Improving Surfing Conditions with Floating Wave Filters

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16/06/2009

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Abstract

The sport of surfing has increased tremendously in popularity in the last decade and surf breaks around the world are progressively getting overcrowded with surfers. This overcrowding is an annoyance to surfers themselves since surfing is an individualistic sport, one wave for one surfer. This coastal problem has been addressed by science through Artificial Surfing Reefs (ASR), however these are highly ambitious projects that haven't been perfected. This thesis introduces and alternative way to approach the problem, which is to improve the conditions at the surf breaks that already exist.

The objective of this thesis is to introduce Floating Wave Filters (FWF), which are floating structures anchored to the sea bottom that aim to block short-period waves and transmit long-period waves in order to improve surfing conditions. Short-period waves are generated by local winds, their periods do not exceed 4 seconds and wave heights are less than half a meter. Long-period waves refer to swell waves, with periods longer than 8-10 seconds and variable heights.

In general the preferred conditions for surfing are long-period waves, light offshore wind or no wind and the right tide for the particular surf break. When the wind at the coast is onshore the conditions for surfing deteriorate for two reasons. The first reason is that waves will tend to spill instead of plunge and surfers prefer plunging waves. The second reason, which FWF address, is that as wind blows toward shore, short-period waves are formed and these waves mix with the long-period waves to tamper or ruin surfing conditions.

The thesis gives a general description of the sport of surfing, discusses the role of surfing in Integrated Coastal Zone Management, describes coastal wind patterns, characterizes good surfing waves and gives the guidelines to perform an experiment with FWF in a wave flume.

Preface

This master thesis is being submitted as part of the requirements to complete the Erasmus Mundus master in Coastal and Marine Engineering and Management (CoMEM). The thesis has been written at the Universitat Politécnica de Catalunya, from February 2009 to June 2009.

Acknowledgements

I would like to acknowledge first of all Prof. Xavi Gironella Cobos, for his supervision, encouragement and guidance with this master thesis. I would also like to thank all the staff and members of the LIM facility for taking me under their wing for these few months, for the helpful conversations, and for their guidance.

I would not have been able to achieve any of this without the efforts and hospitality of the European Commission, the Norwegian University of Science and Technology, Delft University of Technology, The Polytechnic University of Catalonia and all the people within that made this CoMEM Erasmus Mundus program a reality. By welcoming international students into your universities you are making the world a better place. Tusen Takk, Dank je wel, and Merci!

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Words

Crowd: refers to a relatively high number of surfers attempting to surf a single surf break.

Land Breeze: it is offshore wind caused by the differential cooling of land and sea (at night).

Long-crested waves: Ocean surface waves that are nearly two-dimensional, in that the crests appear very long in comparison with the wavelength, and the energy propagation is concentrated in a narrow band around the mean wave direction (AMS Glossary)

Long-period waves: are waves with periods longer than 10 seconds.

Offshore wind: wind that is directed straight from land to sea

Onshore wind: wind that is directed straight from sea to land

Sea Breeze: refers to onshore wind caused by the differential heating of land and sea (during the day).

Seas: refers to waves that are still in the forming stage with waves of different periods and directions (typical of storms).

Set wave: a wave in a group of large moves

Set: A group of large waves.

Short-crested waves: typical of wind-sea or storms, the waves have crests comparable or shorter to their wavelength and there is no well-defined direction in the sea state.

Short-period waves: are waves with periods shorter or around than 4 seconds

Surf break: a place in any coast with consistently good surfing waves.

Surfboard: a shaped plank usually made of wood or foam and fiberglass; it has NO sail.

Surfing: the sport of riding a board toward the shore on the crest of a wave.

Wave Filter: the theme of this document; system with floating structures to block short-period waves and let long-period waves through.

Wind-waves: Strictly speaking all the waves mentioned in this report ARE wind-waves in the sense that all were formed by wind. However this report uses the term to describe waves formed by local winds as opposed to waves formed large distances away.

Swell: is the name given to waves once these travel outside of the generation zone. These waves have long periods, are uni-directional, and a favorite for surfing.

Coefficient of Transmission: refers to the ratio of transmitted wave energy to incident wave energy.

CHAPTER 1 - Introduction

**Words in Italics are defined, in the context of this report, in the previous section (Words)*

Wave Filters (FWF) are floating structures that aim to block *short-period** wind-waves and transmit *long-period* swell waves. The principal objective of blocking short-period waves is to improve the *surfing* conditions at a certain *surf break*.

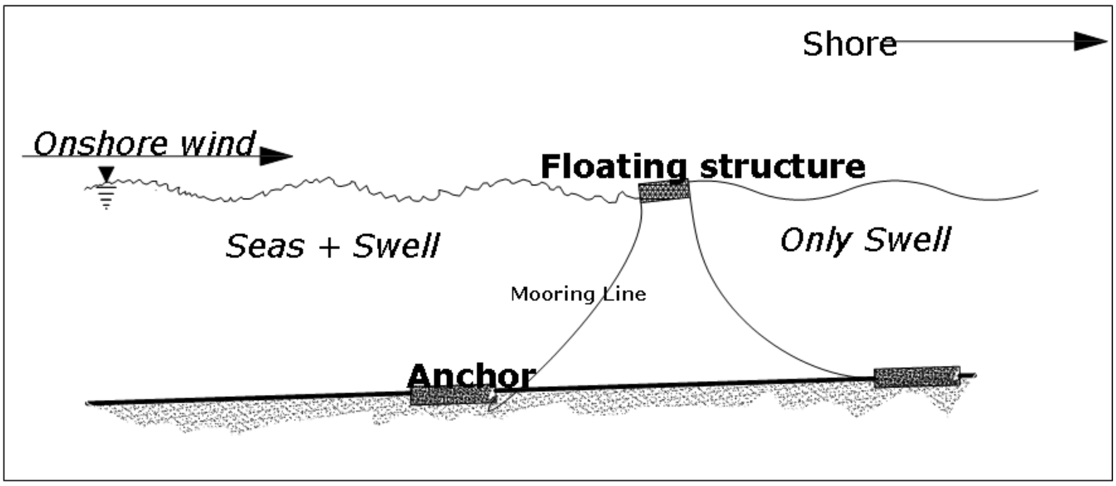
Onshore winds are bad; any surfer around the world can bear witness to this statement. Surfing conditions are deteriorated for two reasons when local winds blow towards shore; the first reason is that waves will break earlier (spill instead of plunge). The second, more critical, reason is that local winds directed towards shore will generate short-period waves (*seas/wind-waves*) that mix with swell waves and create mixed-sea conditions. These conditions are detrimental for surfing since the long waves become less defined and harder to surf. The FWF's purpose is to act as a Low Pass filter, letting only low frequency (long-period) waves through towards the surf zone. A conceptual drawing of the structure is presented below.

The sport of surfing has grown tremendously over the last decades and the overcrowding of surf breaks has been inevitable. *Crowds* bring frustration, conflicts and anger to a place that is supposed to be fun. The most popular answer by coastal engineers and scientists to this problem has been to develop Artificial Surfing Reefs (ASR). There has been considerable research on this topic, and some reefs have been built but without great success. ASR have great potential and certainly are the future of 'surfing science', nevertheless their implementation is yet to be perfected. As an alternative to crowd relief, FWF aim at increasing the amount of quality surf at the surf breaks that already exist. It is a cheaper and more sustainable solution than changing the bathymetry in order to improve surfing.

In order to test the capabilities of FWF a theoretical and a physical approach is taken. The theoretical analysis is based on Linear Wave Theory (LWT), and assumptions to give a rough estimate of *Transmission Coefficients*, C_T, as a function of structure draft and wave period. However in order to get more realistic values an experiment with a physical model is proposed. The initial intention was to include the experiment results into this report however due to time constraints the experiment was not completed.

Within the context of introducing FWF this report gives a general description of *Surfing,* and talks about the importance of taking surfers and surf breaks into account when dealing with Integrated Coastal Zone Management (ICZM). Also related to the subject of surfing and FWF, the relevant factors of meteorology and oceanography are discussed.

This report is divided into chapters; chapter 2 describes the objective of this thesis and motivation for the subject. Chapter 3 introduces the sport of surfing, describes the ideal conditions and discusses the role of surfing in Integrated Coastal Zone Management (ICZM). Chapter 4 contains a theoretical analysis of the performance of FWF, giving a rough estimate of C_T. Chapter 5 describes meteorology and oceanography components that are related to surfing and to the reasoning behind FWF. Chapter 6 focuses on FWF, defining their objective, design, and possible issues in their implementation. Chapter 7 includes the detailed description of the proposed physical model. And finally Chapter 8 gives conclusions and recommendations.



Conceptual drawing of Floating Wave Filters (cross section)

CHAPTER 2 - Problem Definition and Objective

2.1 Problem Definition (Motivation)

The demand for surf breaks is increasing as more and more people take on surfing. Over the past decade a proposed solution has been to build Artificial Surfing Reefs (ASRs). However, despite high hopes and expectations, ASRs have not had great success. The fact is that changing the seabed topography costs a lot of money and could cause serious environmental impact. Instead of these highly ambitious projects, a more sustainable and environmentally friendly solution would be to improve the conditions of the surf breaks we already have.

Onshore winds cause choppy conditions, which are undesirable for practicing the sport of surfing. These choppy conditions can ruin, or severely tamper the quality of a surfing break for half the day (due to sea breeze) or for a whole season in certain places. If choppy conditions could be ruled out or at least diminished the efficiency of many surf breaks could be enhanced and the necessity for large ASR could wait some years.

2.2 Objectives

The main objective is to study the capability of floating structures to improve surfing conditions by blocking wind waves (short periods and crests) and letting through swell (long period) waves. These structures will be referred to as **Floating Wave Filters (FWF)**.

In order to study FWF a few preliminary objectives were established and these are:

- Describe the preferred (atmospheric and oceanographic) conditions for surfing in order for the reader to understand the surfer's point of view.
- Characterize waves that are good for surfing in terms of significant wave height (Hs), Peak wave period (Tp) and Wave frequency spectrum.
- Use a numerical model to find the optimal design of FWF depending on different wave characteristics.
- Build a physical model and run experiments in a small-scale wave flume to find the effectiveness of FWF.

CHAPTER 3 - Surfing

In the context of this study surfing refers to the act of gliding on a board across the unbroken surface of an ocean wave. Figure 1 shows three perfect examples of surfing

Figure 1 Illustrative pictures of Surfing[1].

with a shortboard. There are many variations of board sizes, materials and shapes that make the surfing experience different, but in essence surfing is the act of gliding on a board across a wave. The popularity of surfing has increased tremendously over the last couple of decades; the number of surfers keeps increasing all the time.

As any sport, surfing is a very enjoyable activity that keeps you coming back for more, but unlike other sports the playing field is always changing. Like a photographer is always looking for perfect photos a surfer is always looking for perfect waves. In the search for these perfect waves, surfers have traveled long ways. Nowadays many towns and remote communities around the world with good surf have seen a continuous influx of surfers, from all sorts of places. As an example, surfers from all around the world flock to Indonesia every year during the dry season. This season comes with very consistent offshore winds (preferred winds) and swell to the west coast of the Indonesian archipielago where many surf breaks ‘light up’ with perfect waves like the one pictured in figure 2. Many of the visiting surfers stay for much longer than planned. Good waves will attract surfers wherever these may be.

Figure 2 Perfect Indonesian Wave[1]

[1] Photos taken from http://photos.surfline.com/

3.1 History

The earliest written account of surfing was by Captain James Cook in 1778. On his third expedition to the pacific Captain Cook visited Hawaii and was impressed when he saw the locals riding waves with wood planks. This practice was well established among Hawaiian locals at that time and even the kings practiced surfing (Marcus, 2009). However the art of riding waves was not invented in Hawaii. It is popularly claimed that it was the Polynesian, who eventually populated Hawaii, who started riding waves. Polynesians traveled all around the pacific in small canoes populating far away places; Hawaii to the north, Easter Island to the east and New Zealand to the South. During these long trips Polynesian people probably started riding waves due to necessity during high seas. The practice then translated to near-shore waves giving birth to surfing. Nonetheless, in a different part of the Pacific Ocean, in Peru, the locals were also riding waves as early as 2000 years ago (Valdiria, 2009) The fishermen used "caballitos de totora" (totora reed canoes) to go out fishing, and the proficiency of any fishermen partly depended on his ability to negotiate or ride the near-shore waves.

Even though it is not clear who were the first people to ride waves, it is clear that surfing came of age in Hawaii. Surfing was widely practiced and considered somewhat of a ritual before Cook set foot in Hawaii. But just like many more Hawaiian traditions, surfing fell victim to the European 'discovery' of the archipelago in the beginning of the 19th century. Surfing declined in popularity as the westerners introduced new ways of thinking and behaving (Marcus, 2009). By the early 1900's surfing's popularity was at its worst in Hawaii and ironically it was outsiders, or *haole* as they are called by Hawaiians, who introduced surfing back to Hawaii.

In the first half of the 20th century surfing was popularized by figures like Duke Kahanamoku, who was a Hawaiian gold medalist swimmer and avid surfer. Kahanamoku introduced surfing to Australia and mainland U.S.A., but it was in Hawaii were the roots of surfing kept growing strong. Around the 1950's several people, especially from California, dropped everything and set camp in the North Shore of Oahu in Hawaii. This is, still today, the proving ground for surfers. It was the place where surfing evolved and turned into what it is today. The images of those few brave men in the North Shore sparked a movement that has not stopped.

3.2 The state of surfing

Nowadays surfers do the unthinkable to search for waves and surf them. Professional surfers will travel to the other side of the world in a day's notice to surf a particular swell. Powered Watercrafts are being used to tow surfers into waves 20 meters high and larger. The popularity of the sport has turned 'surfing brands' into multibillion-dollar companies and turned the best surfers into well-earning professional athletes. Surfing has evolved from being part of a counter-culture to being a legitimate water sport with millions of followers.

3.2.1 Professional Surfing

Professional Surfing is a good tool to gauge the popularity of surfing and it is also a possible marketplace for Floating Wave Filters. The *Association of Surfing Professionals* (ASP) holds a Men's and Women's World Tour with venues around the world. The Men's World Tour in 2009 will have ten contests, each with a purse of US$340,000 (ASP 2009). All the contests are sponsored by surfing and non-surfing brands and are used as huge advertisement channels. Every contest has a waiting period of about 10 days, and the contest takes place during the best three days of this waiting period. Unlike most other world-class sport competitions, nature plays a major role in the success of these contests. Currently there is no mechanism used to attempt an improvement of the surfing conditions. A Floating Wave Filter could increase the quality of surf with a very low environmental impact.

The Association of Surfing Professionals also organizes a World Qualifying Series for both men and women. There are well over 50 competitions with different level of importance throughout the year and around the world.

3.3 Surfing and Integrated Coastal Zone Management

As coastal populations grow around the world, Integrated Coastal Zone Management (ICZM) will be an essential role of government; surfers and surf breaks need to be taken into account. The word "Integrated" is key, it means to express that all interest groups are considered when taking development decisions. These interest groups include but are not limited to: fishermen, port authorities, recreational boating, beachgoers, landowners, real estate owners, tourism industry, and others. Surfers would likely be classified as beachgoers, but due to the nature of surfing they should be in a group of their own. Surfing requires surf breaks and coastal development has the potential to modify these surf breaks dramatically. Scarfe (2009) identified the range of physical effects that coastal structures/development can have on an existing surfing break, and analyzed various examples. Table 1 (taken from Corne, 2009) shows various mechanisms that affect wave quality at surf breaks. Corne (2009) analyzed the impact of coastal protection on surf breaks by means of questionnaires to affected surfers. Both authors found that coastal structures have either enhanced, degenerated, destroyed or created surf breaks, although always unintentionally. In other words, historically coastal engineers do not take surf breaks into consideration when designing coastal structures.

"For the best environmental result, recognition is required of surfing amenities as specific natural resources in coastal plans and environmental legislature to facilitate their protection and enhancement (Scarfe, 2009; p. 701)." Any effort to protect a surfing break will be much more solid if this certain break is already recognized as a valuable natural resource. Furthermore, detailed studies of surf breaks will not only give a more tangible value (in the eyes of non-surfers at least) to surf breaks, but also will improve the scientific knowledge of surf breaks. This knowledge will allow the eventual perfection of Artificial Surfing Reefs (ASRs), which are the equivalent to 'playgrounds for surfers'.

Surfing is a well-established sport that will not disappear by any means; people of all ages, races and social classes are practicing it. The sport is an important coastal activity and should be properly reckoned by coastal managers, coastal engineers and anyone with authority on the coast.

