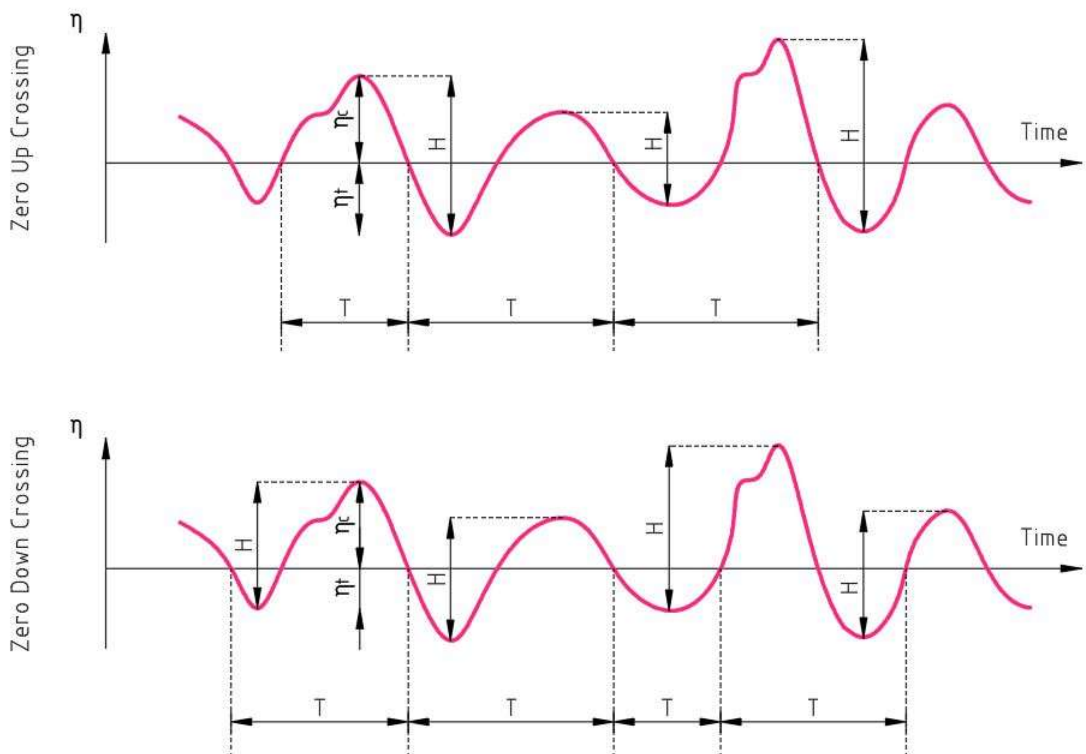

Figure 4.3. The zero-crossing method.

In Figure 4.3, top graph shows a zero up crossing method and bottom graph shows a zero down crossing method (Karimpour, 2018).

The zero-crossing wave height can be defined as difference of water surface elevation of the highest crest and lowest trough between successive zero-crossings. Wave height definition depends on the choice of trough occurring before or after the crest. Event between two successive zero-upcrossings will be identified as wave, wave periods and heights are defined accordingly. Depending on the chosen method, zero upcrossing or zero downcrossing, there can be differences between the definitions of wave parameters. (Demirbilek & Vincent, 2002)

4.3. Measured wave height

Characteristic wave height may be defined in several ways, this thesis uses mean wave height Hertz, significant wave height H_s and maximum wave height H_{max}. Using OCEANLYZ toolbox these parameters are calculated. Equation (4.1) is used for significant wave height Hertz calculation.

$$H_s = \frac{1}{\frac{N}{3}} \sum_{i=1}^{N/3} H_i \tag{4.1}$$

where N is the number of individual wave heights H_i in a record ranked from highest to lowest. As said before, this toolbox is used with MATLAB, for mean wave height Hertz function mean is used in MATLAB and for maximum wave height H_{max} function max is used. (Demirbilek & Vincent, 2002)

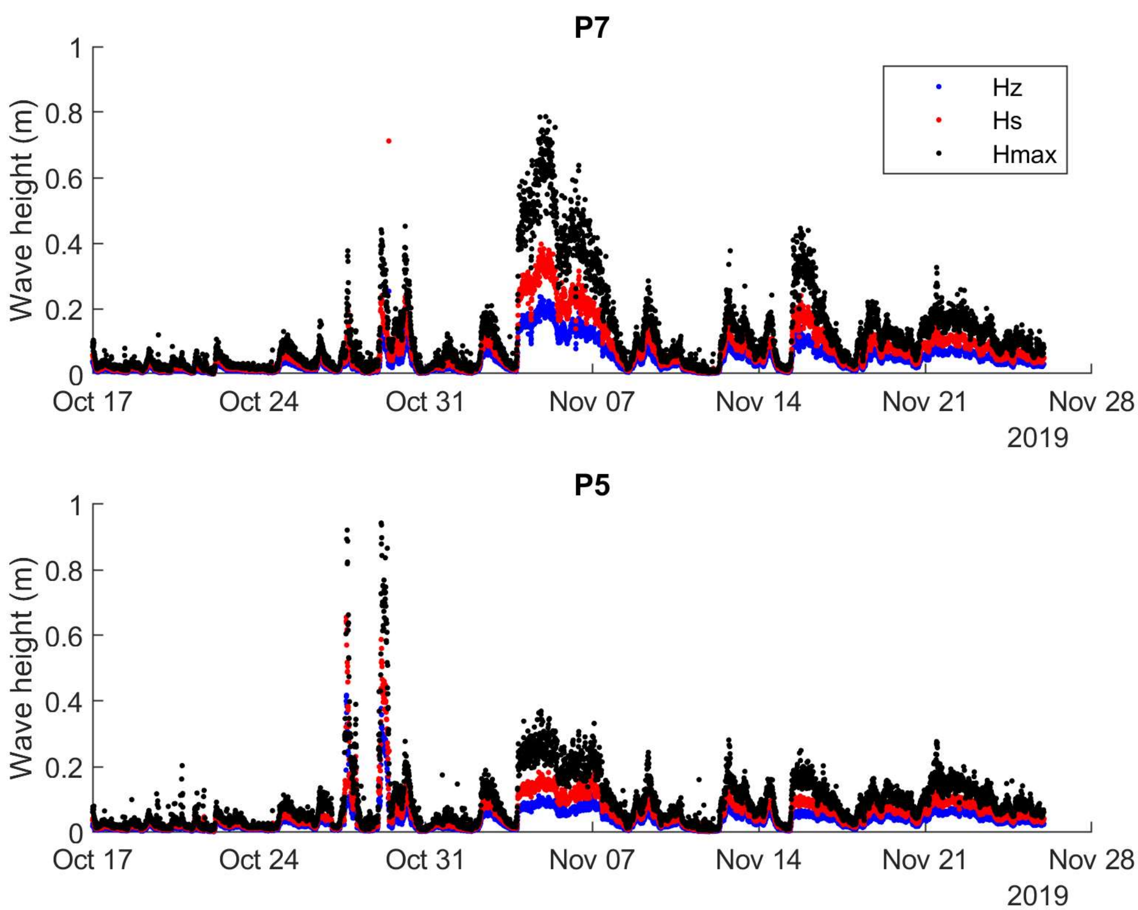

Figure 4.4. Kihnu wave height parameters.

Figure 4.4 represents wave height parameters in Kihnu. Wave height parameters were calculated for time interval of 10 minutes. Wave heights were lower than expected, but there is a difference between wave heights in either side of the breakwater and therefore this data can still be used. High spikes between 24th of October and 31th of October is cause by divers who went to check on devices and had to move them to their original location. Except for that period maximum wave height in field-testing period was 0,8m.

