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faculty of science and engineering

Investigating the effect of varying the distribution of damping coefficients inside a floater blanket on the power extraction for a novel wave energy converter.

PTL05

Coen Hoogerbrugge, S2574667

1st supervisor: Prof dr. A. Vakis
2nd supervisor: Dr. G. Larsen

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Abstract

This report is part of a research into the development of a novel Wave Energy Converter (WEC) called the Ocean Grazer. The WEC uses an array of interconnected floaters in a so called floater blanket to harvest wave energy at open sea. The amount of energy that is extracted from the wave is highly dependent on the damping force. The damping force that each damper exerts on the incoming waves can be separately adapted for each floater, in order to improve the performance of the floater blanket. Considering that each floater has 8 possible damping settings, and that a floater blanket of 100 floaters is considered for this report, this results in $2*10^{90}$ possible configurations. For analysis of the performance of the floater blanket at different configurations a frequency-domain MATLAB model is created by the Ocean Grazer team. This model uses a configuration of damping coefficients as its input, and returns information about e.g. the capture factor (the relation between the amount of power in the incoming wave and the extracted power). With the current available computational power it is however still impossible to run each configuration through the MATLAB-model in order to find the most appropriate setting.

This report focusses on discovering general relations between different damping coefficients and their corresponding performances, measured in capture factors for each frequency. Three methods of data acquisition are applied: an analytical method, a brute force method and a Particle Swarm Optimization-method. The most striking results are:

- That a configuration, which has increasing damping coefficients from the side where the incident wave meets the floater blanket, seems to always provide a higher capture factor than a uniform configuration, which in turn provides a higher capture factor than a configuration which has decreasing damping coefficients from the side where the incident wave meets the floater blanket.
- That there is a cross-over wave frequency at which the optimal configuration for the floater blanket changes from a configuration in which the highest damping coefficients are found in the columns at the edges of the floater blanket, to a configuration where the highest damping coefficients are found in the centre columns of the floater blanket.

1. Introduction

In today's world the human influence on climate change is becoming increasingly recognized by the scientific community[1]. Even though there is still a group of people denying global warming, or any significant human contribution to this phenomenon, the major global consensus is that climate change is real and needs to be taken seriously.

Treaties like the Paris Agreement [2] are exhibits of the rising global moral obligation that is felt to stop and reverse global warming and the matching damage that is done to the earth. In the U.S.A. the generation, transmission and distribution of electricity was responsible for 29% of the greenhouse gas emission in 2015[3], this even transcends the transportation sector, which holds second place with 27%. One of the main focusses in the endeavour to stop and reverse global warming is the transition from fossil fuels to the use of renewable energy sources which can be used without (significant) emissions. The percentage of energy generated in the U.S.A. coming from renewable energy sources has increased from 9.1% in 2007 to 12.2% in 2016[4], this is an indication of a transformation, albeit slow, to increased use of renewable energy in favour of fossil fuels. The implementation of energy generated through wind turbines, solar panels, biomass and hydropower dams is widely spread and makes up practically all of the sources of renewable energy currently adopted[4].

There are however other vast sources of renewable energy which are currently not tapped into. Many of these energy sources lie in the vast oceans that cover more than half of the earth's surface. These enormous water bodies are set into motion on a daily basis under the influence of external forces, such as air currents and tidal forces. In Europe and North America and Japan alone over 1000 wave energy conversion techniques have already been patented [5], indicating the widespread interest in the technology to harvest this enormous energy source. Distinct advantages of Wave energy conversion are the limited negative environmental impact, the high energy density, the high predictability of the energy source and the continuity of the supply in a day [6].

The Ocean Grazer-team seeks to develop a new technology which can be used to exploit wave energy, in an attempt to reduce the use of fossil fuels. The multidisciplinary team is working on a novel wave energy collection and storage device, which converts offshore wave-energy into electrical energy. Even though there is a lot of development in the field of wave energy capture, the Ocean Grazer has some properties which make it distinctly innovative. One of the most important being the possibility to save a determined amount of potential energy for later, this potential energy can be converted to electrical energy when this is desired.

2. Problem analysis

2.1 Problem description.

The Ocean Grazer is an innovative wave energy collection and storage device which is being designed by a multidisciplinary research team at the University of Groningen. For investigation into the energy capturing performance of the Ocean Grazer, a frequency domain simulation model has been created in MATLAB[7]. This analytical model can be used to calculate the power take-off for each floater when different damping coefficients are applied to the multi-pump, multi-piston power take-off (MP^2PTO) system, the functionality of this system will be elaborated on later in this document. The model has already proven to be capable of calculating the wave power captured when all the floaters have uniform damping coefficients. Further analysis has however exposed that the damping distribution at which the capture factor is highest is often not a uniform distribution.

The setup that is considered in this project, with 100 floaters and 8 possible settings for each floater, yields ($8^{100} \approx$) $2*10^{90}$ different piston combinations. Each damping configuration results in a different capture factor, which is the ratio between the power harvested by the floater blanket and the total amount of power present in the incident wave, this parameter is often used to assess the performance of a WEC. Running every possible configuration to find the configuration with the highest capture factor would take too much computational time and be highly inefficient. This constitutes the problem that will be addressed in this report, a way will be sought to approximate the optimal damping configuration without the necessity of running every possible configuration. Fig. 1 depicts the way the Ocean Grazer will be enabled to react to changing characteristics of incoming waves and guarantee a high capture factor with regards to the energy retained in the incoming waves. First the incoming wave is analysed by sensors and expressed in numerical wave characteristics, the frequency with which this can be done most efficiently is unknown yet, and will have to be investigated in later research. The parameterized wave characteristics are then fed into the decision tool, which calculates the (near-)optimal configuration for the floater blanket under those conditions. With this information the actuators of the MP^2PTO system are inhibited to conform to the determined configuration. The diamond shaped box with the red text indicates the part that this report will focus on, the part in which altering incoming wave characteristics are coupled to a specific MP^2PTO configuration.

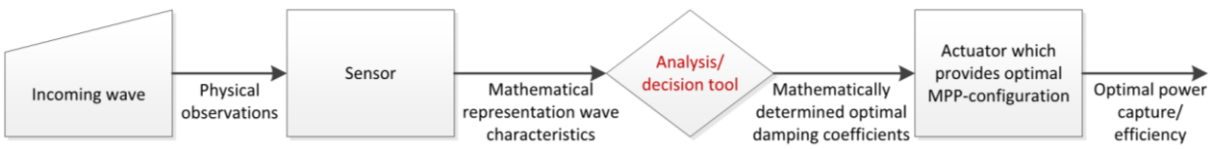

Figure 1. Depiction of the process from incoming wave to the optimal MPP-configuration.

2.2 System description.

The Ocean Grazer is designed to cope with certain limitations that existing wave energy converters encounter:

- The Ocean Grazer employs a hybrid system which allows it to harvest a combination of wind-, solar- and wave-energy.
- The Ocean Grazer employs a way to save up a certain amount of potential energy which can be converted to electrical energy later when desired.

- The Ocean Grazer is suited with an MP^{2}PTO system, allowing it to adapt to changing wave conditions, extending the range of conditions in which it can remain operative and improving its efficiency.

The Ocean Grazer is a concrete construction which uses a floater blanket consisting of multiple interconnected floaters ($B_{1, 2, 3 \& 4}$, fig. 2a) to capture wave energy at open sea. These floaters are excited by the incoming waves in a heaving motion, they are connected to each other lengthwise with joints and broadwise with springs. Attached to each floater is a cable running down into the construction, which is connected on the opposite side to a set of pistons ($P_{1, 2, 3 \& 4,}$ fig. 2a). Through the heaving motion in the floater blanket, the pistons will come into motion and pump the fluid from the lower situated basin to the higher situated basin, or equivalently: the fluid is pumped from a location with less potential energy to a location where it has more potential energy. The fluid can be stored in this top basin until electrical energy is required or the basin is filled. When desired, the valve to the turbine (T, fig. 2a) can be opened, thereby releasing the water from the state of high energy to run down to a state of low energy, converting part of the energy into electricity by means of the turbine.

As mentioned before, each cable is connected to a set of pistons, P_1, P_2, P_3 and P_4, each consist of three separate pistons (fig. 2b). This collection of pistons is called a Multi-pump, multi-piston power take-off (MP^{2}PTO) system[8], it allows the user to vary the water column which has to be lifted in each upstroke. Basically, the system consists of three pistons with surface relations of 1, 2 and 4, which can be activated and deactivated at will, thus creating 8 different piston activation combinations for each floater, these are shown in Table 1. Different activation combinations correspond to different water columns which have to be elevated to the higher basin on each stroke, which results in different damping forces for the floater blanket.

Setting	0	1	2	3	4	5	6	7
Active	0	1	2	1+2	4	1+4	2+4	1+2+4

Table 1. The eight damping settings and corresponding activated pistons.

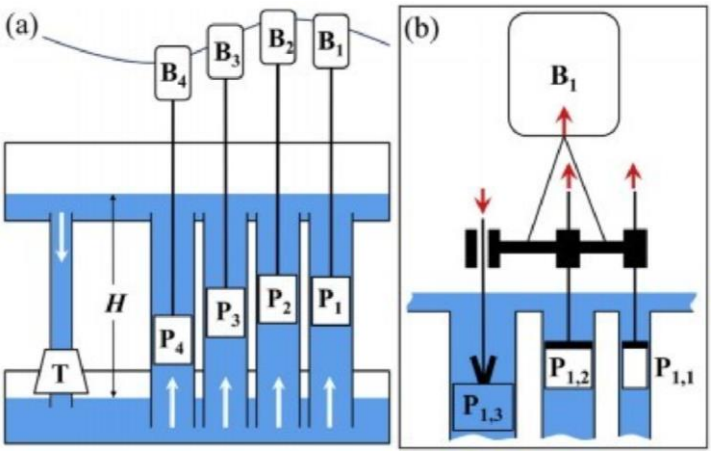

Figure 2. (a) Schematic drawing of the Ocean grazer. (b)Schematic drawing of the MP^{2}PTO system.[5]

The model that was created in MATLAB uses a calculation for the power take off-system that is based on a linear spring-damper system. The formula's used for the reaction force and absorbed power are given by[9]:

$$F_{PTO} = -K_{PTO}\ x\ X_{rel} - C_{PTO}\ x\ \dot{X}_{rel}$$

$$P_{PTO} = -F_{PTO}\ x\ \dot{X}_{rel}$$

F_{PTO} is the reaction force of the floater to the incident wave.
K_{PTO} is the stiffness of the PTO-system.
C_{PTO} is the damping caused by the PTO-system
X_{rel} is the relative heaving motion of the floater
$\dot{X}_{rel}$is the relative heaving velocity of the floater

The damping coefficient represents an external damping-force on the floater, due to the mass of the water column that has to be moved by the pistons. The exerted force is dependent on the damping coefficient and is proportional to the velocity at which the pistons move. The damping force can therefore be described by the following formula:

$$Fd = -c * v$$

In which *Fd* is the damping force, *c* is the damping coefficient and *v* is the velocity. In this research the K_{PTO} value is set to 0 and the C_{PTO} values for the floaters are varied.

Even though the final design of the Ocean Grazer will presumably be assembled with a significantly higher amount of floaters, this report will focus on a small test setup for an analysis of the effects of changing MP^2PTO configurations. The test setup that is considered in this report is a floater blanket of 10 floaters by 10 floaters, of which each floater has dimensions of 7x7 m. This setup will be used in an attempt to develop an energy maximization control strategy for the MP2PTO system.

2.3 Problem statement.

The relations between the damping coefficient configuration of the MP^2PTO system and the total energy capture for a floater blanket are difficult to predict because of the many involved parameters, this makes it computationally demanding to find the optimal configuration.

2.4 Problem owner analysis.

The problem owner is Mr Y. Wei, a post-doctoral researcher in Hydrodynamics at the University of Groningen, currently conducting research into the Ocean Grazer. One of the goals of his research is to create a mathematical model of the ocean Grazer which accurately predicts the optimal multi-piston pump(MPP)-configuration for each floater in a floater blanket, adapted to incoming waves with varying significant wave periods. This integration project, and the conclusions and recommendations that derive from it constitute a step in that research.

2.5 Stakeholder analysis.

Except for Mr. Wei no direct stakeholders can be found, there are however some stakeholders related to the progress which is made on the entire Ocean Grazer project. Each of these stakeholders benefit in their own way from progress that is made on the Ocean Grazer:

- **The Ocean Grazer Team**
  The entire team of Project members, academic staff, lab technicians and researchers associated with the Ocean Grazer Project. This is the most direct group of stakeholders which benefit from progress made on the project.

- **the University of Groningen**
  As the Ocean Grazer-project is conducted by researchers from the RUG and partially financed by the University, it is also one of the stakeholders and will benefit from the Ocean Grazer becoming a success, especially in terms of prestige.

- **(Academic) Network partners**
  Several companies, government bodies, organizations and research institutes have declared to actively support and participate in the research and development of the Ocean Grazer. These are obviously stakeholders in the progress that is made towards reaching a working and viable concept for the Ocean Grazer.

3. Research goal.

In order to reach a viable design for the Ocean Grazer, it is crucial to optimize the control strategy for the MP^2PTO system. Using a suboptimal configuration is an unnecessary loss of potential power take-off, which leads to significant energy losses if the Ocean Grazer is implemented on a sizable scale. This report is a step in the process of finding a way to determine the optimal MPP-configuration for incoming waves of varying characteristic wave heights and periods that is computationally viable. This method can then be used to adapt the piston combinations of the Ocean Grazer in real time in order to maximize the energy extraction at any given moment. The specific research goal for this Integration Project is:

<u>The goal of this project is to document how varying the distribution of damping coefficients in a floater blanket influences the total wave power extraction and to explain why this happens.</u>

3.1 Research questions.

To reach the envisioned research goal, the following <u>main research question</u> and sub questions will have to be answered:

<u>- How do different distributions of damping coefficients inside a 10x10 floater blanket influence the total power extraction?</u>

- Can certain configurations be eliminated beforehand, in order to reduce the computational complexity for finding the optimal solution?
- In what way does the floater blanket react differently to varying characteristic wave periods of incoming waves?
- How do variations of damping coefficients influence the total energy yield when columns with uniform damping coefficients are considered?
- How do variations of damping coefficients influence the total energy yield when rows with uniform damping coefficients are considered?