3.3.1

Table 1 Potential mechanisms that affect wave quality st surveyed locations (taken from Corne 2009)

Type of Coastal Protection	Increase or Decrease in Wave Quality	Proposed Mechanism	Example	Relevant Reference
Seawall	Decrease	1. The position of the seawall directly in the surf zone has effectively removed the surfing resource. Where the wave previously broke and surfers first began their ride, there is now a wall of concrete or other material, and the waves break directly onto this.	Ponta Delgada, Madeira	
		2. Wave frequency. The seawall may cause the surfing resource to be usable only at certain tides, thereby reducing the time that it is available to surf the wave.	Jardin do Mer, Madeira	
		3. Backwash. This is caused when the incoming wave's shape is affected by the action of wave that previously hit the seawall. This can range from a "wobble" in the wave's face to the creation of dangerous conditions.	Lugar de Baixo, Madeira	
		4. A reduction of the flow of sediment to the seabed. The seawall may act to lock the previously free-flowing sediment behind it. This prevents sediment being transported into the ocean and the formation of sandbars that cause the wave to break. Therefore, the wave breaks closer to the seawall, moving the surfing resource closer and potentially causing backwash or reducing wave frequency (as previously described).	Copacabana, Brazil[1]	Pilkey and Wright (1988)
		5. Alteration of the local bathymetry. This could affect the quality of the waves. If the seabed is flattened, then a wave that previously broke with plunging characteristics that are ideal for intermediate to advanced surfers, may break with more spilling characteristics.	The Cowie Hole, N'Castle Australia	Black and Mead (2001)
		6. The seawall may prevent access to surfers and other beachgoers to the beach.	Male Point, Maldives[1]	Houston (1996)
		7. The construction of the seawall may cause a reduction in beach width and therefore decrease its recreational value.	Fongbin, Taiwan	Ford and Brown (2006)
		8. A change in environmental conditions. The seawall blocks the natural view of the coast. This may reduce the aesthetic value of the location and for some surfers may reduce the quality of the experience. Therefore, a reduction in the environmental quality of the location would be interpreted by this user group of surfers as a reduction in wave quality.		
Beach nourishment	Decrease	The addition of sediment effectively buries the sandbars. These sandbars act as focus points for the waves to break. The flattening of the seabed profile changes the wave type from plunging to spilling, thereby reducing the wave quality. This reduction in quality may only be temporary as the scheme shifts to find its equilibrium and may cause the return of the sandbars.	Singleton Swash, City of Myrtle Beach, United States	Black and Mead (2001)
Beach nourishment	Increase	The system may be returning to equilibrium after it was overloaded with sediment.	St Augustine pier beach, Florida, United States	
Jetty	Increase	The mechanism of this enhancement in wave quality is based on the structure's ability to trap sediment. The sediment forms a preconditioning element for the wave or acts as a focus for the wave to break on.	Bastendorff South Chetci, Oregon, United States	Scarfe *et al.* (2003); Preston- Whyte (2002)
Other (rip-rap)	Decrease	Reference mechanism 4. The structures interrupt the movement of sediment, which affects the wave quality.	Lincoln City Beach, Oregon, United States	Pilkey and Wright (1988)
Beach nourishment and groynes	Increase	The sandbars are artificially fed by the beach nourishment scheme and are effectively held in place by the groynes.	Newport Beach, California, United States	Scarfe *et al.* (2003)

[1] Save the Wave (2005).

3.3.2 Economics of a Surf Break

A quantification of the value of a surf break will allow an easier integration of surfing into ICZM. Just like any other sporting facility a surf break attracts people and influences the local economy. Nelsen et al (2007) looked at the socioeconomic impact of a surf break in the coast of California. Their conclusions showed that surfers belong to the same demographic as other beachgoers. This is far from the stereotype of surfers as young, unemployed and uneducated people. Nowadays people from the whole spectrum of society practice surfing. Another important point Nelsen et al. found out was that surfers visit the beach a greater number of times per year than the average beach user. Rainy or cloudy days will not deter a surfer from going to the beach. So a consistent surf spot will consistently attract surfers and hence boost the local economy.

A Floating Wave Filter will increase the amount of time per day that a surf break has quality surf. Usually Sea Breeze is present for half of the day, give or take. So in many instances placing Floating Wave Filters can double the economical attractiveness of a surf break.

3.3.3 Social Impacts of a Surf Break

Completely apart from an economical point of view, surfing has an important influence in a coastal community. Here a list of social aspects that surfing influences in one way or another:

- Exercise: surfing is an intense physical activity, with all the benefits of any intense sport.
- Environment (negative): surfing affects the environment in a negative and also in a positive way. The negative impact comes partly from the creation of specialized equipment, i.e. surfboards, wetsuits, leashes, sunscreen, etc. Another negative impact comes from the fact that most surfers need (or want) to travel a certain distance to their chosen surf break. This entails Carbon Dioxide emissions by cars, airplanes, motorcycles or recreational vehicles utilized by surfers. This is not much different than any other human activity, nevertheless it must be recognized.
- Environment (positive): surfers spend hours at a time in the ocean, so naturally they enjoy a clean ocean. Organizations such as *Surfrider Foundation* (global) and *Surfers Against Sewage* (United Kingdom) are proof that surfers have organized themselves to advocate for cleaner oceans.
- Community (negative): due to the individualistic nature of surfing (one wave for one surfer), surfers tend to be selfish and very protective. The term ‘locals’ is very often used to describe people who feel a sense of ownership over a certain break. This is normal human behavior, however when this ‘ownership’ is enforced by fights, insults or threats there is certainly a negative impact on the community.

These acts have been catalogued as 'surf rage' and there have been well-documented events in California and Australia.

- Community (positive): Surf breaks serve as a leisure spots as much as any urban park. It is a place where young and old can enjoy the outdoors, exercise and/or socialize in a very healthy way. Surf breaks also serve as venues for competitions, which are always nice events for surfers and non-surfers alike to enjoy.
- Aesthetically: although a very subjective issue, it can be argued that surf breaks are very nice spectacle for everyone's viewing pleasure.

3.1 Ideal and preferred conditions for surfing

Surfing is now more popular than ever before, that is an inevitable truth that most surfers dread. The reason being that surfing is a highly individualistic sport; one wave, one surfer. Even though hundreds of waves reach surf breaks every day there are many factors than influence the quality of surf at any given surf spot. These factors include wave height, wave period, wave direction, wave groups, wind direction, wind speed, tides, currents and crowds.

- Wave height: The wave height for surfing should be interpreted as the average of the top 10% of waves, instead of the top third ($H_{1/10}$ instead of $H_{1/3}$) (Scarfe et al. 2003). $H_{1/10}$ is much more representative, since surfers tend to wait for the largest waves. The perfect wave height is very subjective but in general the larger the swell's wave height is, the happier surfers are.

This is due to different reasons depending on your ability, available equipment, and where you are. Large swells have the ability to reach more places in the coast through diffraction. Sheltered places in the coast will be good surf breaks only during large swells, so a large swell usually translates into more places to surf. However this does not necessarily mean less crowds since the swells can be forecasted a few days in advance and with great accuracy.

- Wave period: The more desirable wave periods for surfing are periods higher than 10 seconds. Waves with periods higher than 10 seconds are usually part of a swell and have been generated hundreds of kilometers away. Long periods are desirable for surfing because the waves have long crests, long wavelengths, and considerable energy is concentrated at the crests. Diffraction is proportional to wave period so sheltered places in the coast will benefit from longer periods.

Waves with periods between 6 and 10 seconds can still be very good for surfing but are not as common. The Caribbean coast of Costa Rica and Panama is a good example of a place with very good waves and short wave periods.

- Wave direction: depending on the local bathymetry certain wave (swell) directions will be better than others. Depending on the swell direction, certain surf breaks might work and others might not.

- Wave groups: Due to the irregularity of ocean swell the largest waves will come in groups, popularly known as ‘sets’ in surfing lingo. Surfers typically wait for the set waves, which will provide the best rides. However these sets of waves come sporadically (every 5 to 15 minutes) and usually contain 1 to 5 waves. Surfers compete for these waves and usually not every surfer gets a set wave. This takes us to the next factor, crowds.

- Crowds: In general a group of 10 or more surfers (depending on the surf spot) constitutes a crowd. With the increased popularity of the sport, surf breaks are increasingly more crowded. Naturally as the crowd gets larger, your possibilities of catching a good ride get smaller and the surfer frustration grows. For this simple reason surfers despise crowds. Most surfers’ vacations include a plane ticket to a third world country in the search of un-crowded waves. A big travel industry has grown around the concept of un-crowded waves. The options include secluded resorts, boat trips or safari-like adventures.

- Wave breaking intensity: the wave breaking intensity is a function of the wave period, height, and beach profile. Most surf breaks have changing breaking intensity depending on the tide, wave height and wave direction. Surfers prefer plunging waves.

- Wind direction: the preferred wind direction for surfing is offshore (from land to sea) due to two reasons. The first reasons is that an offshore wind cause waves to delay breaking, break in shallower water and hence are more likely to plunge (Douglass 1990). The other reason is that offshore winds offer cleaner conditions, the ripples and subsequently waves that are formed by the wind travel out of the surf zone and do not affect the surfing waves. On the other hand onshore wind can spoil an otherwise perfectly good surfing scenario. The main reason is that onshore wind, typically coming as sea breeze, creates small short crested waves, which create choppy conditions. The topic of this investigation is how to block these waves with short periods and short crests and only let swell waves to get into the surf zone. Another negative effect of onshore winds is that it causes waves to break earlier than in no wind conditions. By breaking earlier the waves tend to spill and be less attractive for surfing.

- Tides: Most surf breaks are sensitive to tides. While at certain surf breaks the waves will increase or decrease in quality depending on the tide, other places will only be surfable during a short window in the tidal cycle. At some places the tide may get low enough to expose rocks or reefs, which pose a threat to surfers. Another scenario is that the tide gets so high that the waves will barely break, spilling instead of plunging. So a surfer must take into consideration the tide when looking for good waves.

- Currents: depending on the tidal amplitude and swell direction sometimes a strong current will prove very hard or impossible to surf a given surf spot.

CHAPTER 4 - Theoretical Analysis

This theoretical analysis attempts to explain the mechanics behind a Floating Wave Filter and the reason why it should work, hydrodynamically speaking. It also provides a very rough estimate of transmission coefficient, C_T, as a function of structure draft and wave frequency. The C_T is a ratio between the transmitted wave energy and the incident wave energy. This analysis relies on knowledge of floating breakwaters, linear wave theory and heavy assumptions.

The original intention was to use a numerical model to simulate Floating Wave Filters. However due to a lack of time, knowledge, and availability of numerical models, the simulation was not successful. This is explained in more detail in the first section of this chapter.

4.1 Numerical Modeling

The numerical modeling approach was abandoned after different strategies failed. Numerical modeling was consuming too much time of the allowed time to finish the thesis, and there was very little progress.

The first step taken towards getting results from a numerical model was to read publications by Koutandos et. al. (2002), Li and Watanabe (2006) and Fousert (2006). The first two papers briefly explain the way in which they created the model and give some results. The model developed by Koutandos uses “finite difference depth-averaged wave propagation model... …coupled with a 2DV model for the determination of the pressure field beneath the floating structure” (Koutandos, 2002). The model developed by Li uses the finite element method (FEM) to solve the Laplace’s equations. The authors of both of these models were contacted to see wether the models were available for academic use. However it seems that these models are not ‘user-friendly’ and not everyone is willing to ‘lend’ them out.

The third mentioned author (Fousert) wrote a Master Thesis about very large floating breakwaters at Delft University of Technology. He developed a ‘calculation’ model which was relatively simple to serve him in the design of Floating Breakwaters. A copy of the model was attempted in a MATLAB script but it was not possible. Fousert used another program DELFRAC to calculated added masses and other coefficients, and this program was not available. Several people at TUDelft[1] were contacted without any positive answers.

The final attempt to use a numerical model was to use a FEM within the GID software program to model a wave flume with the required characteristics to test FWF. However introducing a floating structure creating many instabilities and a practical solution was not found.

In conclusion the inexperience of the author with numerical models as well as the hydrodynamics aspects of the problem were too much to overcome within the time limit. From there on the focus was on the physical model.

4.2 Floating Breakwaters (FB)

The proposed structures in this investigation will not be floating breakwaters (FB) but rather floating Floating Wave Filters (FWF). However, FB inherently perform as FWF due to their inability to completely block waves with long wave periods. FB are often used for marinas where building a conventional breakwater would be too expensive or it is not necessary. In places of very deep water it would not be cost efficient to build a conventional breakwater so a FB may be chosen instead. In other places the wave attack is of short periods so a floating breakwater is enough protection.

The main disadvantage of FB is their inability to block long-period waves. As it can be shown in Figure 3, the transmission coefficient, C_T, is about 0.8 to 0.9 for the longest waves in the experiment. The longest wave period used was of 9.17 s (B/L = 0.0445). On the other hand the same figure clearly shows how efficient FB are at blocking short-period wave energy. There is only about 40% transmission for the shortest tested period. The shortest tested period for the left graph (Hi = 0.2m) is 2.04 s (B/L = 0.32), and the shortest period for the right graph (Hi = 0.3m) is 2.34 s (B/L $\approx$ 0.245).

We can assume that this tendency, of high C_T for long periods and low C_T for short periods, will continue towards longer and shorter periods. If this assumption holds, the theoretical basis for Floating Wave Filters is solid.

[1] Due to the CoMEM program the author of this report is a full time student at TUDelft.

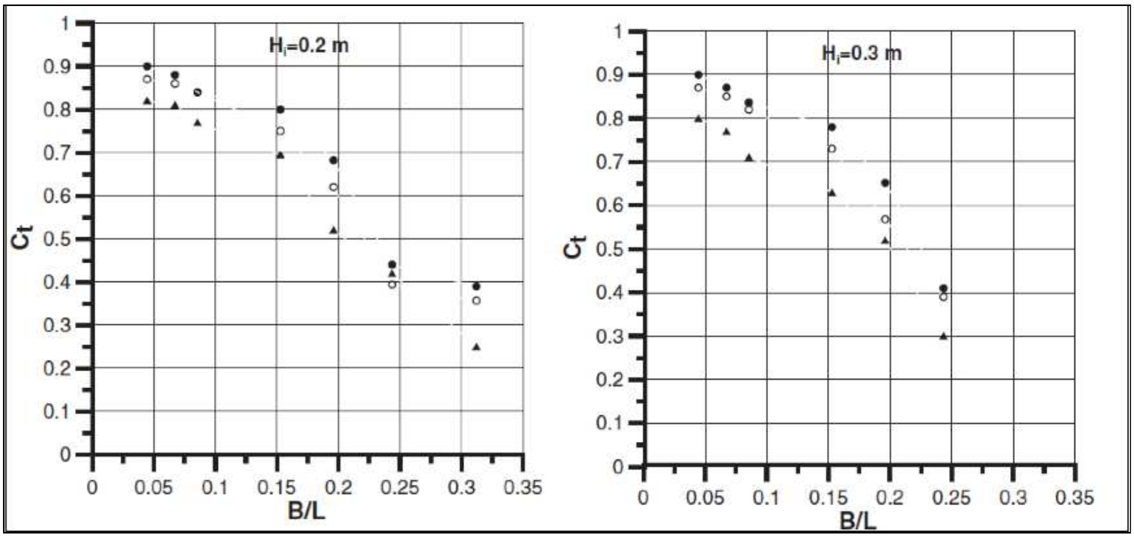


Figure 3 Coefficient of Transmission vs Waterdepth (B) over Wavelength (L) for a single FB. Taken from Koutandos et al. 2005

4.3 Linear Wave Theory

This theoretical analysis uses Linear Wave Theory (LWT) and other assumptions to estimate the Transmission Coefficient, C_T, of FWF as a function of wave period. This analysis is not meant to be an accurate estimation of C_T, it is rather a theoretical explanation of how a FWF works.

The idea of Floating Wave Filters is in a great way inspired by learning Linear Wave Theory (LWT). This simplified theory of wave behavior maintains that wave energy decreases with depth and is inversely proportional to wavelength. Furthermore the theory says that depending on the relation between wavelength and water depth, waves may behave as deep-water waves, intermediate-water waves or shallow-water waves, this is referred to as relative depth.

4.4 Relative Depth

Relative depth is the relation between water depth and wavelength, or the ratio h/L. "The relative depth is a valuable parameter for classifying waves because for certain ranges of relative depth the equations that describe wave characteristics are significantly simplified. And these ranges define the limits for some unique wave behavior patterns." (Sorensen 1993, p.13) The ranges are deep water, transitional or intermediate water, and shallow water. If the wavelength is up to twice the water depth then the wave is in deepwater, for a wavelength 20 times (or more) the water depth the wave is in shallow water, and in between deep and shallow the wave is in a transitional state.

Assuming that a FWF will be placed in at a water depth of 10 m; at this depth waves of periods up to 3.5 seconds will behave as deep-water waves (depth/wavelength > 0.5), and waves with periods between 3.5 and 20.5 seconds will behave as intermediate-water waves (0.05 < depth/wavelength < 0.5). Figure 4 shows this behavior by comparing deep-water wavelength with actual wavelength. It can be seen that for wave periods lower than 3.5 seconds both wavelength are the same. However as the period increases the relative depth decreases (the wave starts to 'feel' the bottom), and the wavelength shortens.

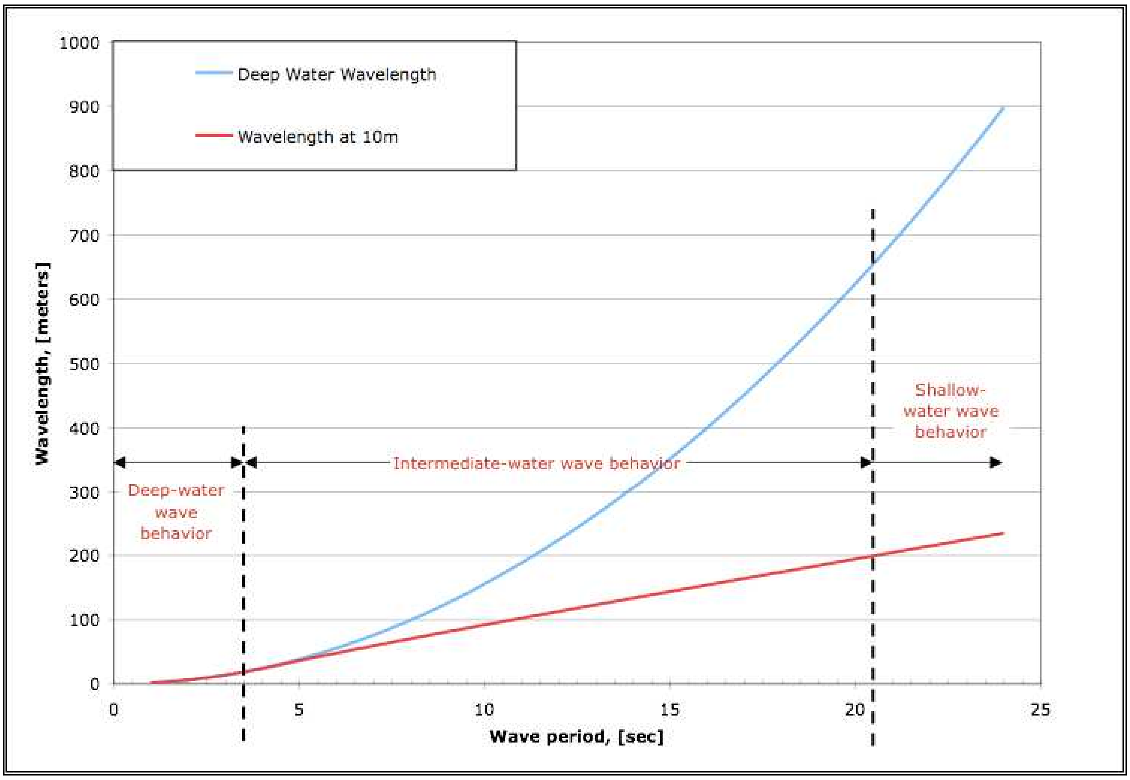


Figure 4 Relative Depth/Wave behavior at 10 m depth.

