Laboratory Investigations

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Publication date:
1999

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Frigaard, P., & Schlütter, F. (1999). Laboratory Investigations: Task 3.1 : methodology. Aalborg: Hydraulics & Coastal Engineering Laboratory, Department of Civil Engineering, Aalborg University.

COMMISSION
OF THE EUROPEAN
COMMUNITIES

MAST III

THE OPTIMISATION OF
CREST LEVEL DESIGN OF
SLOPING COASTAL STRUCTURES
THROUGH PROTOTYPE
MONITORING AND MODELLING

OPTICREST

MAS3-CT97-0116

REPORT

Task 3.1

Laboratory Investigations - Methodology

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Final version

June 1999

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Contents

1 Introduction

Two prototype structures The Zeebrugge breakwater and The dike in Petten are already instrumented and measurements are ongoing.

In the OPTICREST project a focused and well directed set of model tests will have to be carried out in order to compare these prototype measurements with model test results. Furthermore, the model tests will make it possible to generalize the run–up/run–down and overtopping results over a wider range of environmental conditions.

Uniformed data instrumentation, acquisition and analysis methods are essential for both the prototype measurements and the model tests in order to ensure comparable results. Six different hydraulic laboratories, Aalborg University (AAU), Delft Hydraulics (DH), Flanders Community (FC), Leichtweiss Institut fur Wasserbau (LWI), University College Cork (UCC), Universidad Politechnica de Valencia (UPV) will be involved in performing the tests. In the previous MAST II project (Full Scale Dynamic Load Monitoring of Rubble–Mound Breakwaters) very large discrepancies were found in results from testing identical structures in different laboratories. It was believed that the main discrepancy were due to different test condition than due to changes in the parameters being tested.

The aim of the following (Task 3.1) is to describe and prescribe identical test conditions, test setup, data acquisition, data analysis methods and data presentation for the model tests in all the laboratories in order to ensure that test results are comparable. This document only outlines the minimum requirements for the laboratories. Besides that, laboratories are welcome to perform additional testing, so that this document does not become limiting for the ingenuity.

Practically there is a very strong connection between the present subtask (Laboratory investigations – Methodology) and task 4 (Link between prototype and laboratory results). As a part of task 4 UPV is trying to identify the sources of possible discrepancies.

Much attention must be paid to the fields discovered as critical points in this investigation (task 4), and uniform test conditions must be prescribed precisely for these subareas.

All measures in this present document is given in prototype values.

2 Time schedule

This paragraph outlines the planned time frames for carrying out the laboratory testing. According to the MAST III proposal laboratory testing is suggested to take place throughout month 7 till 28. This of course encompass initial testing and revised testing. In the different laboratories testing is planned to commence according to the following list:

AAU	:	March, 1999
DH	:	March, 1999
FC	:	March, 1999
UCC	:	March, 1999

3 The prototypes

This paragraph renders a short presentation of the layout of the Petten dike and the Zeebrugge breakwater. The instrumented sections of the prototypes form basis for the design of the models both in respect to the structures themselves and the instrumentation. For a more thorough description of the field sites please see the report of subtask 2.1: "Description of field sites for the measurement of wave run-up".

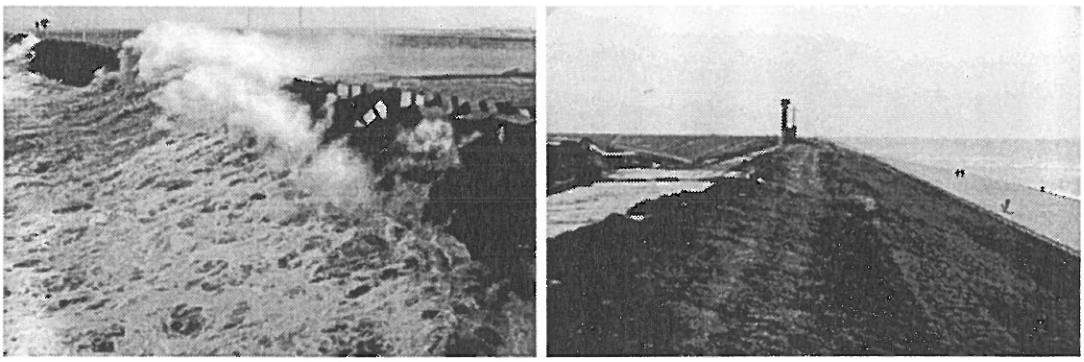


Figure 1: Photos from Zeebrugge and Petten.

3.1 The Petten dike

The Petten dike is located on the coastline of Holland as shown on figure 2.

Figure 2: Location of the Petten dike.

The Petten dike is located in a place with a continuously changing foreshore due to sediment transport. Figure 3 shows the foreshore including the Petten polder in the direction of the wave rider array (RIKZ 1997).

The dike itself has a grass armoured lee side but a front slope armoured with basalt stones and asphalt. The dike has a height of approximately 12.75 m over MWL. The composition of the dike implies that it can be considered to be impermeable. A cross-section of the dike is shown in figure 4.

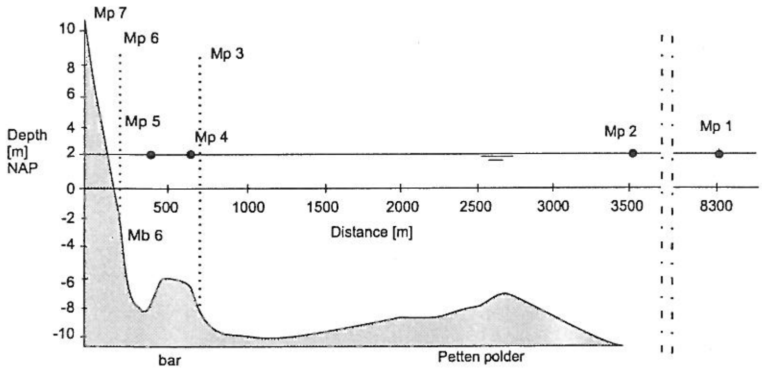


Figure 3: Illustration of the foreshore at Petten.

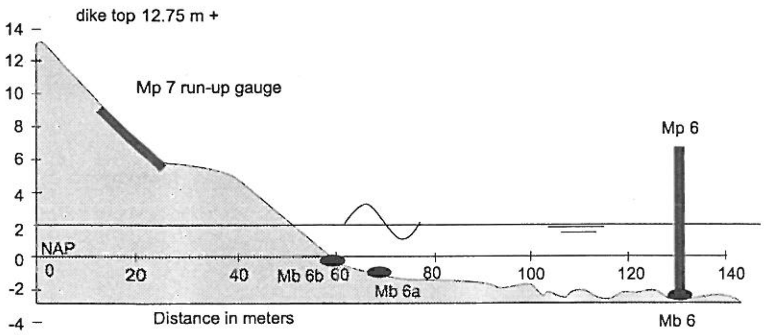


Figure 4: Cross-section of the Petten dike.

The tidal range at Petten is app. 2.5 meters. Six meters of maximum significant wave height have been measured, whereas $H_s = 10\ m$ is the design condition. For design conditions the water level goes at high as 4.7 m above NAP. Figure 3 and 4 indicates a number of prototype instruments according to the following list.

Sensor	description
Mp 1	Directional waverider.
Mp 2	Wave rider.
Mp 3	Staff gauge, water level riser.
Mp 4	Wave rider.
Mp 5	Directional wave rider.
Mp 6	Capacity wire.
Mb 6ab	Pressure transducers.
Mw 6	Wind meter.
Mp 7	Run-up gauge.

3.2 The Zeebrugge breakwater

For information Zeebrugge is located on the coast of Belgium not far from Holland as seen on figure 5.

The distance between the Petten dike and Zeebrugge is only about 250 km along the coast line. As for Petten the waves are depth limited at the breakwater reaching a maximum of app. 7 meters significant wave height. There is a tidal range of app. 4.3 meters. The cross-section of the breakwater can be seen on figure 6 and 10.

Figure 5: Location of Zeebrugge.

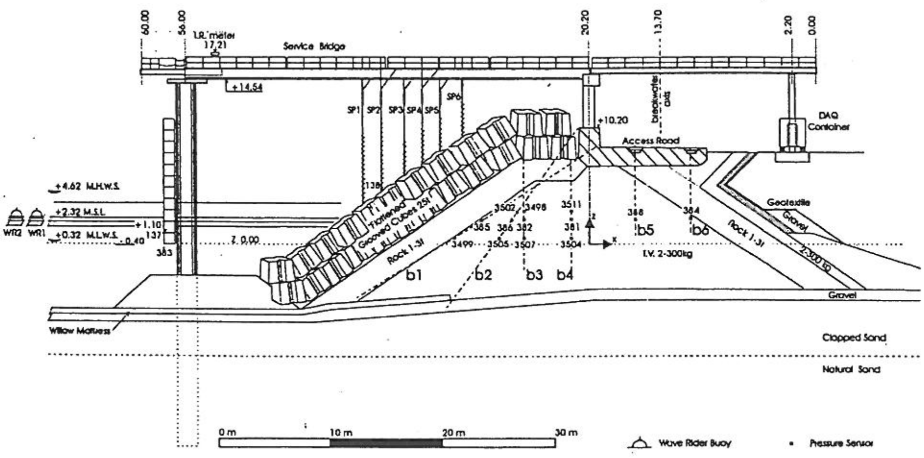


Figure 6: Cross-section of the Zeebrugge breakwater.