4. Research cycle choice.

In order to warrant a well organised approach for a research it is often regarded as convenient to distinguish the steps to be taken based on a cyclical concept. There are different cycles which can be selected, and there is no general, most appropriate method. In order to determine the cycle that is deemed most suitable for this research, a meeting was arranged with Mr. Wei, the Ocean Grazer team member with the most expertise in this field of research. Mr. Wei is a post doctorate in hydrodynamics, and the creator of the MATLAB model that is used. Initially a well-substantiated trial and error approach was elected, which implies a method where multiple iterations are run, and the information extracted from preceding iterations is used to formulate new hypotheses. This method matches perfectly with the design cycle depicted in fig. 3, because both the cycle and the chosen method are iterative. The two other methods that were chosen further into the research are also described and executed according to the steps in the design cycle. The particular way in which the steps of the design cycle have been shaped in the context of this research will be elaborated on in '*Applied methods*'.

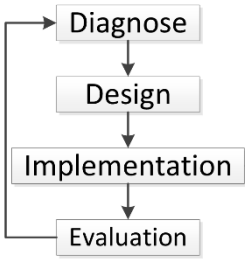

Figure 3. The engineering cycle.

5. Applied methods

During the conducted research three different methods of data collection have been used, these will be elaborated on below. The way in which the steps of the design cycle have been shaped is described for each method separately.

5.1 Analytical method

The first method that was applied was based on repetitive running of handmade test-configurations through the MATLAB model. The idea behind this approach is to test hypotheses which are drafted based on literature research and prior iterations.

- Diagnose: Prior iterations are analysed and literature research is conducted in order to create hypotheses about the relation between the configuration of the floater blanket and its corresponding performance.
- Design: Test configurations are created in such a manner that as little as possible factors differ from each other except the parameter on which the hypothesis was based, this is done in order to reduce the risk of drawing conclusions about the hypotheses based on improper data. To run the test configurations, an extension to the used MATLAB model is created, which can be used to enter the chosen damping coefficients in a quick and straightforward manner.
- Implementation: The created test configurations are entered into- and run through the MATLAB model.
- Evaluation: The resulted data is processed into usable figures which express the reaction of the floater blanket to incident waves of a range of frequencies in terms of example given heave-displacement or capture factor. These figures can be used to analyse and compare the performance of the floater blanket at different configurations and confirm or deny the corresponding hypotheses.

5.2 Brute force Method

The second method is based on a brute force approach, meaning that an extension to the MATLAB-model will be used to run an extensive set of randomly constructed configurations. The data of all the iterations is saved in order to accommodate later analysis when a sufficiently large dataset has been formed. Later comparison of the configurations with the best performance for each of the frequencies, will give new insights in the search for optimal solutions. The configurations are formed using the *randi* function, which creates a matrix of desired dimensions with random uniformly distributed integers between two chosen boundary values. Considering that one iteration takes about 4 seconds, that is equal to 21.600 iterations in 24 hours. Of course this is nowhere near the possible $2*10^{90}$ configurations, but it will provide new information with regards to the performance of the floater blanket:

1. If the configurations with the highest capture factor are to a high degree similar, the similarities can be used to improve the model, and create a function to approach the optimal configuration even further.
2. If all of the optimal configurations are decidedly dissimilar it can lead to the conclusion that the problem is too complex to solve analytically without the computational effort of running (nearly) all the configurations.

In order to keep the data useful, the choice is made to reduce the amount of input-damping coefficients by varying multiple floaters at a time. The randomly created configurations that are used consist of either 10 uniform columns, 10 uniform rows or 25 uniform blocks of four adjacent floaters. This last case divides the floater blanket into 25 squares of four floaters, leaving a 5x5 grid to determine. The configuration is forced to be symmetrical along a horizontal line through the centre, this way the amount of possible configurations is reduced to (8^{15}=) $3.5*10^{13}$, so the chance of gaining valuable data is significantly increased.

- Diagnose: Calculations are made about the effectiveness of the chosen approach and whether a significant proportion of the total amount of possible configuration can be tested in order to deem the data useful.
- Design: A model is created that can produce a substantial amount of randomly created test-configurations.
- Implementation: The created configurations are run and the data is saved for later analysis. The saved data consists of the damping coefficient-configuration of the floater blanket and the corresponding capture factor for each frequency that lies within the range of interest.
- Evaluation: The collected data is analysed and it is decided whether more random configurations need to be tested in order to deem the data useful.

5.3 Particle swarm optimization algorithm

Parallel to the approaches above, the use of particle swarm optimization (PSO) [10] is investigated, in order to assess whether this method can be a useful asset for the Ocean Grazer team. PSO is a computational algorithm used for the optimization of a selected parameter in a problem. The method works with a swarm of initial solutions, referred to as particles, which are spread out across the entire multidimensional field of possible configurations, and which are examined on a given goal-parameter, in this case the capture factor. After the initial swarm has been examined with regards to the goal-parameter, the particles start moving towards the particle with the best known position based on some simple mathematical formulae. This is repeated until a local optimal solution has

been found on which all of the particles have converged. As it is a meta-heuristic approach, there is no guarantee that the solution which is found represents the absolute optimal solution. It is however a fairly reliable way of analysing problems with enormous spaces of candidate solutions, such as the optimization problem presented in this report. As PSO can only optimize for one particular parameter, the solution will not be given for a range of incoming wave frequencies, but only for a specific chosen frequency. MATLAB possesses a built-in PSO algorithm, which is used in this research.

- Diagnose: Explore the MATLAB '*particleswarm'* command, and investigate the corresponding parameters and settings that can be adjusted to improve the performance for this application.
- Design: Create a MATLAB function which applies PSO to the capture factor optimization problem, and adjust the settings to the desired values.
- Implementation: Run the model multiple times for different frequencies and save the data for later use, the output of the system consists of the found optimal configuration and the corresponding capture factor.
- Evaluation: Compare the results of multiple runs and frequencies, looking for relations.

6. Analysis of the used MATLAB model.

6.1 Conventions.

Throughout this report some figures are used to illustrate and clarify the corresponding theory. When the plots give an overview of the full floater blanket, it is shown in such a way that the incident waves come from the left (see fig. 4). These figures can give information about the damping coefficient distribution, the power take off, the excitation force for each floater and many more, but the conventions remain the same for each type of figure.

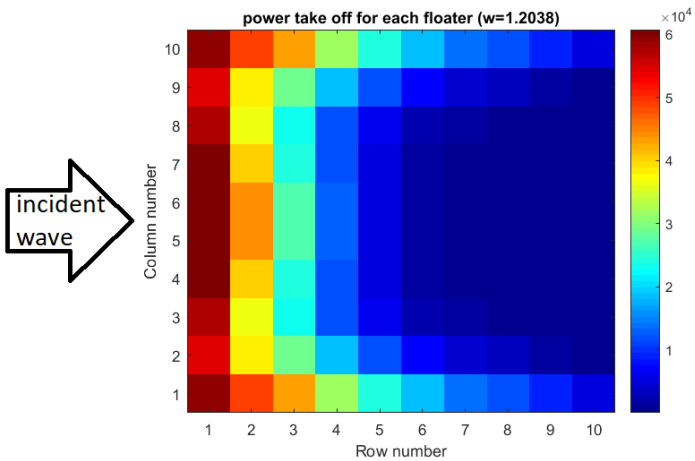

Figure 4. Example of conventions with incident wave.

When rows and columns are discussed, these are considered to be in the order portrayed in fig. 4. This means that row 1 is the one at which the incident wave meets the floater blanket, and after row ten the residual wave leaves the floater blanket. Also, column 10 is the top column, whereas column 1 is the bottom column.

In order to keep the acquired data significant and analysable it was chosen to focus on three different types of configurations for the floater blankets:

1. Horizontally symmetrical configuration with uniform columns of 10 floaters.
2. Uniform rows of 10 floaters.
3. Horizontally symmetrical configuration with uniform squares of 4 adjacent floaters.

The configurations are visually presented in fig. 5, in these figures the different colours solely indicate the damping coefficients of which floaters are uniformly altered, and don't give any information about the assigned values yet.

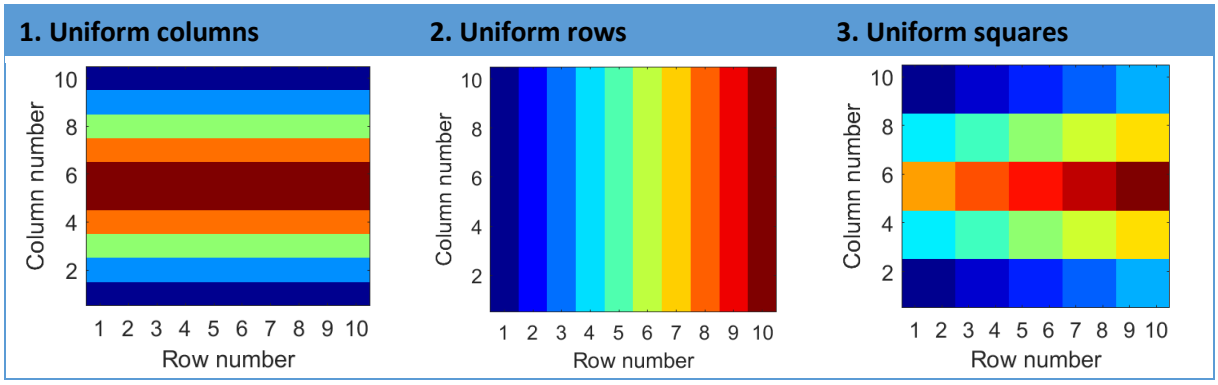

Figure 5. The three types of configurations used in this report to analyse the floater blankets response.

6.2 Choice of MP^{2}PTO values.

As discussed in the system description, each floater can be assigned a separate damping coefficient. The values of these damping coefficients are however bounded by some constraints as there are only three pistons for each floater. Due to the fact that these pistons have different sizes with relations 1, 2 and 4, the eight different damping coefficient settings that can be considered are 0, 1, 2, 3, 4, 5, 6 & 7. The values for the different damping coefficient settings have to be determined as they influence the way the model is used. These values can be chosen arbitrarily, as there is no definite design of the pistons yet, which means the diameters can still be altered to the most appropriate size. Furthermore there is no direct relation between the C_{PTO}-values used in the MATLAB model and the real-life damping forces they constitute. One constraint that is faced when determining the values for the damping coefficient settings, is that there has to be a linear relation between all the settings. An examination will be made which values are most appropriate to accommodate the entire range of frequencies of incoming waves that can be encountered.

Two techniques to approximate the optimal configuration, which were already built into the MATLAB model, were used in the process of determining appropriate values for the damping settings.

1. One technique in which a local minimizing algorithm provided by MATLAB is used to converge on one of the local optimal solutions, which is not necessarily *the* optimal solution since it converges to a local minimum and settles for that solution instead of looking for other (global) minimums.
2. One technique in which the frequency dependent optimal damping coefficient for a single buoy is calculated and this value then used for the entire floater blanket.

Both models that were used are frequency dependent and provide uniform damping coefficients for the entire floater blanket. The range of damping coefficients that was used in the outcomes of these two techniques can be used to determine appropriate values for the damping coefficient settings. The plots of the used damping coefficients for each frequency can be found in fig. 6**.**

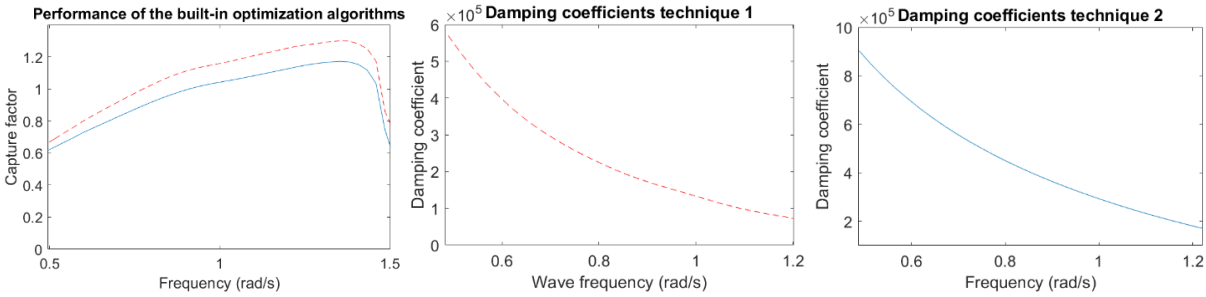

Figure 6. Capture factors for the two optimization techniques and the corresponding damping coefficients at various frequencies. (the red dashed line is technique 1, the blue line is technique 2)

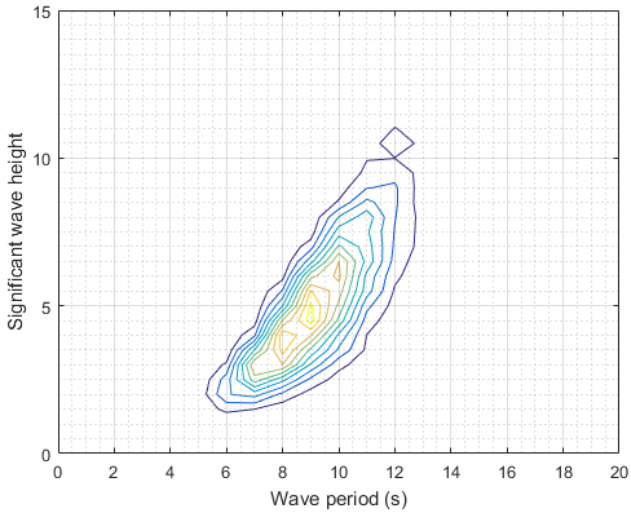

Figure 7. Occurrence of wave periods and significant wave heights off the Irish coast

Even though the two algorithms that were used provide uniform damping coefficients and therefore do not provide the highest possible capture factor, they do give reasonably decent outcomes. This indicates that the used damping coefficients can be used as a tool to determine the values for our MP^{2}PTO settings. We do however still need an estimate of the different wavelengths that the Ocean Grazer is going to encounter. After consultation about the approximate location where the Ocean Grazer will most likely be implemented, which is of the coast of Ireland, data was found regarding the wave characteristics in that region between 2010 and 2015[11]. This data was run through a model written by H. Meijer, to analyse the wave characteristics. One of the figures that were created was fig. 7, from which the occurrence of encountered wave periods and corresponding wave heights can be read. From the plot it can be seen that the wave periods that are of significance to this project lie between 5 seconds and 13 seconds. For the conversion of a wave period (T) in seconds to a frequency (ω) in rad/s the following formula is used:

$$\omega = \frac{1}{\mathrm{T}}\ x\ 2\pi$$

Application of this formula brings the relevant range between 0.5 rad/s and 1.2 rad/s. In combination with the plots in fig. 6 this leads to the assumption that the damping coefficients should cover the range between 0.8*10^4 and 8*10^5. The centre of the graph in fig. 7, which indicates the most common wave periods, corresponds to a frequency of approximately 0.7 rad/s. The damping coefficient that the two approximating test algorithms return for that frequency is in the region of 3.5*10^5. The shape of the contour plot in fig. 7 indicates that the centre of gravity is slightly to the left of the range, corresponding to the lower wave periods. This supports the reason behind the piston settings in fig. 8. With the chosen damping coefficients for each piston the following damping coefficients can be accomplished for each floater: 0, 1*10^5, 2*10^5, 3*10^5, 4*10^5, 5*10^5, 6*10^5 & 7*10^5. These values can not be linked directly to the size of the pistons at this moment because the MP^{2}PTO force is nonlinear, whereas the chosen values are damping coefficients of a linear oscillating system. This means the damping coefficients are just numerical values chosen for the sake of this research with no physical meaning.