4.5 Wave Energy Distribution

The energy distribution throughout the water column is relevant since a floating structure will only block wave energy present near the surface. The amount of energy near the surface (down to the FWF's draft) needs to be compared to the total energy throughout the water column.

The severe assumption made here is that *the horizontal particle displacement with relation to water depth is proportional to the kinetic energy*

By assuming that the *horizontal particle displacement* is proportional to the *kinetic energy* of waves, a comparison can be made between the wave energy near the surface and the energy across the entire water depth. Figure 5 shows the horizontal particle displacement envelopes (amplitudes) for waves of periods of 3.5 seconds and 12 seconds. It is clear from the figure that the short period wave concentrates the energy towards the water surface while the long period wave distributes the energy over the entire water column. More than short period vs. long period it is a matter of deep-water vs. shallow-water behavior.

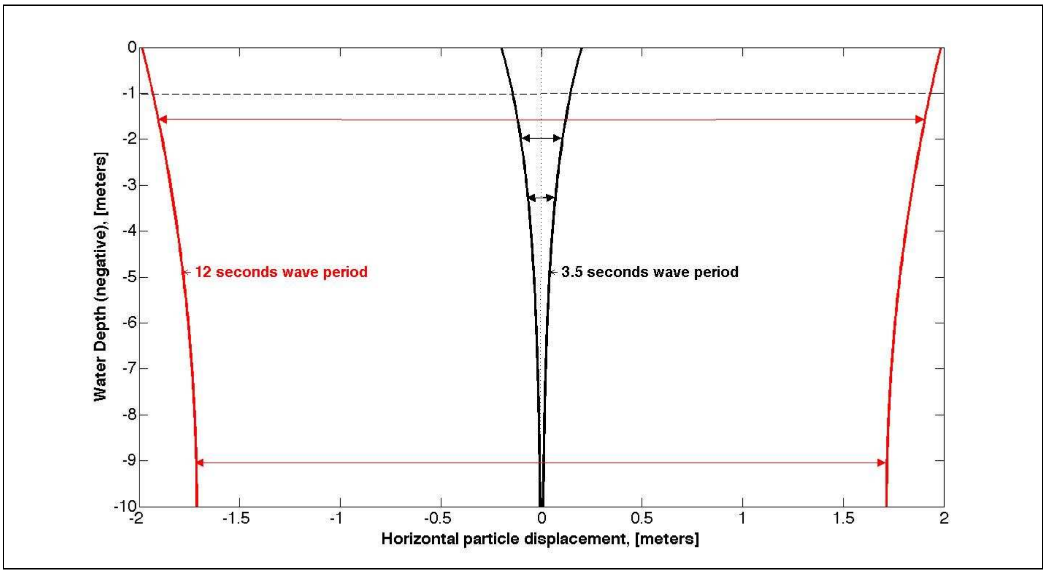


Figure 5 Horizontal particle displacement envelopes

4.6 <u>Wave-Structure Interaction</u>

Comprehensive analyses of the interaction between incoming waves and a floating structure have been done by: Li and Watanabe, 2006, and Koutandos et al., 2002. Such a complex analysis is outside of the scope of this report; in this theoretical analysis severe assumptions are made to have an approximate idea of the resulting transmission coefficients.

The critical assumption made for wave-structure interaction is that *all the energy above the FWF's draft will be blocked (reflected or dissipated), and all the energy below the FWF's draft will be transmitted to the leeward side of the structure.*

Now assuming that a floating structure will block all the energy above its draft and let all the energy below its draft through, the (theoretical) transmission coefficients can be calculated. The horizontal particle displacement envelope is integrated from the sea surface to the draft and this quantity is compared to the integration over the entire depth. Due to the difference in energy concentration, floating structures will block a greater proportion of short-period waves than long-period waves.

4.7 Calculation

Here the steps involved in the calculation are explained with equations and the corresponding MATLAB script is included in Appendix B.

Nomenclature:

a = wave amplitude
λ_0 = deep water wavelength
λ = wavelength (actual depth)
k = wave number
h = water depth
d= FWF's draft
z = vertical coordinate, positive upward from still water level
ξ_{deep} = horizontal particle displacement in deep water
ξ_{int} =horizontal particle displacement in intermediate water
E_T = 'Total energy'
E_B = 'Blocked energy'
C_T = Transmission coefficient

I. Wave parameters

$$\lambda_0 = \frac{g}{2\pi}T^2 \qquad \textbf{Eq. 1}$$

$$\lambda = \frac{g}{2\pi}T^2 \cdot \tanh\left(\frac{2\pi \cdot h}{\lambda}\right) \qquad \textbf{Eq. 2}$$

$$k = \frac{2\pi}{\lambda} \qquad \textbf{Eq. 3}$$

II. Horizontal Particle displacement:

- At deep water:

$$\xi_{deep} = -a \cdot e^{k \cdot z} \cdot \cos(\omega \cdot t - k \cdot x) \qquad \textbf{Eq. 4}$$

- At intermediate water:

$$\xi_{\text{int}} = -a \frac{\cosh\left[k(z+h)\right]}{\sinh(k \cdot h)} \cos(\omega \cdot t - k \cdot x) \qquad \textbf{Eq. 5}$$

Since we are looking for the amplitude, the last term in both equations is eliminated, and it is not multiplied by 2 since the horizontal particle displacement is symmetrical (assuming LWT). So the ratio would be the same if we only take the positive (or negative) displacement or if we take the whole displacement.

$$\xi_{deep} = -a \cdot e^{k \cdot z} \qquad \textbf{Eq. 6}$$

&

$$\xi_{\text{int}} = -a \frac{\cosh\left[k(z+h)\right]}{\sinh(k \quad h)} \qquad \textbf{Eq. 7}$$

Making the assumption that the distribution of energy in the water column is proportional to the distribution of horizontal particle displacement, the two previous equations represent the amount of 'energy' at z.

III. Total Energy:

Integrating the horizontal displacement over the entire water column we can get the 'total energy'.

$$E_T = \int_0^h \xi dz \qquad \textbf{Eq. 8}$$

IV. Blocked Energy:

Integrating the horizontal displacement over the draft we can get the amount of 'blocked energy'.

$$E_B = \int_{(h-d)}^{h} \xi dz \qquad \textbf{Eq. 9}$$

V. Transmission coefficient:

$$C_T = \frac{E_T - E_B}{E_T} \qquad \textbf{Eq. 10}$$

It is interesting to note from the previous calculation that the wave amplitude gets cancelled out in the last equation, so wave height has no influence on the coefficient of transmission according to this analysis.

4.8 Results

The results are separated into short-period waves and long-period waves. For all cases a water depth of 10m was used, and the theoretical transmission coefficient was calculated for 20 drafts from 0.1m to 2.0m (0.1m increments). For the short-period waves, 31 periods from 0.5sec to 3.5sec were used. And for the long wave periods, 26 periods from 10sec to 15sec. The periods for short waves were chosen based on a calculation of wave generation based on the typical fetch and wind speed at coastal zones (section 5.2.2).

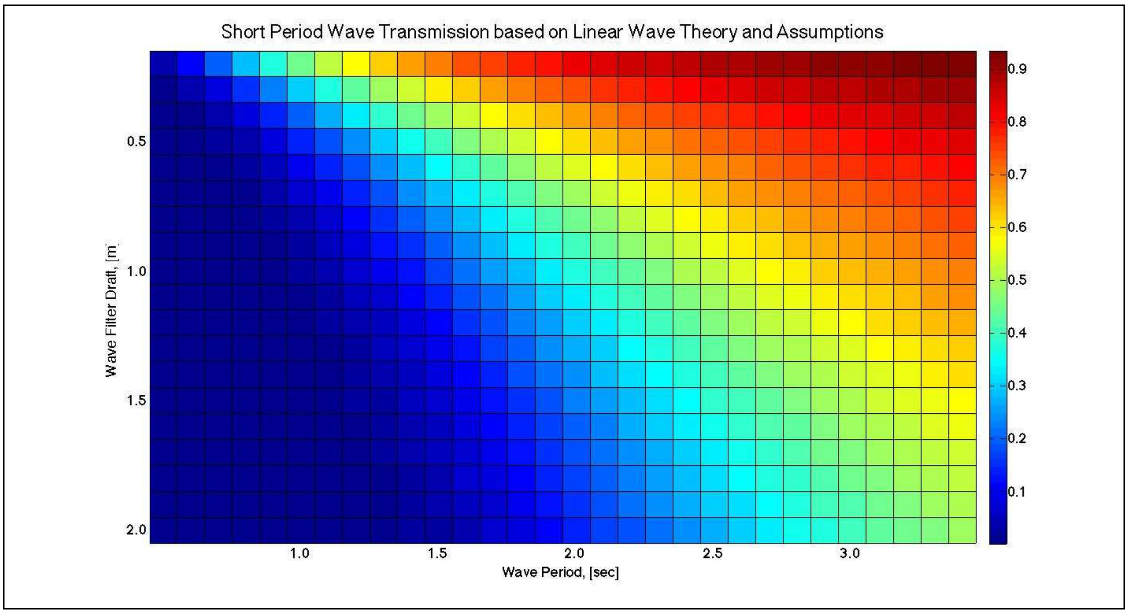


Figure 6 Short-Period Wave Transmission based on LWT and Assumptions

4.8.1 Short-Period Waves

The short-period wave transmission showed dependence on both FWF draft and wave period. As figure 6 shows, the whole spectrum of C_T (0 to 1) is present in the figure.

4.8.2 Long-Period Waves

The long-period wave transmission depends mostly on the FWF draft and very little in the wave period. The reason for this is that all these wave periods are in intermediate water depth (at 10m depth). This causes the shape of the horizontal particle displacement envelope to change very little, so the proportion of energy above the draft to total energy also changes very little between periods. This is illustrated in figure 7, with the almost perfect horizontal color lines.

Another important aspect to notice of figure 6 is that the lowest CT is about 0.77 and the highest is around 0.98. Also note that for a draft of 1 meter the transmission coefficient is around 0.9

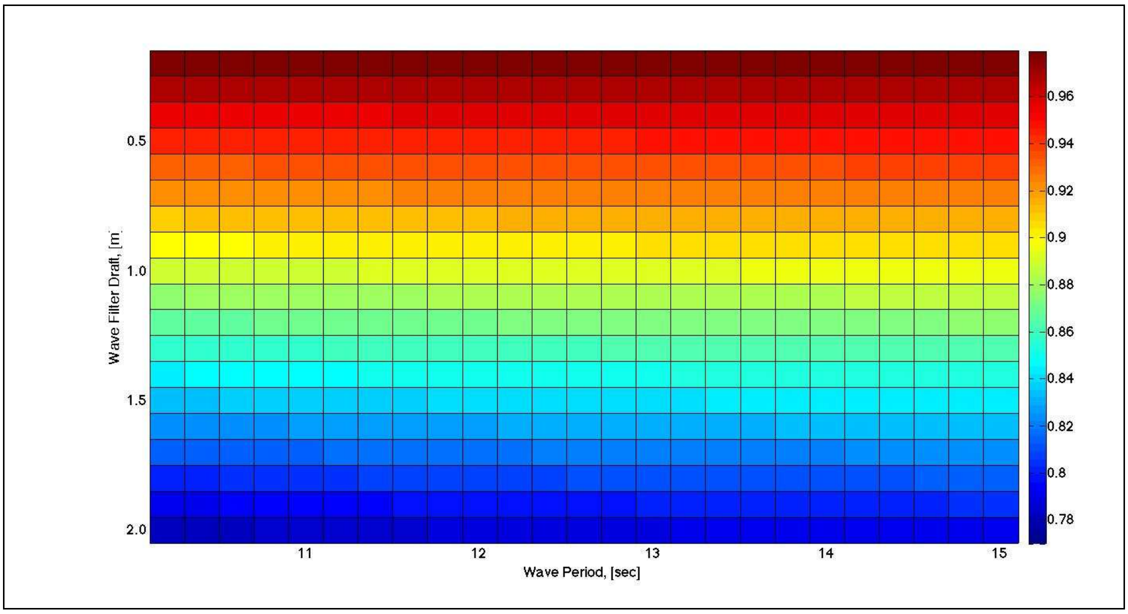


Figure 7 Long-Period Wave Transmission based on LWT and Assumptions

4.8.3 Validation

Since the simplifications and assumptions made in this theoretical analysis can be considered far-fetched, a validation with experiment data can improve the confidence in the analysis. For the comparison the experimental data comes from the same source as figure 3, Koutandos et. al. 2005.

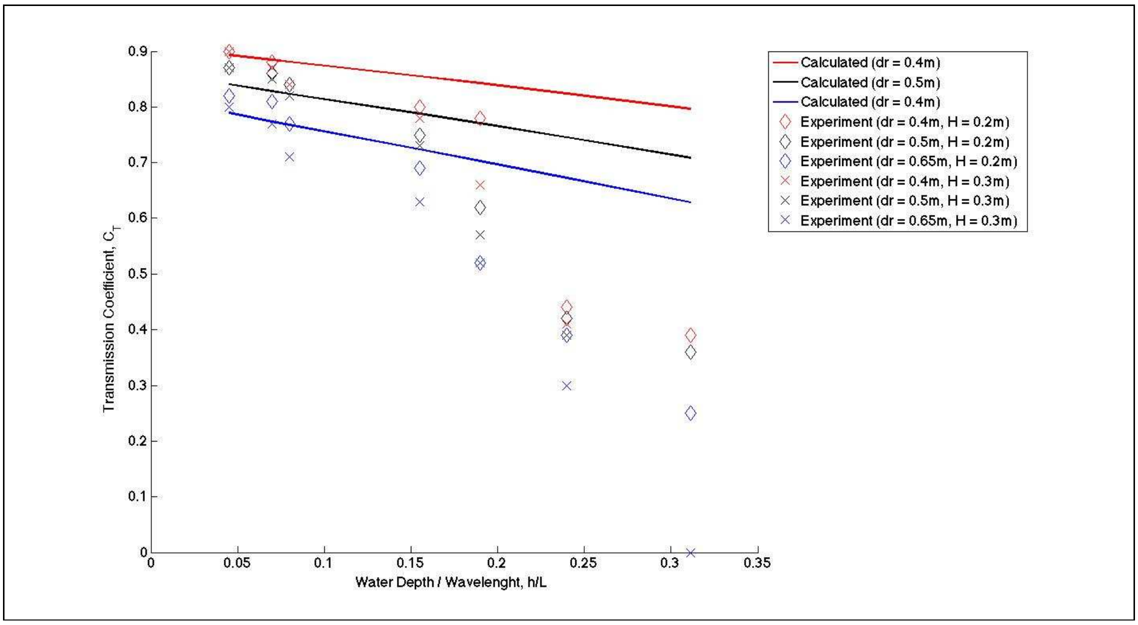


Figure 8 Validation of the theoretical analysis by using data from experiment with floating breakwaters

As figure 8 shows there is a good correlation for the first 4 wave periods and then there is no agreement at all. A possible reason for the deviation is that the values towards the right of the graph have a higher relative depth or h/L ratio (h: water depth, L: wavelength). When the ratio of h/L is greater than 0.5 waves behave as deep-water waves. So we can say that as the value of h/L tends to 0.5 the wave behavior tends to deep-water behavior. Deep-water behavior means less transmission according to this theoretical analysis, and that is what is observed in figure 8.

For the long-period waves analysis the wave periods chosen correspond to a range in h/L of 0.07 to 0.11. In figure 8 the calculated and experimental data are very close for values of h/L of around 0.1.

4.8.4 Commentary

This theoretical analysis ignores two very major processes that occur with floating structures and waves. The first is wave breaking; since the analysis does not take wave height into consideration it also does not take wave steepness. Wave height and steepness are the ruling parameters to know whether a wave will break or not on the structure. Wave breaking would diminish wave energy hence diminishing transmission. The other major process that is ignored is the movement of the floating structure. This movement will change the hydrodynamics and also create waves. Sometimes this movement will decrease the wave transmission and in other cases increase it.

Other important aspects were ignored but the previously mentioned bear the most weight on the transmission.

CHAPTER 5 - Relevant Meteorology

5.1 Coastal Winds

Wind is a response of the atmosphere to spatial differences in pressure. In the coastal zone winds can be forced or created by thermal effects, orographic influences and storms (Rogers, 1995). Wind in the coast is more complex than over land or over water; this is due to the different thermal properties and the orographical influences of the coast. Thermal effects refer to the difference in thermal properties of land and ocean, and orographical influences refer to physical boundaries.

