Project: Multi-fidelity probabilistic design framework for complex marine structures. My part is bottom up research into nonlinear extreme wave loading phenomena.

Topic: For now focusing on green water.

Literature study into green water. A lot of research into simulations has not yet been able to affordably and accurately simulate. Most previous research into the green water itself was conducted with experiments. These experiments are mostly fairly simplified representations of reality. with a static box representing a ship and regular waves. This has given a lot of insight. and five different types of green water events have been identified. It also left questions around the occurrence of green water and various green water event types. As most research has been experimental research, the problem has been scaled. However, during green water events air can be trapped. When this happens. the scaling laws are broken. This prevents the experimental data being used for large scales. Understanding the differences between the scaled and full scale results will make the experiments at model scale more useful.

These insights have led to the main goals of my research. The first focus is to get more insight into the statistics and occurrences of green water event types. This is being researched with long running experiments to obtain large data sets and many occurrences of green water. Secondly, the difference between small and large scale green water events will be investigated. This will be researched by repeating the same experiments at different scales and looking at the differences.

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1 LITERATURE

Ships and offshore structures are out in the ocean to transport the many goods we send around the world. pump up oil, or place wind turbines. Waves impact these structures, causing large loads. Green water is one of these impact types. Green water is water that impacts on deck or superstructures. It can lead to huge impact pressures. As Buchner [11] stated, green water is a non-linear and strongly complex problem. Also as during green water events, free surface, air and water interact in a way that can lead to entrained and entrapped air [82]. It was found that with increased forward speed, the probability of green water increased [30, 33]. Most studies focused on head waves, but green water can also occur on the side of a vessel.

1.1 GREEN WATER RESEARCH

Research into green water can be categorized into three groups: approximations, numerical and experimental [40].

Numerical methods are more accurate than these approximation methods. The problem with numerical simulations is that they take excessive computational time [74].

Experiments for green water events are still being carried out today, as it is an affordable and relatively accurate method.

Approximations are empirical and analytical methods. They are simple and fast but less accurate. They consist mostly of predicting freeboard exceedance, as most greenwater events occur when the freeboard is exceeded. Prediction of exceedence of the freeboard is complex due to the many dependencies [53]. These are for instance wave steepness or structure motions [26, 11]. These parameters also introduce nonlinearities [23]. Researchers have made probability distributions of the free-board exceedance based on empirical parameters. Examples are Buchner [11], Cox and Scott [19] and Guedes Soares and Pascoal [31].

In this literature review, firstly an in depth dive into experimental green water research and what came from it is presented. Afterwards, some research on improving simulation methods is shown.

1.2 EXPERIMENTAL RESEARCH

Experiments are still the most reliable way to find green water loading. A database with experimental results was developed for validation of the simulations [54]. Almost exclusively FPSO type vessels or container ships, or simplified structures (step structures and cubic shapes) have been researched [17]. The focus on FPSO's is because of the equipment on deck, but it is found that green water loadings are significant and should also be considered while designing other ship types [49].

Experimental work has been conducted by Buchner [11] and Greco [26] leading to insight into green water loading, both focussed on FPSO type vessels. From the 2D study by Greco [26], it is found that various aspects of the ship are of importance. From most to least influential on the loading: Freeboard, wave steepness, relative vertical motion, coupled flow between deck and outside, local flow at the bow, 3D effects, local design of deckhouse, stem angle, trim angle, hydro-elasticity during impact. Experiments are conducted, focussing on the influence of the bow overhang for a multipurpose cargo ship. This too is a factor in the resulting amount of green waters [5]. Also, an increase in green water was found with an increase of forward velocity [30]. Experiments using bubble image velocimetry techniques found the full green water velocities. A correlation between velocity and impact pressure was identified [75].

The most common form of water overtopping onto the deck is the dam-break scenario. This can be modelled with the Saint Venant shallow water equation implemented by Ritter [69]. Experiments show that this dam-break model captures the green water events reasonably well [70, 16]. The relationship between the initial water depth of the dam-break and the freeboard exceedance remains unclear [17]. In addition to dam-break solutions, shallow water equations are also directly applied to simulate green water flows [30, 55]. Green water can occur because of a negative freeboard as discussed in paragraph 1.1. However, hammer-fist events can occur when there is a positive freeboard [26]. Still, research is conducted into finding the relative wave elevation to help predict the occurrence of green water [10, 31, 61, 19]. This has not resulted in a generalized method due to the complexity of wave-structure interactions and the non-linear sea states and dynamic structure responses [17].

Something that should be noted is that various papers ([13, 6, 8, 67, 1]) have noted the variance in resulting pressures for seemingly constant conditions. It is explained that the violent and chaotic nature of wave impacts are the cause. It also shows that more understanding around the statistical nature of green water would be valuable.