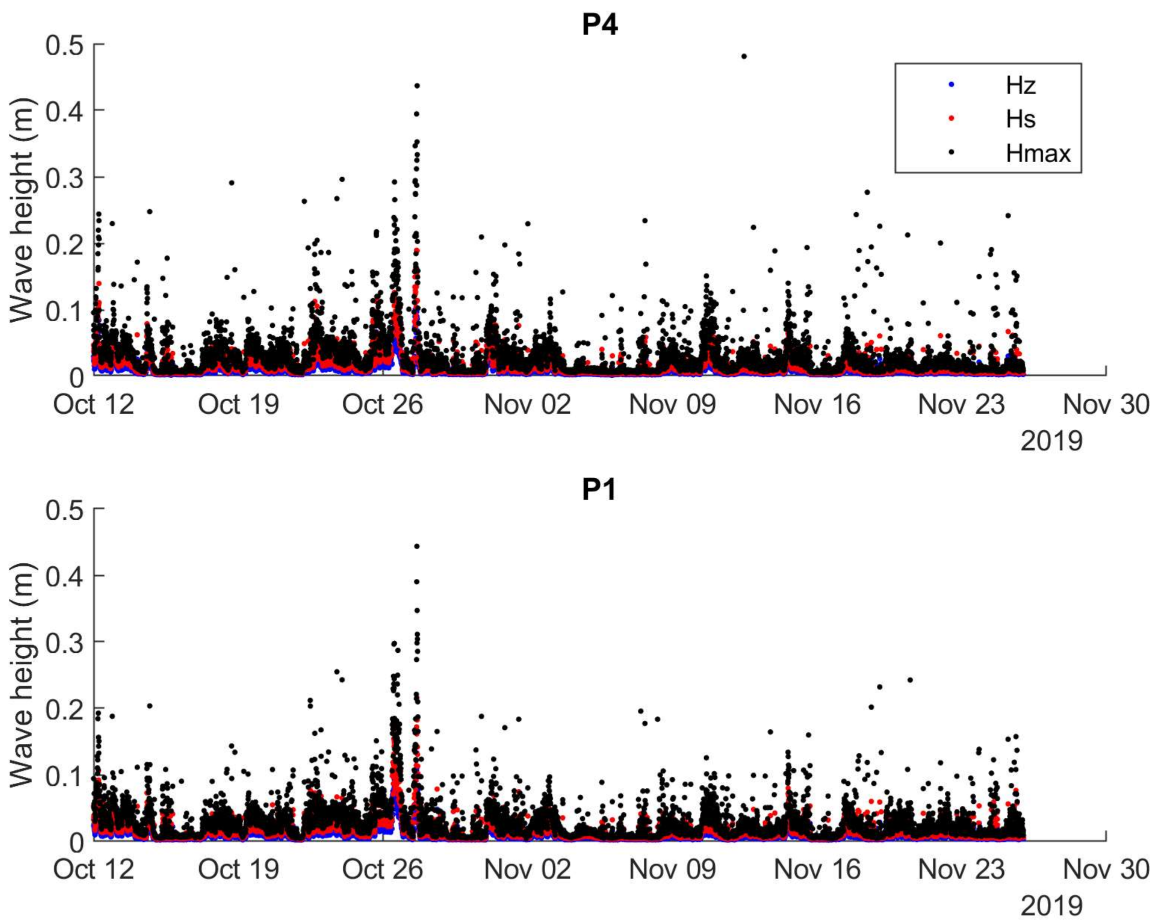

Figure 4.5. Pärnu wave height parameters

Figure 4.5 represents wave height parameters in Pärnu and is calculated similarly to Kihnu for time interval of 10 minutes. As expected, this data can not be used because wave height parameters are basically the same in both sides of the breakwater. In Pärnu, maximum wave height in field-testing period was 0.45m.

4.4. Transmission coefficient

In this thesis, the performance of floating breakwater is defined by the amount of wave attenuation. When waves interact with a structure, part of energy will be dissipated, another part will be reflected. Also, part of the energy may be transmitted past the structure. That depends on the structure geometry. If the crest of the structure is submerged, the wave will simply transmit over the structure. But when crest of the structure is above the still-water, the wave may generate a flow of water over the structure that, regenerates waves on the other side of the structure. Wave transmission is commonly defined by a wave transmission coefficient. (Holthuijsen, 2007)

$$C_t = \frac{H_t}{H_i} \tag{4.2}$$

where

$C_t -$ transmission coefficient

$H_t -$ transmitted wave height (protected side wave height), m

$H_i -$ incident wave height (Sea side wave height), m

The transmission coefficient C_t has the range $0 < C_t < 1$, for which a value of 0 implies no transmission (high, impermeable), and a value of 1 implies complete transmission. Value 1 can mean two things, there is no breakwater or wave height matches on both sides. As seen on Pärnu's, wave heights were low and wave direction matched the longitudinal side of the breakwater. Factors that control wave transmission depends on crest height and width, structure slope, material (permeability and roughness), tidal and design level, wave height, and period. (Pilarczyk, 2010)

Transmission coefficient, equation (4.2), is presented for the whole measurement period in Figure 4.6 and Figure 4.7. Wave height values are added to the figures for complementary information. Reasonable transmission coefficients can only be obtained for higher wave heights, as the division of small wave height can lead to unrealistic damping rations (>1) with a large amount of measuring noise. Therefore, only the time periods with higher wave heights are selected for a more detailed analysis of transmission coefficient, see Figure 4.8.

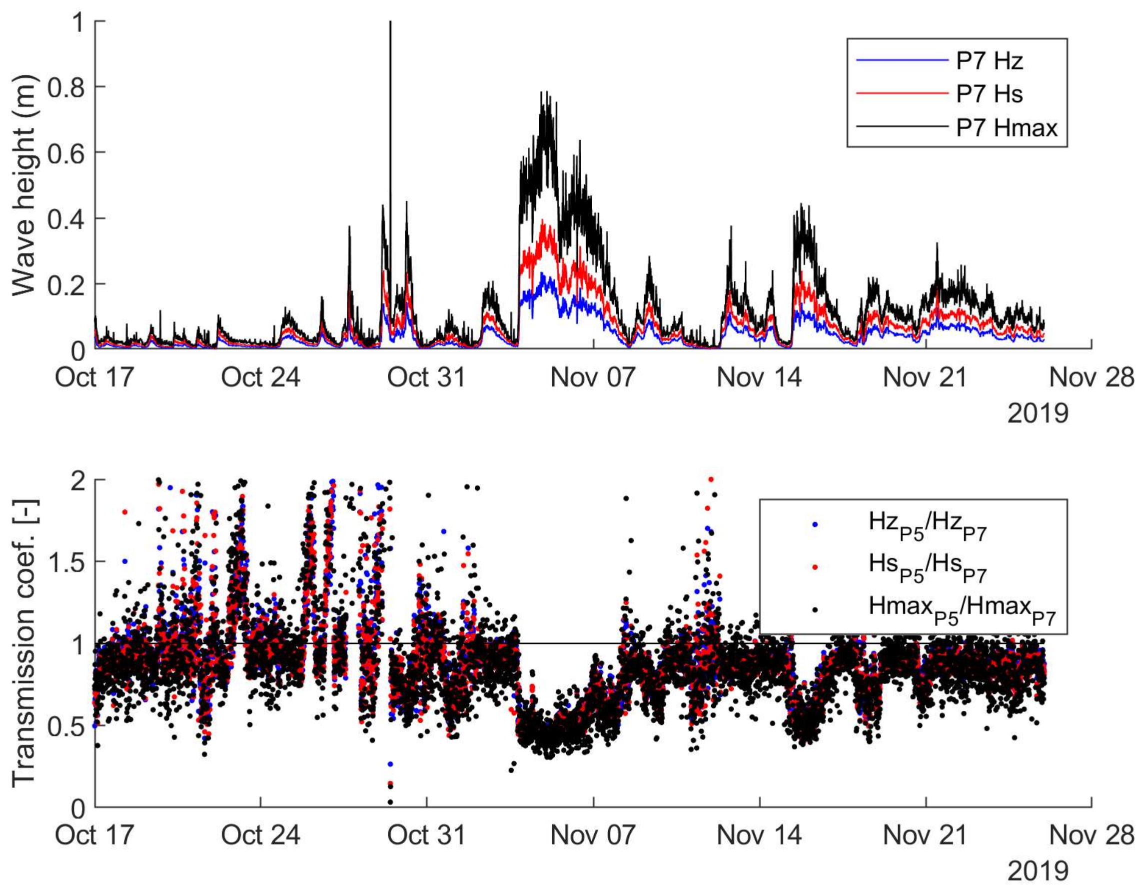

Figure 4.6. Transmission coefficient for P7 & P5 (Kihnu).

In Figure 4.6, wave heights are presented for complementary information. Transmission coefficients C_t are evaluated as a ratio between mean wave heights (Hertz), significant wave heights (Hs) and maximum wave heights (Hmax). Relevant data from Kihnu was collected between 3rd of November and 9th of November and also between 15th of November and 18th of November.