4 The models

The Zeebrugge Breakwater will be modelled in two laboratories. And the dike in Petten will be modelled in two laboratories:

AAU: A 3–Dimensional model of Zeebrugge, scale 1:40
DH: A 2–Dimensional model of Petten, scale 1:40
FC: A 2–Dimensional model of Zeebrugge, scale 1:30
UCC: A 3–Dimensional model of Petten, scale 1:40

Furthermore, LWI will carry out a general study concerning crest stability, and UPV will make a general study concerning the influence of wind on run-up, overtopping and spray.

The reason for having more than one model of each of the prototype structures is that each of the models can focus on different aspects. For example the 2–D model can look into the changes of the waves as they cross the foreshore precisely because a very long foreshore can be modelled. The 3–D models cannot model a long foreshore but they can show effects of wave obliqueness.

4.1 Lay–out of the models

The following paragraphs renders the proposed layout of the model in the different laboratories. First the geometrical layout is shown and subsequently materials and instrumentation is described. It is requested that the models are thoroughly documented after construction by photos. A readable length scale must be seen on the photos.

4.1.1 The Petten model

The Petten model should be constructed according to the lay–out shown in figure 7. Furthermore, it is important to model the bar in front of Petten as seen on figure 3.

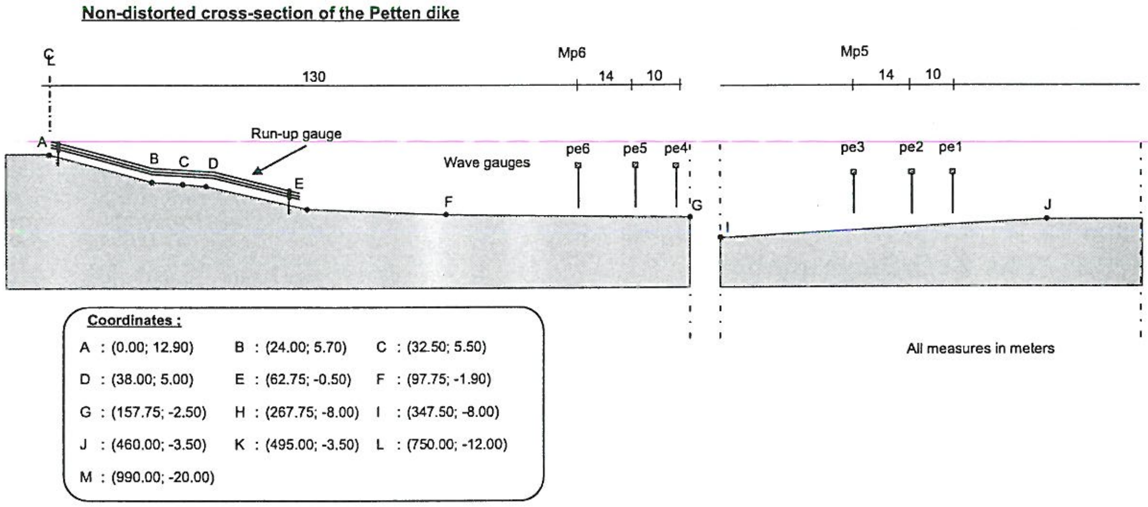


Figure 7: The Petten model.

Meters from dike axis	Z-level [m,NAP]
0.00	12.90
2.40	12.90
24.00	5.70
38.00	5.00
62.75	-0.50
97.75	-1.90
157.75	-2.50
267.75	-8.00
347.50	-8.00
460.00	-3.50
495.00	-3.50
750.00	-12.00
990.00	-20.00

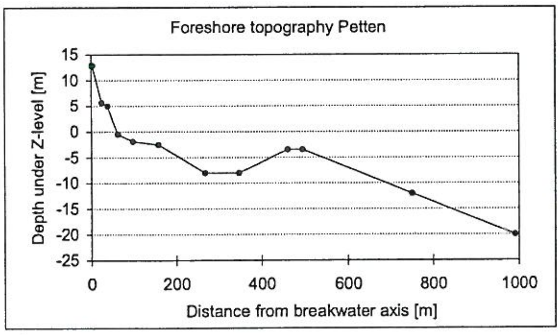


Figure 8: Current foreshore topography at Petten.

Surface roughness must be scaled correctly. Thus, because the roughness of the Petten dike is about 0.05 meters the models should be build with a surface according to this roughness. Petten is assumed to be impermeable, and therefore also the model should be impermeable even though water infiltrates into the dike at some locations. In this case a concrete surface should be applied using suitable rough materials in the top layer. Photos must be taken of the surface indicating the roughness for comparison between the two models.

The foreshore of the Petten model must be constructed according to figure 7 and figure 8. Figure 7 also shows the cross-sectional layout to be used as well as indicating the position of wave gauges. Due to wave breaking it may be difficult to separate incoming and reflected waves at Mp6. Therefore, the group of gauges at Mp5 should be used as reference for incoming waves.

With respect to the 3D-model is should be placed optimally in the basin with regard to the wave generation and having a cross-section according to figure 7. The position of the model in the wave basin at UCC can be seen in figure 9.

4.1.2 The Zeebrugge model

The model of the Zeebrugge breakwater is more complex than that of the Petten dike. In this case the model cannot be considered to be impermeable and therefore core material, filter layers, etc. needs to be modelled.

In the 2D-tests the foreshore must be constructed according to the layout shown on figure 11. Figure 10 shows a detailed cross-section of the Zeebrugge breakwater, whereas figure 12 and 13 shows the cross-section to be used in the laboratory including the position of the wave gauges. Incoming waves are related to wave gauge group A sēen on figure 12.

The concrete units has a base width of 2.43 m, a top width of 2.26 m and a height of 2.0 m. The sections e, f, g, j and k can be considered impermeable (see figure 10) whereas other materials must be scaled correctly. As indicated on figure 10 some sand infiltration into the core of the breakwater has taken place, making this part less permeable. This lower part of the core may be modelled as impermeable. Permeability of the filter layers and the core is very important. No exact scaling law for the filter layers and the core exist. It is proposed to initially apply the Froude scaling law for these layers, as the purpose of the project is not to investigate scaling laws of permeable layers. The materials should correspond to the following parameters seen in table 1. All the stone materials has an app. density of 2.65 t/m^3 and the shape of the stones are fresh or equant. In order to be certain that the two Zeebrugge models are similar some measures must be taken.

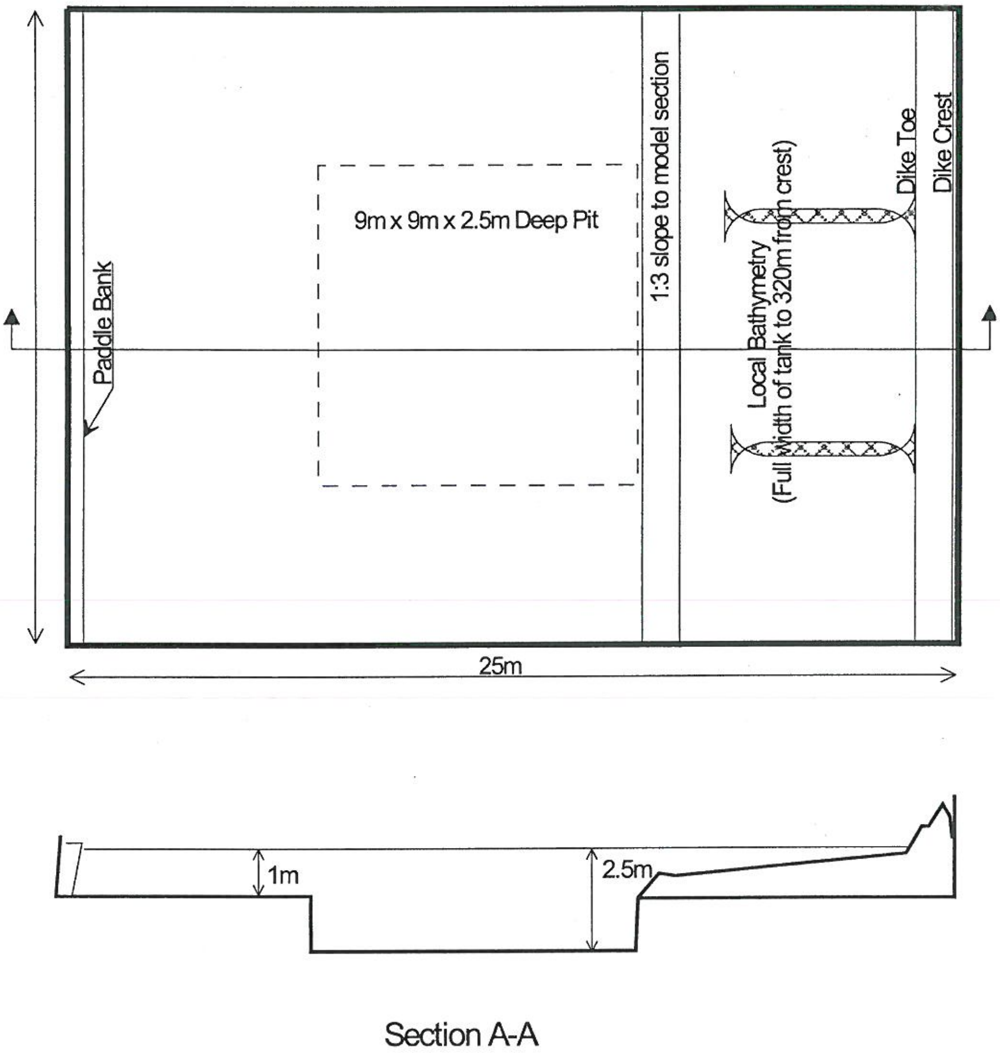


Figure 9: Lay-out of the 3D Petten model.