Overview of experimental green water research

To get a better overview of the experimental work already done on green water, an overview of the found literature discussing experiments is created. This is shown in table 1.1. It shows 24 papers and the structure type used in the research, as well as the flow. Note that only 3 of the 24 considered works also take current into account. 4 papers look at a box placed in its entirety above the waterline.

13 out of the 24 papers considered stated a value for which they scaled. All of them used Froude similar scaling. Using these values and the known values for the generated waves, an overview of the size of waves used, scaled up to full scale so they are comparable, is given in table 1.3. An asterisk

Table 1.1: Overview of experimental green water research considered

Year	Research	Structure type	Wave and flow type
1995	Buchner [10]	Ship	JONSWAP + flow
1998	Hamoudi and Varyani [33]	Ship	JONSWAP + flow
2000	Ersdal and Kvitrud [22]	Ship	Irregular
2001	Stansberg and Karlsen [76]	Ship	Irregular
2001	Cox and Scott [19]	Box above water	JONSWAP
2001	Ogawa et al. [63]	Ship	Regular & Irregular + flow
2002	Faltinsen et al. [23]	Box	Regular
2003	Ogawa [62]	Ship	Regular & Irregular
2003	Mori and Cox [61]	Box above water	JONSWAP
2004	Greco et al. [27]	Ship	Breaking
2005	Guedes Soares and Pascoal [31]	Ship	JONSWAP
2005	Greco et al. [28]	Box	Regular
2007	Greco et al. [29]	Box	Regular
2012	Greco et al. [30]	Ship	Regular
2012	Lee et al. [54]	Box	Regular
2012	Ariyarathne et al. [3]	Box	Breaking
2013	Liut et al. [55]	Ship	Breaking-dam
2015	Song et al. [75]	Box above water	Breaking
2017	Abdussamie et al. [1]	TLP	Irregular
2017	Scharnke et al. [71]	Box above water	Breaking
2018	Chuang et al. [16]	Box	Random
2020	Lee et al. [53]	Box	Regular
2020	Hernández-Fontes et al. [36]	Box	Regular
2020	Hernández-Fontes et al. [37]	Box	Regular

Table 1.2: Amount of research into structure and wave types

	Structure type		Wave type			Current
	Box	Ship	Regular	Irregular	Breaking	Constant
Number of papers	13	10	10	11	5	3
Percentage of papers	57%	43%	38%	42%	19%	13%

Table 1.3: Values of waves and current scaled up to full scale. Asterisk indicates that the research uses breaking waves

Research	Wave period		Wave height		Length structure
	min	max	min	max	
	[s]	[s]	[m]	[m]	[m]
Buchner [10]	11.2	12.9	17.3	17.2	260
Hamoudi and Varyani [33]	8.00	12.0	50.2	8.00	175
Ersdal and Kvitrud [22]	13.0	12.0	7.50	7.00	242
Stansberg and Karlsen [76]	12.0	14.0	10.0	16.0	200
Ogawa et al. [63]	5.26	8.44	1.44	3.60	72.0
Ogawa [62]	6.38	-	3.33	-	78.5
Guedes Soares and Pascoal [31]	12.0	20.0	8.00	14.0	280
Greco et al. [30]	6.20	8.77	0.95	2.39	80.0
Lee et al. [54]	12.0	15.5	9.00	22.5	150
Ariyarathne et al. [3]	10.0*	18.6*	27.7*	28.7*	62.5
Abdussamie et al. [1]	15.3	19.7	21.0	32.6	125
Scharnke et al. [71]	7.91*	47.4*	46.5*	56.5*	78.8
Lee et al. [53]	15.1	-	13.1	-	241

indicates that the research considers breaking waves. This will influence the choice of values.

1.2.1 Green water event types

From the experimental research, green water events have been classified into four main categories: dam-break, plunging, plunging dam-break combination and hammer-fist events [29, 17, 90]. The impacts can be an isolated impact event, but multiple events can also follow each other up, influencing the loading [44]. For dam-break scenarios, a wall of water is created around the deck as a consequence of large relative vertical motions between the ship and the water [11]. As this water exceeds the freeboard, water flows onto the deck. The subsequent fluid motion on the deck resembles a wet dam-break flow [23]. Researchers have developed a good understanding of the impact due to this type of event [3].

However, plunging and hammer-fist type events lead to the most severe impacts [29]. This is because they lead to impulsive pressures. Impulsive pressures have a high pressure rise time, in contrast to non-impulsive pressures which have a slow rise time [17]. The maximum instantaneous pressure is related to this pressure rise time [75].

In contrast to the dam-break event, the plunging wave is not the result of a ship interaction with steep waves causing run-up [17, 23]. Plunging green water events are thought to be caused by an (almost) breaking wave impacting on deck or superstructures [23]. As the wave breaks and overtops the structure, the flow becomes multi-phased and chaotic as an air pocket is formed [80]. This air pocket can lead to pressure oscillations and pressure peaks [53]. Trapped air introduces a randomness which leads to variations in impact pressure [3].