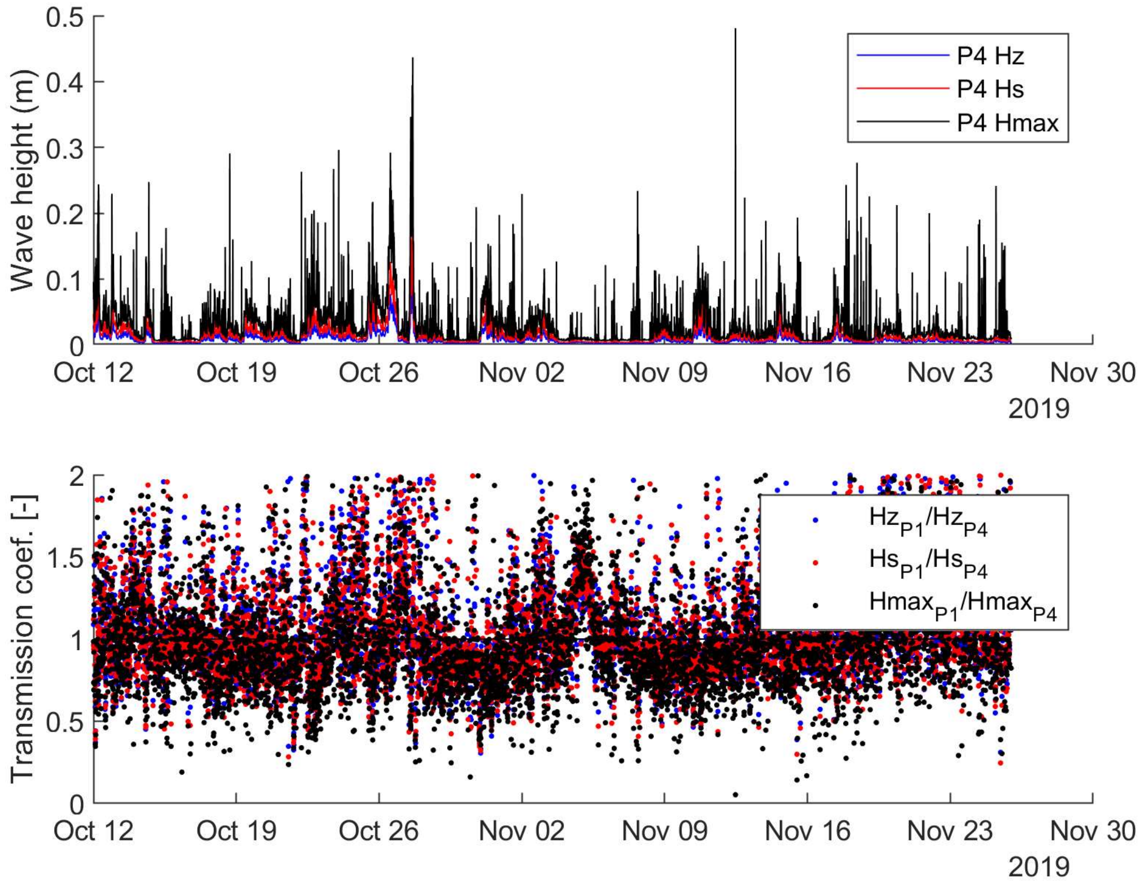

Figure 4.7. Transmission coefficient for P4 & P1 (Pärnu).

In Figure 4.7, wave heights are presented for complementary information. Transmission coefficients C_t are evaluated as a ratio between mean wave heights (Hertz), significant wave heights (Hs) and maximum wave heights (Hmax). In Pärnu, wave transmission coefficient changes between 0 and 2 and there is no specific period where transmission coefficient is relevant.

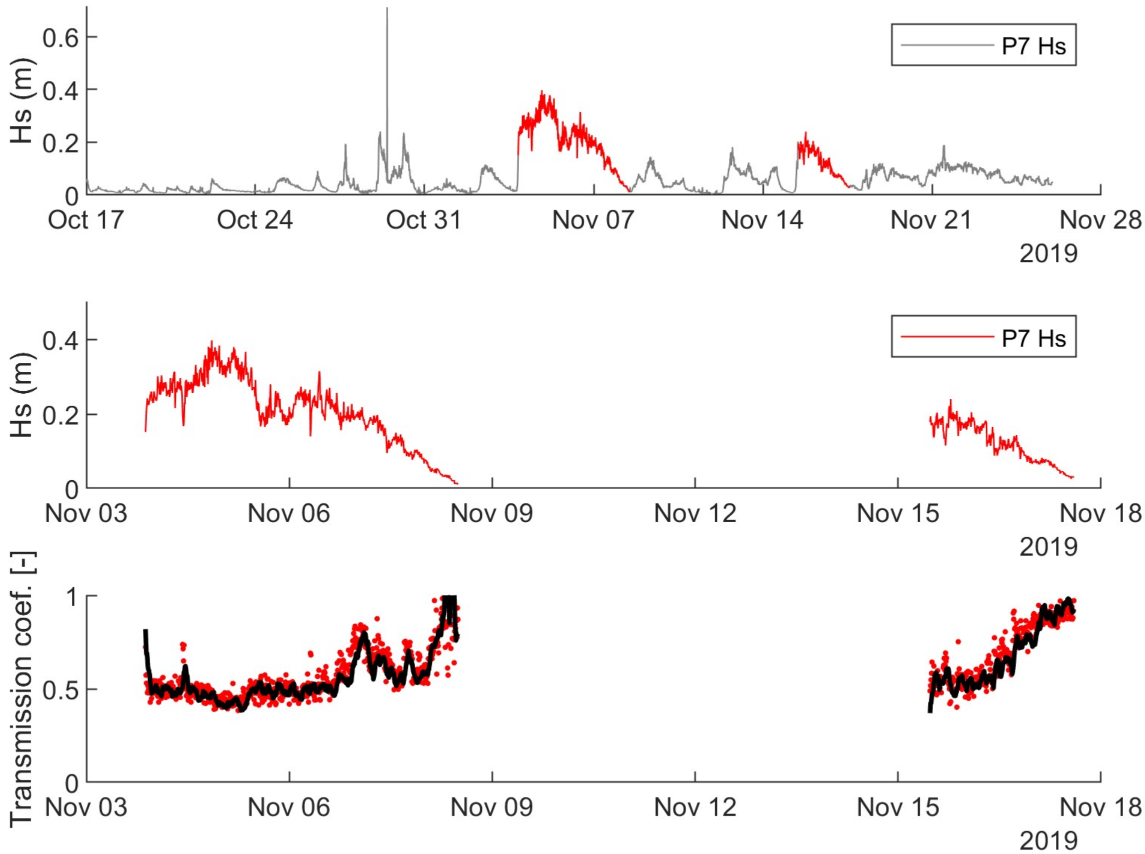

Figure 4.8. Relevant transmission coefficient for P7 & P5 (Kihnu)

Relevant data is separated and put together in Figure 4.8. This data is from a period where higher wave heights appeared and the transmission coefficient was between 0 and 1. Wave heights are presented for complementary information. Transmission coefficients C_t evaluated as a ratio between significant wave heights (Hs). Bold lines present the moving average. Using the same data points and trendline, a conclusion can be reached.

In Figure 4.9, the transmission coefficient, as a function of significant wave heights (H_s), is shown. The transmission coefficient C_t is presented as a function of significant wave height H_s in Figure 4.9 together with the polynomial trendline. The figure reveals that the transmission coefficient decreases as the wave height increases. For instance, the higher waves are damped out more efficiently. Top Marine expected that their floating breakwater transmission coefficient should be around 0.5 when waves with significant height of 0.5 meters appear. Based on Figure 4.9, the Top Marine floating breakwater in Kihnu fulfills its purpose and is properly designed.

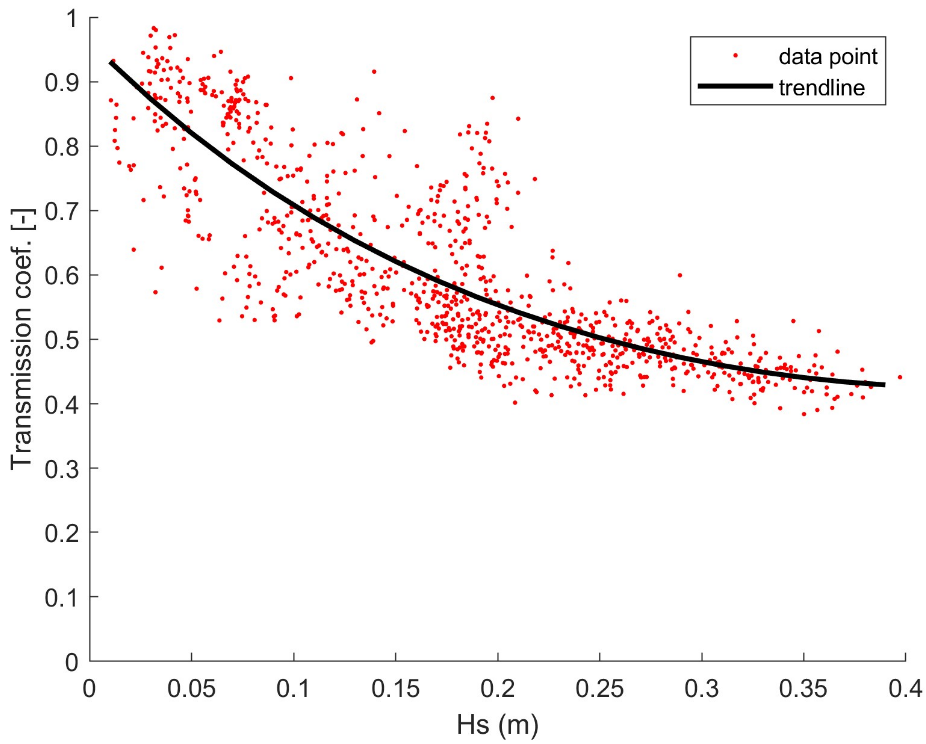

Figure 4.9. Transmission coefficient as a function of significant wave heights.