Piston 1	1 x 10^5
Piston 2	2 x 10^5
Piston 3	4 x 10^5

Figure 8. Chosen piston damping coefficients.

6.3 Frequency choice.

The MATLAB model used in this research is a frequency domain model, whereas the model that was used before was a time domain model. There are a couple of distinct advantages to working with the frequency domain model. First is the reduction of computational time, the frequency domain model is typically less computationally demanding and therefore it is more suitable for the approach that was chosen for this research, considering that this approach relies on running many consecutive iterations. Another advantage is that the model runs a configuration for a range of wave frequencies, it is therefore easier to analyse the reaction for incoming waves of different characteristics. The model uses a range of ω=0.2 rad/s to ω=1.6 rad/s, which provides a proper range for analysis a different types of waves[12]. However, considering the anticipated placement of the ocean grazer and the fact that we have distinguished the relevant frequency range there to be between 0.5 rad/s and 1.2 rad/s, it is chosen to discard the frequencies that lie outside this range.

In order to figure out in what way a uniform floater blanket would react differently to incident waves with various frequencies, a couple of test-configurations where devised. Three floater blankets with different uniform damping coefficients where tested, one with a high damping coefficient ($2*10^6$), one with an average damping coefficient ($2*10^5$) and one with a low damping coefficient ($7*10^4$). These are not part of the determined possible damping coefficients, but were chosen to show clear relations between the damping coefficient, the wave frequency and the corresponding capture factor. The test configurations were run through the model and the resulting data was used to calculate the capture factor: the relation between the total power in the incoming wave and the total power take-off from the floater blanket. The resulting plots can be seen in fig. 9.

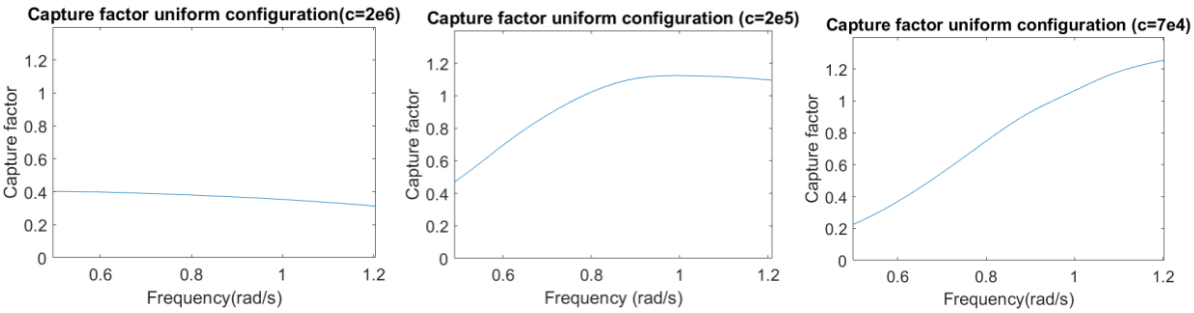

Figure 9a., 9b. & 9c. capture factors for three uniform floater blankets at different incident wave frequencies.

It can be seen that high damping coefficients (as in fig 9a.) yield a higher capture factor at low wave frequencies, whereas low damping coefficients (as in fig 9c.) typically yield a higher capture factor at high frequencies. From these results it becomes apparent that the optimal configuration that leads to the highest capture factor is frequency dependent. It is therefore not possible to find one optimal solution, but the optimal solution will have to be a function dependent on the frequency of the incoming waves. Considering that the frequencies of incoming waves are no integers and that they can have different characteristics each time, this indicates that there is an infinite amount of optimal configurations to be found.

7. Results of the analytical method.

7.1 Analysis of the situation with uniform rows.

In order to analyse the influence of changing the damping coefficients of uniform rows, a couple of test-configurations are created. These test-configurations are based on the configurations from 6.1,

this is done in order to have a baseline with which the data can be compared. The test configurations are set up as follows:

- The middle two rows, 5 and 6, are equal to the baseline damping coefficient of the corresponding plot in 6.1 ($2*10^6$, $2*10^5$ & $7*10^4$).
- The first two rows, 1 and 2, are either higher or lower than the baseline values.
- The last two rows, 9 and 10, are higher than the baseline if rows 1 and 2 are lower than the baseline value, and lower than the baseline if rows 1 and 2 are higher than the baseline value.
- The other rows 3 & 4 and 7 & 8 are assigned values that are the average of the adjacent rows.

This results in two test configurations for each baseline value, one with descending damping coefficients (rows 1 & 2 are higher than the baseline value) and one with ascending damping coefficients (rows 1 & 2 are lower than the baseline value) from left to right, giving 6 test configurations. Each of these are run through the model and the capture factor of the baseline configuration, the descending configuration and the ascending configuration are visually presented in a single line graph. The line graph which depicts the configurations with $2*10^5$ as baseline value is shown in fig 11, the corresponding graphs for the other two baseline values can be found in appendix C.1.

- The black line with stars indicates the capture factor value of the baseline configuration with a uniform floater blanket,
- The blue line indicates the capture factor of the configuration where the floater blanket has increasing damping coefficients seen from the incident wave, an example of which can be seen in fig 10a.
- The red dashed line indicates the capture factor of the configuration where the floater blanket has decreasing damping coefficients seen from the incident wave, an example of which can be seen in fig 10b.

a. MP2PTO configuration with increasing damping coefficients.	b. MP2PTO configuration with decreasing damping coefficients.

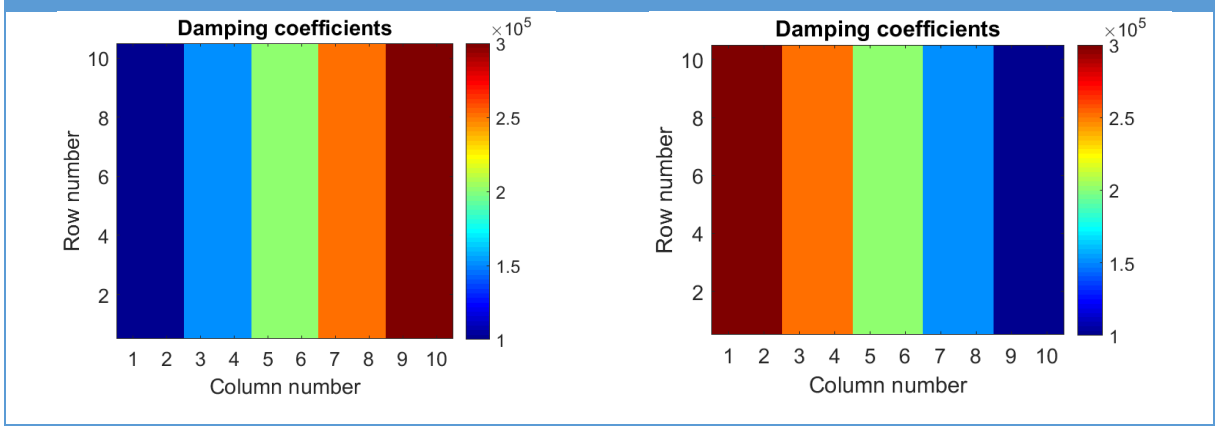

Figure 10. Visual examples of increasing and decreasing damping coefficient configurations mentioned above.

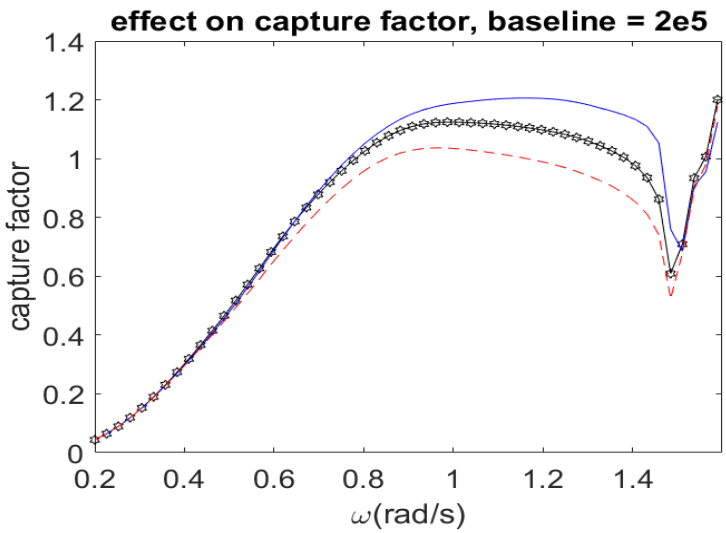

Figure 11. capture factors for the uniform (black line with stars), increasing (blue line) and decreasing (red dashed line) configurations with baseline value $2*10^5$

7.2 Analysis of the situation with uniform columns.

For the analysis of the influence of changing the damping coefficients for uniform columns a similar approach was used as in 7.1. However, considering that the columns run parallel to the wave direction, the configurations were adapted to remain symmetrical along a horizontal line through the centre. This was done in the following way:

- Columns 3, 4, 7 & 8 are appointed to be equal to the baseline damping coefficient.
- Columns 5 & 6 are appointed to be either lower or higher than the baseline value.
- Columns 1, 2, 9 & 10 are appointed to be higher than the baseline value if 5 & 6 are lower than the baseline value, and they are appointed to be lower than the baseline value if 5 & 6 are higher than the baseline value.

The same baseline values are used which are applied in 6.1 and 7.1, this is done in order to make a clear comparison possible. Fig 12 gives a visual presentation of the damping coefficients in the test configurations used to test the influence of altering uniform columns as mentioned above.

a. MP²PTO configuration with higher damping coefficients in the middle columns.	b. MP²PTO configuration with lower damping coefficients in the middle columns.

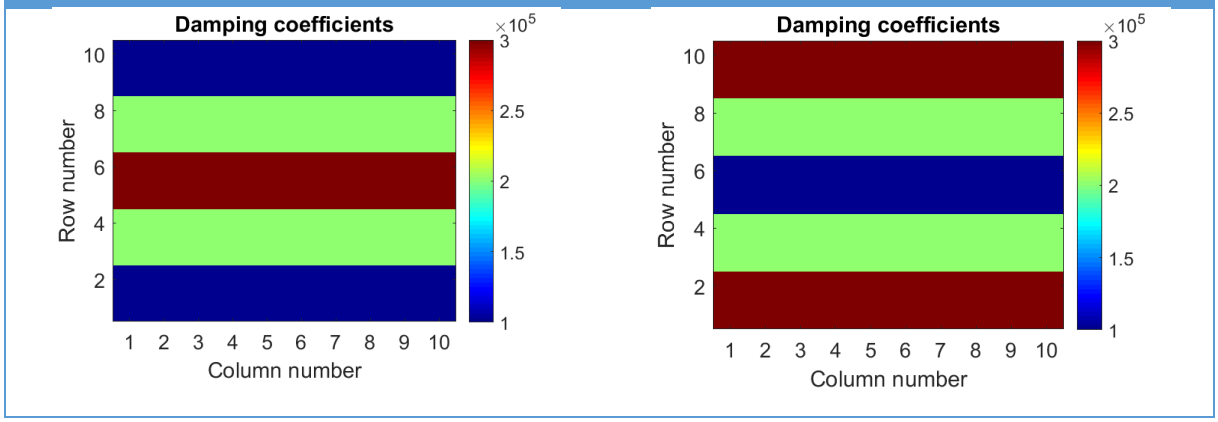

Figure 12. Visual examples of damping coefficient configurations with higher and lower centres.

As these test configurations are created based on the three previous baseline values ($2*10^6$, $2*10^5$ & $7*10^4$), the comparison is done on the basis of 9 situations: 3 uniform configurations with the baseline values as damping coefficient, 3 configurations with higher damping coefficients in the middle columns and 3 configurations with lower damping coefficients in the middle columns. The capture factor plots for each baseline value are printed in a single graph to facilitate analysis, for baseline value $2*10^5$ this plot is shown below in fig. 13, whereas the other plots can be found in appendix C.2.