A hybrid event type called a plunging dam-break event has also been identified. This type of event is the result of the interaction of a steep wave with the bow resulting in a wave breaking on deck. Plunging dam-breaking is the most common type of green water [29, 30]. With this type, air is also being trapped.

Hammer-fist type of events are, together with the plunging events, the most severe as they lead to the largest impacts. A hammer-fist impact happens when either a wave is focused locally in front of the edge of the deck, or when a strong wave impacts the vertical wall of the structure, pushing wave run-up onto the deck while maintaining a positive free-board [17]. The hammer-fist impact is connected to a steep, non-breaking wave. Hammer-fist impacts are blunt water-deck impacts. For these type of events there is no apparent air entrapment near the bow [29]

At this moment no clear quantification of the different events could be found in the literature. The found research made the classifications of the events based off of visuals [29, 17, 90]. Improving the classification can be beneficial for future green water research.

1.3 FUNDAMENTAL WORK FROM SIMILAR PROBLEMS

Similar physics can be at play for different phenomena. This is the case with waves on wall (sloshing), slamming (ship on wave) and green water (wave on ship). When looking at one, it is useful to look if you can use theories and research from the others. With help of [21] a short overview of relevant theories is made. They are mostly for scaling.

Wagner [83]

A model for an object entering a fluid is created by Wagner [83]. This is a model for the water entry problem. The Wagner model provides a solution for the impact pressure. For a Froude scaled problem and equal scaled density, Wagner scaling can be included [21].

Bagnold [4]

Bagnold [4] created a piston model. It models a piston with an initial velocity sliding along a tube with perfect gas entrapped. Bagnold-scaling is useful for scaling problems where the pressure inside gas pockets trapped by breaking waves is relevant [9]. The model can partially correct for the compressibility bias for wave impacts [50]. Brosset et al. [9] has further generalized the model.

Rankine-Hugoniot

For shockwaves a 1D model including the compressibility of a liquid can be used, based on Rankine-Hugoniot conditions. When looking at the pressure calculated using this model, a different scaling than with Bagnold's model is found. This is due to direct liquid impacts [21].

The scaling problem

For accurate sloshing model tests, Froude scaling, density ratio scaling, and speeds of sound have to be Froude scaled. Then the different phenomena should be balanced the same at both scales. This is not practically feasible as shown by Braeunig et al. [7].

For a wave impact on a wall, various elementary loading processes (ELP's) are identified by Lafeber et al. [51]. There are three identified, and each directly relates to one of the main physical phenomena involved. ELP 1, 2 and 3 respectively relate to liquid compressibility, the liquid change of momentum and compressibility of gas. For ELP1 Rankine-Hugoniot's work is relevant, for ELP2 Wagner's, and for ELP3 Bagnold's [21]. The different ELP's do interact, so scaling correctly for one won't mean that the corresponding phenomenon is appropriately scaled. The ELP's do give insight into the problem with scaling for these types of impacts.

Kiger and Duncan [47]

Kiger and Duncan [47] Investigates entrained and trapped air in a plunging jet or breaking plunging wave. It shows an importance of using nondimensional numbers to gain insight into the problem. It also investigates the connection between the simplified cases and the full complex situations, and concludes that nonlinear interactions of multiple dynamic processes is limiting.

Oumeraci et al. [65]

This research is not focused on scaling, but qualitatively classifies four types of breakers. The corresponding impact loads are described, leading to the ability to identify different impact types using the force history [65]. Classifying the impact types for green water is one of the goals, as stated in paragraph 2.2.

1.3.1 Air entrapment

When experiments are conducted, the problem is scaled down to fit inside test facilities. For green water experiments, scaling laws are violated for the effect of air entrapment. Air entrapment in scaled experiments can for instance lead to surface tension influencing the green water [28]. A high level of aeration can increase both the force and impulse on a structure [3].

Air entrapment is also relevant for coastal engineering [14], sloshing [58], and slamming events [32]. The literature from these research areas involving air entrapment is used to look into air entrapment. Through experimental research on waves impacting a vertical wall, it is found that small amounts of entrapped air lead to a significant increase in impact pressure. A large amount of entrapped air has a damping effect on the pressures [34]. With computational simulations, slamming events where air and water mix are also researched. Pockets of bubbles can cushion the pressures, while for small bubbles in the water the pressure oscillations are more intense [78]. Particle image velocimetry (PIV) combined with pressure sensors showed oscillating behaviour for air entrapment during sloshing [58]. The cushioning effect of air entrapment on the loading for a cylinder entering water is investigated numerically and experimentally [32]. Air entrapped for ocean waves impacting on sea walls is experimentally researched. It shows that air can be compressed to a pressure of several atmospheres and pressure shock-waves can lead to pressures comparable with those of the initial impact [8]. Research to improve numerical simulations of air entrapment has also been conducted in recent years [78**?**].