4.5. Proof-testing the pressure gauge

One of the pressure gauges was taken to Small Craft Competence Centre (SCC) in Kuressaare where a model test pool can be used. In that pool, waves are generated by paddle and for this proof test, different paddle frequencies and amplitudes were determined. Water surface elevation was recorded with pressure gauge and pool sensor. The purpose of this was to clarify the range of wave heights and periods that can be record with these devices. Since the data from all the devices was similar, it seemed unnecessary to proof-test all the devices, so one was picked. For comparison between pool sensor and pressure gauge, approximately first 10 waves are taken into account to avoid wave reflections. In Kuressaare, total of 34 tests were made and 30 tests were processed. Summary of the proof-testing is shown in and descriptive results are shown below.

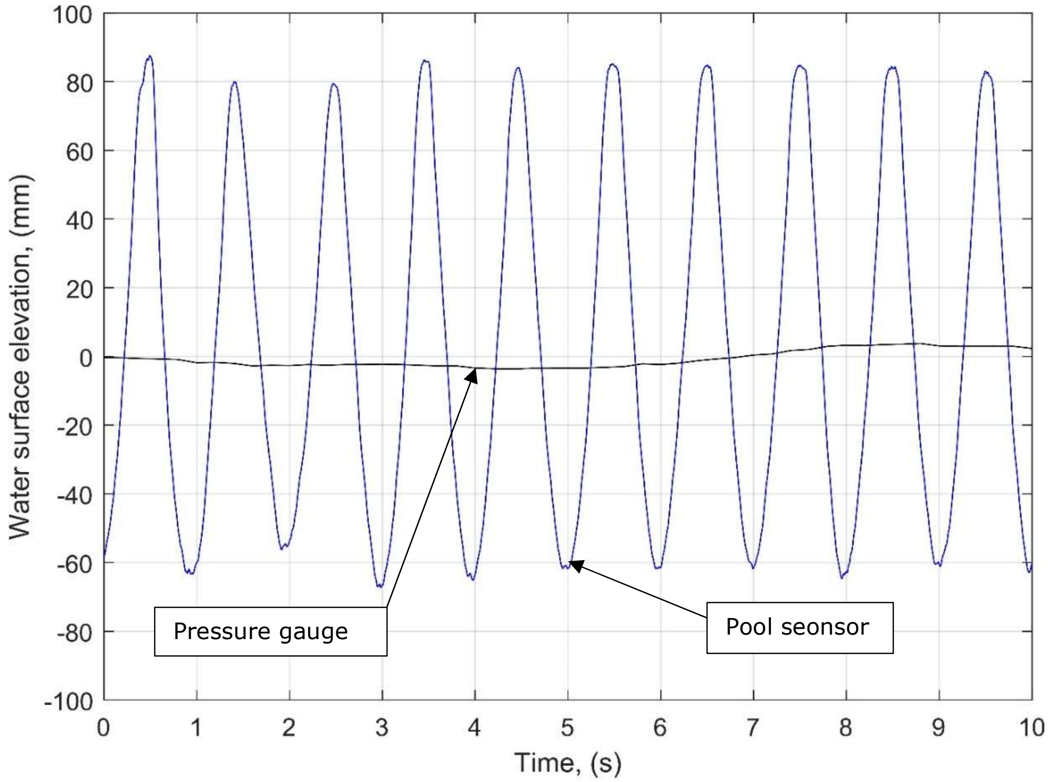

Figure 4.10. Measured surface elevation (RUN11: Paddle period 1 s and amplitude 100 mm).

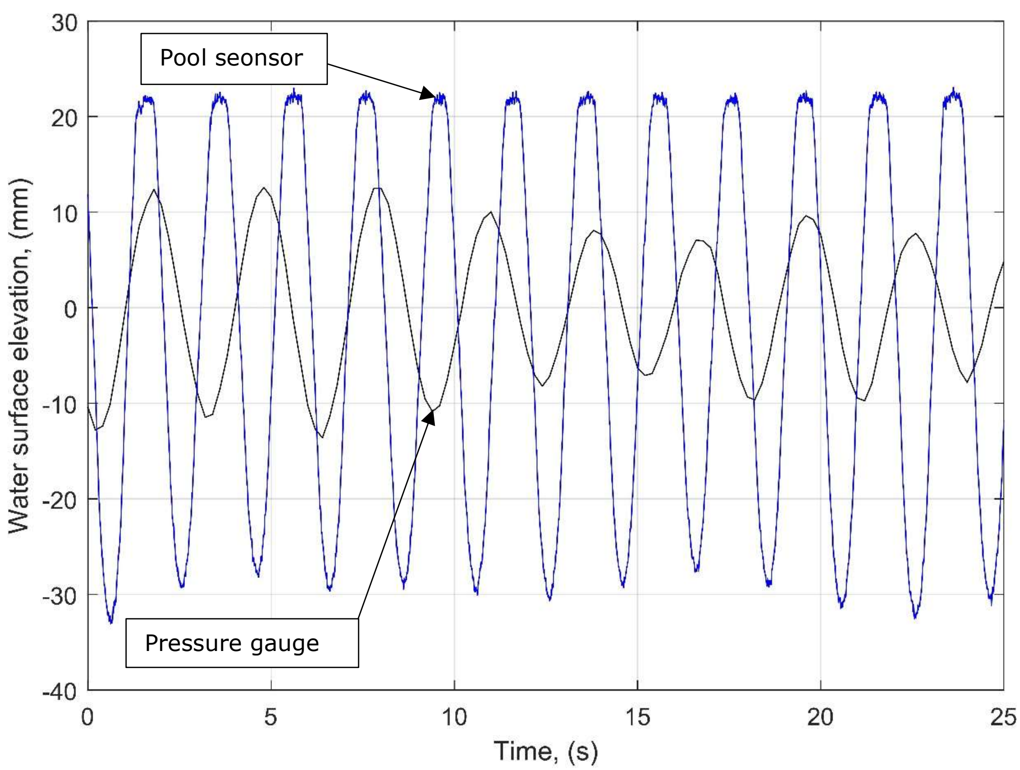

Figure 4.11 Measured surface elevation (RUN3: Paddle period 2 s and amplitude 50 mm).

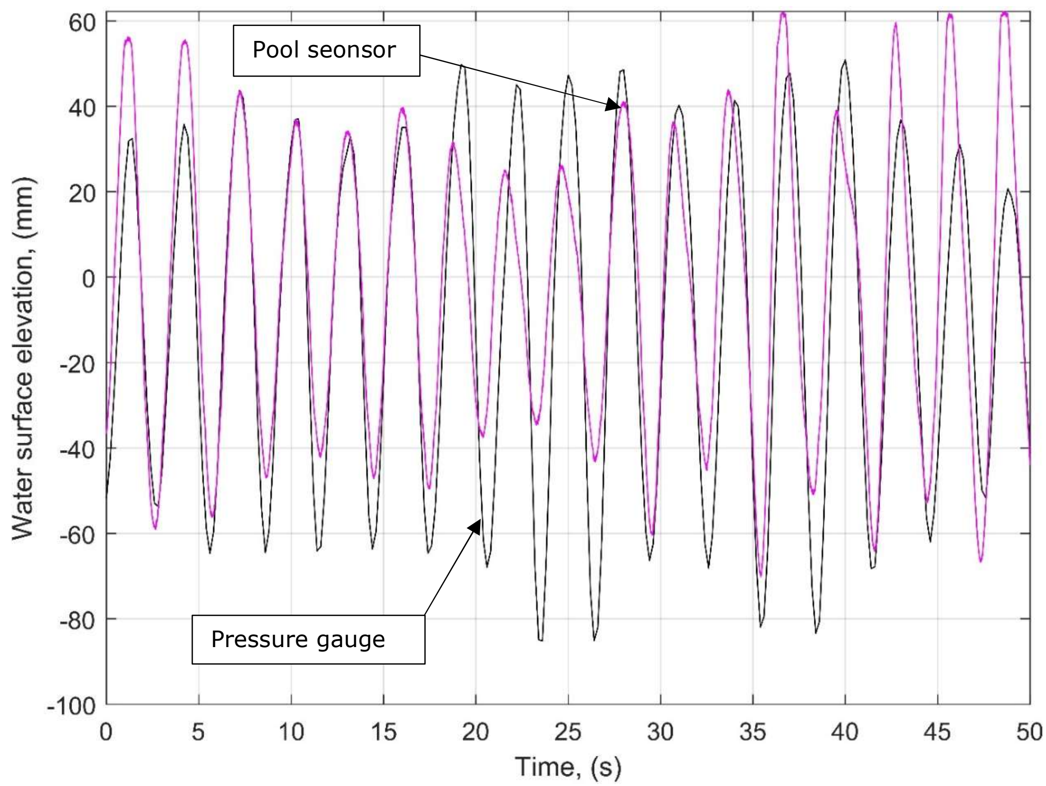

Figure 4.12. Measured surface elevation (RUN13: Paddle period 3 s and amplitude 200 mm).