The ocean has a much greater heat capacity than land. This can easily be explained if one imagines a sandy beach on a warm summer day. The sand will quickly get hot from the Sun's radiation, however the ocean temperature will not rise significantly in a sunny day. The reason is that the ocean is much more efficient in distributing the heat from the sun; on the other hand sand (soil or rock) take much longer through conduction to distribute this heat. The heat from the sand is easily transferred into the air, warming up the air mass over land. Since the same does not happen to the air mass over the ocean, a difference in pressure occurs, which drives a wind circulation. During the day, as the land heats up quicker than the ocean, the wind will be directed towards shore (onshore winds). And during the night, as the land cools down faster than the ocean, the wind is directed towards the ocean (offshore winds).

Thermal effects will dominate when there is no significant influence of geostrophic winds, storms or great orographic influences. Geostrophic winds result from the balance between the Coriolis force and pressure gradients. This force balance is theoretical and the actual wind at any point will differ due to friction and orographical influences. Orographical influences refer to the effect that mountains and such irregularities in the terrain have on the wind. Landforms will affect a wind speed and direction in many ways. At the coast the orographical influence can be much more pronounced due to the water-land interface.

5.1.1 Sea breeze/onshore winds

Winds coming from the sea towards land are popularly referred to as *Sea Breeze* and will be referred in this paper as *onshore winds.* Onshore winds cause the undesirable chop/seas that Floating Wave Filters will attempt to block. Onshore winds can occur due to different reasons but a very common reason is when the land gets hotter than the water. This condition happens almost certainly when it is sunny and warm. The solar radiation heats the body of land much faster than the body of water, causing a wind circulation.

Onshore wind will occur at all coasts on Earth and hence at all surf breaks. Consistently onshore winds spoil surfing conditions. If this factor could be ruled out, surf breaks would be surfable for more hours per day, and more days per year.

5.1.2 Land Breeze/Offshore Winds

Winds coming from the land towards the sea are popularly known as *Land Breeze* and will be referred in this paper as *offshore winds.* These are the most favorable winds for surfing. These winds are typically present at night when the land cools off faster than the ocean, and also during the early morning when sea breeze has not kicked in.

5.1.3 Effect of Wind on Surfing Conditions

As it was mentioned above, offshore winds are the preferred winds for surfing, and onshore winds are not desired. But what about all wind directions which are in betwee straight onshore and offshore orientation? Figure 1 shows the effect of wind direction and speed (knots) on surfing conditions.

Wind direction

An important thing about wind direction for surfing is that it should be measured in relation to the wave crest instead of the coastal orientation. Although in a lot of cases the wave crest of breaking waves is aligned with the coast, this is not always the case, as roughly shown in figure 9. So in surfing lingo when someone talks about offshore wind, the wind direction is not necessarily perpendicular to shore, but rather perpendicular to the wave crest. The same reasoning applies for onshore winds.

As figure 9 indicates the <u>most</u> favorable winds for surfing are offshore (tolerance of ± 60° from straight offshore) winds up to velocity of 20 knots (≈ 10m/s). Then there are winds that are not ideal but still favorable for surfing; these are sideshore winds up to around 15 knots and light onshore winds up to 10 knots. All other winds are not favorable for surfing.

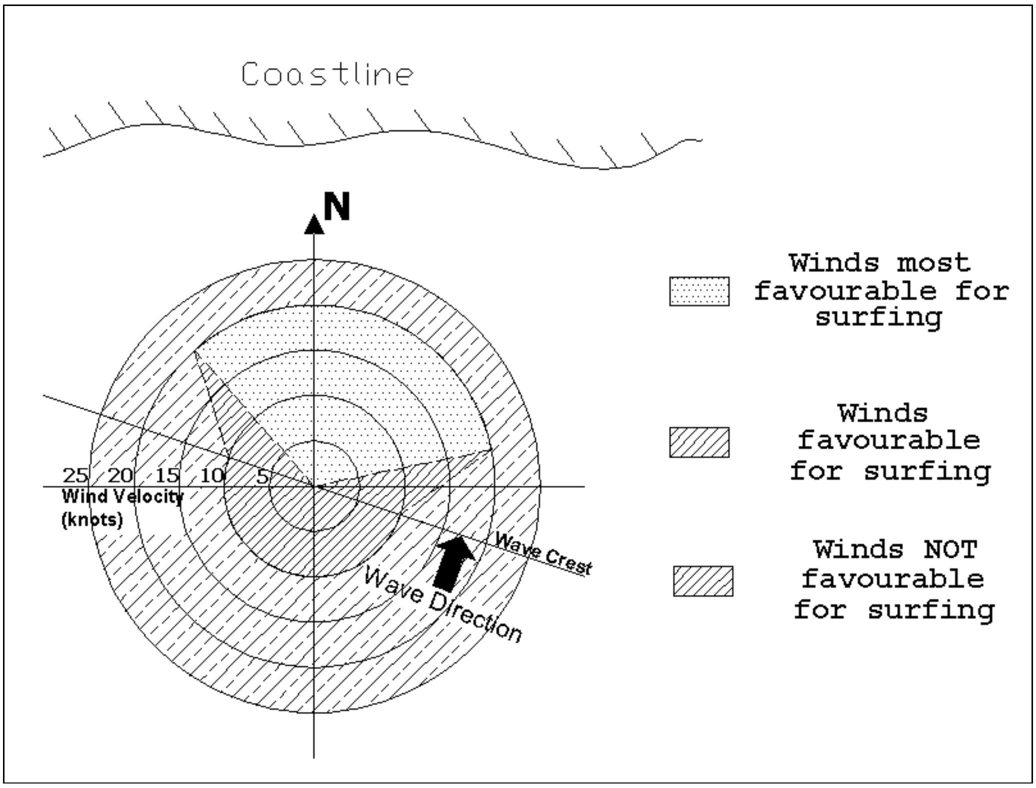


Figure 9 Wave-rose illustrating the effect of wind speed and direction on surfing conditions (modified from Walker, 1972)

Wind speed

High wind speeds are never desired for surfing but there is more flexibility when dealing with offshore winds. Following the analysis from Walker (1972), offshore winds can be as fast as 20 knots without deteriorating surfing conditions. On the other hand onshore winds can reach 10 knots and conditions will remain favorable, although not ideal, for surfing.

Different coasts around the world and different surf breaks in these coasts have different wind patterns. Typical wind direction and speed of a certain location will change with the season as well as with the time of day. For example Indonesia, arguably the place with the best waves on Earth, has mostly offshore winds during the dry season; these winds dominate over thermal effects, i.e. Sea Breeze. Another good example of atypical coastal wind patterns is the southwest coast of Nicaragua. This coast ‘enjoys’ offshore winds most days of the year. The reason for these offshore winds is the Lake of Nicaragua, which lies roughly 20 kilometers inland from the coast. For reasons beyond the scope of this report there is a constant breeze coming from the lake towards the ocean.

5.2 Waves

5.2.1 Differentiating Swell And Wind-waves/Seas

When talking about ocean waves there has to be a clear distinction between swells and seas (also called wind-waves). Swells “refer to waves that have moved outside of the generating area” (CEM II-1-3). And seas are waves that are still being created by winds. The waves preferred for surfing come in the form of swell and the undesired *chop* comes in the form of seas.

Figure 10 A clean swell making its way to the Californian Coast (taken from wavewatch.com)

Swells are much more regular-like than seas, have long periods, long crests and can travel great distances without loosing much energy. A picture of a well defined swell can be appreciated in Figure 10. When a swell starts to be generated the sea surface seems confused with many waves of different heights and periods, and short crests (less than two wavelengths long) (CEM II-1-61). The waves in that stage are *seas*, but as the wind keeps blowing in the same direction the energy converges into peaks and long period waves are formed, with long-crests. Since waves of the same period travel at the same speed, waves of similar periods tend to group together. That way the waves with the longest periods in a swell will be the fastest and the first to reach a coast; waves of shorter periods follow thereafter.

Figure 2 A small Swell and local Seas mix at a beach in Australia (taken from swellnet.com.au)

Seas are present in many ways, from big storms in the middle of the ocean to choppy conditions at a surf break. *Seas* for the sake of this project are the short-period, short-crested waves that reach surf breaks, this situation can be visualized in Figure 11. These waves are locally generated by onshore and side-shore winds, typically have periods lower than 4 seconds, and heights lower than 1m.

The purpose of Floating Wave Filters will be to block *seas* without blocking *swell.*

5.2.2 *Predicting wind waves*

In order to have an idea of the characteristics (wave height and wave period) of wind waves due to sea breeze a simple prediction can be done. This prediction will provide a range of wave periods and wave heights for wind waves or Seas. The parameters needed for this prediction are wind speed and fetch length since we assume a unidirectional and constant wind source. The CEM claims, "the on/offshore extent of the sea breeze is about 10-20km with wind speeds less than 10 m/s" (CEM, pII-2-8). Based on this general statement the maximum fetch length of sea breeze should be 20 km and the maximum wind speed, U_{10} of 10 m/s. Using the fetch limited formulas for wave generation (CEM, formula II-2-36), we can easily predict a wave period and wave height at the coast.

CEM formula II-2-36:

$$\frac{g \cdot H_{m_0}}{u_*^2} = 4.13\times 10^{-2}\left(\frac{g \cdot X}{u_*^2}\right)^{\frac{1}{2}} \qquad \textbf{Eq. 11}$$

$$\frac{g \cdot T_P}{u_*} = 0.651\left(\frac{g \cdot X}{u_*^2}\right)^{\frac{1}{3}} \qquad \textbf{Eq. 12}$$

$$C_D = \frac{u_*^2}{U_{10}^2} \qquad \textbf{Eq. 13}$$

$$C_D = 0.001\left(1.1 + 0.035 \cdot U_{10}\right) \qquad \textbf{Eq. 14}$$

Figure 12 shows the wave height of the wind-waves generated as a function of fetch length and wind speed. The figure shows that the maximum expected wave height due to sea breeze (X: 20km, U_{10}: 10m/s) would be around 0.7 meters. If the wind reaches 20 m/s the significant wave height can reach about 1.5 meters. A similar analysis can be done for figure 13; the wave period for sea breeze is just below 3 seconds and the maximum expected would be around 3.5 seconds.

The wind waves needed in the physical model should correspond with the results from this analysis. The wind waves to be modeled by the fans in the physical model should have wave periods between 1 and 3 seconds and wave heights below 0.7 meters.

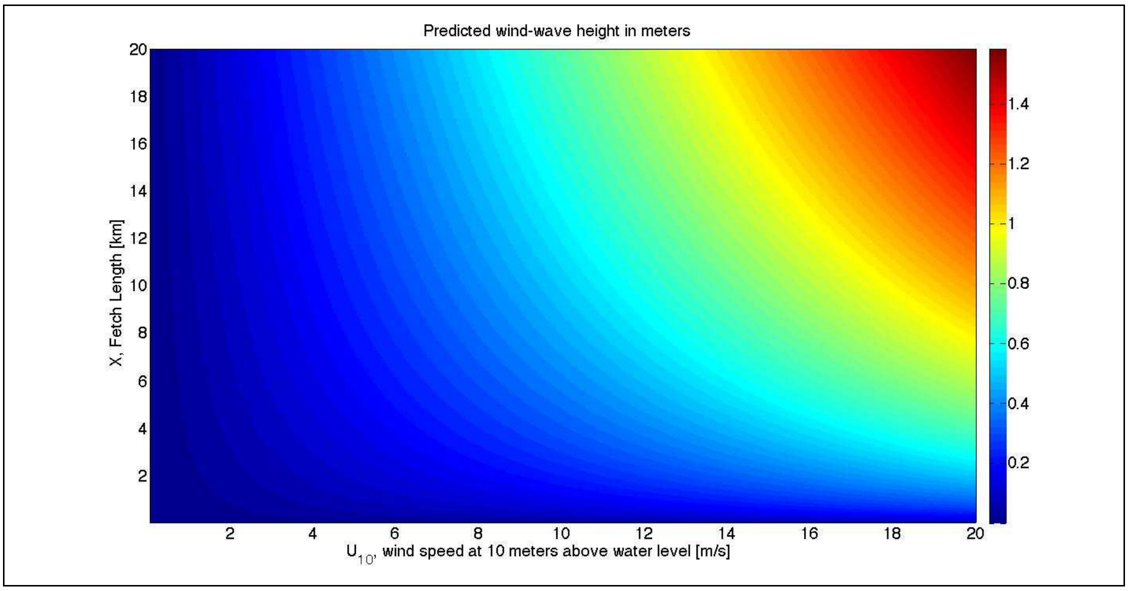


Figure 3 Forecasted wave height of Seas as a function of Wind Speed and Fetch Length

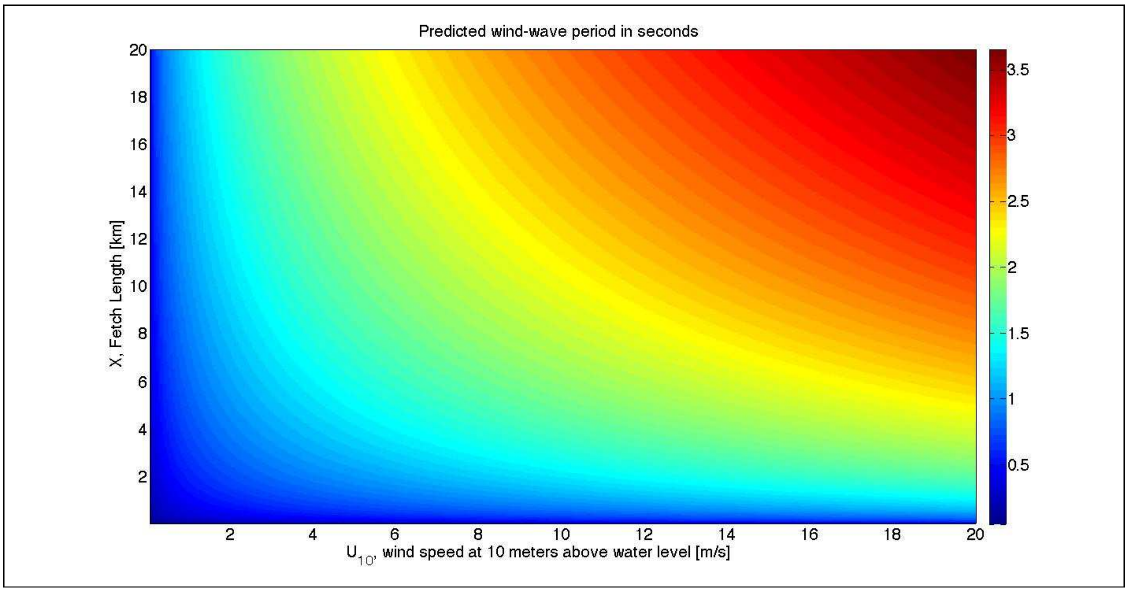


Figure 4 Forecasted wave period of Seas as a function of Wind Speed and Fetch Length

5.3 Swell Analysis off the Coast of California, USA

In order to parameterize the waves of a good quality swell event, real wave records are correlated to written accounts of good surfing days (surf reports). The

analysis will be focused on the coast of California, in the United States of America, since it is a place with good surf breaks and has easily available data on measured waves.
The measured data has been taken from the Coastal Data Information Page (CDIP)[2], managed by the SCRIPPS Institution of Oceanography. The documented surf reports were gathered from Surfline.com, a leading surf-related website based in California.

The parameterized swell will be used to model the waves for the physical model.

5.3.1 Location

Two locations of the Californian coast were chosen, one was Oceanside Beach close to San Diego, and the other was the Santa Cruz area (Monterrey Bay). Both of these locations are well known places for surfing and there are directional buoys near both. The centers of the red squares in figure 14 show the exact location of the buoys.

Figure 5 California coast; the analyzed buoys are shown in red

[2] http://cdip.ucsd.edu/, as of May 13th, 2009

5.3.2 Wave records

The recorded data came from two directional buoys managed by the Scripps Institution of Oceanography. These buoys record the wave incoming direction; this capability allows the user to identify whether the wave energy is coming from one single direction or from more than one directions.

5.3.3 Time window

The waves records analyzed for the directional spectrums belong to the end of October of 2007. During this time South California endured massive wildfires fueled by strong Santa Ana Winds[3]. The same winds provided perfect surfing conditions that mixed with the right swell to produce great surf. This time window was chosen since local surfers can easily remember it as a time window with epic waves. The swell conditions of these days were taken from the buoy records to parameterize a very good swell.

The time window for the parametization of good surfing waves the time windows are shown in the graphs and in table 2.

5.3.4 Surf reports

The reports of excellent surf were gathered from Surfline.com, and can be reviewed in Appendix C.

5.3.5 Results

<u>Typical wave conditions compared to good surfing wave conditions.</u>

In order to distinguish good surfing waves from the rest, a comparison of significant wave height (Hs) and peak period (Tp) is done between a complete wave record and a wave record consisting of good surfing days only. The analysis is performed at the two previously mentioned buoy stations and the results are presented in figures 4 - 7. The select swell events (timeframe) are chosen based on surf reports on Surfline.com.