1.4 SIMULATION METHODS

Despite difficulties with the numerical simulations of green water, work continued. Work on the numerical simulation has been focussed on reducing the costs of calculations and increasing the quality. This research is also mostly conducted for FPSO type vessels or container ships, or simplified structures. Even though several numerical models have been developed to predict impact pressure, most of them are based on simplified assumptions such as inviscid and incompressible fluid, and single-phase flows [3].

One of the simulation methods is numerical time-domain simulations based on an incompressible flow solver operating on unstructured grids. It shows good agreement with experimental results [57]. An SPH method was used to simulate an extreme plunging wave impinging on the deck [74] and to predict the fluid behaviour for green water [52]. A hybrid CFD method involving linear seakeeping and nonlinear CFD analysis, both using 3D modelling of the hull, was introduced [48]. Also, a three-step method (CFD-BEM-FEM) has been introduced to evaluate the loads due to green water on a container ship [49]. The Natural Element Method (NEM) employs a CIP-based method and a particle method to simulate strongly nonlinear wave-body interaction problems and is promising to be a valid alternative for green water simulations [39]. A CFD method with VOF-multiphase and SST-turbulence gives access to high spatial resolution free surface position, water velocities and load distribution, phenomena usually not available from experiments [41]. Simulations with a multiphase-flow software based on a free-surface capturing method are used to evaluate green water for a Wigley hull. To reduce numerical diffusion at the free surface a solid-liquid-gas flow coupling model is developed by adopting Blend Reconstruction Interface Capturing Scheme (BRICS) [35].

From research into simulating green water loading with dam-break simulations it is found using a turbulence model, in this case k-ϵ turbulence closure, gives the most accurate simulation results [45]. By comparing vertical loadings found with experiments to simple potential theory-based simulations and commercial CFD code it was found that potential code is adequate to find vertical loadings due to isolated impact events [44]. A potential theory-based engineering tool called KINEMA3 is developed to predict wave-induced impact loads on FPSOs in steep irregular waves, and for use in design load analysis [72]. A combination of the KINEMA3 and a CFD tool using the finite volume VoF (STARCCM+) is introduced. KINEMA3 is used to generate inlet conditions and STARCCM+ to model detailed flow on the deck [66]. Another way of combining a potential and CFD tool is by using a potential solver which finds the motions of a vessel and then using a CFD solver to find the green water loading [91]. A numerical approach using potential theory in the frequency domain to predict the relative wave elevation response for an FPSO can also be used [85].

2 DELIVERABLES

Here an overview is given of the deliverables. First, the idea of the research is described, then concrete goals are discussed. After this, it is discussed what goals have been (partially) achieved. At the end a plan for the future is shown.

2.1 ABSTRACT IDEAS

SAMENVOEGEN ONDERSTAANDE STUKKEN TEKST
Literature study into green water. A lot of research into simulations has not yet been able to affordably and accurately simulate. Most previous research into the green water itself thus conducted with experiments, as discussed in chapter 1. These experiments are mostly fairly simplified representations of reality, as shown in paragraph 1.2. This has given a lot of insight and five different types of green water events have been identified, discussed in 1.2.1. It also left questions around the occurrence of green water and various green water event types. As most research has been experimental research, the problem has been scaled. However, during green water events air can be trapped. When this happens. the scaling laws are broken. This prevents the experimental data being used for large scales. Understanding the differences between the scaled and full scale results will make the experiments at model scale more useful.

Firstly, long-running experiments will be conducted to obtain long-term data. The long-term data set will allow for the identification of extreme loading events and the frequency of occurrence, giving more insight into the hydrodynamics of the green water problem. The data from these experiments will also be used as input for a probabilistic model, the research subject of WP-C. To do these long-running experiments, the existing flume tank will be adapted. The flumetank is 7 m long, 2.35 m wide, and 0.5 m tank with an inlet and outlet on each end to create a constant current. Adaptations will be made as a wedge-shaped plunging a wavemaker and a parabolic perforated beach will be added. This test facility will allow for continuous experiments with waves and current to be conducted. It will be a unique facility with many possibilities for future research.

Scaling effects will also be researched as lack of knowledge leads to inaccurate results for green water when scaled experiments are used in research. This is problematic because scaled experiments are the main methodology of researching green water. The scaling laws are broken for, for instance, air entrapment during these experiments. The largest green water loads are found when air is entrapped by the water. To research the effects of scaling, parts of the long-running experiments will be repeated at larger scales in the existing towing tanks at TU Delft.