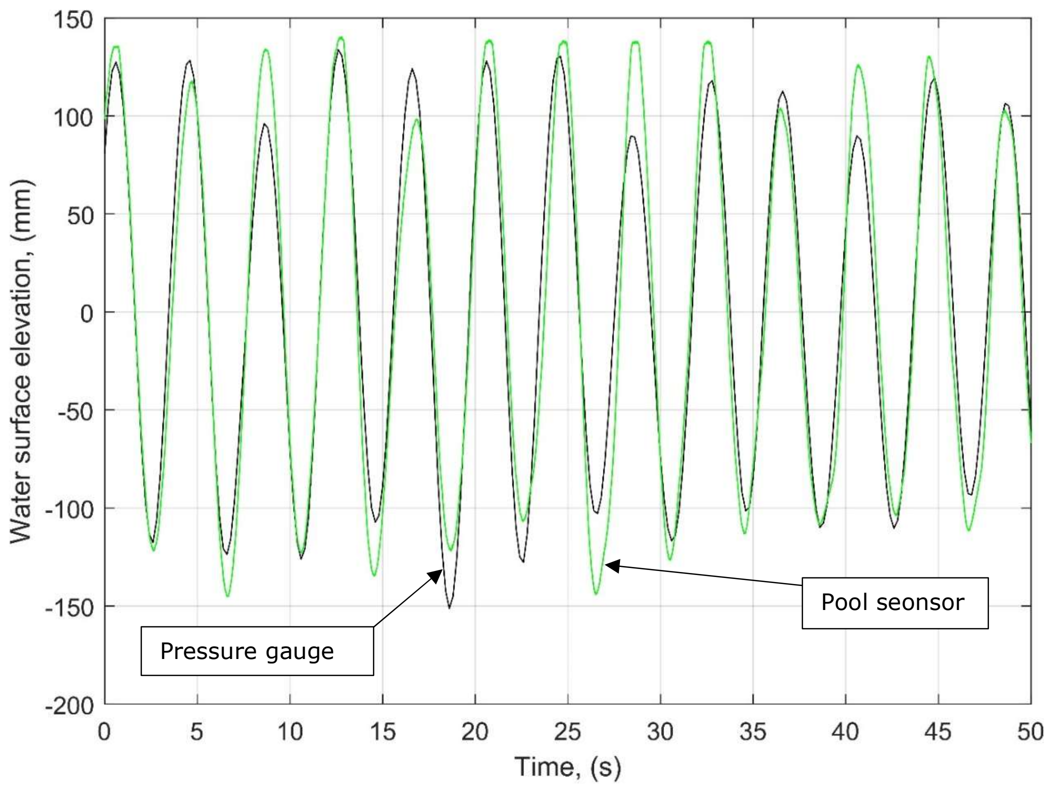

Figure 4.13. Measured surface elevation (RUN16: Paddle period 4 s and amplitude 250 mm).

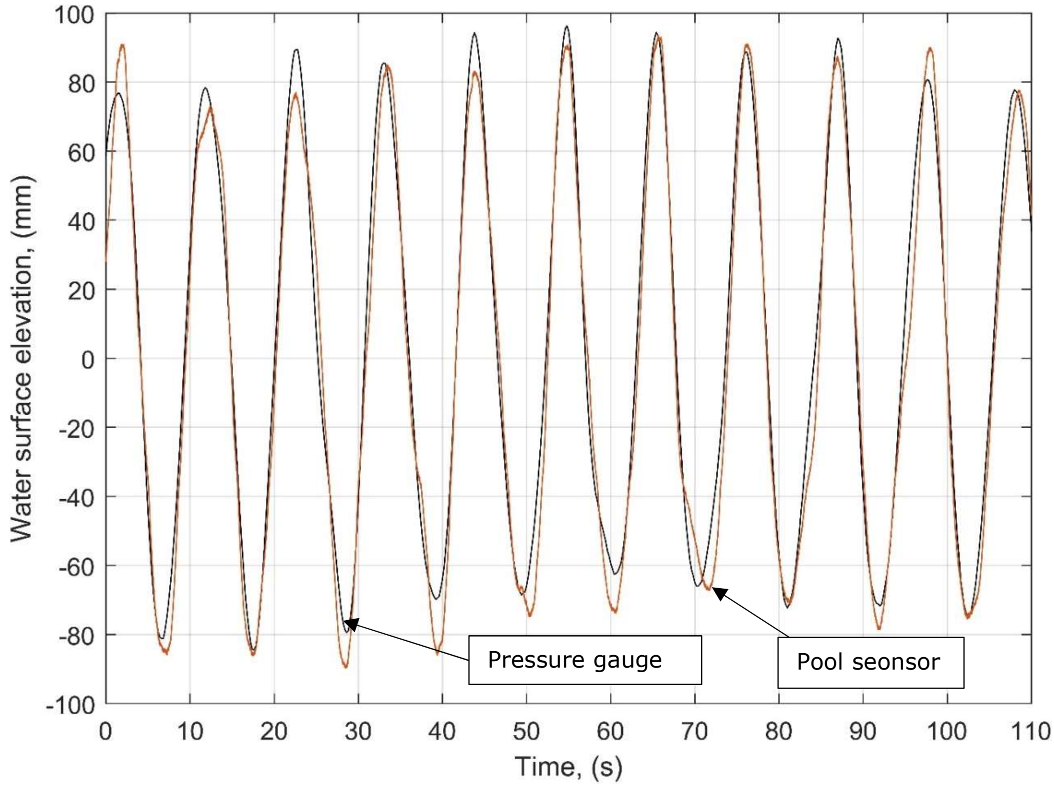

Figure 4.14. Measured surface elevation (RUN15: Paddle period 10 s and amplitude 390 mm).

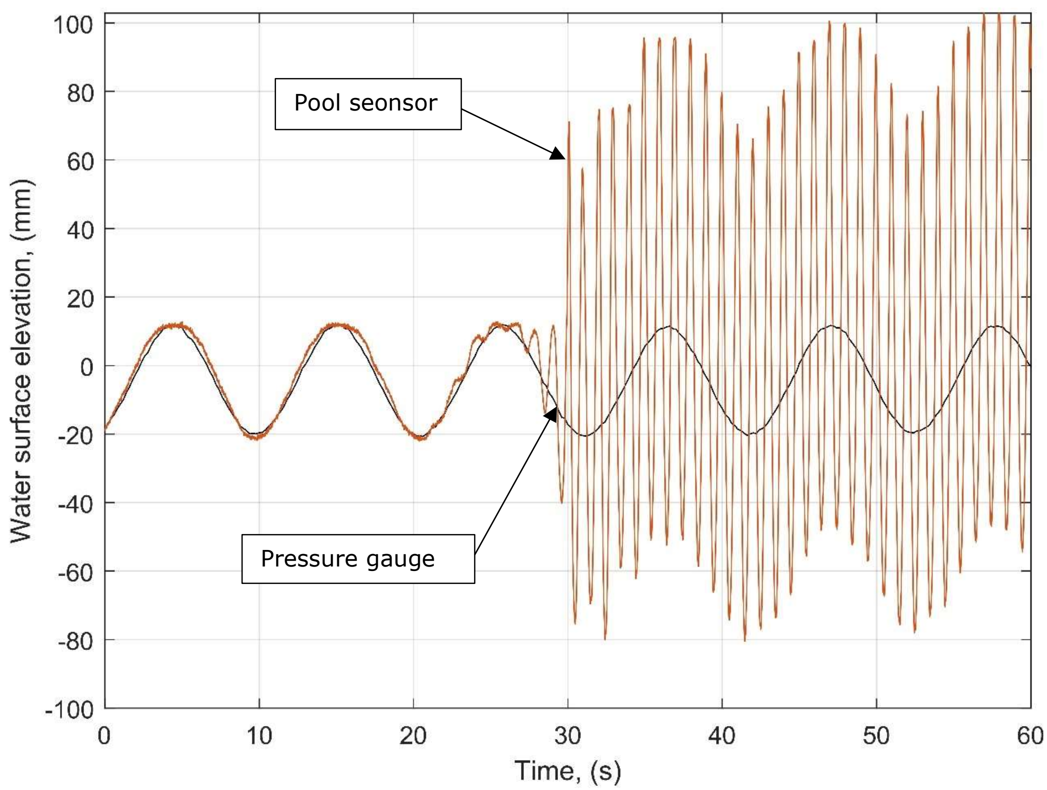

Figure 4.15. Measured surface elevation (RUN21: Paddle period 1 s and amplitude 100mm).