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[3] The Santa Ana winds are strong, extremely dry offshore winds that characteristically sweep through in Southern California and northern Baja California in late fall into winter

Table 2 Timeframes of select swell events (Y = year; M = month; D = day; H = hour)

Swells	Oceanside Beach								Monterrey Bay							
	From				To				From				To			
	Y	**M**	**D**	**H**	**Y**	**M**	**D**	**H**	**Y**	**M**	**D**	**H**	**Y**	**M**	**D**	**H**
1	07	12	02	12	07	12	07	11	07	12	03	19	07	12	09	11
2									07	12	16	12	07	12	20	07
3	07	12	21	23	07	12	28	09	07	12	21	03	07	12	22	14
4	08	01	10	11	08	01	13	23	08	01	09	16	08	01	22	14
5	08	02	24	21	08	03	14	00	08	02	24	12	08	03	13	02
6	08	09	30	00	08	10	09	23								
7	08	11	01	02	08	11	03	12								
8	09	01	17	07	09	01	20	10	09	01	16	20	09	01	10	07
	09	02	18	21	09	02	21	05	09	02	18	19	09	02	22	07

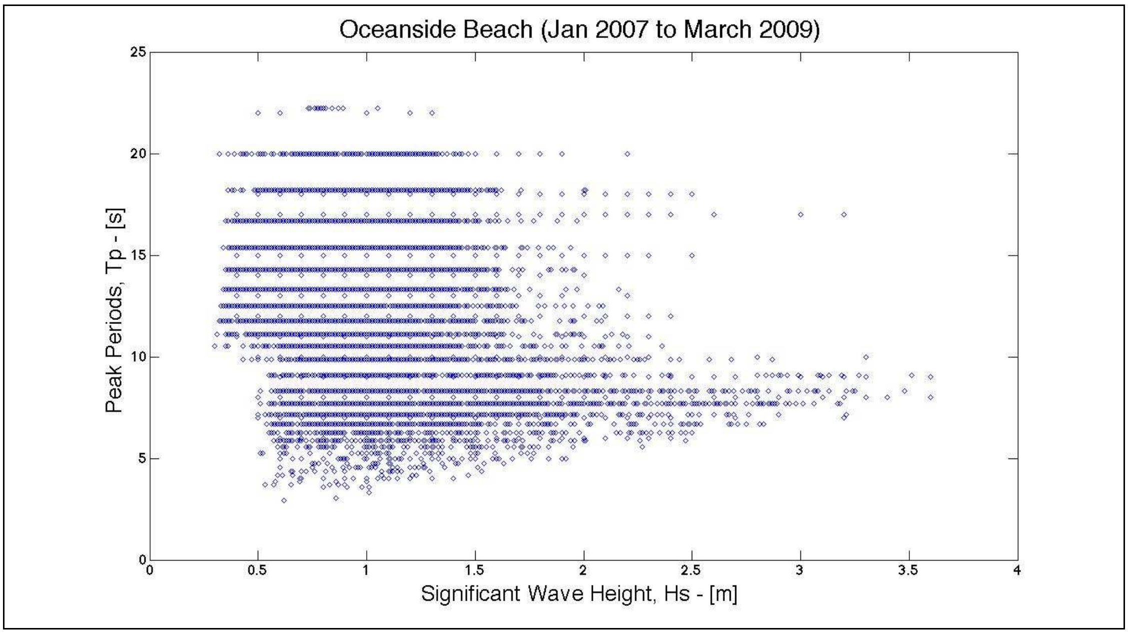

Figure 6 Oceanside Beach wave climate

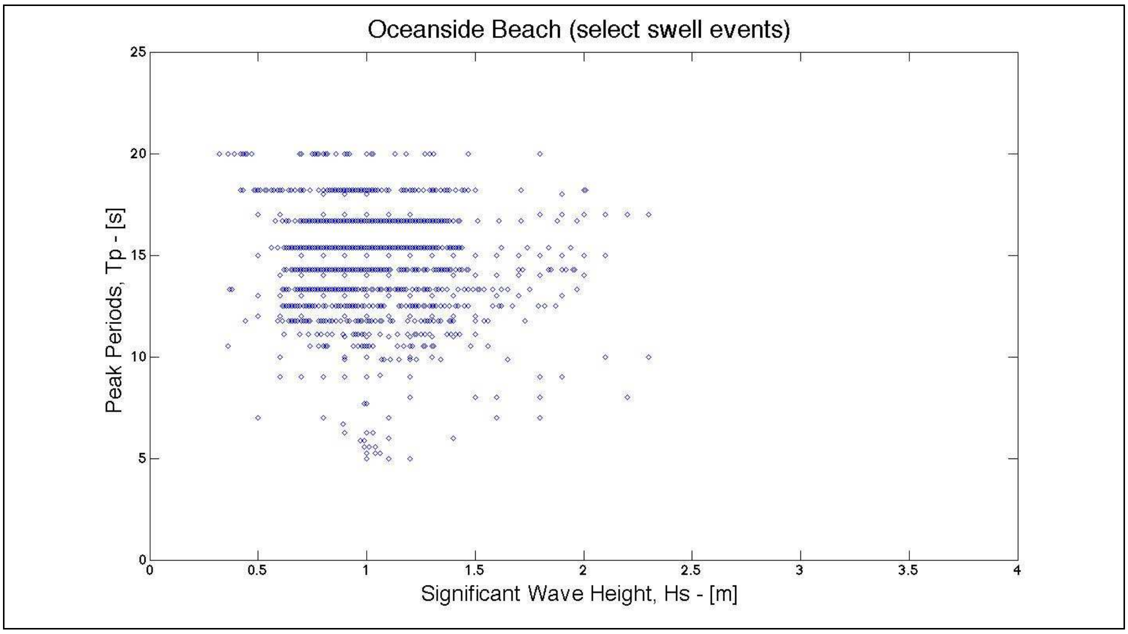

Figure 7 Oceanside Beach 'good-surfing' wave climate

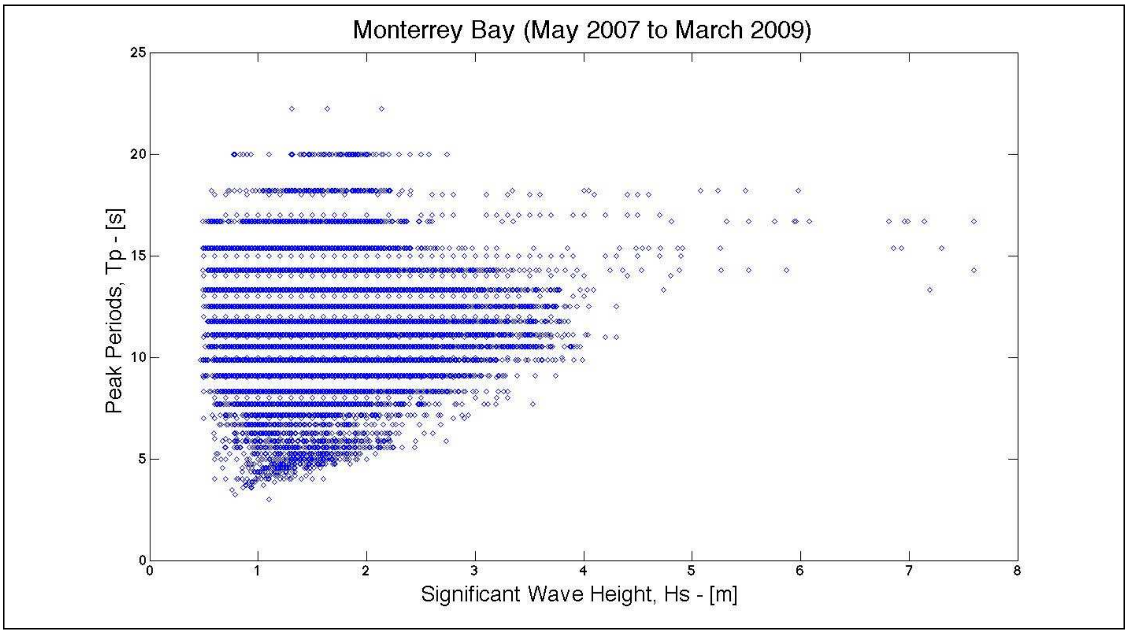

Figure 8 Monterrey Bay wave climate

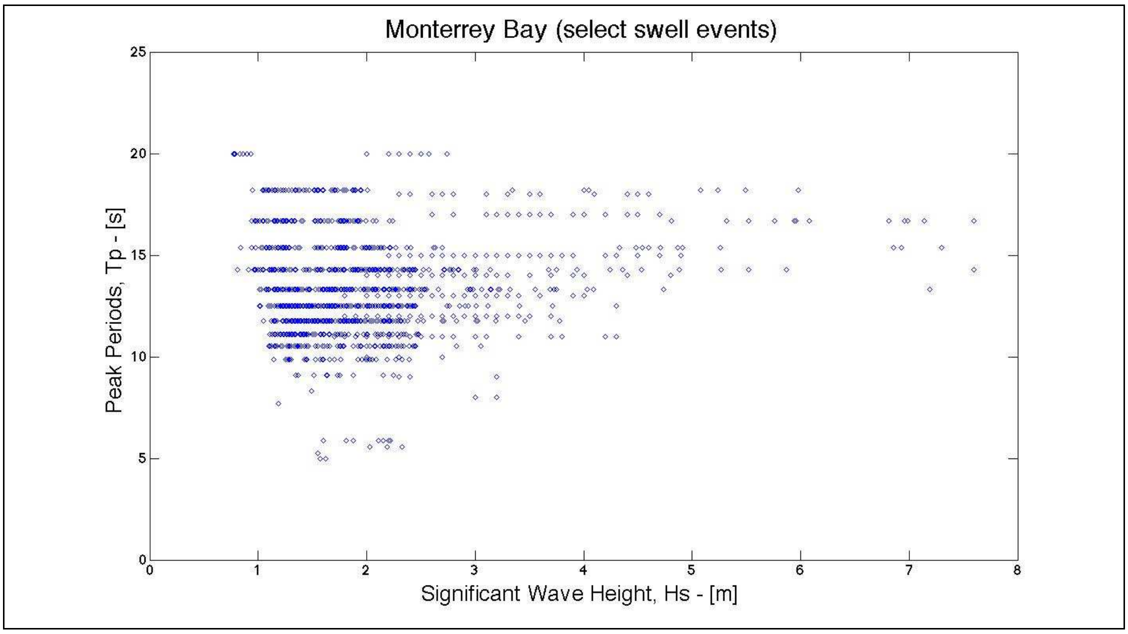

Figure 9 Monterrey Bay 'good-surfing' climate

The main difference between the 'complete record' and the 'select swells record' is the presence of periods lower than 10 seconds in the complete record. This makes it clear that long periods (> 10s) are characteristic of good surfing.

Apart from the cutoff in wave period the two wave records look quite similar. One of the reasons for this is that in order to have high-quality surf a series of conditions (mentioned in chapter 3) have to be met, specially pertaining to wind. So in terms of Hs and Tp two records can be identical, but it does not mean the surf was even similar in these two instances. It is a common thing to have good waves but bad winds, side- or onshore winds. When the winds are offshore and constant is when the best surfing conditions are present. So if we only look at wave records we would have a hard time determining when the surf was good.

Another likely reason for the similarity of Hs and Tp among the complete record and the selected swell events is the nature of these parameters. Hs and Tp are not specific enough to describe or study good surfing. These two parameters are just a crude estimate of the sea state, for a more in depth wave study directional wave spectrums shall be used.

- *Significant wave height:* The significant wave height is calculated as the integral of the wave spectrum. The issue with Hs is that it is a measure of the overall energy present at sea, instead of an estimate for the highest waves expected. As mentioned before *Scarfe et. al. (2003)* proposed to use $H_{1/10}$ instead of Hs to describe the height of surfing waves.

- *Peak period:* The peak period expresses what is the dominant period in the sea state. The dominant period depends on the amount and height (cumulative energy) of the incoming waves. However it does not express how concentrated the energy is or if there are more than one focuses of energy. A frequency wave spectrum is needed to determine how the energy is distributed. For more in-depth analysis a directional frequency spectrum can be used to distinguish waves coming from different directions.

5.3.6 Directional frequency wave spectrum

The buoys selected for the analysis were specifically chosen since they are directional wave buoys. This means the buoys can detect from what direction the measured wave is coming. When the data is plotted in a directional spectrum one can see where the waves are coming from and at what frequency. So with a directional spectrum, different incoming swells can be separated according to their direction. The directional spectrum shows the direction (depending on location in the graph) and energy (colorbar) of incoming waves during a period of 30 minutes.

Figure 19 shows a good example of a case where a simple power frequency spectrum is insufficient. The figure shows a case where there is a long period swell coming from the south, a midrange period swell from the west and wind waves from the west-northwest. The resulting significant wave height and peak period correspond to the sea state but not to the swell. Another interesting thing to note in figure 19 is the directional spreading of the different incoming waves. The wind waves (shortest period) have a large directional spreading, which is characteristic of wind waves or Seas. The two incoming swells have a much more narrow directional spreading, they can be said to be uni-directional. And comparing the two swells, the long period swell has the narrowest directional spreading and is probably generated by a very far away storm.

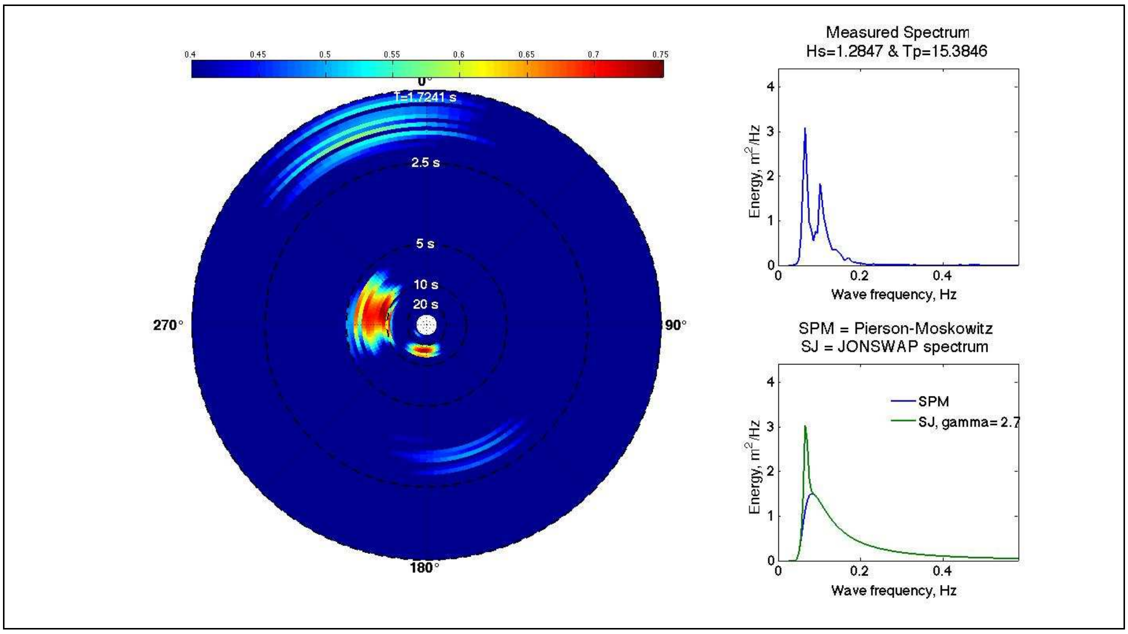

Figure 10 Directional and frequency spectrums for Oceanside buoy (200710220454)

Finding the proper wave regime for the physical model

One of the possibilities with directional wave spectrums is to look for a period of time with only one incoming swell in order to characterize the waves for the proposed physical model. By finding a frequency spectrum with only one defined peak we can compare the measured spectrum to a JONSWAP spectrum. The JONSWAP spectrum is calibrated with different values of *gamma* (peakedness factor) to resemble the peak in the measured spectrum.

The data from the *Oceanside Offshore* buoy is used for this analysis, and the time period chosen was the 22nd, 23rd and 24th of October of 2007. During this period of time the state of California had plenty of good surf, and really heavy forest fires (Wallis, 2007), so it is an easy period for people to remember. The data from the buoy yields results for every 30 minutes; all the 30-minute periods where graphed (as figures 19 and 20) and the graphs with only one, well-defined, swell event were picked out. A directional spectrum with only one incoming swell would be characterized in the graph as a red spot between the 10 and 20 second period lines. Figure 20 is an example of the desirable graph, all the chosen graphs are shown in Appendix A. Analysis of this graphs shows that a JONSWAP spectrum with a *gamma* value of about 3 or 4 matches the measured spectrum.

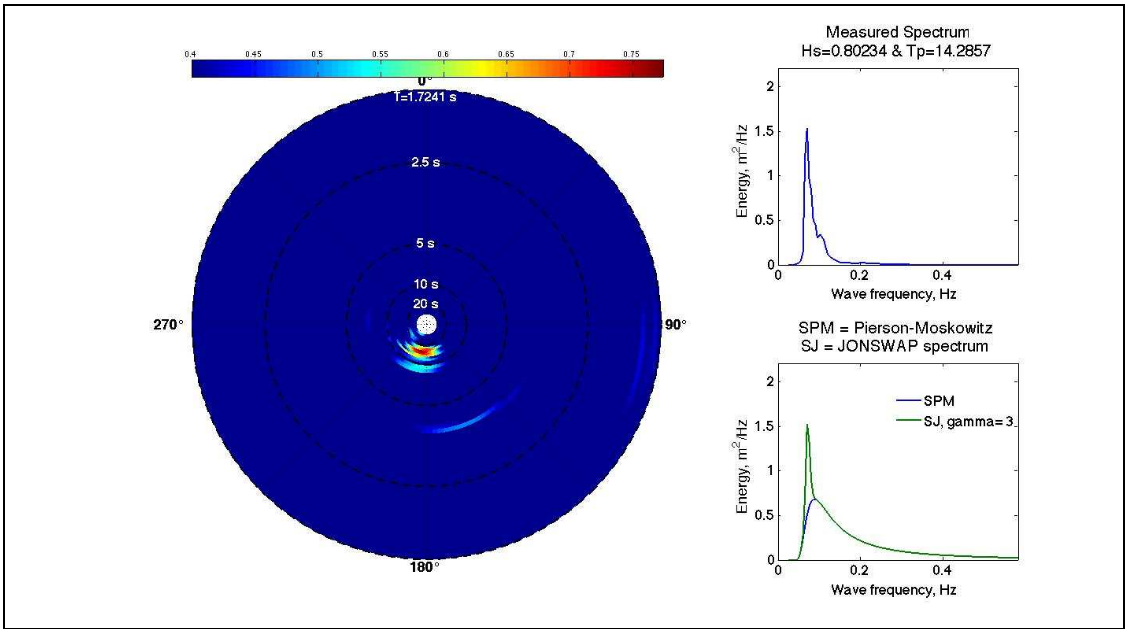

Figure 20 Directional and frequency spectrums for Oceanside buoy (200710241824)

Finally the chosen spectrum for the physical model is a JONSWAP spectrum with a gamma value of 4. The election of a JONSWAP spectrum can be misleading since this spectrum was developed based on measurements of the North Sea, which is not a place known for its good surf. However the physical characteristic of the North Sea, makes its wave climates be more homogenous than in an open ocean. The waves on the North Sea at any given time are, most likely, coming from one single storm. That is the same characteristic as a moment with only one well-defined swell, which is what we were looking for in the analysis above.