- The black line with stars indicates the capture factors for the configuration with uniform baseline damping coefficients.
- The red dashed line indicates the capture factors for the cases where the middle columns have higher damping coefficients than the baseline value. (fig. 12a)
- The blue line indicates the capture factors for the cases where the middle columns have lower damping coefficients that the baseline value. (fig. 12b)

It can be seen that the capture factor exhibits unexpected behaviour above 1.4 rad/s, this is believed to be due to antiresonance inside the floater blanket. Since 1.4 rad/s is outside of the wave frequency-range chosen for this research, this phenomenon will not be elaborated on in this report. It was chosen to leave the results for frequencies outside the chosen range in the graphs in order to show how the found relations evolve with increasing and decreasing wave frequencies.

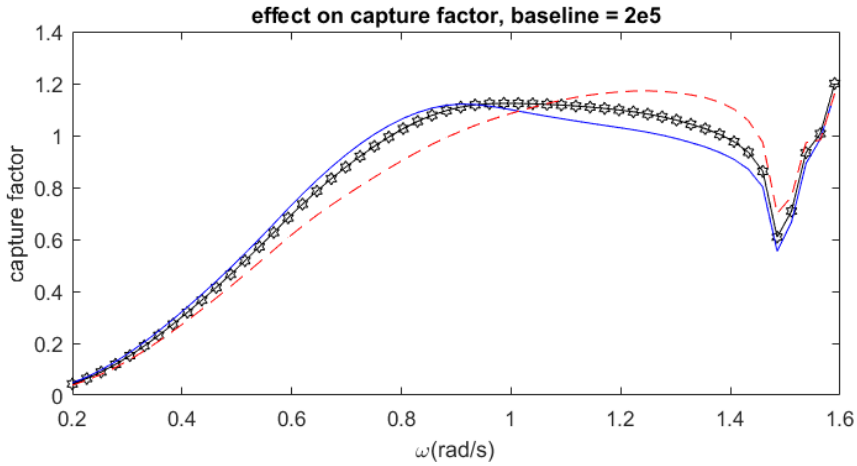

Figure 13. Capture factors for the test configurations of 7.2.1, the black line with stars is the baseline uniform configuration, the red dashed line is the configuration with a higher centre, the blue line is the configuration with a lower centre.

8. Results of the brute force method.

In pursuit of the brute force method a vast database was created for each of the three chosen configurations (uniform columns, uniform squares and uniform squares). Each entry in these databases consists of the randomly created test configuration and the corresponding capture factor for each of the frequencies that lie within the chosen range. This way a perception can be made of how optimal solutions evolve under the influence of increasing or decreasing wave frequencies. The visual analysis of the data is performed by ordering the entries based on the capture factor at a particular frequency and taking the 100 configurations with the highest capture factor at that frequency. For each column, row or square, depending on what is analysed, the average is then taken of these 100 configurations, to provide one configuration which shows the parallelism between these “best” solutions. The same calculations have been performed for the top 10 configurations and the top 1000 configurations, but as this did not show any significant discrepancies

with each other or the chosen approach of the top 100 configurations, it was decided to maintain the chosen approach.

The hypothesis is that averaging the configurations with the highest capture factor at a certain frequency will fabricate a configuration which, in general terms, approaches the shape of the optimal solution. In order to test this, some of the averaged configurations were entered into the model sample-wise, and compared to the randomly created configuration with the highest capture factor. The averaged configurations performed satisfactory, which gives the impression that the used method could indeed be used as an indication towards the general shape that an optimal solution for the problem at hand will take. In all of the cases the capture factors were among the highest observed for that frequency and in some cases the averaged configurations provided a higher capture factor. This test was also done for the cases in which the top 10 configurations and the top 1000 configurations were considered, these cases returned noticeably similar results.

8.1.1 Analysis of the results for the brute force method with uniform rows.

For the analysis of altered damping coefficients in uniform rows 100.000 iterations with random configurations were run and stored in a database. The plots that were acquired to analyse this approach are given in appendix C.3. These plots show great similarities with what was found and hypothesised after the analytical approach. For the entire frequency range the consensus seems to be that a configuration which starts with a relatively low damping coefficient on the side of the incident wave, and increases gradually towards the side where the wave exits the floater blanket generates the highest capture factor when uniform rows are considered.

8.1.2 Analysis of the results for the brute force method with uniform columns

Since the case with uniform columns was forced to be symmetrical along a horizontal line through the centre of floater blanket, the amount of possible configurations is gravely reduced. Therefore a database of only 40.000 random configurations was created to analyse the behaviour of a floater blanket under these circumstances. The plots that were acquired to analyse this case at different frequencies are presented in Appendix C.4. Upon analysis of these plots, analogies can again be found with the prior results from the analytical method. For all the frequencies lower than 1 rad/s the average of the best configurations constitute an image in which the damping configurations in middle columns, column 5 and 6, are lowest, and the damping coefficients increase outwards from there. At wave frequencies of 1 rad/s and higher something changes in the dynamic of the floater blanket, and suddenly the centre columns become higher than the outer columns. Between 0.99 rad/s and 1.04 rad/s the acquired image turns completely and this continues towards higher frequencies. Noteworthy is the fact that during the aforementioned transformation the intermediate columns, column 7 and 8, don’t seem to be influenced, but they remain stable.

8.1.3 Analysis of the results for the brute force method with uniform squares

In this case 25 squares of four floaters with uniform damping coefficients are regarded, and these squares are assigned in such a way that the floater blanket remains symmetrical along a horizontal line through the centre of the floater blanket. As the amount of possible configurations for this case was by a great deal the highest, it was decided that it also required the largest database. For that reason a database of 150.000 entries was created to analyse this situation. The averaged

configuration of the 100 randomly created configurations with the highest capture factor for a particular frequency is shown in Appendix C.5.

Upon analysis of these plots it is discovered that the phenomena that were previously observed for uniform rows and columns can again be identified in the current case. When observing the graphs in a consecutive order from the situation for incoming waves with low frequencies (ω = 0,515 rad/s) to the situation for incoming waves with high frequencies (ω = 1,197 rad/s), a transformation can again be perceived. At low frequencies the damping coefficients maintain a funnel- or net-like shape, where the damping coefficients in the 3 centre columns of the first 3 rows from the left are significantly lower than the surrounding squares. The described shape of the distribution of damping coefficients can be seen in fig. 14a, in which the figure for ω = 0,541 rad/s is depicted. As can be seen from the figures in the appendix, this general shape remains intact for all cases with incoming wave frequencies of below ω = 0,934 rad/s. Between the figures for incoming waves of ω = 0,934 rad/s and ω = 1,013 rad/s a transformation takes place, the damping coefficients don't resemble a funnel anymore, but rather something quite the opposite, like a sideways cone. What is meant can be seen in fig. 14b, this general shape remains for all the situations with wave frequencies above 1,013 rad/s.

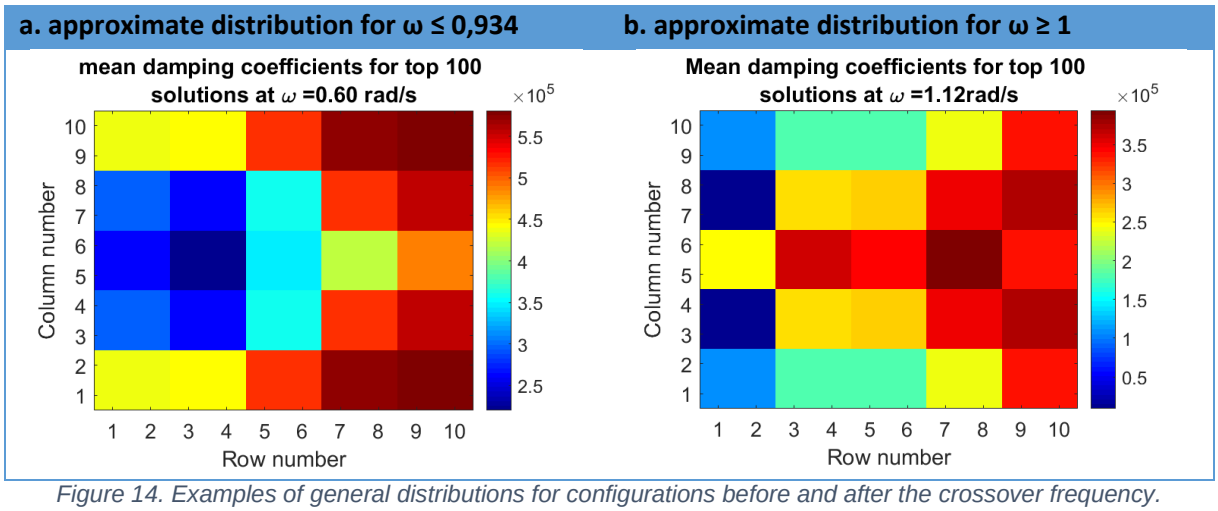

Figure 14. Examples of general distributions for configurations before and after the crossover frequency.

9. Results of the Particle Swarm Optimization-algorithm.

The technique that was used for the last type of research into the floater blanket, was the Particle Swarm Optimization-algorithm that is incorporated in the MATLAB optimization-toolbox. The code in Appendix B.3 was written to link the PSO-algorithm to the MATLAB-model. The script is written in such a way that the PSO-algorithm can only alter the inputs (the damping coefficients) and monitor the relevant output (the capture factor at a certain frequency), it has no insight in the internal operation of the MATLAB model. As the PSO-algorithm can merely work with continuous variables, it was necessary for this method to acquit the idea of the chosen values for the damping coefficient settings.

The resulting configurations from the PSO algorithm are displayed in Appendix C.6, and fig. 15. The results display some peculiarities that will be discussed in this chapter and in the discussion. One of the oddities in the results was that every time the model finished a cycle, it returned the exact same capture factor for the local minimum that was found. This is especially strange considering that this capture factor is well below the highest capture factor that was found with the brute force method.

Another thing that strikes the eye is that in the case where all the squares are altered independently the returned answers are seemingly random. This is endorsed by the fact that there seems to be no demonstrable relation between the found solutions.

In the cases where a symmetrical floater blanket was forced the returned configurations appear to be more highly related, and some of the phenomena that were observed before can be discovered here as well. However, these configurations still return the exact same capture factor, and are thus highly sub-optimal.

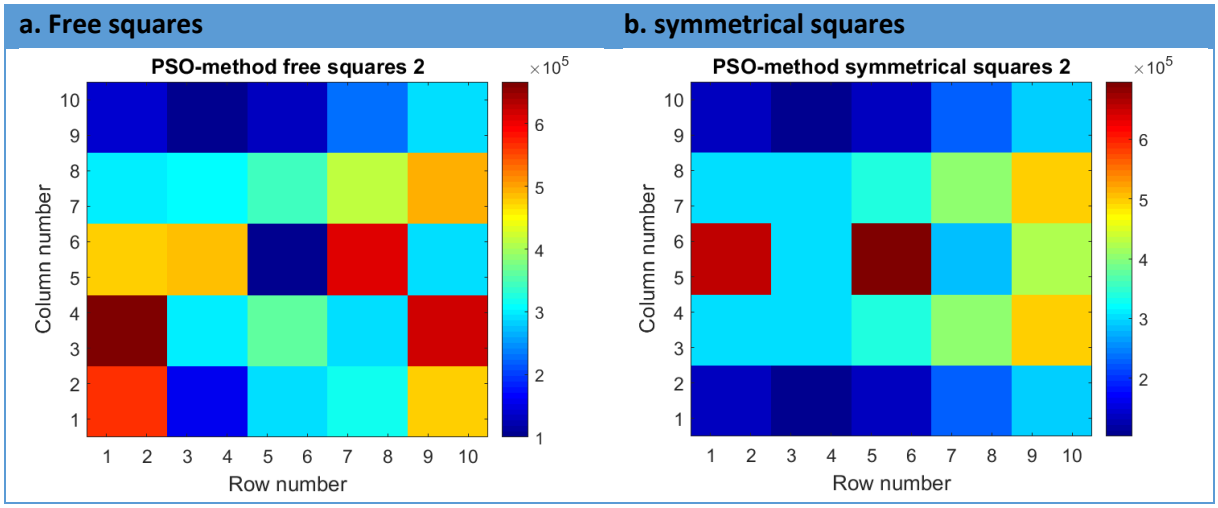

Figure 15. Examples of configurations resulting from the PSO-method.

10. Discussion

After having collected, processed and visualized the sizable amount of data that was involved in this research, the next step is to dive into the results and see what information they hold. One has to analyse the results and investigate if useful relations can be found, that can later be used to improve new attempts at finding optimal damping coefficient configurations or give new insights into the dynamics of the floater blanket.

The first remark that needs to be made is about the validity of the brute force method. As mentioned before databases of 40.000, 100.000 and 150.000 entries have been created for respectively the case with uniform columns, the case with uniform rows and the case with uniform squares of 4 floaters. In fig. 16 an oversight of the percentages of the total amount of possibilities is provided. What can be seen is that in some cases only a miniscule part of the total amount of possibilities have been considered. It is however still believed that the data gives valuable insights into the general performance of the floater blanket under different damping configurations, especially since this research is not focussed on finding the *optimal* solution, but rather on looking for relations between *well-performing* configurations.

	Database	Total possibilities		% of total
Uniform rows	40.000	8^5	32.768	100 %
Uniform columns	100.000	8^{10}	$1{,}1 * 10^9$	0,01 %
Uniform squares	150.000	8^{15}	$3{,}5 * 10^{13}$	$4{,}3 * 10^{-7}$ %

Figure 16. Overview of the total amount of possible configurations for the considered cases.

10.1 Discussion of the results from the analytical and brute force method with uniform rows

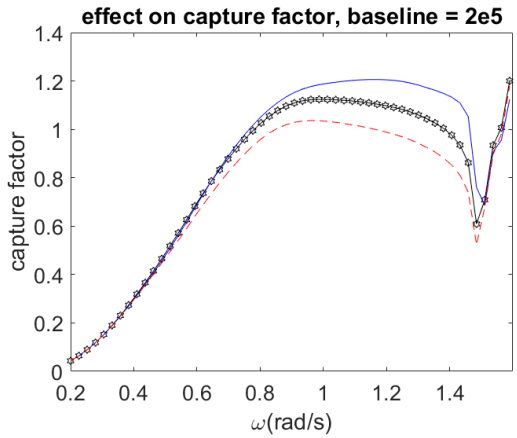

Figure 17. The red dashed line is a decreasing configuration, the blue line is an increasing configuration and the black line with stars is a uniform configuration.