No.	Layer	Size	d_{n50}	$\frac{d_{n85}}{d_{n15}}$
a	Core	Quarry run 2-300 kg	0.23	3.0
b	Armour	"Antifer" 25 t	2.18	-
c	Filter	1 - 3 t	0.95	1.4
d	Filter (rear side)	1 - 3 t	0.95	1.4
i	Toe	3 - 6 t	1.2	1.2
-	Seabed protection	80 - 300 kg	0.38	1.5

Table 1: Material characteristics.

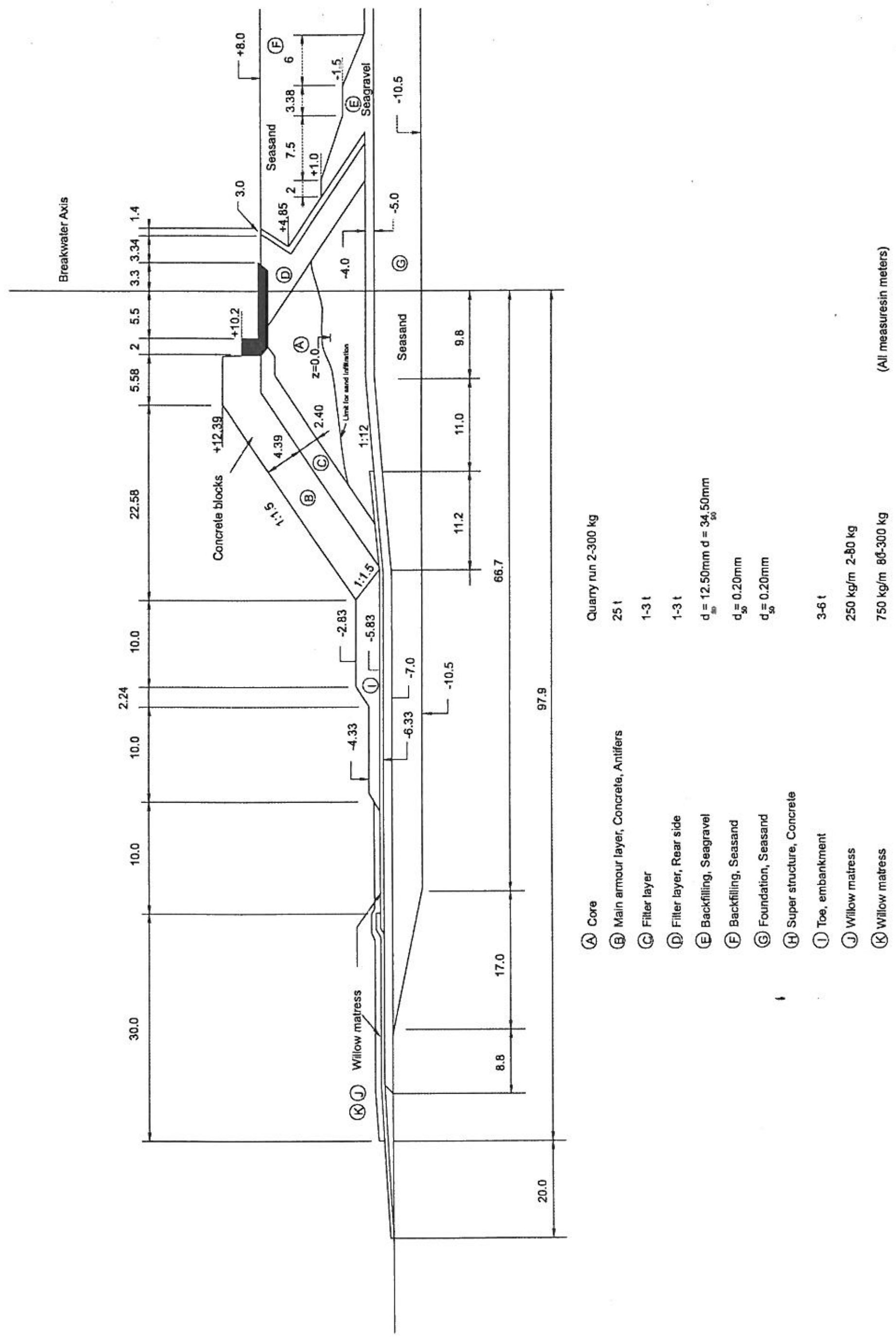


Figure 10: Design layout, cross-section of the Zeebrugge breakwater.

Meters from breakwater axis	Depth in meters Z-level
0	2.1
50	2.5
100	5.4
150	9.2
200	12.6
250	12.9
300	14.0
350	13.1
400	13.3
450	13.3
500	11.3
550	9.7
600	9.5

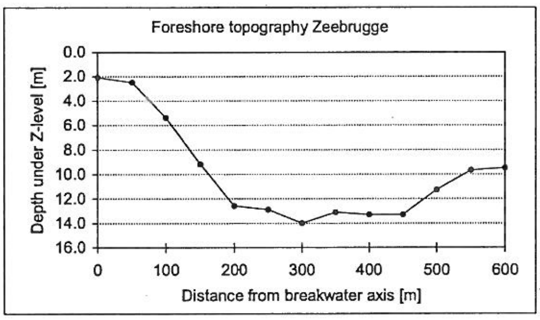


Figure 11: Illustration of the foreshore in front of the Zeebrugge breakwater.

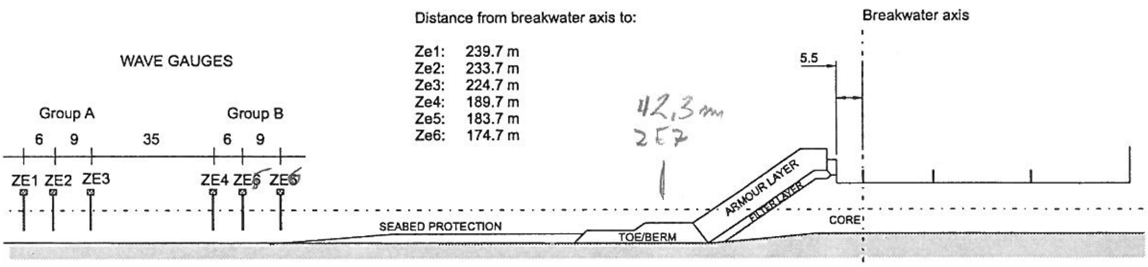
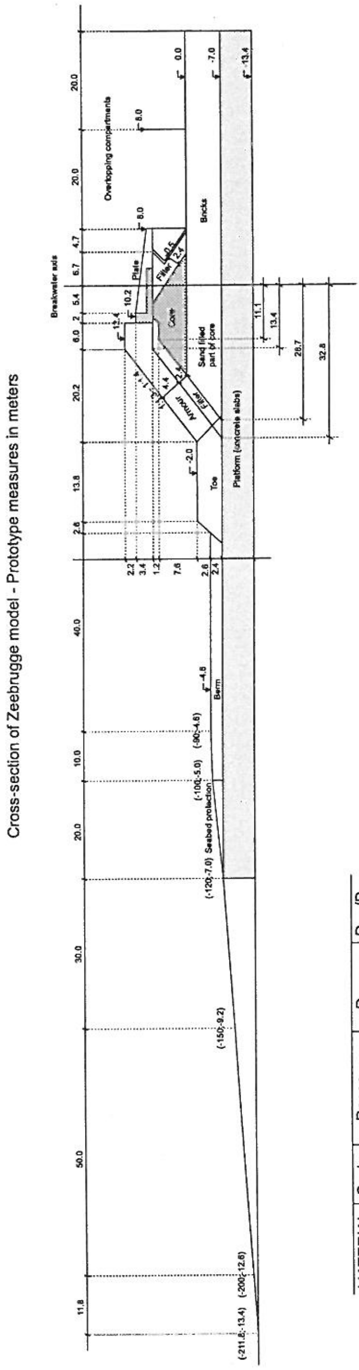


Figure 12: Cross-sectional view of the Zeebrugge model - wave gauge location.



MATERIAL	Scale	Range	D_{n50}	D_{n85}/D_{n15}
Core	1:40	2.3 - 12 mm	5.8 mm	3.0
Core	1:24	3.8 - 20 mm	9.6 mm	3.0
Filter	1:40	18 - 26 mm	23.8 mm	1.4
Toe	1:40	26 - 33 mm	30 mm	1.2
Berm	1:40	18 - 26 mm	23.8 mm	1.4
Seabed	1:40	7.8 - 12 mm	9.5 mm	1.5

Figure 13: Cross-section of the Zeebrugge model.

1. Photos must be taken indicating size, shape and roughness.
2. For each material d_{15}, d_{50} and d_{85} are determined by weighing a sample of 250 stones.
3. The density of the stone samples are measured.

In order to determine whether the permeability and porosity of the layers are similar in the two models all materials used for the models needs to be weighed and the volume taken up by each material recorded. Subsequently porosities are calculated. After construction, before testing, the mean porosity of the breakwater should be measured. This measurements are also performed after the test schedule is completed. The measurements of mean porosity may, though, turn out to be to troublesome to be worth while.