Spectral data analysis:[4]

The directional frequency wave data, available from the CDIP website, can be viewed or downloaded in three different ways. The easiest way to see the spectral polar graph from one specific time period is to access the 'Historic' data page for a certain buoy and select

[4] As experienced by the author during the writing of this thesis

the ‘spectral (polar)’ plot from the ‘Interactive Plot’ submenu, under the ‘Interactive Product’ menu. Figure 17 is an example of such a graph

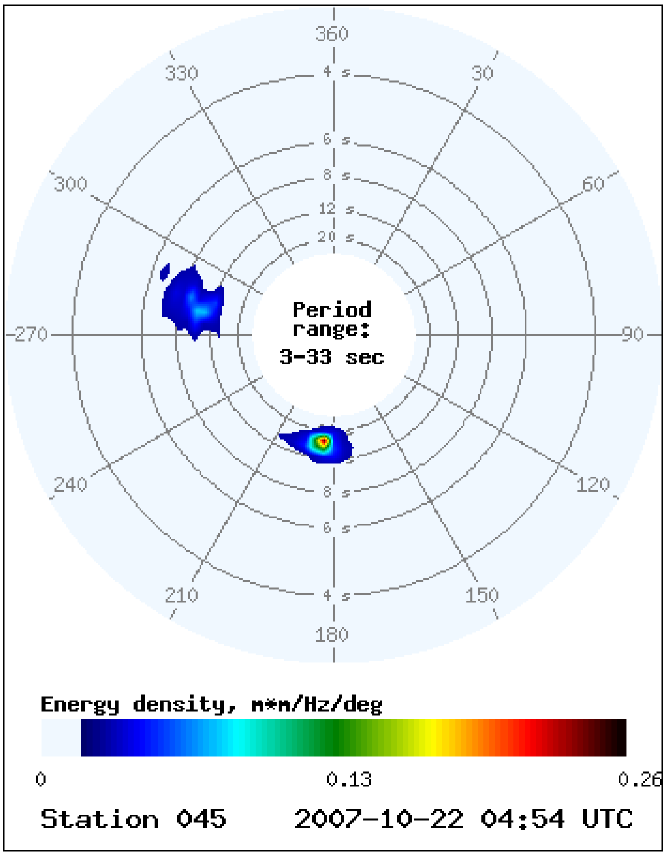

Figure 11 Spectral (polar) plot from Scripps' CDIP webpage (cdip.ucsd.edu)

Another way to retrieve data is through this web address: <http://cdip.ucsd.edu/data_access/MEM_2dspectra.cdip>, which has the directions to retrieve a matrix of wave energy as a function of wave direction and frequency. The direction is separated into 5-degree bins and there are 64 frequency bins. The third way to retrieve the directional frequency wave data is by accessing the ‘Historic’ data page for a buoy, and under ‘Interactive Products’ choose the spectral data from ‘Interactive Data’. This option gives you a text file with the data separated into 30-minute periods, and the energy data comes in the way of Fourier coefficients. With the Fourier coefficients the matrix of wave energy can be calculated. This matrix is the same as the one obtained through the second method just mentioned; however with the Fourier coefficients we can choose what size of directional bins to use. It is necessary to obtain or create a code or program to analyze this data.

The third alternative was used in this investigation for a few reasons and these are:

- the educational value of creating your own code,
- the possibility to use smaller directional bins (higher resolution),
- the possibility to graphs dozens of directional spectrums in one step,
- and the chance to compare directional, measured, and JONSWAP spectrums in one step.

A MATLAB code was developed (included in Appendix B) to draw a graph as shown in figures 18 and 19. It was a great advantage to be able to analyze the data of one whole day (around 50 graphs), in one MATLAB run. All the graphs were automatically saved as images and these could be quickly analyzed in a slide show. In order to analyze more than one event at once, the data had to be carefully arranged. I used the program Automator (Apple®) to arrange the data, but it can be done in many ways.

The analysis of the Fourier coefficients is based on the following equations, which were retrieved from Wang, 2003.

$$D(f,\theta) = \frac{1}{\pi}[0.5 + r_1\cos(\theta-\theta_1) + r_2\cos 2(\theta-\theta_2)] \qquad \textbf{Eq. 15}$$

$$r_n = (a_n^2 + b_n^2)^{0.5} \qquad \textbf{Eq. 16}$$

$$\theta_n = \frac{1}{n}\tan^{-1}\left(\frac{b_n}{a_n}\right) \qquad \textbf{Eq. 17}$$ [5]

where:

D(f, θ) = directional distribution function

f = wave frequency

θ = wave direction ($-\pi \le \theta \le \pi$)

a, b =coefficients of Fourier Harmonics

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[5] *note: in MATLAB for the* $\tan^{-1}$ *operation 'atan2' should be used instead of 'atan' because the former gives values from -180° to 180 and 'atan' only gives values from -90° to 90°.*

r = Fourier coefficient

n = 1, 2

CHAPTER 6 - Floating Wave Filter

Floating Wave Filters (FWF) are floating structures placed outside the breaker zone in surf breaks to improve surf conditions. These structures improve surfing conditions by blocking *seas* and letting *swell* through. In other words Floating Wave Filters block short-period, short-crested waves and transmits long-period, long-crested waves. The final objective of Floating Wave Filters is to increase the efficiency of existing surf breaks to alleviate the crowd issue. Like Artificial Surfing Reefs (ASR), Floating Wave Filters aim to increase the amount of surfable waves in a certain coast. However FWF will not create a new surf break, they will increase the efficiency of existing surf breaks. Floating Wave Filters are a cheaper and more environmentally friendly alternative than ASR to improve surfing conditions in a community. It most be recognized that ASR are the future of 'surfing science' and places without quality waves will rejoice with their installation. However in places where there already are quality surf breaks, building ASR makes little sense. Instead the surf breaks that already exist can be improved, and one way to do this is by installing FWF.

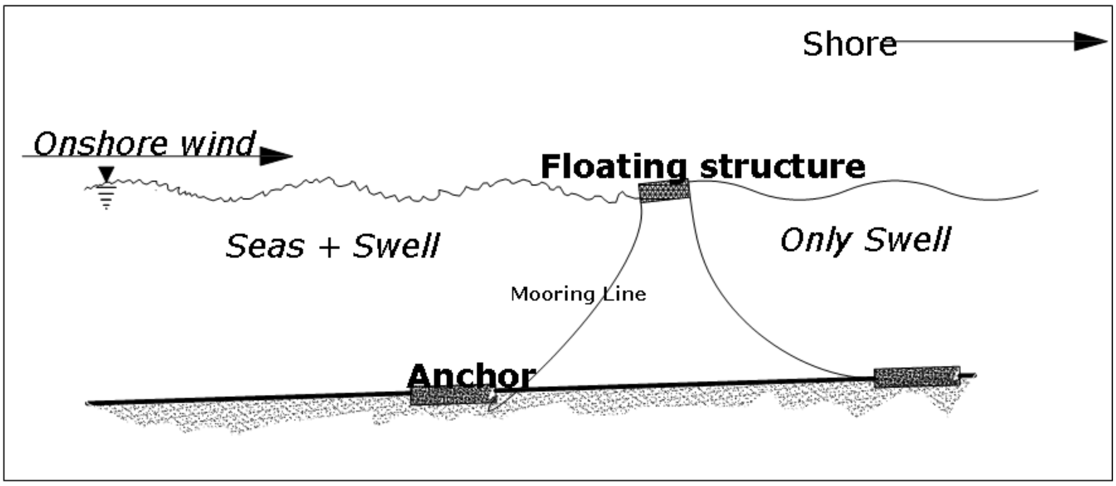

Figure 12 Physical description of a Floating Wave Filter function

6.1 Floating Wave Filter Design Factors

Floating Wave Filters will consist of three integral parts: the anchors, the mooring system and the floating structure (as shown in figure 22). The anchors will hold the system in position and it is critical for these to stay in place. The mooring system is the connection between the anchors and the floating structure. Different systems can be used depending on local conditions. Finally the floating structure is the working component of Floating Wave Filters; its dimensions, materials and design will be adjusted depending on incoming wave height and period.

Since Floating Wave Filters are floating structures the installation and removal is quite simple. They can be towed from a harbor for installation and back to the harbor for maintenance or to guard them from storms. Once the anchors and anchoring system is in place the floating structure can be easily removed and reinstalled later in case of a large storm.

The factors to take into account when designing a Floating Wave Filter will be:

- Breaker zone extension
- Change in beach profile
- Expected wave heights
- Expected onshore wind speed
- Economics
- Installation
- Possible hazards

6.1.1 Breaker zone extension:

The breaker zone extension will regulate the location for the Floating Wave Filter. The Floating Wave Filter has to be installed deep enough so that no waves break on the structure and shoaling is not too large. If waves break on or before the structure surfing activities will be disrupted and the anchoring system can be overloaded. The anchoring will also be overloaded if the shoaling is too high. For these two reasons the location of the Floating Wave Filter has to be deep enough and well outside the breaker zone. The Floating Wave Filter will probably be installed in a place deep enough to affect boating. For this reason the structure should be signalized with lighted buoys.

6.1.2 Change in beach profile:

The response of the beach profile to storms or calm periods must be predicted to accurately calculate the breaker zone. As the beach (and surf zone) profile change, the breaker zone will also change and the anchors might be dug out. The Floating Wave Filter must be installed far enough from shore to be immune to any beach profile changes. For the design of the physical model the working depth of FWF was chosen to be over 10 meters. In real life the working depth should be analyzed on a case-by-case scenario.

6.1.3 Expected wave heights:

The Floating Wave Filter will have a working limit with respect to wave height. Whenever this maximum wave height is reached the floating structure will have to be temporarily removed. Otherwise the system could fail and the floating structure can be washed to the beach or sunk. The expected number of times per year (or month) this wave is exceeded has to be calculated. The system should be designed in a way to balance construction costs with the cost of temporarily removing the structure.

6.1.4 Expected onshore wind speed:

The onshore wind speed and duration will dictate what kind of *seas* will have to be blocked by the Floating Wave Filter. The size of the floating structure will be proportional to the size of *seas* being blocked. However the larger the floating structure is, the more *swell* it is going to block. Once again a compromise has to be made, this time between maximum *seas* to be blocked and *swell* being blocked.

6.1.5 Economics:

Although FWF are not as expensive as ASR, they still cost money and somebody will have to pay for all costs. The economical feasibility of Floating Wave Filters depends on the increase in revenue for a community or local government due to the improvement in surfing conditions. This is more likely to happen at urban surf breaks or breaks that are already crowded during good conditions. An urban surf break will certainly benefit from a Floating Wave Filter because it could be the only surfable place, during certain wind conditions. This means that under certain wind conditions local government revenue will increase without a doubt. On the other hand a surf break (urban or rural) that is crowded during offshore conditions but has only a few people during onshore conditions is a perfect spot for a Floating Wave Filter. The crowd is being deterred from that place only because of the onshore conditions, with a Floating Wave Filter the spot can be surfed all day.

6.1.6 *Installation/Location:*

The installation procedures and costs will depend on the location of the Floating Wave Filter. Whether the place is close to a harbor, marina, or boat ramp will be important for installation and removal procedures. Also it must be feasible (legally and economically) to place a large anchor on the seabed. Sites with rocky or reef bottoms will represent a challenge for anchoring.

6.1.7 *Possible Hazards:*

Many people with different purposes share the ocean, and it is not uncommon for certain groups of users to disregard other groups' interests. This shall not be the case with FWF. A list of the possibly affected users should be prepared and their worries should be addressed. In different locations the affected people will be different but in general some of the groups affected can be:

- Swimmers
- Fishermen
- Boat owners
- Coast Guard
- Navy
- Real Estate owners (the 'view')
- Surfers

6.2 <u>Prototypes</u>

6.2.1 *Kelp-like*

Part of the inspiration to undertake this investigation was that actual kelp beds in California and South Africa act as wave filters. An illustrative example is shown in figure 23. A kelp-like Floating Wave Filter will attempt to simulate a 'blanket' of floating kelp.

6.2.2 *Cylindrical*

A second design is floating cylinders. This would be placed perpendicularly to wave direction. The floating cylinders can be tested in single and multiple configurations.

6.2.3 Rectangular cylinder (or prism)

The same shape as floating breakwaters, like a rectangular box. This shape is easy to build and most of the research on wave transmission has been on this shape.

Figure 13 Kelp beds offshore of surf break (photo taken from Surfline.com archives)

CHAPTER 7 - Physical Model/experiment set-up

Note: The experimental part of this master thesis was not completed due to time constraints. This chapter serves as a guide to construct a physical model of Floating Wave Filters and perform the experiment in the small-scale flume of LIM. This chapter is addressed to whoever will undertake the experiment.

A physical model of Floating Wave Filters will be constructed in order to get a transmission coefficient as a function of wave frequency. The hypothesis is that large frequencies will have low coefficients of transmission, and inversely for low frequencies. The experiment will test three different floating structures with 6 different wave climates. The experiment will be carried out in a small scale wave flume, CIEMito, located in the Laboratori d'Enginyeria Marítima (LIM) at the Universitat Politècnica de Catalunya (UPC). The flume is made up of steel frames and glass panels, figure 24 shows a picture of CIEMito. The approximate dimensions are 18m of length, 60 cm of height, and 40 cm of width.

Figure 14 Photo of CIEMito in its inauguration day

One of the main challenges of this physical model is to mimic the wind waves. Long waves (swell) will be generated by the wave paddle, and the wind waves will have to be created with high-speed fans.

7.1.1 Scale

The model will use Froude similitude criterion to scale from prototype to model. This means the Froude number has to be the same for prototype and model. The Froude number is:

$$N_{Fr} = \frac{V}{\sqrt{g \cdot L}} \qquad \textbf{Eq. 18}$$

where:

N_{Fr} = *Froude Number*

V = *velocity*

g = *gravitational constant*

L = *length*

For a Froude similitude criterion the scale ratios are as following:

$$N_{Fr}(\text{prototype}) = N_{Fr}(\text{model}) \qquad \textbf{Eq. 19}$$

$$N_L = \frac{L_p}{L_m} \qquad \textbf{Eq. 20}$$

$$N_t = \sqrt{\frac{N_L}{N_g}} = \sqrt{N_L} \qquad \textbf{Eq. 21}$$

$$N_M = N_L^3 \cdot N_\rho \qquad \textbf{Eq. 22}$$

where:

N_L = *length scale ratio*
L_m = *Length in the model*
L_p = *Length in the prototype*
N_t = *time scale ratio*
N_g = *gravitational constant scale ratio (most likely = 1)*
N_M = *mass scale ratio*
N_ρ = *density scale ratio*

The model scale will be 1/30. This scale was chosen based on the working water depth of FWF. In prototype FWF will be working at a depth of around 10 meters, and the flume has a maximum working depth 35 cm. If the prototype depth is set at 10.5 meters, a scale of 1/30 gives us a model water depth of 35 cm.

7.1.2 Wave conditions:

The wave conditions in the experiment are meant to represent ‘good’ surfing waves. These types of waves have long periods, long crests, and have a homogenous direction. However in a flume all waves generated by the wave paddle have long crests (relative to flume width), and are certainly unidirectional. The only parameters to control are wave height, wave period and the frequency distribution (frequency spectrum). For the experiment six irregular wave climates will be used. The shortest period (in prototype dimensions) is 8 seconds and the longest is 13 seconds. The *six* wave regimes include three different peak periods, Tp, three different wave steepness, S, and six different significant wave height, Hs.

Wave Periods from 8 to 13 seconds would be at the shorter end of surfing waves, usually good swells have longer periods. However these used periods would be the more critical to test, since longer periods will transmit better. In other words if FWF work with long-period waves of 8 to 13 seconds, they will certainly work for periods longer than 13 seconds. This scenario is convenient since longer periods cannot be modeled in this flume at this scale.

Table 3 Wave conditions

Wave type	**A**	**B**	**C**	**D**	**E**	**F**
Hs, prototype [m]	1.1	2.2	3.3	1.4	2.8	1.9
Tp, prototype [sec]	8	8	8	10	10	13
S, Wave steepness	0.015	0.03	0.045	0.015	0.03	0.015
Hs, model [cm]	3.7	7.3	11.0	4.7	9.3	6.3
Tp, model [sec]	1.5	1.5	1.5	1.8	1.8	2.4
S, Wave steepness	0.015	0.03	0.045	0.015	0.03	0.015

Table 4 Experiment nomenclature

Irregular Waves---> / Floating Wave Filters	A	B	C	D	E	F
FWF1	A1	B1	C1	D1	E1	F1
FWF2	A2	B2	C2	D2	E2	F2
FWF3	A3	B3	C3	D3	E3	F3

7.1.3 Floating Wave Filters (FWF)

'Floating Wave Filter' refers to the whole system including anchoring, mooring line and floating structure. This experiment will test the behavior of different floating structures under different wave conditions.

7.1.4 Floating Wave Filter model

The Floating Wave Filter will be modeled using low-cost materials and a simplistic approach.

7.1.5 Floating Structure

There will be three different types of floating structures; a rectangular cylinder, a circular cylinder, and a flexible structure.