2.2 CONCRETE GOALS

To give a clear view of what the research is focused on, some concrete goals are stated below. Goals 1, 3, 4, 5, 8, 9 hold potential to lead to publications.

1. The flumetank will be adapted to become a wave-current tank and the test facility will be validated by recreating experimental data from the towing tank
2. Large data sets will be generated with a model in irregular waves running for 40 hours
3. From the large data set correlations between measured parameters and green water event types will be found
4. The difference between various green water event types will be quantitatively formulated
5. Using the large data sets the stochastics of green water event types will be quantified
6. Other possible research using the wave-current tank will be started (e.g. slamming, different models, different sea states)
7. Short time series where green water and air entrapment occur will be repeated at different scales, keeping the other parameters constant
8. The effect of scaling on the resulting pressures of the green water event will be evaluated
9. With the knowledge of the effect of scaling, a procedure to minimize the effect or effectively compensate for it is set up

2.3 ACHIEVED GOALS

From the above, concrete goals, goal 1 has been PARTIALLY????? achieved. In figures HERE FIGURES OF THE ADDITIONS TO THE FLUMETANK the parts that have been physically build are shown.

Work on fulfilling goals 2 and 3 is started. This is shown in the form of paper setups in appendixes A and B.

2.4 PLANNING FOR COMING YEARS

2.4.1 Data Management Plan

A SETUP PAPER 1: WAVE-CURRENT TANK TO GENERATE LARGE SETS OF EXPERIMENTAL DATA

ABSTRACT

Large data sets can lead to new insights into old problems. Even though we are able to handle and store large sets of data, for extreme wave impacts on maritime structures like green water and slamming there is not yet a cheap way to generate large sets of data. Large data sets can be obtained cheaply by doing long running, continuous experiments as tank time and man hours are drastically reduced. Creating a testing facility where these long running, continuous experiments with waves and current can be conducted is thus the goal. This test facility is built by equipping an existing current-flumetank with a wavemaker and wave dissipater (beach). The test facility is first validated by reproducing experimental results obtained in a towing tank. Afterwards it is shown that it is able to cheaply generate large data sets.

A.1 INTRODUCTION

The next big shift in scientific methods is happening now, according to Tolle et al. [81], George et al. [25] and Frické [24], as "Big Data" is suggested to be the fourth paradigm for scientific exploration — the first three are experiments, theories and simulations. This shift comes as over the years computer capabilities have steadily improved. With these improvements we can now store and handle large data sets cheaply, which is thought to go and change scientific methods. Frické [24] even asks the question if this might lead to a routine or semi-mechanical way of producing valuable scientific theories.

Looking at the field of ship hydromechanics however, it seems large data sets have not made their introduction. There are some examples of the use of big data in the offshore engineering for, for example, route optimization [87, 42], ship traffic and collision evaluation [84, 43, 89, 42, 88], performance monitoring [12] or maintenance cycles [73]. These examples show that there is some use, but not for the hydromechanics of a ship.

Large data sets provide new ways of viewing a problem, giving new insights into old problems. Looking at for instance extreme nonlinear wave impacts like sloshing and green water. There is no method to model them yet. The problem is complex, with a statistical component to these impacts, with variability within 'constant' conditions [13, 6, 8, 67, 1]. Also many parameters and nonlinear effects are at play [26, 11, 23] and the events do not occur often as they are rare events.

For complex problems like sloshing and green water, experiments are needed as they can not yet be accurately and affordably be simulated [31]. It is an option to drive up and down many times in a towing tank and then knit all the runs together to obtain a large data set. However, the man hours, tank time and post-processing needed are costly. This, in turn, limits the amount of data that can be obtained.

Problem statement

This shows the problem: even though we are able to handle and store large sets of data, we can not yet cheaply generate large sets of experimental data in a controlled environment. This means we are missing out on a new way of doing research. To generate the required data, we need to limit the amount of tank time and man hours needed to generate data. This can be achieved by doing long running, continuous experiments. This way the waiting time, in which you wait till all the waves and disturbances are dissipated, in between runs is eliminated. This significantly reduces the time the tank is in use, and also the hours of manpower needed. There are tanks where you could do long running, continuous experiments with waves *or* currents in wave- or current-flumetanks. In wave-flumetanks there is no current. Without the current, waves are free to flow back after reflecting behind the model, disturbing incoming waves, which in turn reduces the quality of the experiments. Also, no forward velocity or current flow can be modeled in these tanks. In current-flumetanks, there are no waves. This is problematic as, as discussed before, the use of large data sets would be interesting mostly for extreme wave impacts.
What is needed is a testing facility where long running, continuous experiments with waves and current can be conducted.

Goal: A new testing facility that can cheaply generate large sets of data by allowing continuous long running experiments with waves and current.