The data of the analytical and Brute force method shows some great similarities and can be considered as decent grounds on which to look for relationships that might aid in the search for optimal configurations. One of the most unambiguous relations that was found was the relation between having increasing damping coefficients from left to right and increased performance of the floater blanket. 'increased performance' in this sense is viewed as achieving a higher capture factor. This can be seen for the cases in which uniform rows are considered, and appears to be true independent of the frequency of the incoming wave. From fig. 17 it becomes clear that the opposite is true as well, decreasing damping coefficients from left to right causes decreased performance of the floater blanket. These findings were also reflected in the results of the brute force method when uniform squares were considered. As can be seen in Appendix C.5, even though the rows are not uniform in this case, nearly every column still has an increasing damping coefficient from left to right.

As to the reason behind this phenomenon, it is believed that the amount of friction or counterproductive forces in the floater blanket is decreased because the excitation difference between two consecutive floaters is decreased as well. By absorbing the full power of the wave gradually over the entire floater blanket instead of abruptly in the first rows, the connected floaters will counter each other's motion less and guarantee a smooth motion for the floaters. This hypothesis is supported by the graphs in fig. 18, where the power take off can be seen for each floater in a decreasing and increasing configuration. It can be seen that in the case of the increasing configuration the total power is more evenly spread among the floaters, decreasing turbulence and counterproductive motions.

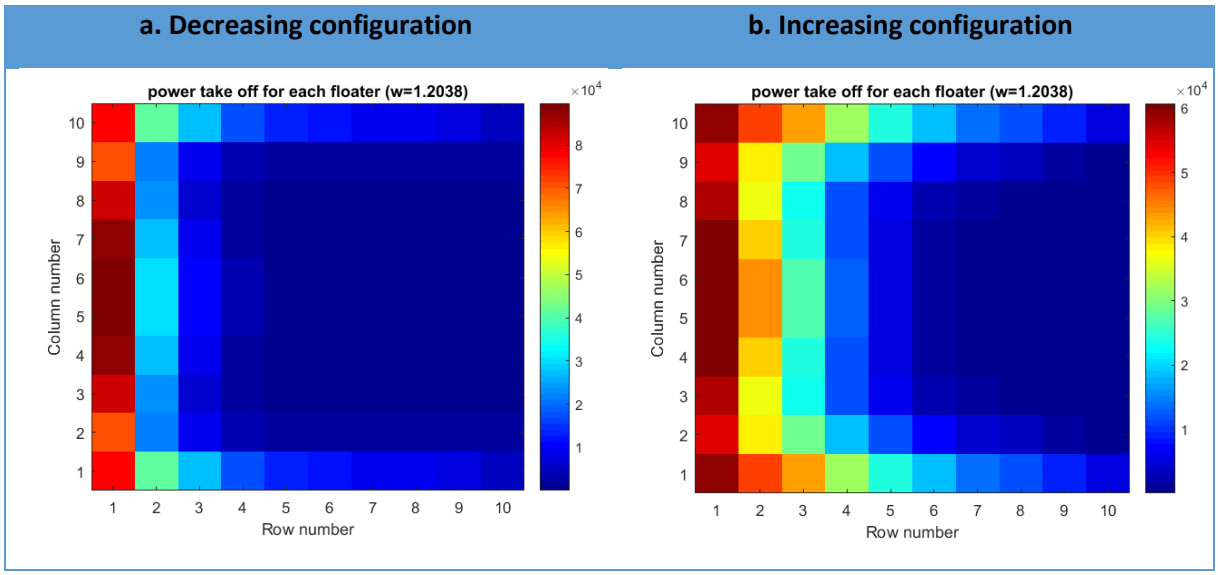

Figure 18. the power take off for each floater illustrated for a decreasing and in increasing configuration.

10.2 Discussion of the results from the analytical and brute force method with uniform columns

After having considered the horizontal distribution of damping coefficients, the next point of interest was the effect that the vertical distribution of damping coefficients has on the performance of the WEC. The analytical study of this issue gave some interesting results, in which it became clear that the performance of several vertical distributions were highly dependent on the incoming wave frequency. There appeared to be a crossover frequency, at which the better distribution (either high centre/low outsides or low centre/high outsides) changed and the opposite became the better configuration. As the crossover frequency is highly dependent on the used damping coefficients, which can be seen in appendix C.2, it was not possible to pinpoint a specific crossover frequency for every configuration. These findings incited interest for further research, which was performed through the brute force method. The results of the brute force method in which uniform squares were considered give a clear oversight of the prior observation in Appendix C.5. In the case with uniform squares the described phenomenon expresses itself through the transformation from a kind of funnel to a kind of sideways cone. The crossover frequency that is observed with the brute force method lies at approximately 1 rad/s.

As to the reason behind this phenomenon there are two hypotheses:

1) The observed phenomenon is caused by the connecting elements and the resulting dynamics of the floater blanket.
2) The observed phenomenon is caused by the radiation waves, which differ from low to high incoming wave frequencies.

Establishing if one of these two hypotheses is true, and if so, which one, would require more research.

10.3 Discussion of the results from PSO- method

Due to the limited time that was spent on the PSO-algorithm approach, the results are not as elaborate as they could have been, and the same goes for the accompanying analyses. The information given can however be useful for future research into the use of PSO or other genetic algorithms for the Ocean Grazer.

What remains unclear, is why the returned configurations all yield the exact same Capture Factor when run through the model. The fact that the Algorithm returned the same cut-off capture factor on each iteration may have a couple of reasons:

1. The problem at hand has a tremendous amount of local minima at the returned value, which causes the PSO-algorithm to end up in one of these minima over and over, instead of converging to a more optimal local minimum.
2. An error was made in the script that was used to couple the built-in PSO-algorithm to the problem at hand. This way the algorithm received wrong information from the MATLAB-model which obstructs its functionality.
3. The built-in PSO- algorithm is not compatible with- or not tuned for- the optimization problem at hand, and therefore does not converge to a global minimum.

Even though too little investigation has been performed to rule out one of the possibilities, the first option is rather unlikely, considering that each configuration gave the *exact* same capture factor. However, since a mathematical simulation tool is used, these kinds of abnormalities can exist.

11. Conclusion

After thorough analysis of the gathered data, some conclusions can be drawn which will provide new insights for further research into the Ocean Grazer.

- A configuration with increasing damping coefficients from the side where the incident wave enters to the side where the incident wave leaves the floater blanket yields a higher capture factor than the other way around or a uniform configuration.
- There is a certain frequency at which the optimal damping configuration changes from one where the highest damping coefficients are in the outer columns of the floater blanket to a configuration where the highest damping coefficients are in the centre columns of the floater blanket.
- The PSO-algorithm in the way that it is applied in this research has no potential for the ocean grazer, but it is shown that evolutionary algorithms can be used to solve the problem at hand.

The most distinct conclusion is related to the distribution of damping coefficients from left (where the incident wave enters the floater blanket) to right (where the incident wave leaves the floater blanket). It is found that, regardless of the frequency of the incoming wave, a configuration in which the damping coefficients increase from left to right always yields a better capture factor than cases in which a uniform floater blanket is considered, a uniform floater blanket in turn yields a better capture factor than a case with a configuration in which damping coefficients decrease from left to right.

Another interesting conclusion arose upon analysis of the data, when the distribution of damping coefficients over the different columns of a floater blanket are considered. The data showed that when the incident waves exhibit low frequencies (approx. <1 rad/s), the configuration that yields the highest capture factor is one with higher damping coefficients along the top, bottom and right edge, creating a kind of funnel. If the incident waves however exhibit high frequencies (approx. >1 rad/s) a transformation takes place and the configuration that yields the highest capture factor is one that has its highest damping coefficients in the centre on the right side, shaped as a kind of cone pointing left. The crossover frequency at which this transformation takes place is dependent on the damping coefficients present in the floater blanket, but was found to be around 1 rad/s when near-optimal solutions were considered.

The PSO algorithm in the form that was used for this research has no direct application in the ocean grazer, mainly because it did not converge to a near optimal solution and because it can only solve non-integer problems. It is however shown that this type of evolutionary algorithm has potential to play a role in the further development of the Ocean Grazer project, if more research is conducted.

12. Recommendations

For further research it might be interesting to investigate the crossover frequency at which the shape of the 'optimal' solution transforms from a configuration where the centre columns have a relatively low damping coefficient to a configuration where the centre columns have a relatively high damping coefficient. If this phenomenon and the value of the crossover frequency can be explained, it could provide new insights into the functionality of the floater blanket. These insights could help to drastically reduce the amount of possible configurations that need to be analysed to find the optimal configuration, decreasing the computational effort required. Elements that could be investigated are for example the linking between the floaters and the effect of radiation waves.

Another aspect that might require more research, is to investigate whether a real-life floater blanket will have similar dynamics to the dynamics simulated by the MATLAB-model. Even though the used model is highly substantiated and complex, it does not give any surety as to the validity of the model when compared to real life implementations. Comparing the simulated results with actual results will ensure that no research is done on the basis of a model that does not give a truthful reflection of the reality.

The PSO-algorithm proved to be able to handle the vast amount of possible solutions offered by the optimization problem at hand, even though the results were not yet satisfactory. It is therefore believed that Genetic Algorithms might provide a useful solution to the more complex optimization problems that the ocean grazer can encounter, such as the one in this research. What was discovered during the making of this report is that there is an enormous class of Evolutionary Algorithms, of which the genetic algorithm and the PSO-algorithm are just two of many possibilities. One of the disadvantages of the PSO-algorithm is the fact that it can only work with continuous parameters, whereas for this problem it would be better to find an algorithm that can operate with bounded integer parameters (in this case integers 1 through 8, for the different MP^2PTO-settings). Investigation into the most appropriate algorithm would of course be dependent on a lot of factors such as: computational time, the optimality of the outcome and the possibility to bound the outcome to integers.

Throughout this research the provided MATLAB-model has remained rather unaltered: instead of changing the model, it was chosen to write extensions to the model. On further analysis it became clear that the original purpose of the model was to be run a limited amount of times, instead of multiple consecutive times as was done in the brute force-method and the PSO-method. This can for example be seen from the way that all of the parameters and coefficients have to be loaded into MATLAB for each consecutive iteration over and over again. This is one of the main reasons why one iteration of the used PSO-method took approximately 3,5 hours to complete. For further research into methods that require multiple iterations of the MATLAB-model, it is recommended to rewrite the model in such a way that it runs more computationally efficient in order to reduce runtimes.

All of the cases that the MATLAB model can analyse at this moment, are cases in which the connections between the buoys are either parallel or perpendicular to the incoming wave. Prior research [13] has however shown that when the floater blanket is turned a certain amount of degrees in relation to the incident wave, it can have a positive influence on the capture factor. Investigating whether this theory is also valid for the current design of the Ocean Grazer might constitute another interesting research proposal.

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Appendix A: Logbook.

Date	Time	till	hours	Activity
11-sep	13:00	14:00	1,00	Kick off
11-sep	14:00	15:00	1,00	Project preference
11-sep	19:00	22:00	3,00	Completed literacy test on nestor
12-sep	09:00	09:05	0,08	Made appointment with supervisor
18-sep	11:00	15:00	4,00	Literacy meeting / assignment information literacy
18-sep	13:00	13:45	0,75	First meeting with Marijn van Rooij
20-sep	14:00	18:00	4,00	Literature research
23-sep	15:00	17:00	2,00	Literature research
24-sep	17:00	19:00	2,00	Writing PAL
25-sep	13:00	18:00	5,00	Writing PAL
26-sep	10:00	11:00	1,00	Meeting with Marijn van Rooij and Yanji Wei
26-sep	15:00	15:05	0,08	Delivered PAL
3-okt	15:00	16:00	1,00	making presentation PAL
4-okt	09:00	11:00	2,00	Meeting and presentations PAL
5-okt	13:00	14:30	1,50	Weekly project-meeting ocean grazer
9-okt	12:00	13:00	1,00	Writing RDP
10-okt	11:00	17:00	6,00	Writing RDP
12-okt	09:30	11:30	2,00	Writing RDP
12-okt	13:00	14:30	1,50	Weekly project-meeting ocean grazer
12-okt	14:30	15:30	1,00	Meeting with Marijn van Rooij
12-okt	16:00	18:00	2,00	Finishing RDP
13-okt	09:00	09:15	0,25	Delivered RDP
15-okt	11:00	16:00	5,00	Making presentation RDP + general work
17-okt	13:00	18:00	5,00	RDP meeting and presentations
18-okt	10:00	12:00	2,00	Improved RDP based on feedback
26-okt	10:00	20:00	10,00	Weekly project-meeting ocean grazer and general work
2-nov	09:00	19:00	10,00	Weekly project-meeting ocean grazer and general work
15-nov	12:00	16:30	4,50	Literature research Matlab model
16-nov	09:30	13:00	3,50	Investigation into Matlab model
16-nov	13:00	14:30	1,50	Weekly project-meeting ocean grazer
17-nov	10:00	13:00	3,00	Meeting with Yanji Wei & investigation into matlab model
17-nov	14:00	19:00	5,00	Working on Matlab model and background
18-nov	09:00	18:00	9,00	Working on Matlab model and hypotheses
19-nov	12:00	19:00	7,00	Working on Matlab model and hypotheses
20-nov	11:00	18:00	7,00	Working on Matlab model and hypotheses
21-nov	10:00	16:00	6,00	Working on Matlab model and hypotheses
22-nov	10:00	17:00	7,00	Working on Matlab model and hypotheses
24-nov	09:30	19:30	10,00	Working on Matlab model and hypotheses
25-nov	10:30	20:00	9,50	Writing preliminary report
26-nov	10:30	21:00	10,50	Writing preliminary report
27-nov	10:00	20:00	10,00	Writing preliminary report
28-nov	10:00	19:00	9,00	Writing preliminary report
29-nov	10:00	19:00	9,00	Writing preliminary report
30-nov	09:30	19:00	9,50	Writing preliminary report and elaborating new approach