Table 4.1. Summary of proof-testing

Run number	Paddle period	Paddle amplitude	Pool sensor		Pressure gauge		Wave height difference, %
			Wave height, (mm)	Wave period, (s)	Wave height, (mm)	Wave period, (s)	
RUN3	2	50	52	2,0	2	10,4	96
RUN4	3	100	50	2,9	38	4,0	25
RUN5	4	120	117	4,0	121	5,0	3
RUN6	5	190	49	4,5	43	4,5	12
RUN7	6	250	150	5,7	154	5,7	3
RUN8	1	70	106	1,0	5	5,5	95
RUN9	2	90	100	2,0	11	5,0	89
RUN10	3	160	108	2,9	107	3,0	1
RUN11	1	100	146	1,0	7	10,6	95
RUN12	2	50	51	2,0	25	2,0	51
RUN13	3	200	106	2,9	86	3,0	19
RUN14	4	390	132	4,0	225	4,0	70
RUN15	10	390	160	10,6	158	10,6	1
RUN16	4	250	250	4,0	246	4,0	2
RUN17	7	300	55	7,2	65	7,2	18
RUN18	5	390	107	5,0	108	5,0	1
RUN19	10	490	223	9,6	220	9,6	1
RUN21	1	100	146	0,9	31	10,7	79
RUN22	5	490	135	4,5	131	4,5	3
RUN24	9	300	58	9,4	60	9,3	3
RUN25	8	275	57	7,8	58	7,9	2
RUN26	6	490	309	5,7	310	5,7	0
RUN27	7	500	78	7,1	82	6,4	5
RUN28	6	550	345	5,7	345	5,7	0
RUN29	1	100	160	1,0	17	5,6	89
RUN30	1	70	105	1,0	5	5,6	95
RUN31	1	40	58	1,0	3	10,2	95
RUN32	2	50	51	1,8	8	2,0	84
RUN33	3	100	40	2,9	41	3,0	2
RUN34	4	120	122	4,0	124	4,0	2

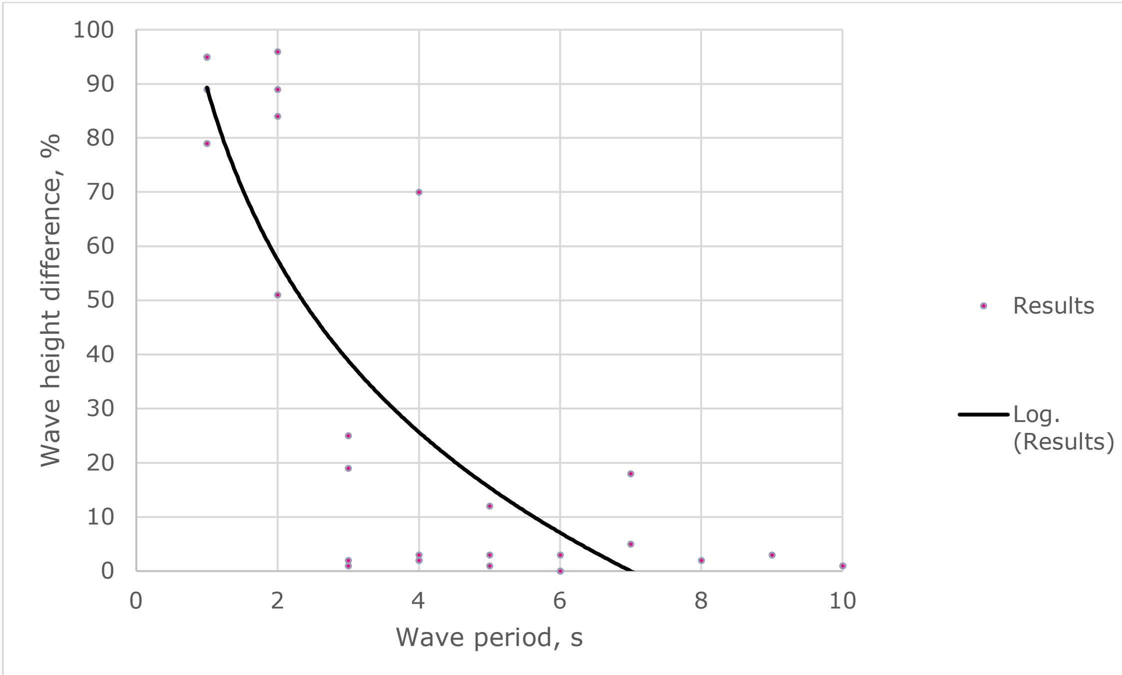

Figure 4.16. Function of wave period and wave height difference.

Figure 4.15. Measured surface elevation (RUN21: Paddle period 1 s and amplitude 100mm).

Table *4.1* shows a summary of proof-testing, and in Figure 4.16, function of wave period and wave height difference is presented. For shorter waves with wave period up to 2 (s), pressure gauge failed to register proper wave height and reported significantly lower waves, see Figure 4.10. For RUN21 pressure gauge recorded residual surge from previous run, see Figure 4.15. It can be said that pressure gauges did not record enough data points to get correct wave height when the wave period was lower than 2 (s).

For longer waves, with a period longer than 2(s), pressure gauge registered wave heights properly. RUN4 and RUN33 had the same parameters but both runs had different outcome in wave height difference. Previous runs of RUN4 were made with lower paddle period and amplitude but previous runs of RUN33 were made with higher paddle period and amplitude, that may had some effect in RUN33 results. In RUN14 wave height difference was bigger than in other similar runs. The reason for that could be error in pressure gauge that reported in lower wave heights. Because of low wave height, difference in percent can be higher than it would be with a bigger wave height.

From proof-testing a conclusion can be drawn that pressure gauges recorded data when waves with a period of at least 2 (s) appeared. Based on Figure 4.16, it can be surmised that results are more accurate with longer wave period. In Kihnu, majority of waves that appeared were with a longer wave period than 2 (s). Therefore, it can be said that, pressure gauges registered wave heights properly.

5. ANALYTICAL MODELLING

This paragraph introduces different wave transmission formulas. This contains some older and newer theories on wave transmission. At first, the theories are described and after that these theories are put in use to calculate Top Marine floating breakwater wave transmission coefficient for breakwaters in Kihnu and Pärnu.

5.1. Wave transmission

When wave makes contact with breakwater the wave energy will reflected from, dissipated on, transmitted through or over the breakwater structure. In perfect world, breakwaters in harbours should reflect or dissipate any wave energy approaching the harbour. Transmission of wave energy through a breakwater should be minimized. Different formulas can be used to predict wave transmission through breakwaters. (Coastal Engineering Research Center, 1984)

5.1.1. Macagno's wave transmission formula

According to (Bouwmeester & Van der Breggen, 1984) in development of formula for calculating floating structure wave transmission, Macagno made assumptions that

- Structure is rigid
- Structure is fixed
- Water will not overtop the breakwater
- Linear wave theory

From these assumptions Macagno developed the following equation

$$C_t = \frac{1}{\sqrt{1 + \left[\frac{k_i B sinh(k_i d)}{2cosh\,(k_i d - k_i D)}\right]^2}} \tag{5.1}$$

where

$k_i -$ incident wave number, Rad/m

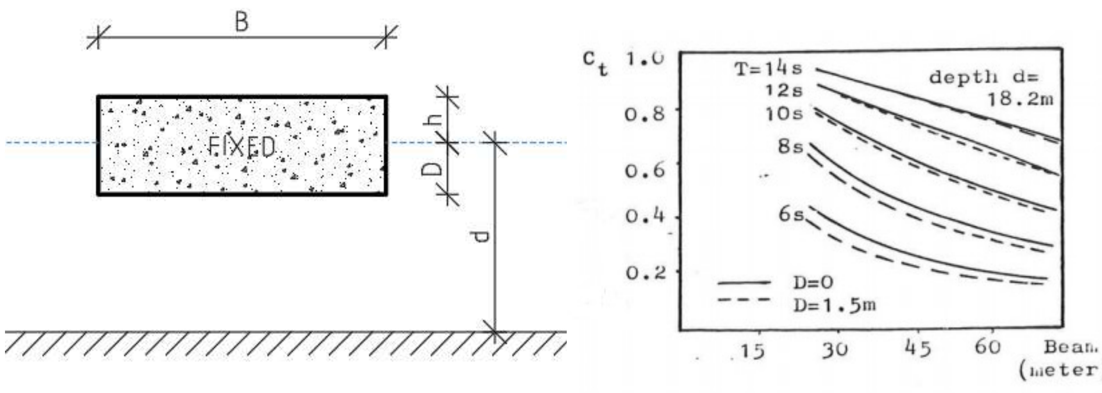

Figure 5.1. Macagno: definition sketch and theoretical transmission coefficient. (Bouwmeester & Van der Breggen, 1984)

Macagno's relationship was derived for rectangular, box-type, fixed breakwater and may only be applied to predict transmission coefficients for this kind of structures only. This formula also has some essential limitations such as, if draft is equal to water depth some transmissions are predicted but there are none. (Ruol, Martinelli, & Pezzutto, 2013)

5.1.2. Wiegel's wave transmission formula

Wiegel developed a linear theory, also known as power transmission theory, to predict the wave heights transmitted past a barrier. This barrier is rigid, vertical, thin and extending from above the water surface to a depth D. Wiegel also made the same assumptions that Macagno did

- Structure is rigid
- Structure is fixed
- Water will not overtop the breakwater
- Linear wave theory
- No reflection

Wiegel also assumed that the power transmitted by a wave between the bottom of the vertical barrier and the channel bottom, will be the power transmitted past the structure if the structure would not be there. (Bouwmeester & Van der Breggen, 1984)

$$C_t = \left[\frac{2k(d - D + \sinh 2k(d - D}{\sinh 2kd + 2kd}\right]^{\frac{1}{2}} \qquad (5.2)$$

Figure 5.2 shows that structure draft divided with wavelength (D/L) and water depth divided with water depth shows how those parameters affect the transmission coefficient. Based on Figure 5.2, it can be said that in deep water conditions where d/L>0.5 wave attenuation is larger than in water conditions where 0.05<=d/L<0.5.