Rectangular cylinder: The rectangular cylinder is the most used shape in Floating Breakwaters (FB), so the results can be somewhat related to results in previous FB tests. This model can be built with any lightweight wood. Wood can be easily reshaped, and in case of needing a heavier structure metal elements can be nailed or glued to the wood.

Circular cylinder: this is an interesting shape because it is of easy construction, rigid, and its rolling motion doesn't generate waves. This model can be constructed with aluminum cans, and adhesive tape. The cans by themselves are not heavy enough, so they have to be partially filled with something. The filling could be sand, resin, glue, etc.

Flexible structure: this shape is inspired on large bodies of kelp that serve as FWF in California and South Africa. The hypothesis here is that a flexible structure could have larger dimensions than a rigid structure and maintain the transmission of long waves. The construction of this model could be done with string net, expanded polystyrene and light chain segments.

***Glass protection*:** since the floating structures will not be fixed and could move transversally to the flume orientation, their sides should be covered so that the glass is not damaged. The rectangular and circular shapes can have glued expanded polystyrene at their sides.

7.1.6 Anchoring and Mooring lines

The anchoring and mooring will not be objective in this experiment. The anchoring will be fixed, so forces on it or its stability will not be tested. And the mooring lines will not represent the elasticity of a prototype nor will it represent the forcing capacity. At this scale scaling the forces will give many errors and this type of analysis is outside of this work’s scope. This experiment is focusing on the behavior of the floating structure.

To keep things cheap the anchoring can be achieved with suction pads and the mooring line with nylon string. Initially there will be 4 anchors/pads, but depending on how the floating structure is moving, more or less can be installed. Also depending on the structure’s response, the mooring line might be changed to an elastic string.

7.2 Wave generation

There are three limiting factors for wave generation, the wave paddle capacity, flume water depth, and maximum wave steepness. The wave paddle in this flume is a piston-type paddle, its limitations are maximum velocity and maximum displacement. The water depth imposes a limit on maximum wave height, maximum wave height must be below 0.78 times the water depth or the wave will break immediately. Finally the waves must be stable, or not too steep; the steepness must not surpass 1/10. All this can be visualized in figure 18. Furthermore the figure shows the proposed wave regimes; the round markers represent the significant wave height, H_s, and the triangular markers represent the maximum expected wave height, H_{max}. Both wave heights are graphed against peak period. The H_{max} is simply calculated as twice the significant wave height.

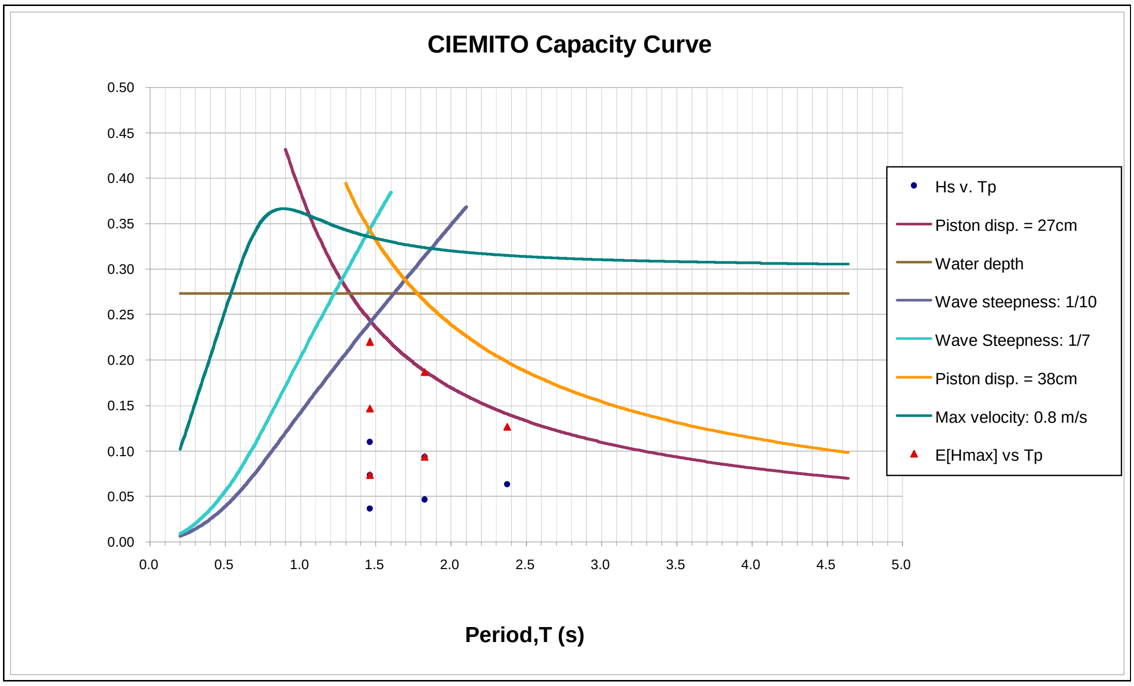

Figure 15 Wave-paddle/flume capacity curves and proposed wave regimes

7.2.1 Desired Wave Spectrums

Since the waves to be used are irregular, a spectrum must be presented to the wave paddle. The following spectrums (figure 25-30) are all based on the wave characteristics mentioned in table 2. Based on the directional spectrum analysis (chapter 5) the chosen spectrum is a JONSWAP spectrum with a peakedness factor (gamma) of 4.0.

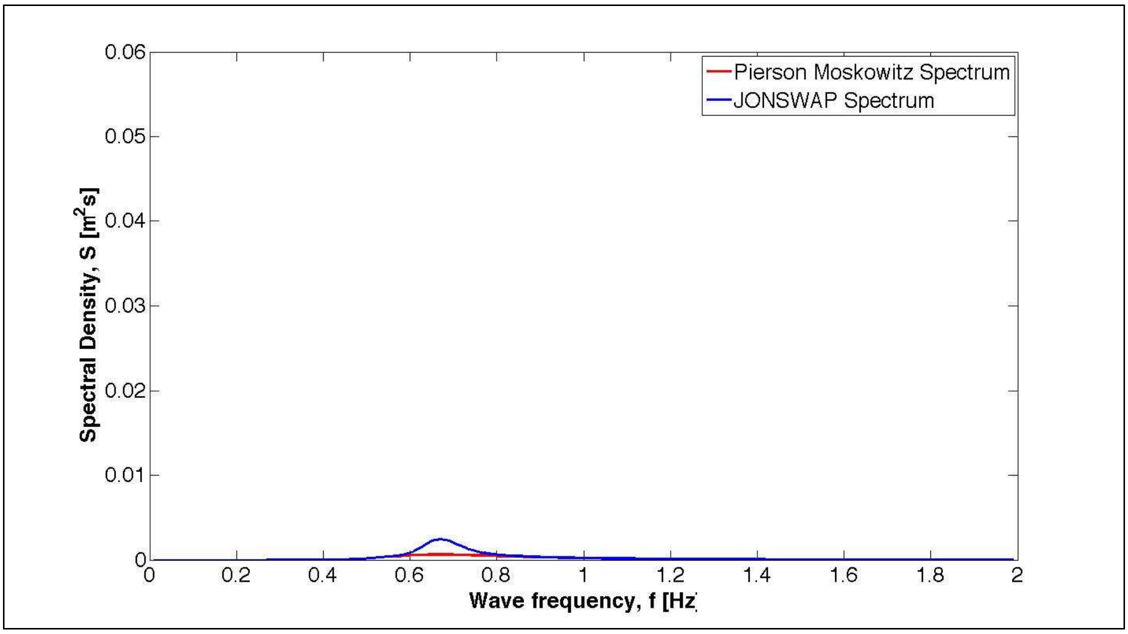

Figure 16 Spectrums for wave regime A; Hs=3.7 cm, Tp=1.5 sec.

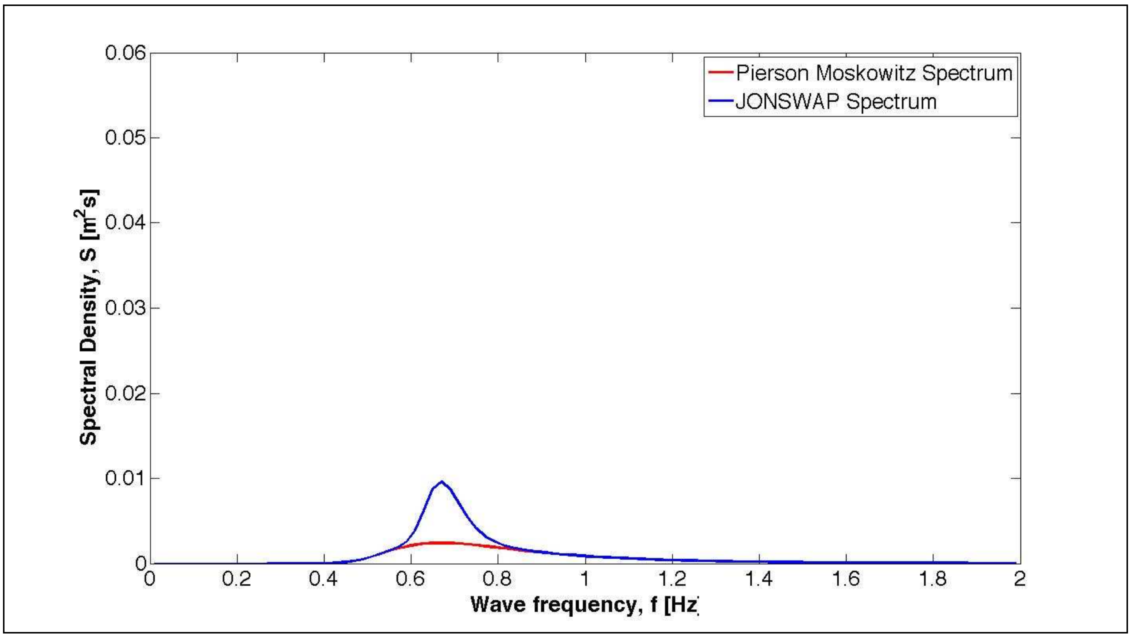

Figure 17 Spectrums for wave regime B; Hs=7.3 cm, Tp=1.5 sec.

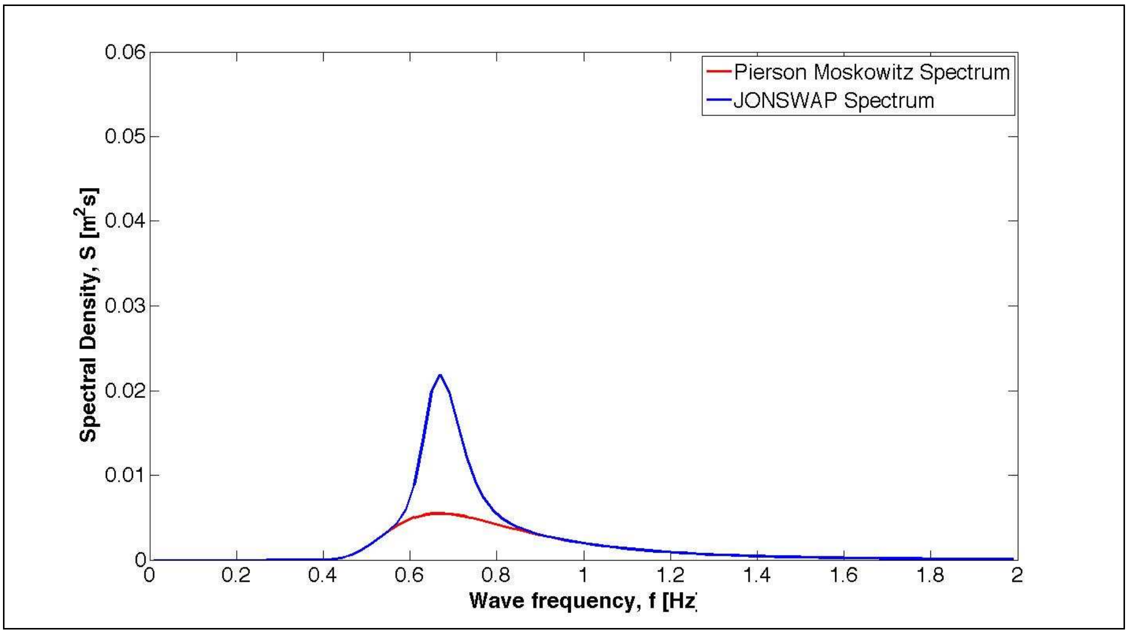

Figure 18 Spectrums for wave regime C; Hs=11 cm, Tp=1.5 sec.

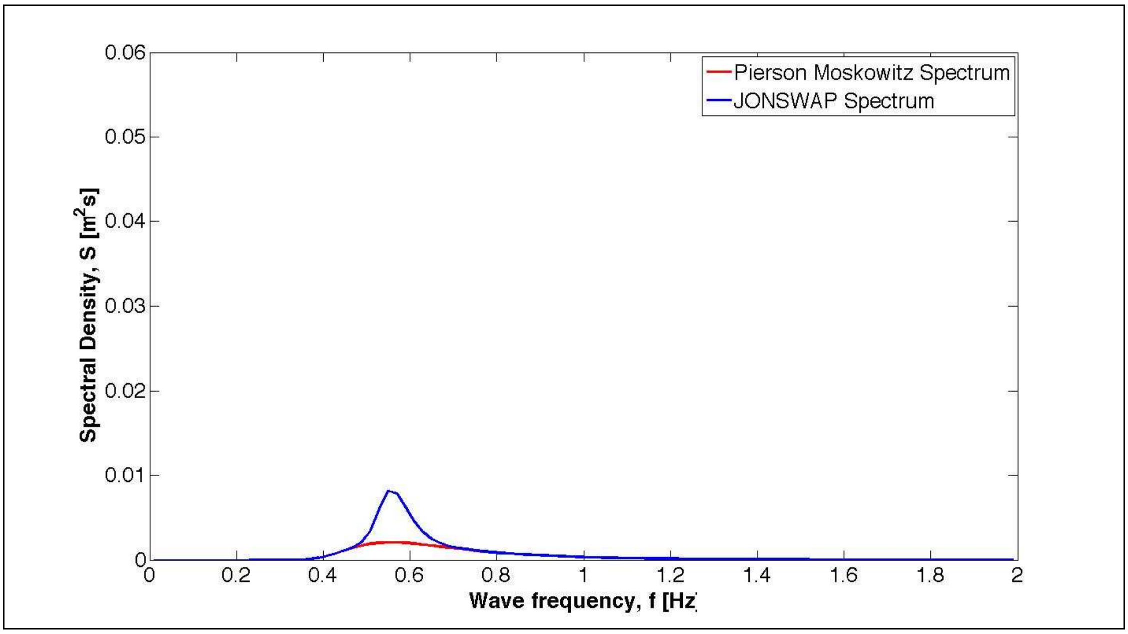

Figure 19 Spectrums for wave regime D; Hs= 4.7 cm, Tp=1.8 sec.

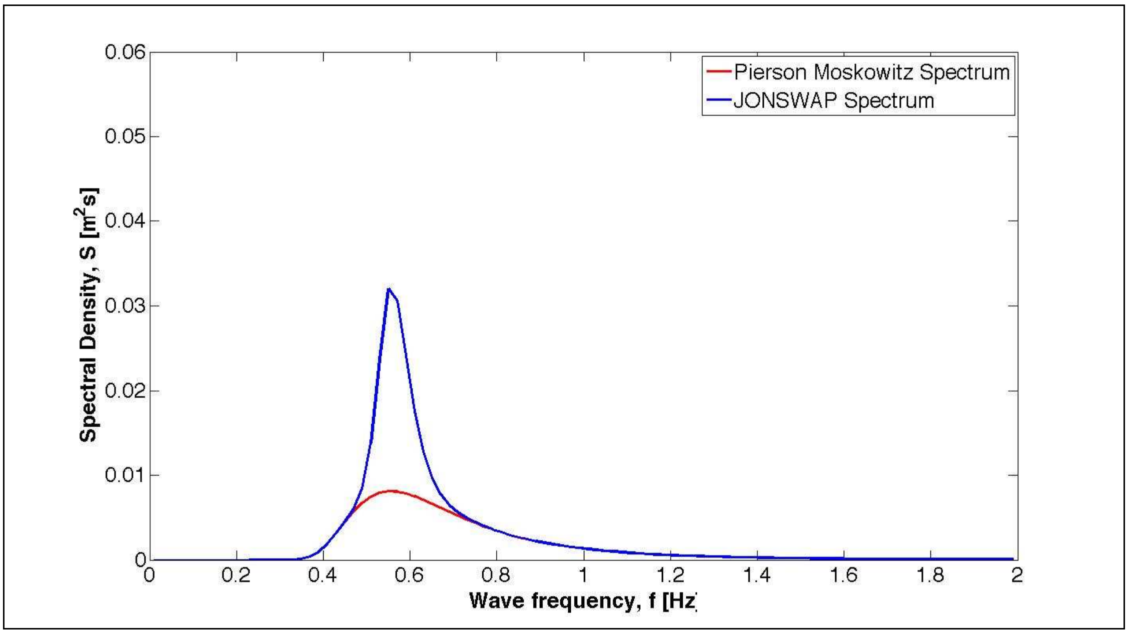

Figure 30 Spectrums for wave regime E; Hs=9.3 cm, Tp=1.8 sec.