The "Antifer" cubes should be placed carefully on a 'plane' surface and with exactly $\frac{116}{924} \frac{blocks}{m^2} = 0.1255 \frac{blocks}{m^2}$ in each layer. This number was 0.115 as design for the breakwater. A recording of the actual location of the units can be seen on figure 14. The pattern in prototype should be imitated if possible. The considerations concerning placement of the armour units are of paramount importance because differences may result in different run-up characteristics.

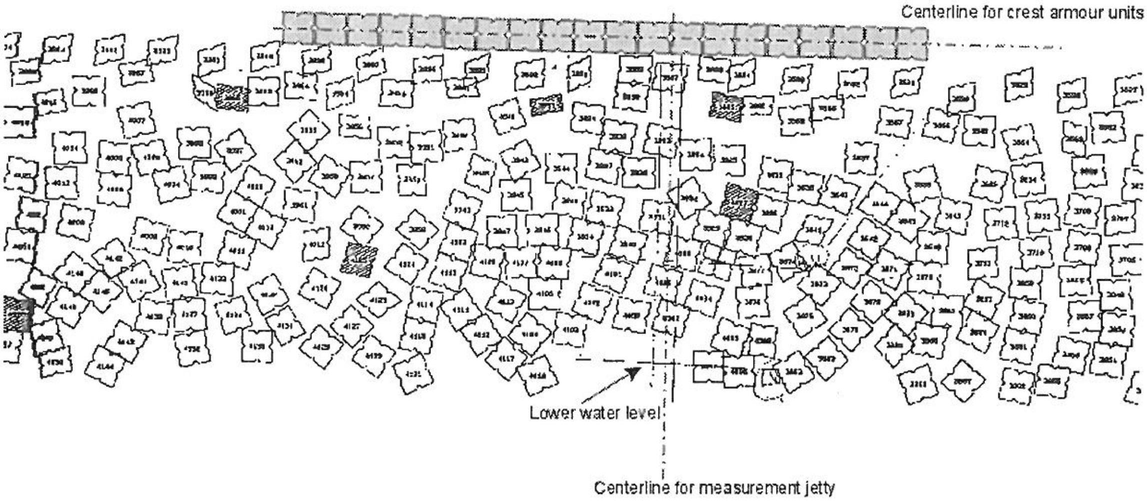


Figure 14: Top Armour layer pattern in prototype.

The layout of the 3D Zeebrugge model can be seen in figure 15.

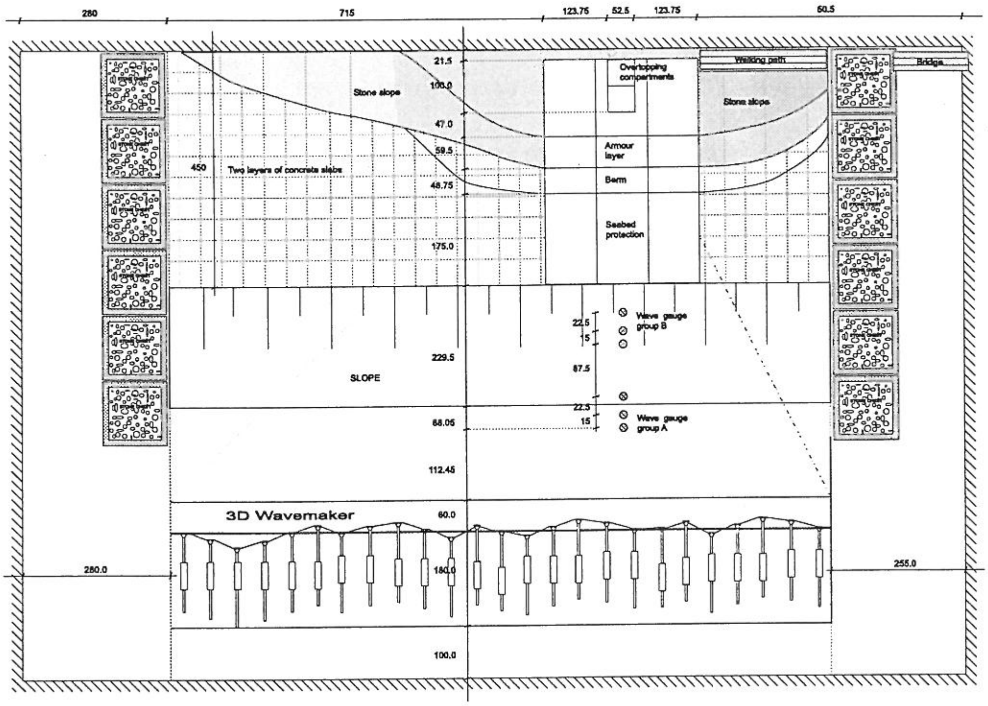


Figure 15: Lay-out of the 3D Zeebrugge model. (measures in centimeters, scale 1:40)

5 Data acquisition

First of all, normal precautions must be taken to ensure measured data. This means that all raw data must of course be backed up during the test period. This enables later analysis if necessary.

5.1 Length of timeseries

In order to achieve the correct statistical values for run-up/run-down and overtopping some rather long time series must be considered. The length should correspond to as high number of waves as 2000 – 5000. This is equivalent to a length of the time series of app. 6 to 15 hours.

Obviously such a length of the timeseries is very inconvenient for many purposes, and also it might be impossible within the prototype measurements. Therefore the following length of the timeseries should be used:

Time series length: 1000 waves ($\simeq$ app. 200 minutes)

5.2 Sample frequency

In Petten data are sampled with 1.28 Hz, 4 Hz and 10 Hz depending on the type of measurement. In Zeebrugge data are sampled with 10 Hz. All relevant information is found in the frequency range 0 – 0.5 Hz. The used sample frequency should be 2 Hz during all tests. This results in the following sample frequencies in the laboratory scale:

Scale	Sample frequency in laboratory
Model scale 1:30	10.9545 Hz
Model scale 1:40	12.6491 Hz

In case the sample frequency is not possible to apply in a specific laboratory data must be sampled at a higher frequency and subsequently data subsampled at the correct sample frequency by interpolation before any analysis takes place.

Analog lowpass filtering with a cutoff frequency of app. 5 Hz (laboratory scale) must be applied on all measurements in order to avoid aliasing.

5.3 Bandpass filtering

Because zero adjusting is very difficult, and because leakage from this missing zero adjustment might occur it is chosen to cut off (high pass) the signal at frequency of 0.05 Hz. Also because the higher frequent part of the time series will affect the calculations of waves both in time domain and in frequency domain it is chosen to cut off (low pass) the signals at a frequency of 0.5 Hz (prototype).

The bandpass filtering can be performed digitally.

5.4 Spectral bandwidth

When FFT is being performed it is always very important to specify the spectral bandwidth and the degrees of freedom.

From one time series it is possible to calculate several different spectra. In general one has to choose between high resolution and large variability or high reliability and low resolution. The coefficient of variation of a raw spectral estimate is 100%. Of cause, this large variance has to be reduced in one way or another.

It is proposed to use subseries with a length of 1024 data points, which is equal to a length of 512 seconds. All subseries should be overlapped with 20 % in each end. This means that the time serie, see section 5.1, will consist of app. 30 subseries. Each subserie should be multiplied by a cosine squared data window with a taper equal to 20% of the subserie. Calculate average and spreading of all subseries, then the coefficient of variation (deviation divided by average) will be app. 20% for the time series.

6 Waves

A unique and correct measure and description of the waves is maybe the most essential part of all the measurements in the whole project, because all results will be related to these measurements.

In order to make the comparisons easier also a comparable method for generating the waves in the laboratory must be considered.

All wave analysis will follow recommendations given by IAHR.

6.1 Equipment for measuring surface elevation

Two types of wave gauges are commonly used, namely the resistance type wave gauge and the capacitance type wave gauge. It is believed that both of these gauges are well documented and can be used without any problems. Nevertheless, the electronics connected to the gauges might sometimes work as a lowpass filter. This means that the higher frequent part of the signals will be removed. Also a certain time delay may be seen on the signals.

6.2 Position of measurements of surface elevation

Wave gauges must be placed on deeper water and also on more shallow water near the structures. Wave gauges should be placed in groups of three gauges. Distances between gauges should be 10.0 meter and 14.0 meter respectively. That is a total distance of 24 meter for each group. This configuration of the wave gauges is not always optimal for separating incoming and reflected waves, but it is believed to constitute a good compromise.

6.3 Analysis method for wave measurements

In general surface elevation time series can be analyzed in time domain and in frequency domain. But before just doing these type of analysis it must be remembered that a high amount of reflection is present and therefore the waves must be separated into incident and reflected waves.

6.3.1 Bandpass filtering of the surface elevation signals

The required bandpass filtering, see section 5.4 is important both for wave heights calculated in time domain and wave heights calculated in frequency domain.

6.3.2 Separation of incident and reflected waves

Several methods for separating the wave field into *incident* and *reflected* waves exist. The method described by Mansard & Funke is chosen in the further analysis.

The Mansard & Funke method is working in frequency domain. Therefore the unique description of the FFT must be defined.

6.4 Frequency domain wave parameters

Most of the analysis of signals carried out in this project is based on frequency domain analysis. All frequency domain wave parameters can be calculated either from the incident part of the wave spectrum or from the total wave spectrum. Of cause main attention must be given to the incident part of the spectrum.

All frequency domain wave parameters are very influenced by the choice of bandpass filtering, see section 5.4.