A.2 METHOD

Adapting the existing flumetank to create a wave-current tank, capable of continuously generating waves and currents. This allows for long running experiments — up to hours or days. This will be done by converting an existing current-flumetank to a wave-current tank by placing a wave generating device (wavemaker) and wave dissipating device (beach) on it. The new testing facility will be validate by comparing the same experiments from the towing tank with the results obtained from the new wave-current tank. Afterwards long experiments will be conducted to verified that it can indeed also generate large data sets.

A.3 FACILITY

Existing flumetank is used
ALL INFO ABOUT EXISTING FLUMETANK
A schematic of the tank is shown in HIER EEN FIGUUR VAN DE BESTAANDE FLUMETANK MET AFMETINGEN.

A.3.1 Wavemaker

Wavemaker: some design conditions
1: has to operate in flow (no obstruction but still good waves)
2: has to operate within the dimensions of the tank
3: has to be able to make regular and irregular waves
Plunging wedge type wavemaker. based in theory developed over the years by Madsen [59], Wu [86], Lowell and Irani [56]
Designed for waves of a length between 0.05 meter and 3 meter with a maximum wave height over length of 1/25. These values are chosen because at maximum water depth the waves will be deep water to intermediate gravity waves in this range.
These design choices have led to the wavemaker shown in figure A.1. The maximum amplitude of the stroke of the wavemaker is 0.12 m and the maximum velocity is 0.6 m/s. To move and control the wavemaker a servo motor (EMMT-AS-80-M-HS-RSB). servo motor controller (CMMT-AS-C3-11A-P3-EP-S1) and electric cylinder (ESBF-BS-50-300-10P-S1-R3) are used.

Waves wavemaker

To be able to generate the waves that we want to generate, we need to know how well the wavemaker works. This will be tested by systematically testing the wavemaker and measuring the results. HIER OVERZICHT VAN GOLVEN DIE GEMETEN GAAN WORDEN (CONSTANT/SPREIDING. MAX. MIN. ONREGELMATIG)

A.3.2 Beach

To minimize reflections which will interfere with the created waves. the waves should be dissipated as much as possible once they have moved passed the model. For this a dissipation device, also called a beach, is used. It is shown in figure A.2

Instead of making this beach impermeable. it is more effective to introduce perforations help dissipate wave energy. The size of the perforations for the beach were based on the research by Chegini [15]. The beach is made of 1 mm thick stainless steel with 5 mm wide squares and a total perforation rate of 45%.
For the shape of the beach a parabola was chosen. From a survey conducted by Ouellet and Datta [64] the parabolic shape profile was recommended. Based on the results found in Hodaei et al. [38] and scaling those to our experiments. a parabolic shape of $y = -3.32 \cdot x^2 + 0.04 \cdot x$ was chosen. The

Figure A.1: PLACEHOLDER The wavemaker, placed to generate waves

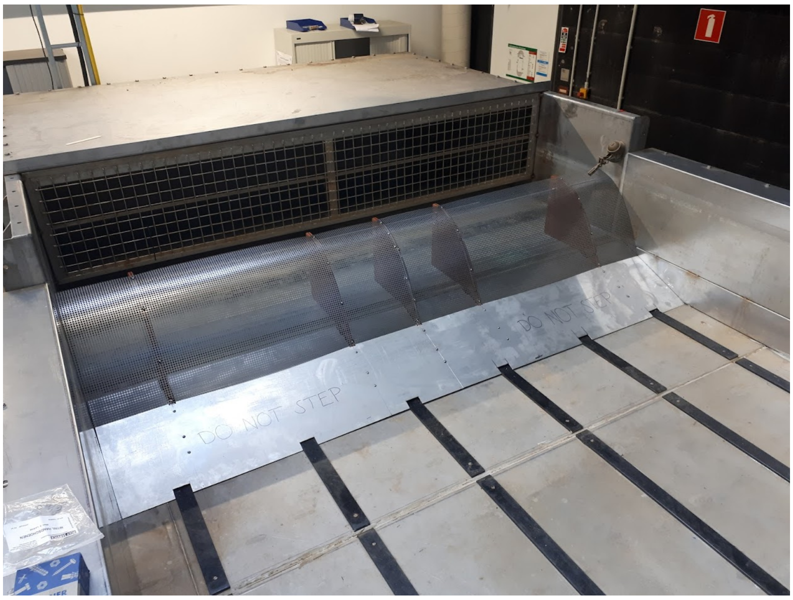

Figure A.2: PLACEHOLDER The beach, placed to dissipate wave energy beach is placed such that the highest point is at the waterline. The scaling and design of the beach is done with a focus on long waves. This because for the longest waves the largest reflection coefficients are found. as shown in [77]. They also contain more energy compared to shorter waves of similar steepness. Also. they move faster thus could actually be able to move towards the model even if there is current. and they have the highest chance of influencing the results. Because of all these reasons the focus during the designing of the beach has been on damping these largest waves.