3-dec	15:00	18:00	3,00	Finishing preliminary report
5-dec	11:00	18:00	7,00	Writing new MATLAB model
6-dec	09:00	21:00	12,00	Writing new MATLAB model/analysis first results
7-dec	09:00	20:00	11,00	presentation for meeting
8-dec	09:00	18:00	9,00	preliminary presentation & analysis results
10-dec	10:00	19:00	9,00	research PSO-algorithm
11-dec	10:00	21:00	11,00	research PSO-algorithm and writing model
12-dec	10:00	21:00	11,00	research PSO-algorithm and writing model
13-dec	13:00	21:00	8,00	Write and test PSO model
14-dec	11:00	19:00	8,00	Weekly project-meeting ocean grazer and improve PSO model
16-dec	09:00	20:00	11,00	Test PSO model and analyse brute force data
17-dec	09:00	19:00	10,00	Test PSO model and analyse brute force data
18-dec	09:00	18:00	9,00	Test PSO model and analyse brute force data
20-dec	11:00	21:00	10,00	write final report
21-dec	11:00	21:00	10,00	write final report
23-dec	16:00	21:00	5,00	write final report
24-dec			0,00	caught flu
4-jan	09:00	12:00	3,00	write report
5-jan			0,00	got better
5-jan	09:00	22:00	13,00	write final report
6-jan	10:00	20:00	10,00	write final report
7-jan	10:00	20:00	10,00	write final report
8-jan	09:00	20:00	11,00	write final report
9-jan	09:00	12:00	3,00	finalize and hand in final report
11-jan	13:00	15:00	2,00	Weekly meeting Ocean Grazer
16-jan	13:00	15:00	2,00	poster workshop
17-jan	15:00	15:30	0,50	feedback session with Antonis Vakis
18-jan	13:00	15:00	2,00	Weekly meeting Ocean Grazer
19-jan	09:00	18:00	9,00	improved final report
22-jan	10:00	11:00	1,00	finalized final report
23-jan	11:55	12:00	0,08	hand in final report
23-jan	13:00	14:30	1,50	workshop presenting
25-jan	13:00	14:30	1,50	Weekly meeting Ocean Grazer
31-jan	11:00	17:00	6,00	IP symposium
			0,00	
	hours worked		414,75	

Appendix B: Matlab codes.

Appendix B.1: Code that implements the chosen situations (uniform rows, uniform columns and uniform squares) into the MATLAB model.

```
switch PTOtype

    case 4  %uniform columns
        [Kpto,Cpto]=PTO_cols(c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,nf,nw);
    case 5  %uniform rows
        [Kpto,Cpto]=PTO_rows(c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,nf,nw);
    case 6  %squares of 4

[Kpto,Cpto]=PTO_square(c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,c11,c12,c13,c14,c15,c16,c17,c
18,c19,c20,c21,c22,c23,c24,c25,nf,nw);


function [Kpto,Cpto]=PTO_rows(c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,nf,nw)
Kpto=zeros(nf*6,nf*6,nw);
Cpto=zeros(nf*6,nf*6,nw);
for j=1:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c1;
end
for j=2:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c2;
end
for j=3:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c3;
end
for j=4:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c4;
end
for j=5:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c5;
end
for j=6:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c6;
end
for j=7:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c7;
end
for j=8:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c8;
end
for j=9:10:nf
    Cpto(6*j-3,6*j-3,1:nw)=c9;
end
for j=10:10:nf
     Cpto(6*j-3,6*j-3,1:nw)=c10;
end
end

function [Kpto,Cpto]=PTO_cols(c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,nf,nw)
Kpto=zeros(nf*6,nf*6,nw);
Cpto=zeros(nf*6,nf*6,nw);
for j=1:10
    Cpto(6*j-3,6*j-3,1:nw)=c1;
end
for j=11:20
    Cpto(6*j-3,6*j-3,1:nw)=c2;
end
for j=21:30
    Cpto(6*j-3,6*j-3,1:nw)=c3;
end
for j=31:40
```

```
    Cpto(6*j-3,6*j-3,1:nw)=c4;
end
for j=41:50
    Cpto(6*j-3,6*j-3,1:nw)=c5;
end
for j=51:60
    Cpto(6*j-3,6*j-3,1:nw)=c6;
end
for j=61:70
    Cpto(6*j-3,6*j-3,1:nw)=c7;
end
for j=71:80
    Cpto(6*j-3,6*j-3,1:nw)=c8;
end
for j=81:90
    Cpto(6*j-3,6*j-3,1:nw)=c9;
end
for j=91:nf
     Cpto(6*j-3,6*j-3,1:nw)=c10;
end
end


function
[Kpto,Cpto]=PTO_square(c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,c11,c12,c13,c14,c15,c16,c17,c
18,c19,c20,c21,c22,c23,c24,c25,nf,nw)
Kpto=zeros(nf*6,nf*6,nw);
Cpto=zeros(nf*6,nf*6,nw);
r1=[1,2,11,12];
for j=r1
    Cpto(6*j-3,6*j-3,1:nw)=c1;
end
for j=r1+2
    Cpto(6*j-3,6*j-3,1:nw)=c2;
end
for j=r1+4
    Cpto(6*j-3,6*j-3,1:nw)=c3;
end
for j=r1+6
    Cpto(6*j-3,6*j-3,1:nw)=c4;
end
for j=r1+8
    Cpto(6*j-3,6*j-3,1:nw)=c5;
end
for j=r1+20
    Cpto(6*j-3,6*j-3,1:nw)=c6;
end
for j=r1+22
    Cpto(6*j-3,6*j-3,1:nw)=c7;
end
for j=r1+24
    Cpto(6*j-3,6*j-3,1:nw)=c8;
end
for j=r1+26
    Cpto(6*j-3,6*j-3,1:nw)=c9;
end
for j=r1+28
    Cpto(6*j-3,6*j-3,1:nw)=c10;
end
for j=r1+40
    Cpto(6*j-3,6*j-3,1:nw)=c11;
end
for j=r1+42
    Cpto(6*j-3,6*j-3,1:nw)=c12;
end
for j=r1+44
    Cpto(6*j-3,6*j-3,1:nw)=c13;
end
```

```
for j=r1+46
    Cpto(6*j-3,6*j-3,1:nw)=c14;
end
for j=r1+48
    Cpto(6*j-3,6*j-3,1:nw)=c15;
end
for j=r1+60
    Cpto(6*j-3,6*j-3,1:nw)=c16;
end
for j=r1+62
    Cpto(6*j-3,6*j-3,1:nw)=c17;
end
for j=r1+64
    Cpto(6*j-3,6*j-3,1:nw)=c18;
end
for j=r1+66
    Cpto(6*j-3,6*j-3,1:nw)=c19;
end
for j=r1+68
    Cpto(6*j-3,6*j-3,1:nw)=c20;
end
for j=r1+80
    Cpto(6*j-3,6*j-3,1:nw)=c21;
end
for j=r1+82
    Cpto(6*j-3,6*j-3,1:nw)=c22;
end
for j=r1+84
    Cpto(6*j-3,6*j-3,1:nw)=c23;
end
for j=r1+86
    Cpto(6*j-3,6*j-3,1:nw)=c24;
end
for j=r1+88
    Cpto(6*j-3,6*j-3,1:nw)=c25;
end
end
```

Appendix B.2: code to create and run random configurations for the brute force method

```
PTO_val = [0 : 1e5 : 7e5];
r = randi([1 8], [1000000 25]);
iterations = 100000;


for i = [1:iterations]
       % c1=PTO_val(r(i,1));
       % c2=PTO_val(r(i,2));
       % c3=PTO_val(r(i,3));
       % c4=PTO_val(r(i,4));
       % c5=PTO_val(r(i,5));
       % c6=PTO_val(r(i,6));
       % c7=PTO_val(r(i,7));
       % c8=PTO_val(r(i,8));
       % c9=PTO_val(r(i,9));
       % c10=PTO_val(r(i,10));

%symmetric rows
       % c1=PTO_val(r(i,1));
       % c2=PTO_val(r(i,2));
       % c3=PTO_val(r(i,3));
       % c4=PTO_val(r(i,4));
       % c5=PTO_val(r(i,5));
```

```
        % c6=c5;
        % c7=c4;
        % c8=c3;
        % c9=c2;
        % c10=c1;

%symmetric squares
        % c1=PTO_val(r(i,1));
        % c2=PTO_val(r(i,2));
        % c3=PTO_val(r(i,3));
        % c4=PTO_val(r(i,4));
        % c5=PTO_val(r(i,5));
        % c6=PTO_val(r(i,6));
        % c7=PTO_val(r(i,7));
        % c8=PTO_val(r(i,8));
        % c9=PTO_val(r(i,9));
        % c10=PTO_val(r(i,10));
        % c11=PTO_val(r(i,11));
        % c12=PTO_val(r(i,12));
        % c13=PTO_val(r(i,13));
        % c14=PTO_val(r(i,14));
        % c15=PTO_val(r(i,15));
        % c16=c6;
        % c17=c7;
        % c18=c8;
        % c19=c9;
        % c20=c10;
        % c21=c1;
        % c22=c2;
        % c23=c3;
        % c24=c4;
        % c25=c5;


%[w,M,A,B,Fe,KH,Kpto,Cpto,nx,ny,nf,PTOtype]=Hydro_matrix(dir,c1,c2,c3,c4,c5,c6,c7,c
8,c9,c10,c11,c12,c13,c14,c15,c16,c17,c18,c19,c20,c21,c22,c23,c24,c25);
%[w,M,A,B,Fe,KH,Kpto,Cpto,nx,ny,nf,PTOtype]=Hydro_matrix(dir,c1,c2,c3,c4,c5,c6,c7,c
8,c9,c10);
[Fh,Xh,Ks,FBtype]=Constraint_matrix(dir);
[Xi,Fi,Cpto]=MotionEq(w,M,A,B,Fe,KH,Ks,Kpto,Cpto,Fh,Xh,nx,ny,nf,PTOtype,FBtype);
[X3,c,p,ptot,CF,CW,La_A,kw]=Power_calc(Cpto,Xi,w);

%ans(i,:) = [c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13 c14 c15 c16 c17 c18 c19 c20
c21 c22 c23 c24 c25 CF(1:54)];
% ans(i,:) = [c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 CF(1:54)];

i
%end
```

Appendix B.3: code to run PSO-algorithm.

```
objfcn = @objective;
nvar = 15
lb = ones(1,15)*100000;
ub = ones(1,15)*700000;

options = optimoptions('particleswarm');
options.FunctionTolerance = 1E-4;
options.UseParallel = true;
[d,fval] = particleswarm(objfcn,nvar,lb,ub,options);
ans = [d, fval];
save('results','ans')
```

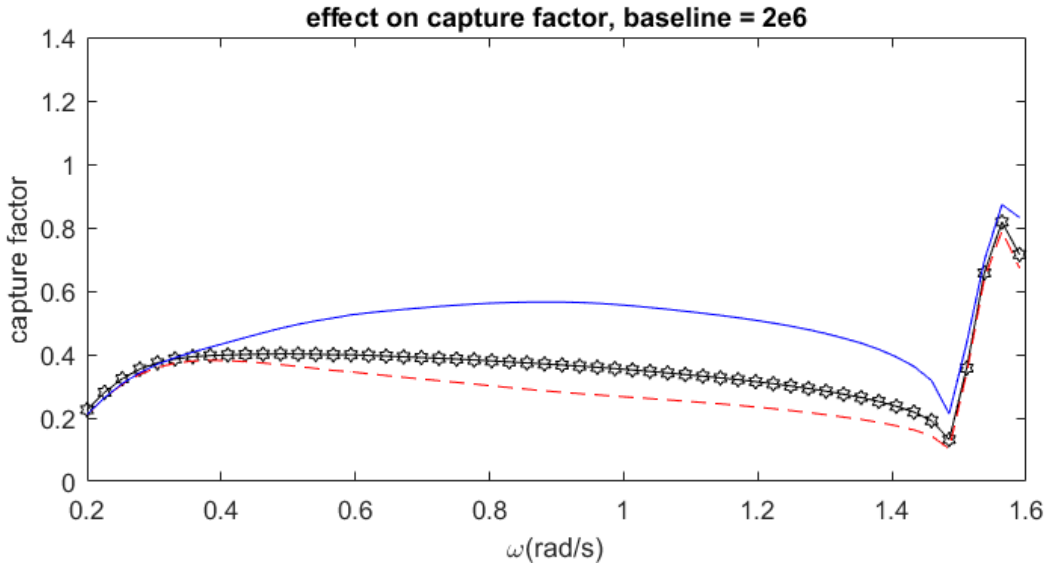
```
function opt = objective(d)

%% Hydrofynamic coefficient
```

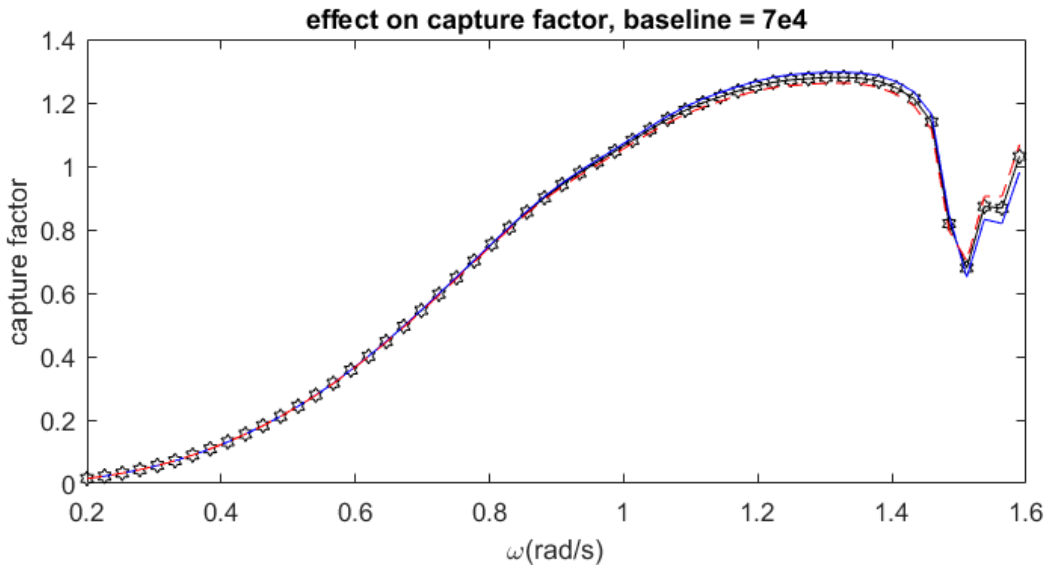
```
PTO_val=[0:1e5:7e5];

 c1=d(1);
 c2=d(2);
 c3=d(3);
 c4=d(4);
 c5=d(5);
 c6=d(6);
 c7=d(7);
 c8=d(8);
 c9=d(9);
 c10=d(10);
 c11=d(11);
 c12=d(12);
 c13=d(13);
 c14=d(14);
 c15=d(15);
 c16=d(6);
 c17=d(7);
 c18=d(8);
 c19=d(9);
 c20=d(10);
 c21=d(1);
 c22=d(2);
 c23=d(3);
 c24=d(4);
 c25=d(5);

[w,M,A,B,Fe,KH,Kpto,Cpto,nx,ny,nf,PTOtype]=Hydro_matrix(dir,c1,c2,c3,c4,c5,c6,c7,c8
,c9,c10,c11,c12,c13,c14,c15,c16,c17,c18,c19,c20,c21,c22,c23,c24,c25);
 [Fh,Xh,Ks,FBtype]=Constraint_matrix(dir);
[Xi,Fi,Cpto]=MotionEq(w,M,A,B,Fe,KH,Ks,Kpto,Cpto,Fh,Xh,nx,ny,nf,PTOtype,FBtype);
[X3,c,p,ptot,CF,CW,La_A,kw]=Power_calc(Cpto,Xi,w);

opt = -CF(24)
end
```

Appendix C: Figures.