6.4.1 Significant wave height H_{m_0}

This significant wave height is often referred to as the H_{m_0}–wave height in contradiction to the definition of the significant wave height given in section 6.5.1.

The significant wave height is calculated as $4 \cdot \sqrt{m_0}$. Unit of H_{m_0} is meter. m_0 is the total amount of energy in a certain frequency range. This means that the calculated wave height will depend on the defined frequency range.

The IAHR recommendations states that the lower frequency boundaries should be minimum of $1/3 f_p$ and 0.05 Hz, and the upper frequency boundary should be $3 f_p$. Where f_p is the peak frequency. This rises two problems. First of all we are mainly working with incident spectra, and the separation algorithms (Mansard & Funke) gives very poor results in the frequency ranges where subharmonic energy or superharmonic energy is present. Furthermore the integration boundaries depending on f_p are not unique defined because f_p normally depends on the whole spectrum, see section 6.4.2.

In the case of Zeebrugge the rule stated above is applied, whereas in the Petten case the frequency range 0.03 Hz to 0.5 Hz has been agreed upon.

6.4.2 Peak period T_p

The spectral peak period T_p is calculated as $1/f_p$, f_p being the peak frequency. Unit of the peak period is seconds.

The peak frequency may be estimated by different methods such as:

- frequency at which the spectrum is maximum (This method is very depending on the resolution of the spectrum, and it is easily affected by scatter) Due to the number of subseries this method should be applicable.
- fitting a parabolic curve to the three estimates in the vicinity of f_p (This method also depends on the spectral resolution)
- fitting a theoretical spectral model to the spectral estimates. (This method requires spectra more or less of a given form) In the OPTICREST project the first method will be used and consequently choice of spectral resolution is important.

6.4.3 Average wave period T_0

The average wave period T_0 is defined from the spectrum (incident or total part). T_0 can be defined in two ways. $\boxed{T_{0,1} = m_0/m_1}$ or $T_{0,2} = \sqrt{m_0/m_2}$, where m_i is the i'th order moment of the wave spectrum. In the OPTICREST project **the first definition $T_{0,1}$ is chosen** because it is less influenced be the high frequent part of the signals. Unit of T_0 is seconds.

Another period based on spectral moments can be given as $T_{m-1,0} = \frac{m_{-1}}{m_0}$.

6.4.4 Reflection coefficient α

In OPTICREST *amplitude* reflection coefficients should be used. The reflection coefficient is a function of frequency f. $\alpha(f) = \sqrt{S_{\eta,reflected}/S_{\eta,incident}}$. The overall reflection coefficient α_{total} is given by $\alpha_{total} = \sqrt{m_{0,reflected}}/\sqrt{m_{0,incident}}$. The reflection coefficient is a dimensionless parameter.

The same frequency ranges as described in 6.4.1 must be applied for this analysis.

6.4.5 Spectral width parameter ε

The spectral width parameter ε is defined by $\varepsilon = \sqrt{m_0 m_2/m_1^2 - 1}$. The spectral width parameter is dimensionless.

6.4.6 Surf similarity parameter

Dependent on the used input parameters it is possible to define a number of different surf similarity parameters.

$$\xi = \frac{tan\alpha}{\sqrt{s}} \tag{1}$$

$$\xi_m = \frac{tan\alpha}{\sqrt{s_m}} = \frac{tan\alpha}{\sqrt{\frac{2\pi}{g}\frac{H_s}{T_m^2}}} \tag{2}$$

$$\xi_{0p} = \frac{tan\alpha}{\sqrt{\frac{2\pi}{g}\frac{H_{s0}}{T_{p0}^2}}} \tag{3}$$

$$\xi_p = \frac{tan\alpha}{\sqrt{\frac{2\pi}{g}\frac{H_s}{T_p^2}}} \tag{4}$$

$$\xi_{s,-1} = \frac{tan\alpha}{\sqrt{\frac{2\pi}{g}\frac{H_s}{T_{m-1,0}^2}}} \tag{5}$$

6.4.7 Groupiness factor GF

For calculation of GF the Hilbert transform should be applied.

6.5 Time domain wave parameters

All time domain wave parameters can be calculated either from the incident part of the time series or from the total time series. Of cause main attention must be given to the incident part of the time series.

The number of waves is determined by the duration divided by $T_{0,1}$. Also water levels are of significance. Mean water level (MWL) equals the mean of the timeseries, whereas still water level (SWL) is only conceivable in the laboratory and must not be confused with MWL.

All time domain wave parameters is very sensitive to the choice of *noise cut-off levels* and bandpass filtering, see section 5.4

6.5.1 Significant wave height H_s

This is the definition of the of the significant wave height in contradiction to the H_{m_0} described in section 6.4.1. H_s is defined as the average of the highest one–third of the individual wave heights found from zero–downcrossing. Unit of H_s is meter.

The significant wave period is calculated as $T_s = T_{H_{s\frac{1}{3}},d}$.

The reason for choosing zero–downcrossing analysis is that first the structure sees the wave through and then it feels the wave crest.

In the calculation of H_s the number of waves becomes very important. Also low frequent and high frequent part of the signals will change the zero crossing points. It is thus of importance to correct for false waves when performing the downcrossing analysis.

6.5.2 Average wave period T_m

Average wave period T_m is average of all the periods of the individual waves found from zero–crossing analysis. In OPTICREST zero–down crossing analysis is performed. Unit of T_m is seconds.

6.5.3 Reflection coefficient α

Frigaard and Brorsen 1995 demonstrated a time–domain method for separating incident and reflected irregular waves. Using this method it is possible to calculate incident amount of energy relative to the reflected amount of energy for a time window of 64 seconds. Length of filters should be 128 coefficients with a time spacing of 0.5 sec. For analysis it is suggested to use the definition given in 6.4.4

6.5.4 Groupiness factor GF(t)

To characterize the actual (instantaneous) groupiness of the wave train the groupiness factor can be calculated as function of time GF(t). The method is described by Hald 1995 and is based on a temporal Hilbert filter. This time varying groupiness factor is suitable for comparing the correlation between structural response and the wave grouping.

Length of digital filters should be 128 coefficients, with a time spacing of 0.5 sec.

7 Wave generation in the laboratories

The laboratories must be able to reproduce wave trains measured on site. This reproduction should be 'correct' in time domain on the position where it was measured. Discrepancies in elevations upto 5 % between prototype measurements and generated waves is accepted at any point in time. Furthermore, standardized wave spectra should be tested.

7.1 Wave synthesis method

A correct reproduction of the target wave spectra should be achieved. The only problem seems to be the very long duration of the time series. A wave synthesis method able to generate wave with the correct statistical parameters is required. A type of white noise filtering seems to be the most convenient method.

7.2 Correction for bounded long waves

Long waves will give high run–up's. In case wave generation omits the bounded long waves in the generation synthesis, altered run–up results can be experienced. Especially the flume tests will be sensitive to a correct reproduction of bounded long waves.

7.3 Active absorption of reflected waves

Active absorption of reflected waves is used in order to avoid the reflected waves to be rereflected at the paddle and subsequently altering the incident waves in such a way that control of the incident waves are lost.

8 Run–up/Run–down

Basis for the OPTICREST project is a statement saying that measurements on site have demonstrated that the present design rules for sloping coastal structures underestimate the run–up levels. Consequently, run–up must be measured very carefully in order to compare on site measurements with measurements in the laboratories.

8.1 Instruments for measuring run–up/run–down

UCC is working with this subject. Though, from AAU it is believed that most equipment will work properly.

In order to evaluate results from Zeebrugge also a model of the Zeebrugge stepgauge should be made.

8.2 Position of measurements of run–up/run–down

It has been recommended from the run-up measurement technique study (subtask 3.2) that three gauges should be applied. The gauge closest to the face of the structure must be placed as close as possible. The first gauge should be placed 8 cm above the surface of the slope, the next gauge 20 cm, and the last 40 cm above the surface of the slope, see figure 16.

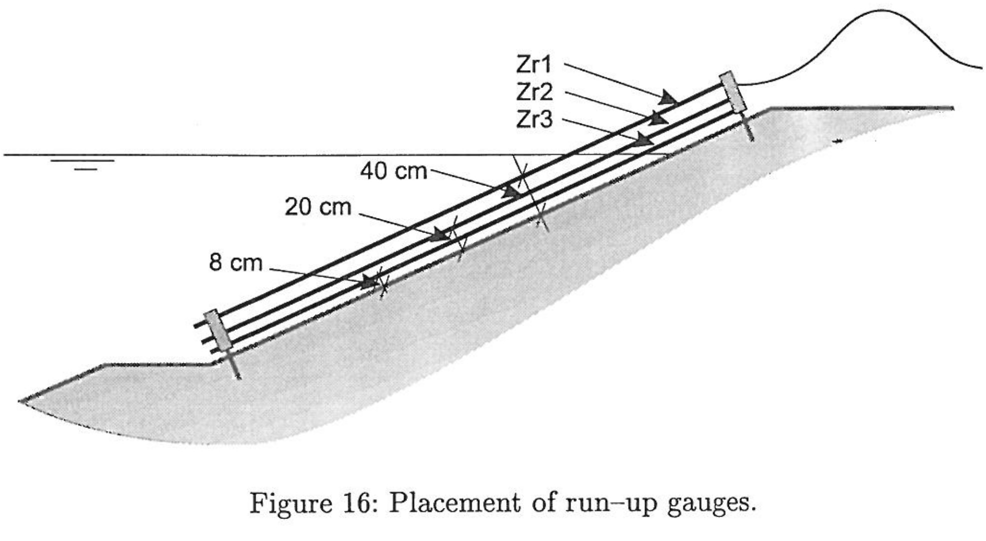


Figure 16: Placement of run–up gauges.