Effectiveness beach

To see how effective the beach is, thorough measurements will be conducted with various regular and irregular waves, and various current velocities. The reflection coefficients for different waves and wave spectra should be known as this will pollute the generated wave spectra during long running experiments.

A.3.3 Validation facility

Tests are conducted in the towing tank in an irregular wave spectrum. These experiments will be repeated in the wave-current tank to validate the testing facility.

A.3.4 Data handling

Goal of test facility is to create large amounts of data, but this data also needs to be saved, stored and processed. The data acquisition flow is visualized in figure A.3. Video footage is obtained and saved using the open source software Open Broadcaster Software (OBS). This, together with the acquired data can be viewed live during the experiments, allowing for active supervision.

Data analysis

To find the events the wetness sensors are used
EXPLAIN HOW I HANDLED ALL THE DATA

A.4 EXPERIMENTS

A.4.1 Chosen conditions

The peak frequency and significant wave height are based on rough sea conditions or storm conditions found in sources [20, 60, 18, 79].

At full scale the depth would be about .... This might seem unrealistic as the average of the worlds oceans is 3729 m [68]. The North Sea and Gulf of Thailand however. areas with a lot of ship traffic. have respectively and

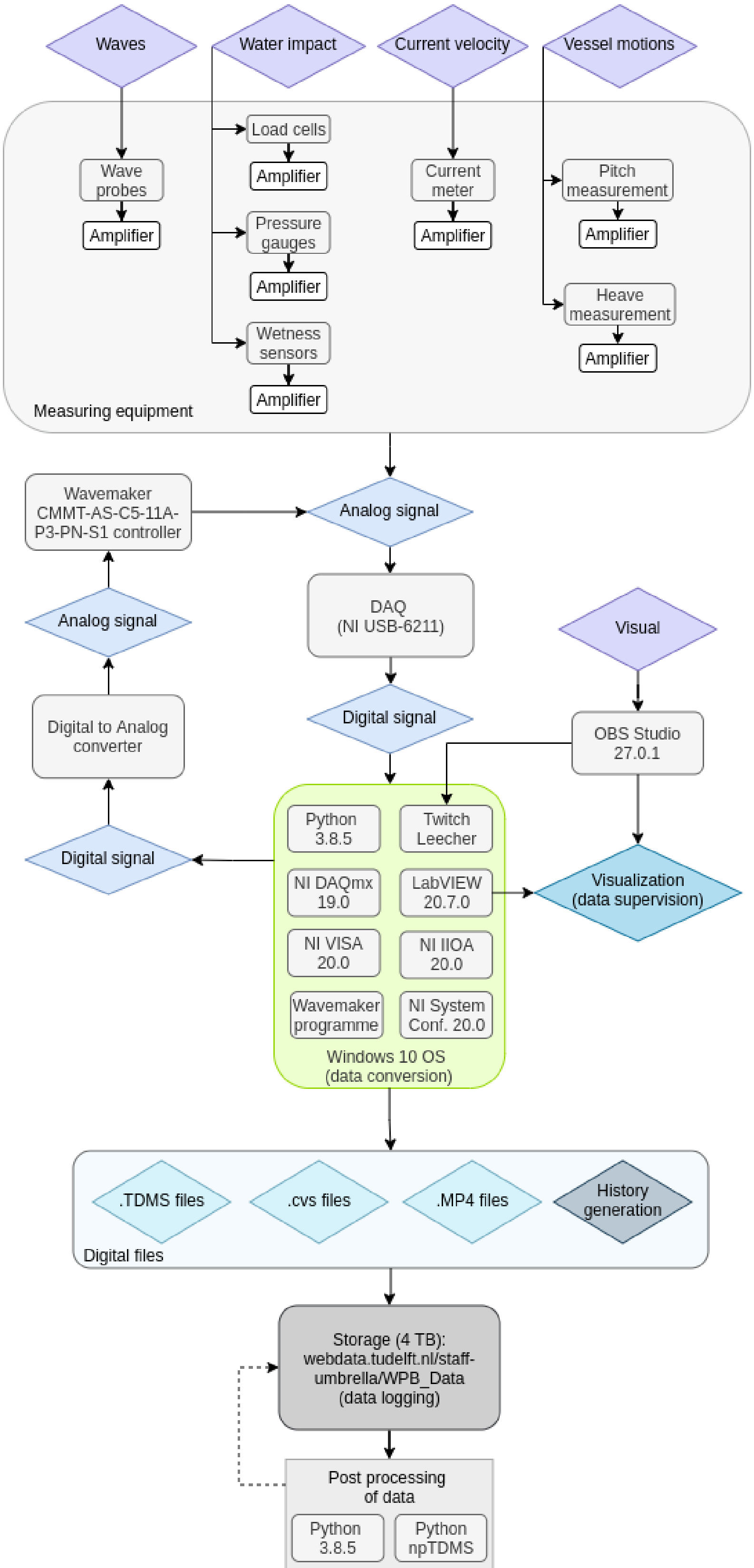

Figure A.3: Flow of the data during experiments, from acquisition to storage average depth of 95 m [2] and 58 m [46]. This shows that the wave conditions where bottom effects play some role are not unreasonable.