Appendix C.1: results analytical method with increasing and decreasing uniform rows

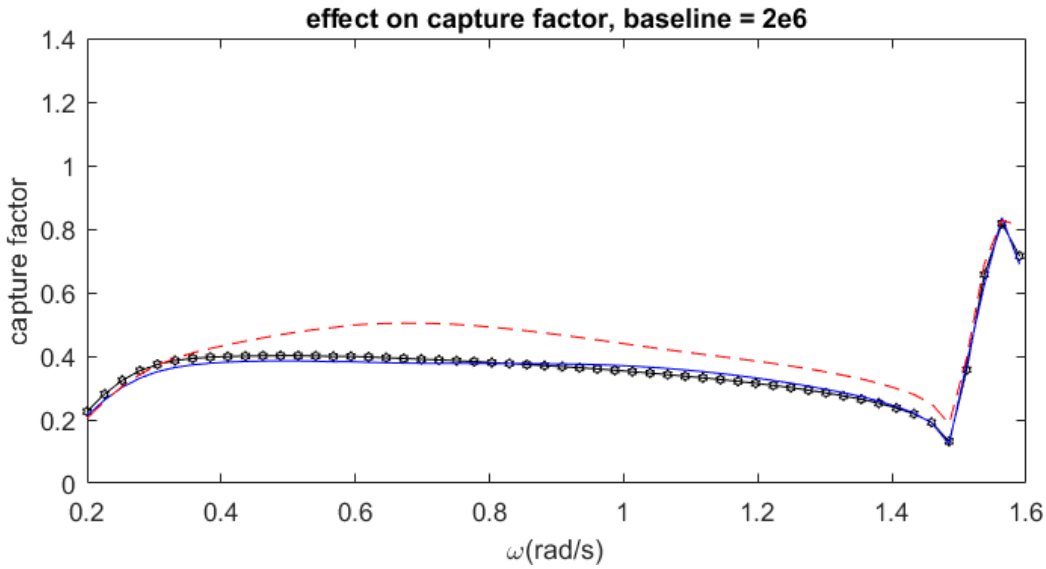
- The black line with stars indicates the capture factor for the uniform baseline configuration.
- The blue line indicates the capture factor for the configuration with increasing damping configurations from the side where the wave enters the floater blanket to the side where the wave leaves the floater blanket.
- The red dashed line indicates the capture factor for the configuration with decreasing damping configurations from the side where the wave enters the floater blanket to the side where the wave leaves the floater blanket.

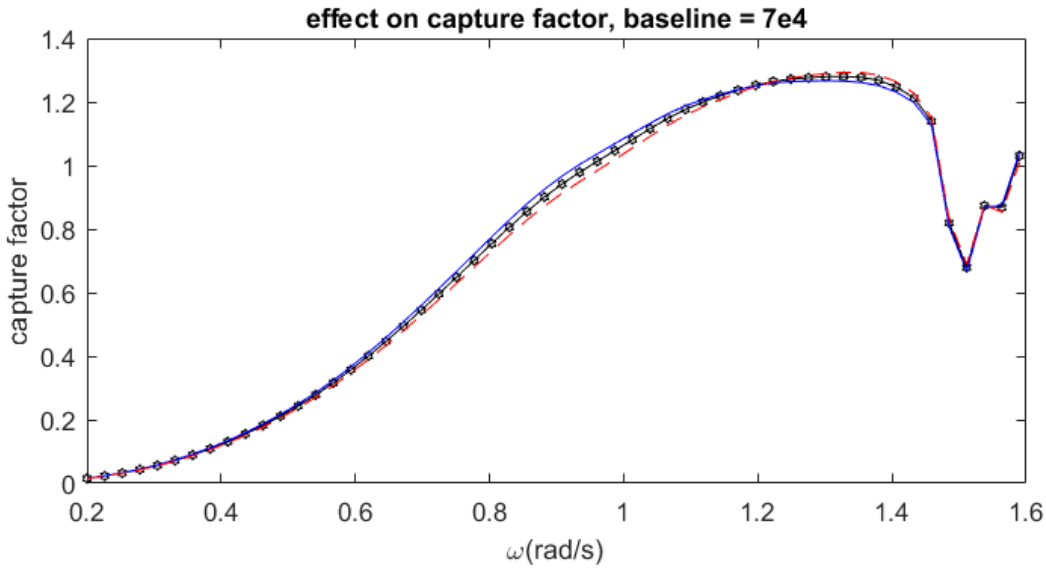




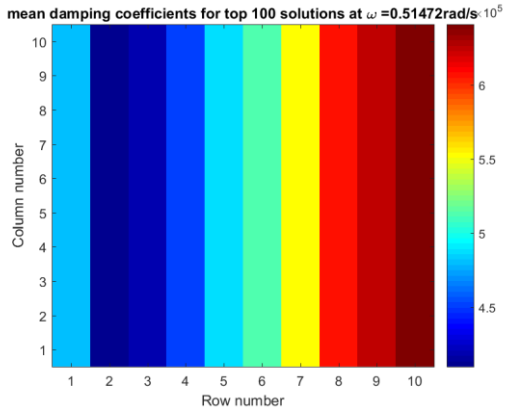
Appendix C.2: results analytical method with higher and lower centre columns

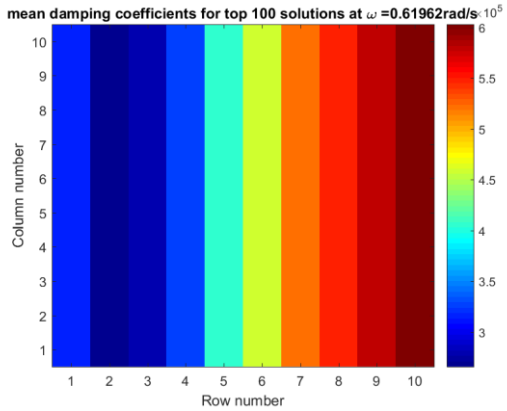
- The black line with stars indicates the capture factor for the uniform baseline configuration.
- The blue line indicates the capture factor for the configuration where the centre columns are lower than the outer columns.
- The red dashed line indicates the capture factor for the configuration where the centre columns are higher than the outer columns.

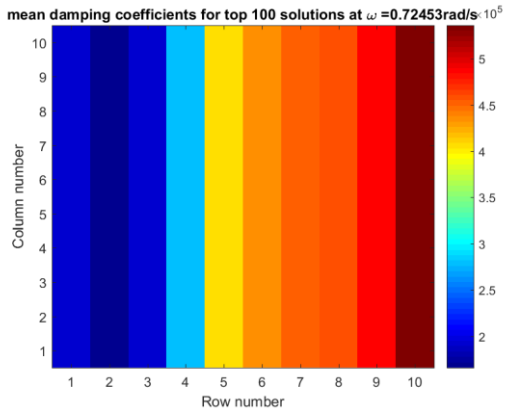


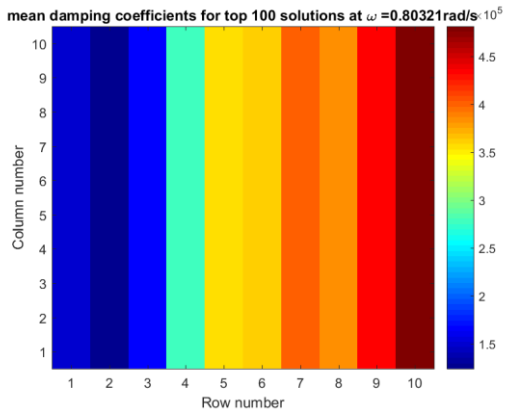


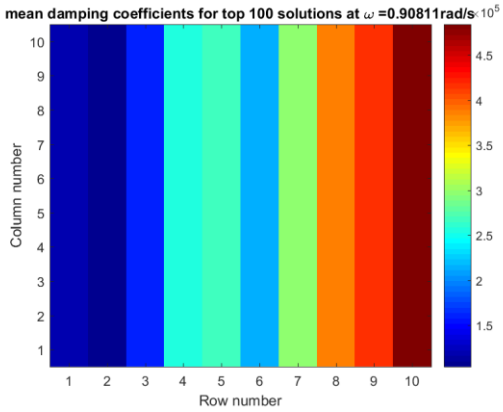
Appendix C.3: Results brute force method with uniform rows of 10 floaters

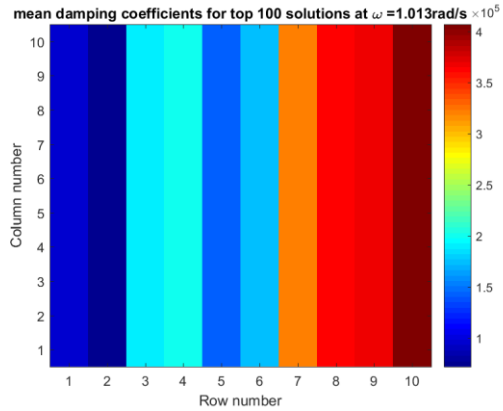


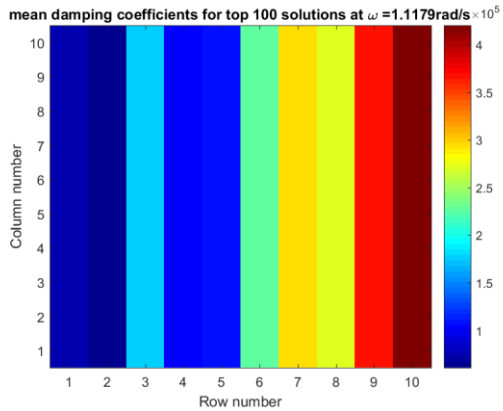


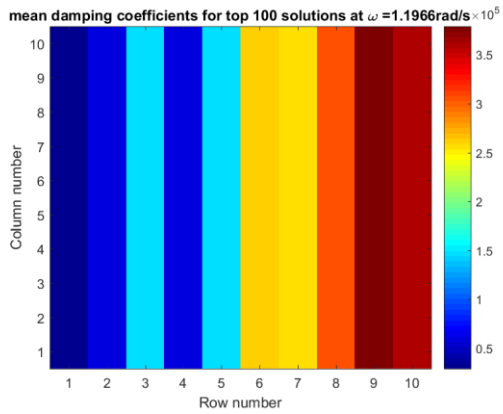




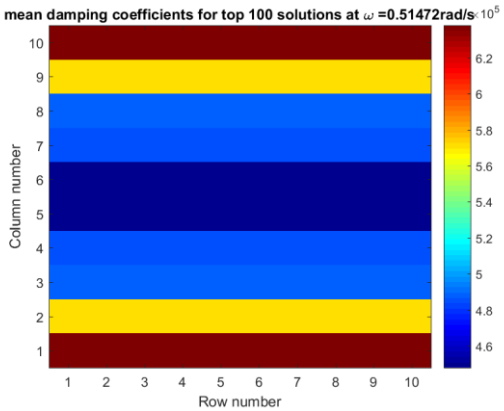


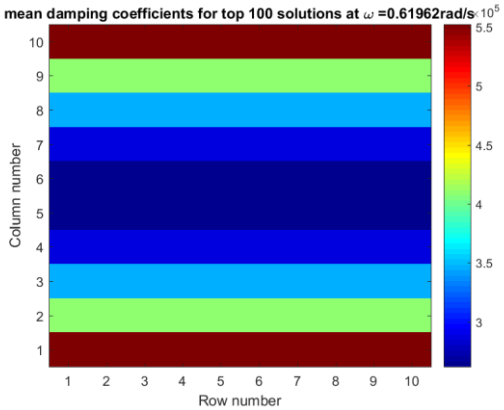


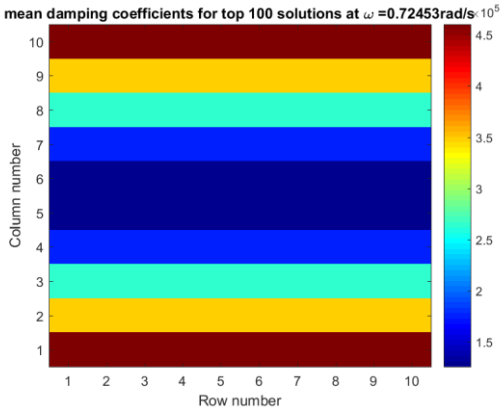


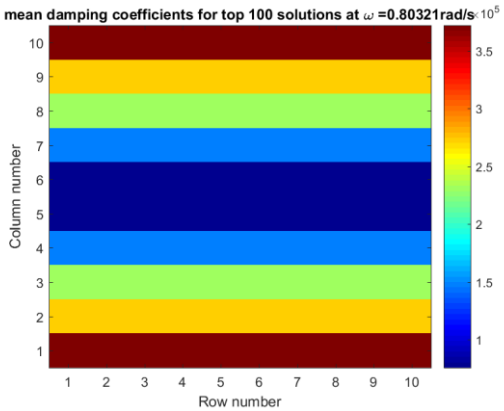


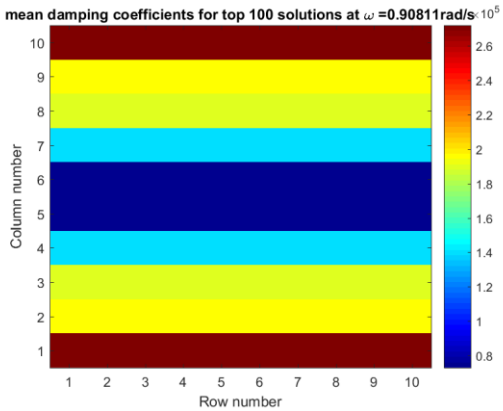
Appendix C.4: Results brute force method with symmetrical uniform columns