The traditional resistance gauges may be supplemented by stepgauges in order to mimic the prototype measurements.

8.3 Definition of zero level

In storm situations wind setup, wave setup, barometric setup and tides will change the water level in front of a structure. Normally the run–up/run–down levels are defined relative to the mean water level (MWL). It must be remembered that the mean water level changes in a line perpendicular to the structure.

In the laboratories it must be remembered that the mean water level is not the same as the still water level.

8.4 Analysis method for wave run–up/run–down

Run–up/run–down levels must be given in terms of the statistical parameter $R_{u_{1/x}}$ and $R_{d_{1/x}}$, giving the run–up/run–down levels with a certain exceedence probability per wave (1/x). I.e. $R_{u_{2\%}}$ is the run-up level which is exceeded by 2 % of the waves.

A definition of the *per wave* is then required.

As the literature normally gives the run–up/run–down levels in a dimensionless form given by $R_{u_{2\%}} = c \cdot \xi \cdot H_s$, plots using this form is wanted in order to compare with literature.

During the start–up meeting of the OPTICREST project Raf Verdonck focused on several different ways of calculating the Iribarren number ξ. It should be calculated as $\xi = \frac{tan\alpha}{\sqrt{s_m}}$, α is slope of construction at MWL, s_m is wave steepness based on wave length of wave with average wave period taken at MP5 and ZE3.

8.5 Output from run–up/run–down analysis

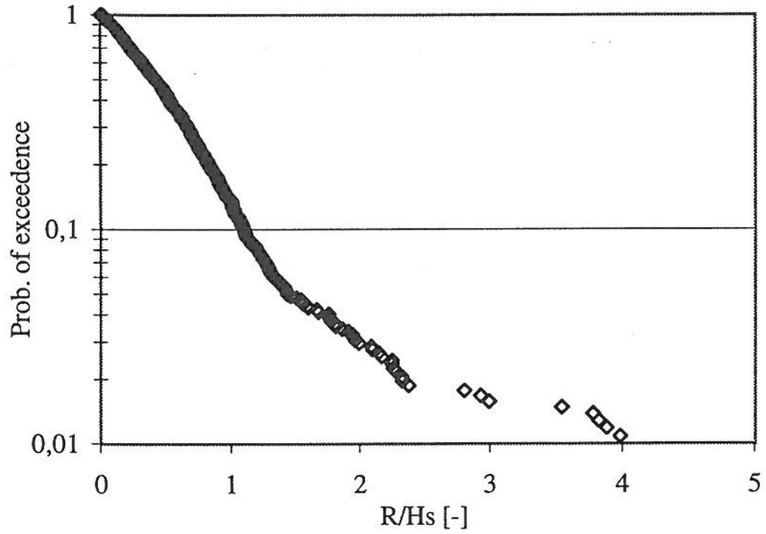


Figure 17: Example of distribution of Run–up per wave.

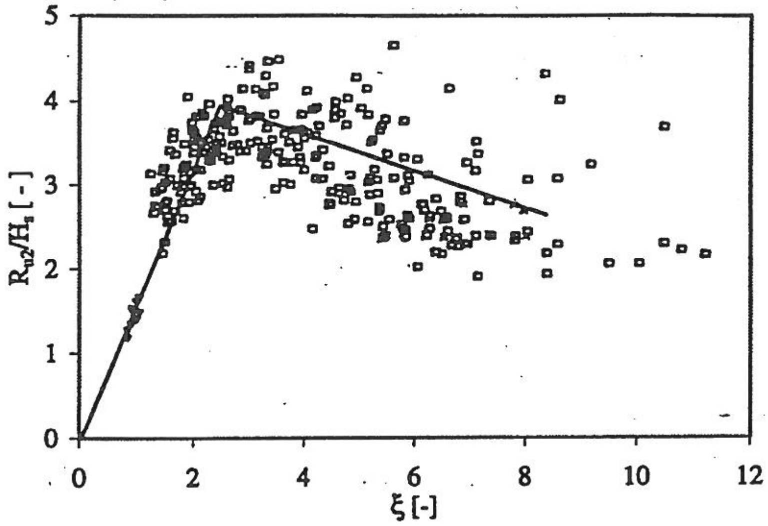


Figure 18: Run–up $R_{u_{2\%}}$ versus the Iribarren Number ξ.

9 Overtopping

The amount of overtopping is in general varying in time and space. Some averaging of the overtopping must be accepted. Nevertheless, the distribution of the overtopping in time is essential because designers want to protect the constructions for the 'maximum' overtopping. Knowledge about spatial distribution of the overtopping is also required.

9.1 Positions of measurements of overtopping

In figure 13 the containers used for measurements of overtopping are shown. The container is a flat box with four compartments as shown. The width of the container should be 21 meter, which is the flume width at Flanders Hydraulics. Of cause the width of the container is only important when overtopping per wave is being computed.

The layout of the overtopping container (figure 13) is chosen in such a way that the first compartment has the same dimension as the trough in front of the wave screen n the prototype.

9.2 Analysis method of overtopping

First of all the average overtopping Q_m must be computed. The average overtopping should preferably be based on measurements with long time series (9 hours prototype) in order to ensure a proper statistical estimate of Q_m. Dimension of the average overtopping Q_m should be $m^3/sec/m$.

In case the overtopping per wave is computed a curve shoving the extreme statistics should be made. A definition of the *per wave* is then required. The probability of exceedence should be plotted against the overtopping per wave $Q_{1/x}$ (exceedence probability 1/x) divided by the average overtopping Q_m.

9.3 Output from Overtopping Analysis

In the figures 19 – 21 typical output graphs from the analysis of the overtopping measurements are shown.

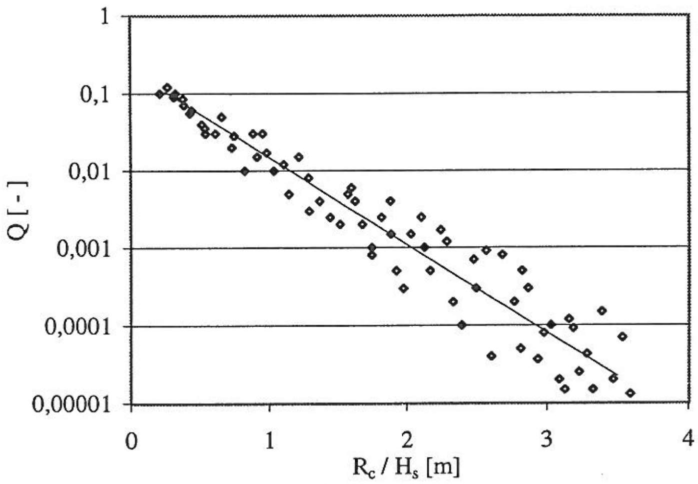


Figure 19: Example of measured overtopping of structure.

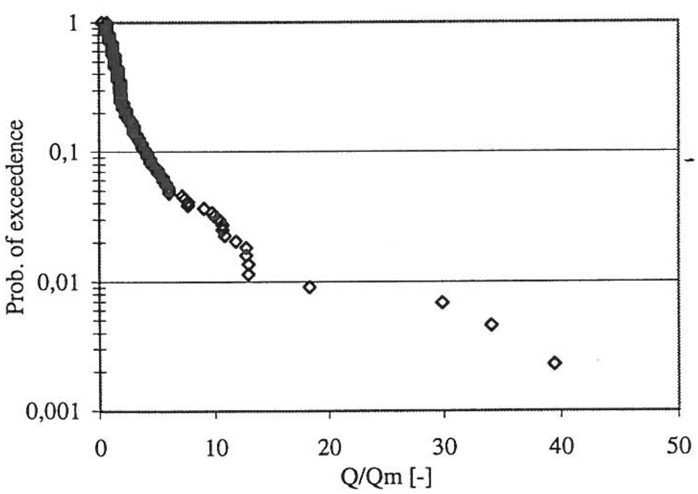


Figure 20: Example of statistical distribution of overtopping per wave.

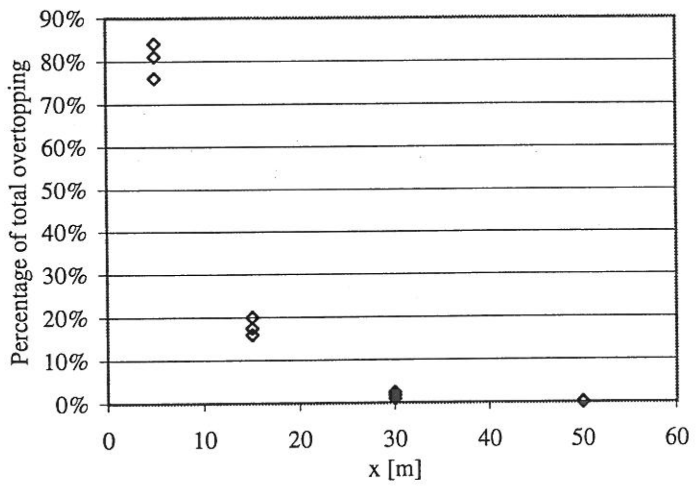


Figure 21: Example of distribution of overtopping behind structure.