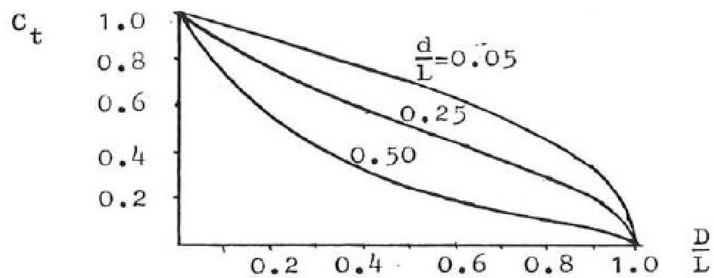

Figure 5.2. Power transmission theory of Wiegel. (Bouwmeester & Van der Breggen, 1984)

5.1.3. Ruol's wave transmission formula

Macagno's and Wiegel's wave transmission formulas assumed, that the floating structure is fixed. Ruol assumed that the structure is non-fixed and rigid. Ruol proposed a new formula that given in form, is a correction to Macagno's relationship, accounting for the dynamic effects of the pi-shaped floating breakwaters. Macagno's formula is estimate by

$$k_{tM} = \frac{1}{\sqrt{1 + \left[kw \frac{sinh\, kh}{2cosh(kh - kd)}\right]^2}} \tag{5.3}$$

where

$k -$ wave number

$h -$ water depth, m

Predicting transmission coefficient using Macagno's formula could only be applied for rectangular, box-type and fixed breakwater. (Ruol, et al,.2013)

Ruol's formula aims at overcoming the incorrect prediction of Macagno's relationship. The formula developed by Ruol is a function of a dimensionless variable that is based on laboratory experiments and is a function of the relative period (T_p/T_h). Because the natural period of heave oscillation is not simply obtainable alternative nondimensional variables had to be found. Ruol found out that using the equation for the natural frequency of a simplified vertical undamped oscillation of a floating body, ignoring possible coupling terms of the heave motion with the rest of the motions of the structures, equation (5.4).

$$\omega_h = \sqrt{\frac{K}{M_s + M_a}} = \sqrt{\frac{\rho_w g y w}{M_s + M_a}} \tag{5.4}$$

where

$\omega_h -$ Natural heave radian frequency, rad/s
$K -$ Vertical stiffness, N/m
$M_s -$ Structure mass, kg
$M_a -$ Added mass (mass of water that accelerates with the body), kg
$\rho_w -$ Water density, kg/m^3
$g -$ Acceleration of gravity, m/s^2
$y -$ Vertical coordinate
$w -$ Width of floating breakwater, m

Variable M_a is simplified by the water mass that is trapped under the floating breakwater that is in half of circle shape with the radius equal to half of the floating breakwater width. Ruol estimated that the mass is tow-dimensional and because the body mass is equal to the mass of the displaced water, the total estimated mass is evaluated as

$$M_s + M_a = \rho_w w(d + 0.39w) \tag{5.5}$$

Ruol replaced vertical stiffness and sum of masses in the general expression of heave natural frequency and made a regression analysis on it based on experimental evaluation of the natural frequency, Ruol presented equation (5.6).

$$\omega_h \approx \sqrt{\frac{g}{d + 0.35w}} \tag{5.6}$$

Ruol assumed that scaling parameter $\chi \approx T_p/T_h$ is obtained directly from equation (5.7).

$$\chi = \frac{T_p}{2\pi}\sqrt{\frac{g}{d + 0.35w}} \tag{5.7}$$

Correction function β(χ), which relates the transmission coefficient of a general pi-type floating breakwater to the one derived analytically for a fixed rectangular breakwater using Macagno's relationship. Ruol assumed that transmission coefficient for floating breakwater should be calculated using equation (5.8).

$$C_t = \beta(\chi) k_{tM} \tag{5.8}$$

Ruol imposed the boundary condition $C_t = k_{tM}$ for very long and very short waves that resulted in $\beta = 1$ for $\chi > 1.3$ and $\chi < 0.3$. (Ruol, et al,.2013)

5.2. Predicted wave transmission coefficient for floating breakwater in Kihnu

In paragraph 4, the experimental wave transmission coefficient for floating breakwater in Kihnu was calculated based on field-testing data. In that paragraph, the wave transmission coefficient was calculated based on wave heights of either side of the floating breakwater. From that same data, other wave parameters can be calculated, again using the OCEANLYZ toolbox. The author of this thesis assumes that predicting wave transmission coefficient with known wave transmission formulas (paragraph 5.1) for the floating breakwater in Kihnu would approximately be the same as results in experimental modelling and the most accurate formula for test site conditions would be found. Pärnu's data was not used because it was irrelevant for analytical modelling.

5.2.1. Wavelength from field data

In this thesis, the end result is shown as a function of wavelength and a transmission coefficient, therefore experimental data needs to be converted into wavelength. From field-testing data, mean wave period is calculated similarly to wave height parameters. Data is split into a series of data bursts of equal durations; the duration of single burst is 10 minutes that is one burst consists of 3000 data points.

According to (Demirbilek & Vincent, 2002) in conditions were irregular waves appear, wavelength can be calculated by using equation (5.9).

$$\mathrm{L} = \frac{gT^2}{2\pi} tanh\left(\frac{2\pi d}{L}\right) \tag{5.9}$$

where

$T -$ Wave period, s

$L -$ Wavelength, m

To calculate wavelength dispersion relationship has to be used. To save time, MATLAB solve function is used to calculate wavelengths.

5.2.2. Characteristics of wave

To use wave transmission formulas initial data has to be presented. Floating breakwaters are typically used to protect small marinas where wave period is up to 4.0 (s) and wave height is smaller than 1.5m (Ruol, Martinelli, & Pezzutto, 2013). For this analytical modelling, a wave period is chosen to be up to 10.0 (s) and needed characteristics of a wave are calculated. Characteristics of a wave and floating breakwater needed for different formulas are shown below.

Values needed for Macagno's formula

- Wave number (k)
- Floating breakwater width (B)
- Water depth (d)
- Draft depth (D)

Values needed for Wiegel's formula

- Wave number (k)
- Water depth (d)
- Draft depth (D)

Values needed for Ruol's formula

- Wave number (k)
- Floating breakwater width (B)
- Water depth (d)
- Draft depth (D)
- Acceleration of gravity (g)
- Wave period (T)

Wavelength can be calculated based on equation (5.9). Wave number (k) is equal to $2\pi/L$. Top Marine's floating breakwater HD 3.16x15m, that is used in Kihnu Port, width (B) is 3.16 meters and draft depth (D) is equal to 0.9 meters. Water depth (d) from still water level to sea bed is equal to 3.08 meters. From these values, wave transmission coefficients can be calculated, results are shown in Figure 5.3.