B SETUP PAPER 2: USING LARGE SETS OF EXPERIMENTAL DATA TO INVESTIGATE GREEN WATER

ABSTRACT

Green water is a non-linear and strongly complex problem. Green water events are also extreme events, which means that they do not occur often. Long running experimental research is be conducted to collect different occurrences of green water. *Rest will have to be written once data is collected and we know what we can get out of it*

B.1 INTRODUCTION

Ships and offshore structures are out in the ocean to transport the many goods we send around the world. pump up oil, or place wind turbines. Waves impact these structures, causing large loads. Green water is one of these impact types. Green water is water that impacts on deck or superstructures. It can lead to huge impact pressures. As Buchner [11] stated, green water is a non-linear and strongly complex problem. Green water events are also extreme events, which means that they do not occur often.

Previous research into green water can be categorized into three groups: approximations, numerical and experimental [40]. Approximations are empirical and analytical methods. They are simple and fast but less accurate. They consist mostly of predicting freeboard exceedance, as most greenwater events occur when the freeboard is exceeded. ADD A PIECE ABOUT IDENTIFICATION OF DIFFERENT TYPES OF GREEN WATER EVENTS BY GRECO Prediction of exceedence of the freeboard is complex due to the many dependencies [53]. These are for instance wave steepness or structure motions [26, 11]. These parameters also introduce nonlinearities [23]. Researchers have made probability distributions of the free-board exceedance based on empirical parameters. Examples are Buchner [11], Cox and Scott [19] and Guedes Soares and Pascoal [31]. Numerical methods are more accurate than these approximation methods. The problem with numerical simulations is that they take excessive computational time [74]. Experiments for green water events are affordable and the most accurate method or researching green water.

An overview of literature discussing experiments is created. This is shown in table B.1. It shows 24 papers and the structure type used in the research, as well as the flow. Most experiments are conducted for a simplified model and in regular waves. Only 3 of the 24 papers take current velocity into account. All the research discussed was conducted with limited testing times,

Table B.1: Overview of previous experimental green water research

Year	Research	Structure type	Wave and flow type
1995	Buchner [10]	Ship	JONSWAP + flow
1998	Hamoudi and Varyani [33]	Ship	JONSWAP + flow
2000	Ersdal and Kvitrud [22]	Ship	Irregular
2001	Stansberg and Karlsen [76]	Ship	Irregular
2001	Cox and Scott [19]	Box above water	JONSWAP
2001	Ogawa et al. [63]	Ship	Regular & Irregular + flow
2002	Faltinsen et al. [23]	Box	Regular
2003	Ogawa [62]	Ship	Regular & Irregular
2003	Mori and Cox [61]	Box above water	JONSWAP
2004	Greco et al. [27]	Ship	Breaking
2005	Guedes Soares and Pascoal [31]	Ship	JONSWAP
2005	Greco et al. [28]	Box	Regular
2007	Greco et al. [29]	Box	Regular
2012	Greco et al. [30]	Ship	Regular
2012	Lee et al. [54]	Box	Regular
2012	Ariyarathne et al. [3]	Box	Breaking
2013	Liut et al. [55]	Ship	Breaking-dam
2015	Song et al. [75]	Box above water	Breaking
2017	Abdussamie et al. [1]	TLP	Irregular
2017	Scharnke et al. [71]	Box above water	Breaking
2018	Chuang et al. [16]	Box	Random
2020	Lee et al. [53]	Box	Regular
2020	Hernández-Fontes et al. [36]	Box	Regular
2020	Hernández-Fontes et al. [37]	Box	Regular

except for the research by Hamoudi and Varyani [33] which used measurements from a full scale vessel.

This makes sense because long testing times in a controlled and measurable environment could be achieved by doing many separate runs in a towing tank and knitting them together, but this is very expensive. The other option to research green water is to make the occurence of green water very likely, making it possible to research it with a short testing time. This leaves many questions open around the statistics of green water, and also makes it likely that green water events that occur in situations where researchers won't expect them, won't be researched. To overcome this, long running experiments with many waves passing a model should be conducted.

B.2 METHOD

Experiments with long testing times will be conducted in the wave-current tank.
Pre-processing of the large data sets (eliminate what is not good, what is good, label/categorize, simplify data (make it clear points))
cluster points / do something else with the cleaned up data

be on the look out of passive handling of the data due to its size, or unsound statistical fiddling [24].

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