10 Overview of measurements

The table below serves as an identification scheme for how to abbreviate different signals if necessary.

Name	Measure	Unit	Preprocessing
E1	Elevation	Meter	Bandpass filtering
E2	Elevation	Meter	Bandpass filtering
E3	Elevation	Meter	Bandpass filtering
E4	Elevation	Meter	Bandpass filtering
E5	Elevation	Meter	Bandpass filtering
E6	Elevation	Meter	Bandpass filtering
E7	Calculated elevation	Meter	Mansard & Funke used on E1, E2 and E3
E8	Calculated elevation	Meter	Mansard & Funke used on E4, E5 and E6
R1	Run–up	Meter	Bandpass filtering
R2	Run–up	Meter	Bandpass filtering
R3	Run–up	Meter	Bandpass filtering
R4	Calculated run–up	Meter	Method described in 9.2
O1	Overtopping	$m^3/sec./m$	Bandpass filtering

11 Environmental parameters

First this section will describe relevant environmental parameters and relevant range of these environmental parameters to be tested in the laboratory models. Structural/geometrical parameters will not be changed in the tests. Finally, a test matrix is given by a reduction of the total number of the test cases.

By not investigating structural parameters the set of potentially variable parameters are reduced. Traditionally, run-up and overtopping is related to among others the Irribarren number ($\xi = \tan\alpha/\sqrt{2\pi H/gT^2}$). This parameter is a mix of a structural parameter and wave conditions and test conditions should encompass a wide range of the Irribarren number. The list below shows most of the relevant parameters including structural parameters:

H	:	Wave height.
T	:	Wave period.
L	:	Wave length.
γ	:	Peak enhancement factor.
Θ	:	Wave direction (obliqueness).
σ	:	Wave spreading.
GF	:	Wave groupiness.
v_c	:	Current velocity.
ξ	:	Irribarren number.
s	:	Wave steepness.
α	:	Structure slope.
r	:	Slope roughness.
d	:	Water depth.
d_{berm}	:	Water depth above berm.
h	:	Height of the crest above the seabed.
R_c	:	Crest freeboard.
n	:	Structure permeability.

11.1 Significant wave heights

In Petten wave heights up to 3.3 meters have been measured. In Zeebrugge wave heights up to 3.5 meters have been measured. As design wave heights are significantly higher test conditions must encompass an expanded range of wave heights.

The test conditions for Petten and Zeebrugge should be:

Location	Significant wave heights [m]
Petten	1.0, 1.5,..., 7.0
Zeebrugge	1.0, 1.5,..., 7.0

Wave heights cannot though be generated without considering water level and wave periods and structural stability.

11.2 Wave periods

In Petten peak wave periods up to 17.5 sec have been measured. In Zeebrugge wave periods up to 8.0 have been measured.

The test conditions for Petten and Zeebrugge should be:

Location	Peak wave periods T_p [s]
Petten	6.0, 8.0,..., 18.0
Zeebrugge	5.0, 6.0,..., 10.0

Due to breaking all peak wave periods cannot be combined with all wave heights indicated above. Furthermore, wave height and period does not occur independently as is illustrated on figure 22, which covers measured conditions at Zeebrugge from four recorded storm sessions.

Measured data at Zeebrugge:	
Tp [s]	Hs [m]
8.9	3.5
6.4	3.03
8.9	2.25
8.5	1.95

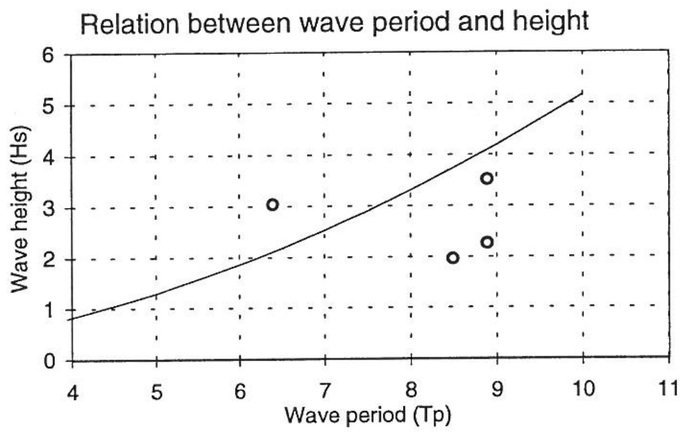


Figure 22: Relation between wave heights and periods, curve showing $T_p = \sqrt{\frac{190H_s}{g}}$ which is a relation applicable to the Danish part of the North sea.

11.3 Water levels

In Petten water level varies from -0.5 to +2.3 NAP. In Zeebrugge water levels varies from -0.32 to +5.92.

The test conditions for Petten and Zeebrugge should be:

Location	Water levels [m]
Petten	-1.0, -0.5,..., 2.5 (NAP)
Zeebrugge	0.0, 1.0,..., 6.0 (Z-level)

11.4 Spectral shapes

The wave spectra should be described by the JONSWAP spectrum. Variations of the spectra will be given through H_s, T_p and γ. In case a two peak spectra is required superposition of two JONSWAP spectra is used.

The 'standard' spectral width of the JONSWAP spectrum is given by a γ–parameter equal to 3.3. Nevertheless the spectra measured at Petten and Zeebrugge might be somewhat broader (γ = 4–7), therefore a testing range for γ should be 1.0 – app. 7.

The test conditions for Petten and Zeebrugge should be:

Location	Peak enhancement factor (γ-parameter)
Petten	1.0, 3.3, 7.0
Zeebrugge	1.0, 3.3, 7.0

11.5 Currents

Some currents are seen at Petten up till 1 *m/sec* parallel to the coastline. In Zeebrugge tidal currents up to 1.5 m/sec can be seen. The Zeebrugge model should be tested for currents equal to 0.5 m/sec and 1.0 m/sec as well.

The test conditions for Petten and Zeebrugge should be:

Location	Current [m/s]
Petten	0.0
Zeebrugge	0.0, 0.5, 1.0, 1.5

11.6 Wind speeds

In storm conditions wind speeds are 15 m/sec – 30 m/sec. This should be the testing range for the flume in Valencia if possible. Steps corresponding to 5 m/sec should be adequate.

11.7 Wave groupiness

It is proposed not to carry out tests with designated wave groupiness, but of course analyse the incoming waves for this parameter instead.

11.8 Wave directions

In Petten waves are almost perpendicular to the dike. Wave directions will vary from -10 deg. – 10 deg (0 deg is head on). Nevertheless, as we are also performing some basic parametric study of run–up and overtopping wave directions should be varied up to 45 deg.

In Zeebrugge wave directions will vary from -20 deg. – 20 deg. Also the breakwater in Zeebrugge should be tested for wave obliqueness up to 45 deg.

The test conditions for Petten and Zeebrugge should be:

Location	Wave direction [deg]
Petten	0, 10, 20, 30, 45
Zeebrugge	0, 10, 20, 30, 45

11.9 Wave directionality, spreading of waves

Because of the shallow water conditions in both Petten and Zeebrugge only narrow spreading ($\sigma \leq 15$ deg) of the waves are observed. The test range should though also encompass a larger spreading value for comparisons with other studies.

The test conditions for Petten and Zeebrugge should be:

Location	Wave spreading σ [deg]
Petten	0, 15, 30
Zeebrugge	0, 15, 30

12 Test matrix

If all combinations for the proposed parameters were tested it would come to more than a hundred thousand tests. Therefore, it is necessary to reduce the set of tests. This is done by choosing one or two areas of interest with regard to the wave climate and then varying the parameters with offset in this approach. There are two possible approaches to developing the test matrix. One aim could be to concentrate solely on comparisons with the prototypes and the conditions measured on site. Another approach could be to focus on a range of possible storm events with different severity. The test matrix for Petten and Zeebrugge tries to reflect a useful compromise between these two approaches.

The test matrix are shown on the following pages. It is important to notice that these test matrix are not final ones. As for all other experimental work, changes may become relevant during the test period and subsequently to these first set of tests. It is assumed that results from the first period of testing will entail needs for additional test at some or all the laboratories. Additional testing can involve changes to the models, wave conditions and measurements setup.

13 References

Darras, M.: IAHR List of Sea State Parameters: A Presentation. IAHR Seminar on wave generation and analysis in basins, Lusanne 1987. List of Sea State Parameters. IAHR Seminar on wave generation and analysis in basins, Lusanne 1987.

Frigaard, P., Brorsen, M.: A time–domain method for separating incident and reflected irregular waves. Coastal Engineering 24, 1995.

Frigaard, P., Helm–Petersen, J., Klopman, G., Stansberg, C.T., Benoit, M., Briggs, M.J., Miles, M., Santas, J., Schaffer, H.A., Hawkes, P.J.: IAHR List of Sea State Parameters – an update for multidirectional waves. IAHR Seminar Multidirectional Waves and their Interaction with Structures, San Francisco 1997.

Funke, E.R. and Mansard, E.P.D.: On the synthesis of Realistic Sea States in a Laboratory Flume, Technical Report, LTR–HY–66, National Research Council of Canada, Hydraulics Laboratory, Ottawa, 1979.

Gal, J.H. Andorks: Verification set Petten. Ministry of Transport, Public Works and Water Management, Report RIKZ/OS–96.137, Rijkswaterstat 1996.

Hald, T.:Wave group analysis by means of the Hilbert transform technique. Hydraulics & Coastal Engineering Laboratory, Aalborg University 1995.