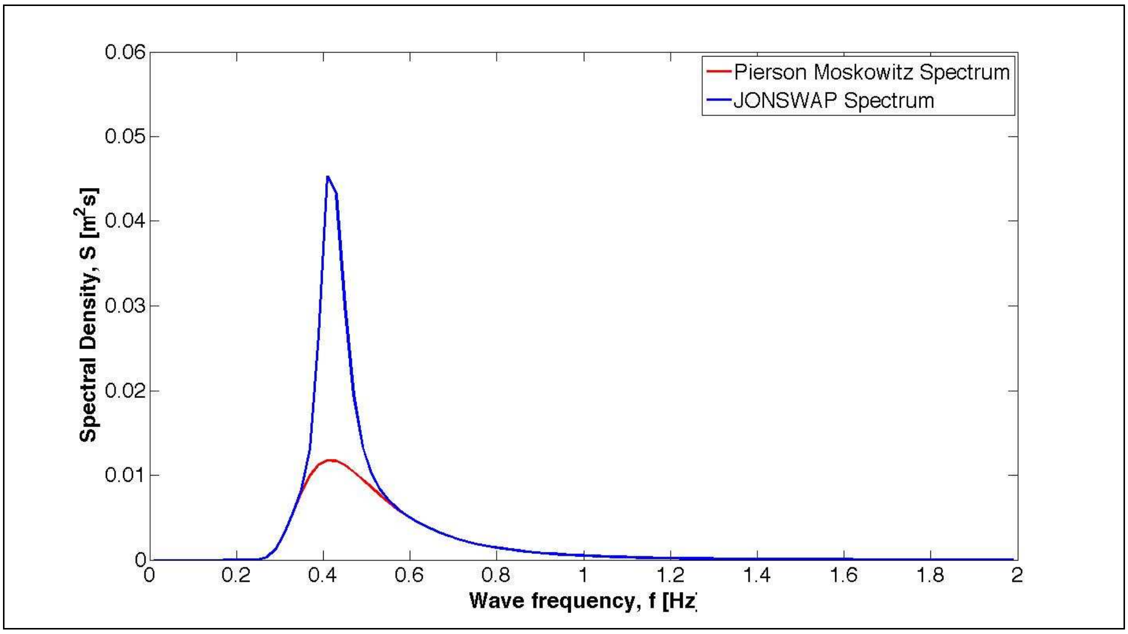

Figure 1 Spectrums for wave regime F ; Hs=6.3 cm, Tp=2.4 sec.

7.3 Wind-waves generation

In this experiment wind-waves refer to waves that are not generated with the paddle but rather with wind. In order to model the wind-waves or seas, fans will be utilized. These fans are located in between wave gages 2 and 3, as shown in figure 32, and are directed in the direction of wave propagation. In this manner the first two wave gages will measure the waves generated by the paddle and the next three gages (3, 4, and 5) will measure the combined wave climate generated by the paddle and the fans.

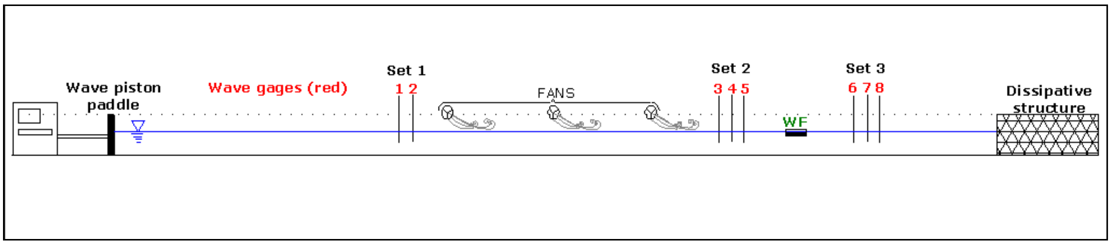

Figure 20 Overall setup at CIEMito for the experiment

The wind speed and orientation of the fans will be calibrated in order to mimic the wind-waves as predicted in section 5.2.2.

7.4 Wave gage locations

The wave flume is equipped with 8 wave gage mounts, set with resistance wave gages. The eight gages will be placed in three groups; two gages in front of the generating paddle, three in front of the structure and three behind the structure. The spacing between gages has to meet the requirements for the Funke and Mansard and Goda methods. Both of these methods will be used to obtain the wave spectrums at each of the three gage group locations.

In order to satisfy the requirements for these numerical methods the gage location has to satisfy these conditions:

I. Place the nearest probe at least a wavelength away from any reflecting structure; this avoids undesired effects caused by stationary waves. Stationary waves will cause the spectra from the three probes to differ up to 10%

II. Avoid critical spacing; at certain spacing a denominator in the formulas will become zero. The critical distances are:

$$X_{12} \neq j \cdot \frac{L_k}{2} \qquad \textbf{Eq. 23}$$

and

$$X_{13} \neq \frac{m}{n} \cdot X_{12} \qquad \textbf{Eq. 24}$$

where:

X_{12}= *distance from probe 1 to probe 2*

X_{13}= *distance from probe 1 to probe 3*

J, m, n= integers

L_k= *wavelength*

To meet the requirement of the first condition only the longest wavelength is of importance. The longest expected wavelength corresponds to wave regime F, and is around 4.2 meters. Hence a clearance of 4.2 meters should be kept in front of the wave paddle.

Table 5 Values of critical X_{13} (for values of 'm' and 'n' up to 10) [m]

n	1	2	3	4	5	6	7	8	9	10
m										
1	0.20	0.40	-	-	-	-	-	-	-	-
2	-	0.20	0.30	0.40	0.50	-	-	-	-	-
3	-	-	0.20	0.27	0.33	0.40	0.47	-	-	-
4	-	-	-	0.20	0.25	0.30	0.35	0.40	0.45	0.50
5	-	-	-	-	0.20	0.24	0.28	0.32	0.36	0.40
6	-	-	-	-	-	0.20	0.23	0.27	0.30	0.33
7	-	-	-	-	-	-	0.20	0.23	0.26	0.29
8	-	-	-	-	-	-	-	0.20	0.23	0.25
9	-	-	-	-	-	-	-	-	0.20	0.22
10	-	-	-	-	-	-	-	-	-	0.20

The second condition requires special attention to the distance between gages, the first distance is between the first and second gage, X_{12}. This distance must not be a multiple of half the wavelength, so X_{12} should be less than half the (shortest) wavelength. X_{12} for this experiment was set at 20 cm. Then the spacing between the first and third gage, X_{13}, should not be a multiple of a fraction of X_{12}. This is a somewhat confusing statement so table 5 and figure 33 are an attempt to clarify this. Table 3 shows the computed values of critical X_{13} as a function of integers *m* and *n* from 1 to 10. Figure 33 shows critical and proposed values for the distance X_{13}. The chosen value for X_{13} is 38 cm.

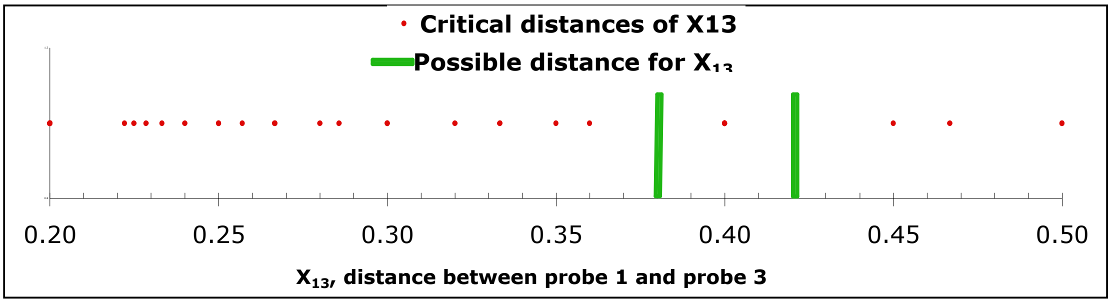

Figure 21 Diagram of critical and proposed spacing X_{13}

7.4.1 Wave gage location

This table shows the proposed configuration for the 8 wave gages, the distances are measured from the equilibrium position of the wave paddle.

Table 6 Wave gage location

Wave gage	Location [meters]
1	4.20
2	4.40
3	8.90
4	9.10
5	9.28
6	10.90
7	11.10
8	11.28

7.5 Overall set-up

The overall setup with specified dimensions is presented in figure 34, showing the wave gage exact positioning, the location of the fans and of the FWF. The distance from the neutral position of the wave paddle to the beginning of the dissipative structure was taken as 13.5 m. The most important factor is the X_{12} and X_{13} distances are respected (centimeter precision), the overall positioning of the gages does not have to be precise to the centimeter.

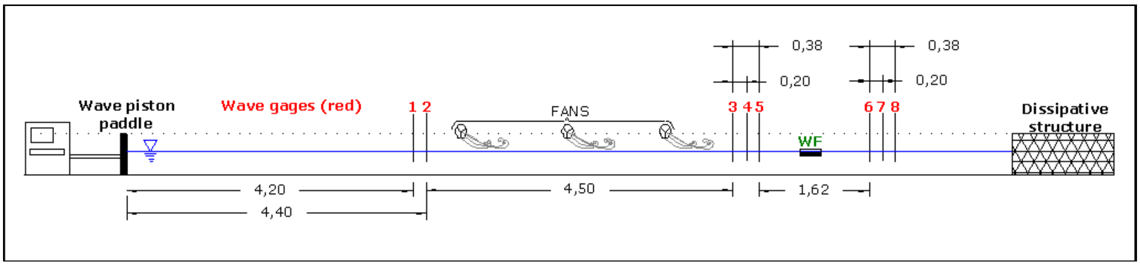

Figure 22 Setup for experiment at CIEMITO wave flume (assumes 13m from wave paddle to dissipative structure)

7.6 Procedure

These are the guidelines to follow when performing the experiment.

7.6.1 Calibrating

The calibration of the wave paddle and the resistor gages has to be done before the actual structure testing goes on.

I. Wave paddle: Once the resistor gages have been calibrated, waves can be measured and the paddle can be calibrated. The way to do this is to input a desired wave spectrum to the computer and compared this with the measured output.

II. Resistor gages: The resistor gage consists of an electrical circuit with a pair of semi-submerged stiff wires. The electrical circuit is closed by water, so the more submerged the cables are, the less resistance on the circuit. The resistor gages are connected to a *computer* that records the voltage changes (due to change in resistance). In order to correlate the voltage changes with the water level, the resistor gages have to be calibrated. The way these are calibrated is by submerging them a series of pre-determined distances and recording the voltage changes.

III. Fans: The waves/ripples caused by the fans most be measured before running the tests. The wind waves in the physical model must correspond with the wind wave forecasting done in chapter 5. At this scale the fans should generate a wave with period of 0.5 seconds. That corresponds to 3 seconds' period waves in the prototype (real life). The fans must be ran with no waves from the paddle, to measure the wind-waves. Also the dissipation of wind-waves should be measured by comparing the measurements at the second set of wave gages with the measurements at third/last set of wave gages (without a FWF present). In case of a very high dissipation, actions should be taken; more fans, different arrangement, or more powerful fans could be tried. The procedure to calibrate the Fans is described in the next section (Run).

7.6.2 Run

There are 6 wave regimes and 3 different Floating Wave Filters for a total of 18 runs with everything installed. However before installing any Floating Wave Filter, a few runs should be made with no Floating Wave Filter in order to test the fans' performance and observe the dissipation of wind waves.

These will be the major steps to complete the experiment

1. Run without waves from the paddle, without a FWF and calibrate fans.
2. Run with waves from the paddle, without a FWF and confirm that fans remain calibrated.
3. Record the waves at wave gages set 2 and 3.
4. Run with waves from the paddle, with FWF and with the fans calibrated and confirmed.
5. Record the waves everywhere.

The first run needs to calibrate the fans so that they generate wind waves compared to the ones forecasted in Chapter 5. The fans speed and orientation should be changed until these waves are generated, measured and confirmed. The next step is to run the fans at the calibrated speed and confirm that in the presence of long waves the wind waves are still present and within the parameters set for wind waves. If this requirement is met, then the waves should be recorded and the spectrums should be quantified. From these analysis the dissipation of wind waves will be calculated. The way to do this is to compare the waves at wave gages' set 2 and 3. This dissipation must be recorded. Then the experiment with everything in place should be performed.

In order to maintain certain order, Table 5 should be used during the experimental phase to make any important observations. It is also important to write down the date and time to avoid any computer file disorganization.

7.7 Data Analysis

The final results should be a comparison of wave spectrums at set 2 and at set 3 of wave gages. However this is not straight forward, a series of analysis are needed to reach the final conclusion.

As shown in figure 34, there will be 3 sets of wave gages. The first set will measure the undisturbed waves generated at the paddle. In between sets 1 and 2 the fans will be installed, so set 2 of wave gages will measure the waves coming from the paddle plus the waves generated by the fans. And finally set 3, which will be behind the FWF, will measure the transmitted or dissipated waves; transmitted when there is a FWF and dissipated when there is not. Each of these sets of gages needs a separate analysis using either the Goda or Funke and Mansard method. These methods will separate the incident and reflected waves into two separate spectrums. In this experiment only the incident spectrum is relevant, since reflection is of no importance to FWF.

Once the incident wave spectrums are obtained the first cases to be analyzed should be the tests with no FWF. Special attention should be paid to the spectrum transformation between wave gage sets 2 and 3. The dissipation of wind waves from the fans location to the end of the flume most be quantified in order to accurately test the FWF's performance. A dissipation of the wind waves would translate in a decline in the high-frequency part of the spectrum.

The final analysis will highly depend on the dissipative behavior of wind waves. If the dissipation of wind waves is small (<5%), the performance of FWF can be easily assessed. On the other hand if there is a considerable dissipation of wind waves a slightly different approach needs to be taken. In the best of cases if the dissipation is not high, then simply the transmitted spectrum will be compared to the incident (paddle + fans waves) and a coefficient of transmission can be calculated. However if the dissipation of wind waves is considerably high and the same approach is taken, the FWF's performance will be overestimated. The 'normal' dissipation of wind waves would be attributed to the FWF. So in the case of considerable dissipation the transmitted spectrum should be compared to the spectrum from the same gages when there was no FWF. We will be comparing two spectrums measured at the same place, with the same wave conditions but one with FWF and one without.

The performance assessment will depend on the ability of blocking short-period energy and transmitting long-period energy. It would then be convenient to separate the spectrum into long and short frequency, and obtain a transmission coefficient, C_T, for each. Then the grade of efficiency of FWF can be described as:

$$WF_{efficiency} = \frac{\left(1 - C_{T_{short}}\right) + C_{T_{long}}}{2} \qquad \textbf{Eq. 25}$$

where:

C_{T_short} = *Coefficient of Transmission of short-period waves*

C_{T_long} = *Coefficient of Transmission of long-period waves*

Table 7 Observation sheet for the experiment

RUN	Waves	Floating Wave Filter	Date	Started (time)	Finished (time)	Observations
1	**A**	**FWF1**				
2	**B**	**FWF1**				
3	**C**	**FWF1**				
4	**D**	**FWF1**				
5	**E**	**FWF1**				
6	**F**	**FWF1**				
7	**A**	**FWF2**				
8	**B**	**FWF2**				
9	**C**	**FWF2**				
10	**D**	**FWF2**				
11	**E**	**FWF2**				
12	**F**	**FWF2**				
13	**A**	**FWF3**				
14	**B**	**FWF3**				
15	**C**	**FWF3**				
16	**D**	**FWF3**				
17	**E**	**FWF3**				
18	**F**	**FWF3**				
19	**A**	***none***				
20	**B**	***none***				
21	**C**	***none***				
22	**D**	***none***				
23	**E**	***none***				
24	**F**	***none***				

CHAPTER 8 - Conclusion and Recommendations

8.1 Conclusion

The idea and reasoning behind Floating Wave Filters (FWF) have been presented in this thesis report. These structures have the potential to improve the efficiency of surf breaks by blocking short-period wind waves (chop) and transmitting long-period waves (swell). However without experimental data it is impossible to claim that in fact FWF do work. Although the experiment could not be carried out, the physical model proposal was prepared. Chapter 7 includes an in-depth explanation of the procedure to be completed in order to test FWF in a wave flume.

Data from buoys off the California coast, in the United States of America, was analyzed to complete the characterization of good surfing waves. These waves are characterized by wave periods higher than 10 seconds and variable wave height, with Hs greater than a meter. For the characterization of the wave frequency spectrum a directional spectrum was used to isolate cases with a single incoming swell event. Then this swell event was graphed in a frequency spectrum and compared to JONSWAP spectrums of variable gamma. A JONSWAP spectrum with gamma equal to 4.0 was chosen as the proper spectrum to model a swell event in the physical model.

The numerical modeling was not completed due to different factors, mainly inexperience in numerical modeling and an unusual modeling problem (floating structures). Instead of the numerical modeling a simple theoretical analysis was done using Linear Wave Theory and several assumptions. This yielded a theoretical transmission coefficient as a function of FWF's draft and wave period.

8.2 Recommendations

8.2.1 Complete experiment and publish

The physical model presented in Chapter 7 should be carried out at the CIEMito facility at the Universitat Politécnica de Catalunya. If the data obtained is satisfactory, a paper should be published on the subject of FWF.

8.2.2 Numerical Modeling

If anyone attempts to numerically model FWF, he or she should have extensive experience or guidance on numerical models. The basic problem with modeling floating structures is that they are dynamic as opposed to a conventional breakwater or waterway.

8.2.3 3D Physical Models

In order to properly model the behavior of FWF a wave tank should be used instead of a wave flume. In a wave tank the wind waves can be better modeled, the diffraction and refraction around the structure can be observed, and different configurations can be tested. The wind direction and wave attack does not have to be straight onshore in a wave tank instead different angles can be tested.

8.2.4 Recruit marine biologists

In order to have a positive impact in the marine environment, the floating structures of FWF can be biologically friendly, like a floating artificial reef. Marine biologist could give advice on the design shape, what materials to use and which materials to avoid in order to encourage a thriving marine life around FWF.

8.2.5 Real Case Application Somewhere in the World

In order to get public acceptance and to do a definite test of FWF, these have to be installed in a popular surfing beach. Then the public reaction will deem FWF either a failure or a success. The location should be an urban setting to get a quick reaction from the local population.

8.2.6 Field Measurements

Once a FWF is installed in a surf spot, field measurements should be taken in order to analyze the performance and improve the design. One important field measurement is the surfers attitude towards FWF.

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