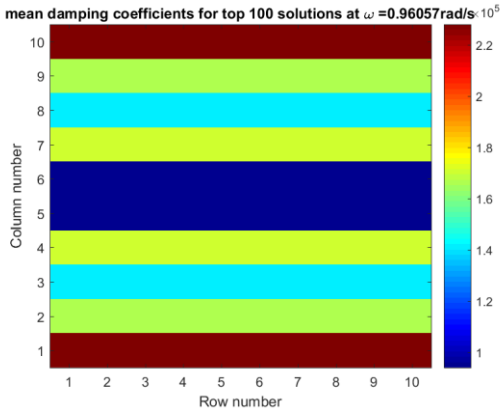


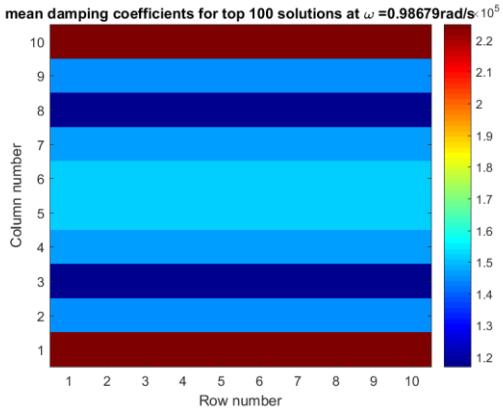


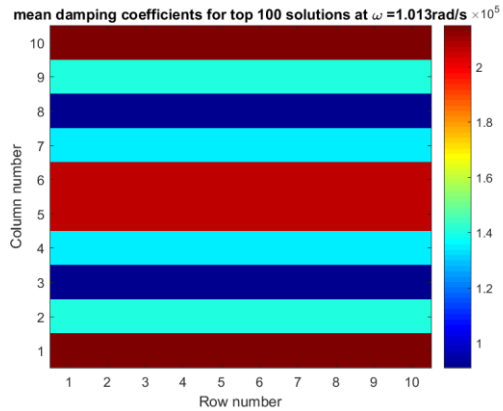


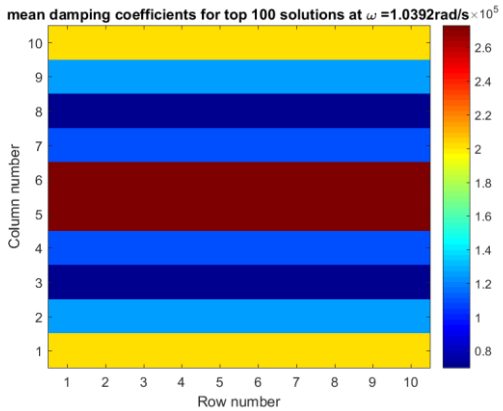


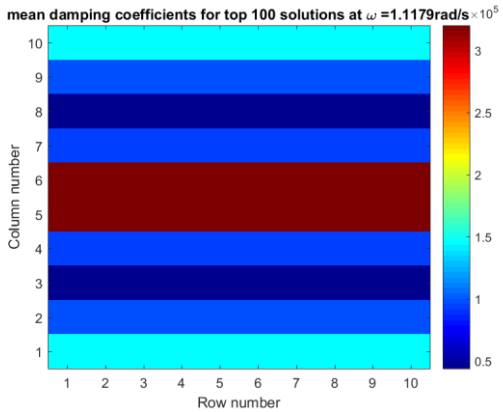


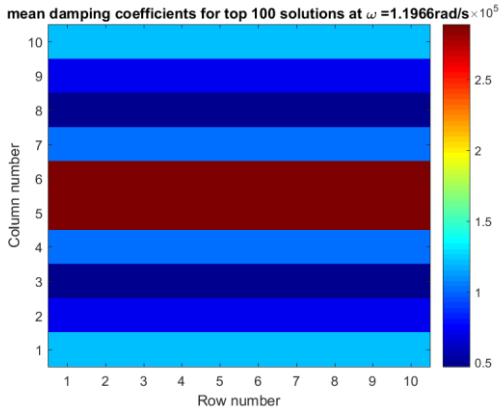




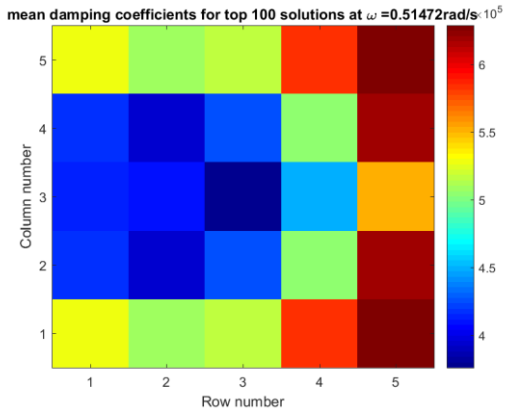


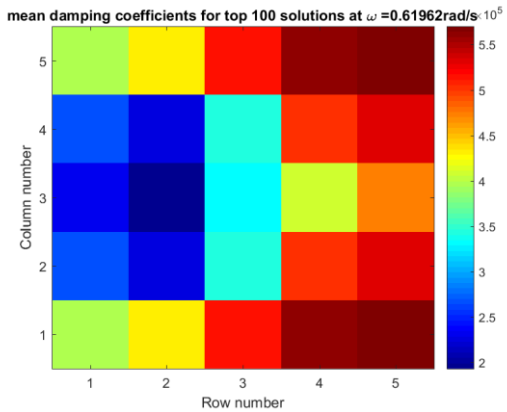

mean damping coefficients for top 100 solutions at ω =1.0392rad/s
×10^5
Column number
Row number
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8

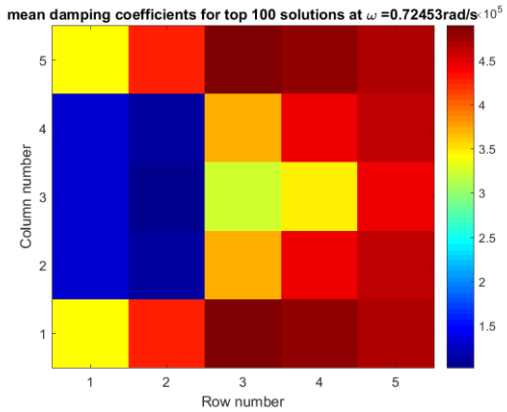

mean damping coefficients for top 100 solutions at ω =1.1179rad/s
×10^5
Column number
Row number
3
2.5
2
1.5
1
0.5

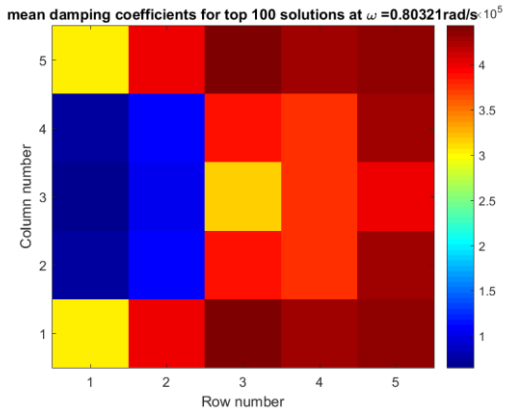

mean damping coefficients for top 100 solutions at ω =1.1966rad/s
×10^5
Column number
Row number
2.5
2
1.5
1
0.5

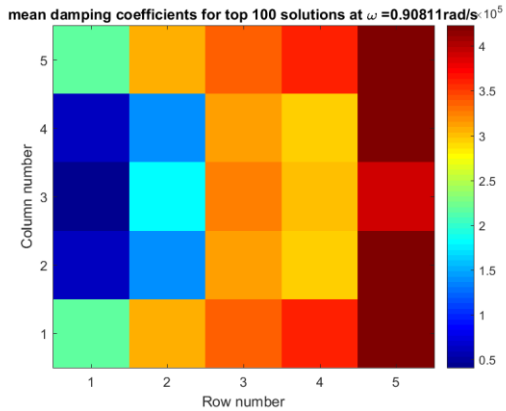
Appendix C.5: Results brute force method with uniform squares of 4 floaters

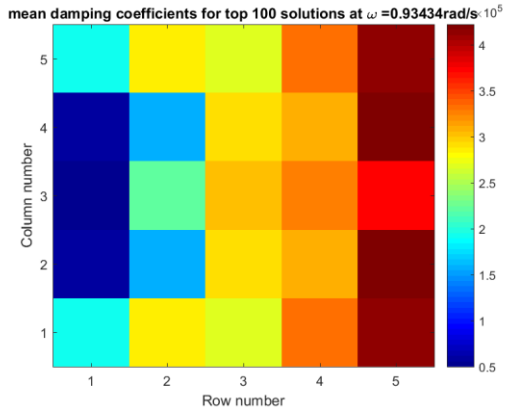


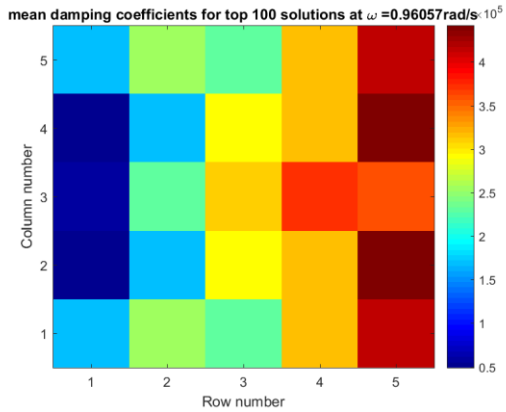


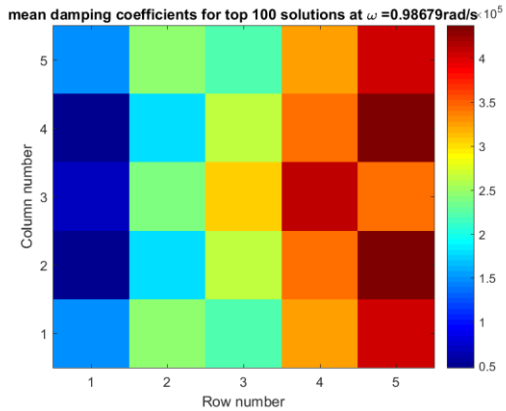


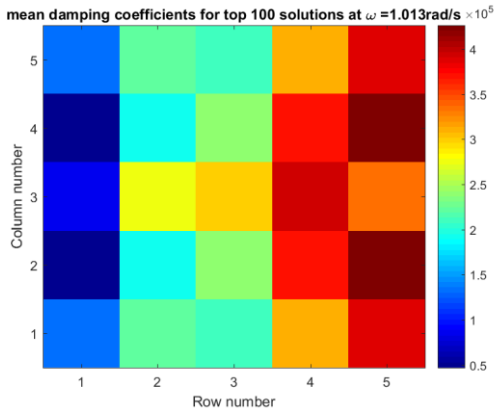


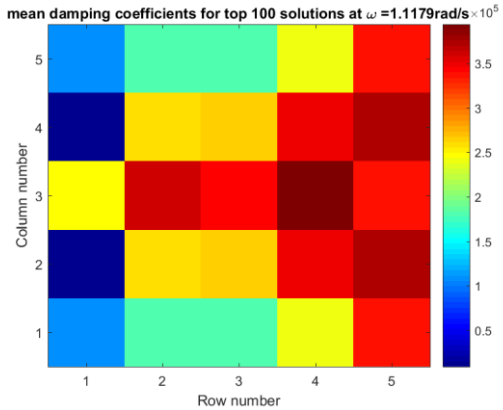


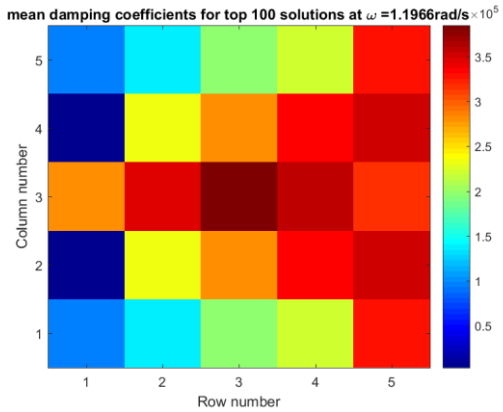







mean damping coefficients for top 100 solutions at ω =1.013rad/s
×10^5
Column number
Row number
1
2
3
4
5
0.5
1
1.5
2
2.5
3
3.5
4


mean damping coefficients for top 100 solutions at ω =1.1179rad/s
×10^5
Column number
Row number
1
2
3
4
5
0.5
1
1.5
2
2.5
3
3.5


mean damping coefficients for top 100 solutions at ω =1.1966rad/s
×10^5
Column number
Row number
1
2
3
4
5
0.5
1
1.5
2
2.5
3
3.5

Appendix C.6: results Particle Swarm Optimization method