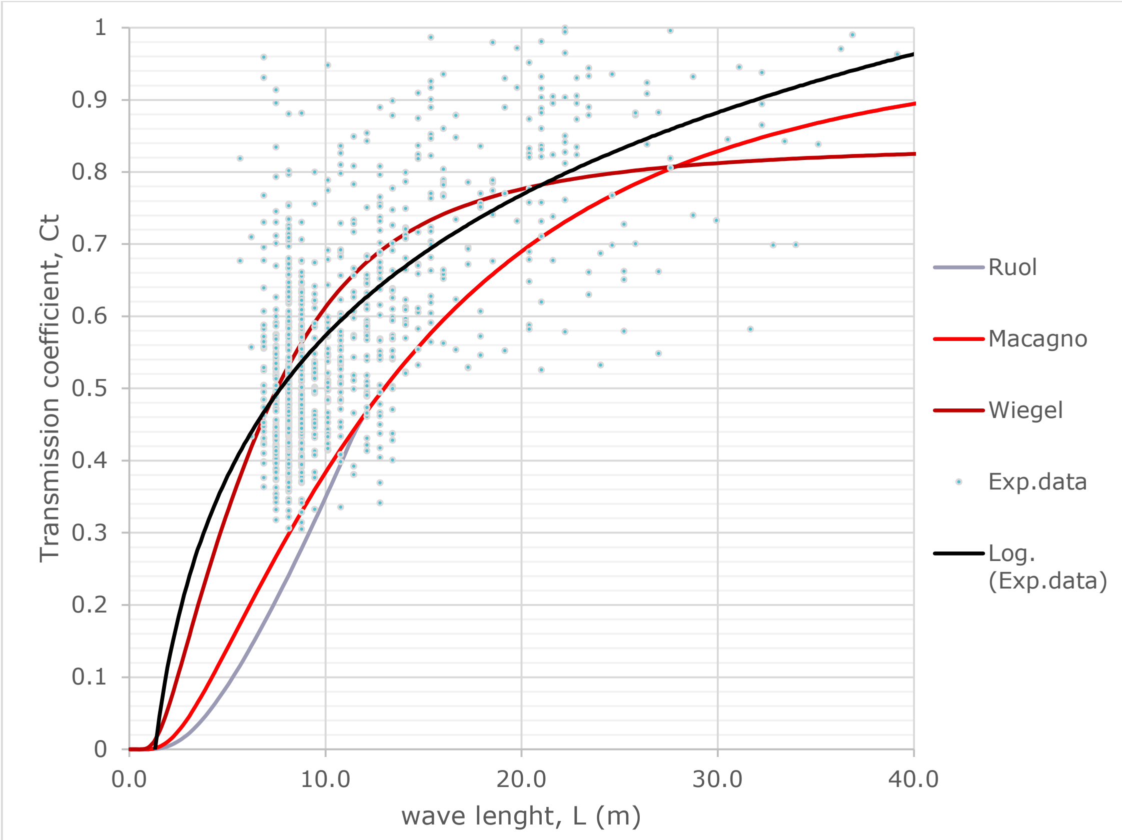

Figure 5.3. Function of wavelength (L) and transmission coefficient (Ct).

Figure 5.3 represents the function of wavelength and the transmission coefficient for Ruol's, Macagno's, Wiegel's and experimental data. Small circles are data points from field testing. Figure 5.3 shows that most of the data points regarding wavelength are around 10 meters.

Predicting wave transmission coefficient for Top Marine floating breakwater formula should be chosen depending on marina requirements. Macagno's formula is suitable to be used for conditions were wave length is over 20 meters. If Macagno's formula is used for these waves then based on this thesis, Top Marine pontoons have 7% of calculation margin. For wave lengths lower than 20 meters, all the formulas could be used. Wiegel's formula shows that if wave length is between 8 and 20 meters, in reality, Top Marine pontoons transmission coefficient value would be 5% lower than predicted by Wiegel's formula. Also, Ruol's formula should not be used because when wave length that appears is under 12 meters, Ruol's formula predicts the lowest transmission coefficient than any other formula and when wave height is over 12 meters Ruol's formula values matches with Macagno's. In prediction of wave transmission coefficient for Top Marine floating breakwater HD 3.16x15m, Wiegel's formula should be used consciously and Macagno's formula should be used for most of the times. That is said, based on Figure 5.3.

6. SUMMARY (IN ENGLISH)

The research problem of the master's thesis was addressed and the research purpose was fulfilled. The purpose of this thesis was to find out the capability of the Top Marine pontoons to attenuate waves that are used in Kihnu and Pärnu. Also, it was necessary to understand which formula should be used to predict wave transmission coefficient for the similar conditions of Pärnu and Kihnu.

Devices equipped with a pressure sensor were installed to Pärnu marina and Kihnu port. In Pärnu, devices were installed on the longitudinal side of Top Marine HD 2.4x12m, and in Kihnu, devices were installed on the longitudinal side of Top Marine HD 3.16x15m. Devices were installed 4 meters of the side so the distance between the 2 devices were 8 meters plus the width of pontoon. The proof-testing that was done in Kuressaare, showed that the pressure gauges recorded data when waves with period of at least 2 (s) appeared.

The research revealed that Pärnu's field testing data was unreliable and could not be used, mainly due to wrong direction of the waves. After a discussion with the representatives of Top Marine, Rain Männikus, and the supervisor of the thesis, the conclusion was made that even if the direction of waves would have been perpendicular with breakwater, the wave of sufficient size could not be generated at the measured location. Based on field-testing data from Kihnu, it was determined that Top Marine floating breakwater HD 3.16x15m wave transmission coefficient is equal to 0.5 when waves of height 0.4 meter appear. This result was approximately the same as the expectations of representatives of Top Marine.

In analytical modelling conclusion was reached that using Top Marine floating breakwater HD 3.16x15 in similar conditions to Kihnu. Macagno's formula should be used most of the time to predict wave transmission coefficient for floating breakwater. Depending on conditions, Wiegel's formula could also be used. Macagno's formula predicts better wave attenuation for breakwaters than in reality.

The author was satisfied with the findings of the master's thesis, but in retrospect, instead of Pärnu, another port could have been chosen where Top Marine HD 2.4x12m pontoons are used. Proof-testing gave the author confidence to reach such a conclusion. The author hopes that the results and conclusions of this thesis are suitable for Top Marine, also will improve quality of floating solutions and would help to expand to field that has few competitive firms.

In future researches, pressure gauge exact work range should be specified with more tests and for breakwater wave attenuation analysis, field-testing period should be longer.

7. KOKKUVÕTE (IN ESTONIAN)

Magistritöö uurimisprobleem sai käsitletud ja uurimiseesmärk sai täidetud. Uurimiseesmärgiks oli vaja välja selgitada, milline on Kihnus ja Pärnus kasutatavate Top Marine pontoonide lainete summutusvõime. Samuti oli vaja teada saada, millist meetodit tuleks kasutada, et eeldada nende lainete summutusvõimet kui neid kasutatakse sarnaste parameetritega asukohtades.

Mõõteseadmed sai paigaldatud Pärnu jahisadama Top Marine HD 2.4x12m pontooni pikkikülgedele, 4 meetri kagusele pikkiservast ning Kihnu sadamas Top Marine HD 3.16x15m pontooni külgedele sarnaselt Pärnu jahisadamale. Kuressaares teostatud seadme kontrollmõõtmine näitas, et lõputöö mõõdistuste jaoks kasutatud seadmed salvestasid laineid, mille periood oli vähemalt 2 sekundit.

Uurimisprobleemile vastuse leidmisel selgus, et Pärnus teostatud mõõtmistulemusi ei saa kasutada, sest lainetus oli valest suunast. Hilisemal diskuteerimisel Top Marine esindajatega, Rain Männikuse, ning lõputöö juhendajaga, jõudsime arusaamale, et mõõdetud kohas ei saagi tekkida piisava suurusega laineid. Kihnu mõõtmistulemuste põhjal sai vastatud Top Marine küsimusele, milline on kasutatava pontooni lainete summutusvõime. Kihnus kasutatakse pontooni HD 3.16x15m ning nende lainete summutusvõime 0,4 meetriste lainete puhul oli ligikaudu 0,5. Antud tulemus kattus ka Top Marine esindajate eeldustega.

Analüütilisest mudeldamisest selgus, et Top Marine pontooni HD 3.16x15m, kasutamisel sarnastes oludes nagu on Kihnu pontoon. Enamus ajast tuleks kasutada Macagno valemit laine summutus võime arvutuslikul määramisel. Olenevalt sadama asukohast ning ettekirjutustest võib kasutada ka Wiegel'i valemit, kui mitte suurmate laine pikkuste kui 12 meetrit. Magacno valemit kasutades on ujuvkai lainete summutusvõime väärtus tegelikkuses suurem kui arvutuslikult.

Autor jäi magistritöö tulemustega rahule, kuid tagantjärgi võib öelda, et Pärnu asemel oleks võinud valida mõne teise sadama, kus kasutatakse Top Marine HD 2.4x12m pontoone. Seadmete kontrollmõõdistuse teostamine Kuressaares andis magistritöö autorile kindluse, et lõputöös jõutud järeldused on täpsed. Magistritöö autor loodab, et töö käigus tehtud tulemused ja järeldused on sobilikud Top Marine'l ning aitab tõsta ujuvlahenduste kvaliteeti ning siseneda alale, kus on vähe häid tegijaid.

Tuleviku uurimistes tuleks mõõteseadmete tööpiirid täpsemalt paika panna. Kaide summutamisvõime analüüsimisel tuleks teha veel katseid, kuid mõõteperiood peaks olema pikem kui 1,5 kuud.

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