Mansard, E. and Funke, E.: The measurement of incident and reflected spectra using a least squares method. Proc. 17th Int. Conf. on Coastal Engineering, Sydney, 1980.

Verdonck, Raf: Report of Task 1: Litterature review. Mast03/497 project: The Optimisation of Crest Level Design of Sloping Coastal Structures through Prototype Monitoring and Modelling. Report from kick–off meeting, Ghent 1998.

MAST-OPTICREST: ZEEBRUGGE

Date: Februrary 1999

Test	Hs [m]	Tp [sec.]	Spectrum	Gamma	WL [m]	Current [m/sec]	Direction [deg]	Spreading [deg]	Laboratory	Irribarren
Z001	1.00	4.40	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.67
Z002	1.50	5.40	JONSWAP	3.3	3	0	0	0 (2D)	FC	3.67
Z003	2.00	6.20	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.65
Z004	2.50	7.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	3.69
Z005	3.00	7.60	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.66
Z006	3.50	8.20	JONSWAP	3.3	3	0	0	0 (2D)	FC	3.65
Z007	4.00	8.80	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.67
Z008	4.50	9.30	JONSWAP	3.3	3	0	0	0 (2D)	FC	3.65
Z009	5.00	9.80	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.65
Z010	5.50	10.30	JONSWAP	3.3	3	0	0	0 (2D)	FC	3.66
Z011	6.00	10.80	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.67
Z012	6.50	11.20	JONSWAP	3.3	3	0	0	0 (2D)	FC	3.66
Z013	7.00	11.60	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	3.65
Z014	1.00	5.00	JONSWAP/PM	1.0	3	0	0	0 (2D)	FC	4.17
Z015	1.50	6.10	JONSWAP/PM	1.0	3	0	0	0 (2D)	FC	4.15
Z016	2.00	7.10	JONSWAP/PM	1.0	3	0	0	0 (2D)	FC	4.18
Z017	2.50	7.90	JONSWAP/PM	1.0	3	0	0	0 (2D)	FC	4.16
Z020	4.00	10.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	4.17
Z027	3.00	5.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	2.40
Z028	3.00	6.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	2.89
Z029	3.00	10.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	4.81
Z030	3.00	11.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	5.29
Z031	5.00	5.00	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	1.86
Z032	5.00	6.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	2.24
Z033	5.00	7.00	JONSWAP	3.3	3	0	0	0 (2D)	FC	2.61
Z034	5.00	8.00	JONSWAP	3.3	3	0	0	0 (2D)	FC/AAU	2.98
Z035	5.00	9.00	JONSWAP	3.3	0	0	0	0 (2D)	FC	3.35
Z036	5.00	9.00	JONSWAP	3.3	1	0	0	0 (2D)	FC	3.35
Z037	5.00	9.00	JONSWAP	3.3	2	0	0	0 (2D)	FC	3.35
Z038	5.00	9.00	JONSWAP	3.3	4	0	0	0 (2D)	FC	3.35
Z039	5.00	9.00	JONSWAP	3.3	5	0	0	0 (2D)	FC	3.35
Z040	5.00	9.00	JONSWAP	3.3	6	0	0	0 (2D)	FC	3.35
Z041	5.00	11.00	JONSWAP	3.3	0	0	0	0 (2D)	FC	4.10
Z042	5.00	11.00	JONSWAP	3.3	1	0	0	0 (2D)	FC	4.10
Z043	5.00	11.00	JONSWAP	3.3	2	0	0	0 (2D)	FC	4.10
Z044	5.00	11.00	JONSWAP	3.3	4	0	0	0 (2D)	FC	4.10
Z045	5.00	11.00	JONSWAP	3.3	5	0	0	0 (2D)	FC	4.10
Z046	5.00	11.00	JONSWAP	3.3	6	0	0	0 (2D)	FC	4.10
Z047	3.00	7.00	JONSWAP	3.3	3	0.5	0	0	AAU	3.37
Z048	3.00	7.00	JONSWAP	3.3	3	1	0	0	AAU	3.37
Z049	3.00	7.00	JONSWAP	3.3	3	0.5	20	0	AAU	3.37
Z050	3.00	7.00	JONSWAP	3.3	3	1	20	0	AAU	3.37
Z051	5.00	9.00	JONSWAP	3.3	3	0	0	15	AAU	3.35

Z052	5.00	9.00	JONSWAP	3.3	3	0	0	30	AAU		3.35				
Z053	5.00	9.00	JONSWAP	3.3	3	0	10	0	AAU		3.35				
Z054	5.00	9.00	JONSWAP	3.3	3	0	10	15	AAU		3.35				
Z055	5.00	9.00	JONSWAP	3.3	3	0	10	30	AAU		3.35				
Z056	5.00	9.00	JONSWAP	3.3	3	0	20	0	AAU		3.35				
Z057	5.00	9.00	JONSWAP	3.3	3	0	20	15	AAU		3.35				
Z058	5.00	9.00	JONSWAP	3.3	3	0	20	30	AAU		3.35				
Z059	5.00	9.00	JONSWAP	3.3	3	0	30	0	AAU		3.35				
Z060	5.00	9.00	JONSWAP	3.3	3	0	30	15	AAU		3.35				
Z061	5.00	9.00	JONSWAP	3.3	3	0	30	30	AAU		3.35				
Z062	5.00	9.00	JONSWAP	3.3	3	0	45	0	AAU		3.35				
Z063	5.00	9.00	JONSWAP	3.3	3	0	45	15	AAU		3.35				
Z064	5.00	9.00	JONSWAP	3.3	3	0	45	30	AAU		3.35				
Z065	3.00	7.00	JONSWAP	1.0	3	0	0	0	AAU		3.37				
Z066	3.00	7.00	JONSWAP	7.0	3	0	0	0	AAU		3.37				
Z067	5.00	9.00	JONSWAP	1.0	3	0	0	0	AAU		3.35				
Z068	5.00	9.00	JONSWAP	7.0	3	0	0	0	AAU		3.35				
Z0XX1	5.00	9.00	2 peaked Tp2=5		3	0	0	0	AAU		3.35				
Z0XX2	5.00	9.00	2 peaked Tp2=6		3	0	0	0	AAU		3.35				
Z0XX3	5.00	9.00	2 peaked Tp2=7		3	0	0	0	AAU		3.35				
Z070	-	-	Measured storm		-	0	0	0 (2D)	FC/AAU						
Z071	-	-	Measured storm		-	0	0	0 (2D)	FC/AAU						
Z072	-	-	Measured storm		-	0	0	0 (2D)	FC/AAU						
Z073	-	-	Measured storm		-	0	0	0 (2D)	FC/AAU						
Z074	-	-	Measured storm		-	0	0	0 (2D)	FC/AAU						
Z075	2.00	9.00	Regular		3	0	0	0 (2D)	FC/AAU		5.30				
Z076	3.00	9.00	Regular		3	0	0	0 (2D)	FC/AAU		4.33				
Z077	4.00	9.00	Regular		3	0	0	0 (2D)	FC/AAU		3.75				
Z078	5.00	9.00	Regular		3	0	0	0 (2D)	FC/AAU		3.35				
Z079	6.00	9.00	Regular		3	0	0	0 (2D)	FC/AAU		3.06				
Z080	5.00	7.00	Regular		3	0	0	0 (2D)	FC/AAU		2.61				
Z081	5.00	8.00	Regular		3	0	0	0 (2D)	FC/AAU		2.98				
Z082	5.00	9.00	Regular		3	0	0	0 (2D)	FC/AAU		3.35				
Z083	5.00	10.00	Regular		3	0	0	0 (2D)	FC/AAU		3.73				
Z084	5.00	11.00	Regular		3	0	0	0 (2D)	FC/AAU		4.10				

MAST-OPTICREST: PETTEN

Date: February 1999 By: Jimmy Murphy and Marcel van Gent

Test-number	Description	Deep water (NAP)	Hs0	Tp	Spectrum	WL (NAP)	Tot-depth	sop	Dir (deg.)	Spr. (deg.)						
P00	Regular waves	20	4	12		2.10	22.1	0.0178	0	0						
										date	time	Hm0	Tm	Tm-1,0	Nwaves	Rup-2% ###
P01	Measured spectra	20	4.24	11.1	#	2.10	22.1	0.0220		1 jan '95	15:40	4.20	6.8	8.9	530	833.00
P02		20	4.24	11.1	#	2.01	22.0	0.0220		1 jan '95	17:00	4.23	6.5	8.6	551	759.85
P03		20	3.84	16.7	#	2.18	22.2	0.0088		2 jan '95	04:00	3.95	6.5	10.2	551	866.00
P04		20	4.24	16.7	#	1.64	21.6	0.0097		2 jan '95	05:40	4.29	6.9	10.4	518	689.41
P05		20	3.08	14.3	#	1.60	21.6	0.0096		2 jan '95	16:20	3.10	7.1	9.8	503	644.00
P06		20	3.70	10.0	#	2.00	22.0	0.0237		10 jan '95	11:00	3.75	6.3	8.8	566	767.14
P11	Hs-Water level (low)	20	1.8	6.5	J	2.10	22.1	0.0273	0	0						
P12		20	2	8.5	J	2.10	22.1	0.0177	0	0						
P13		20	3	10.5	J	2.10	22.1	0.0174	0	0						
P14		20	4.5	12	J	2.10	22.1	0.0200	0	0						
P15		20	5	13.5	J	2.10	22.1	0.0176	0	0						
P16		20	2.5	18	J	2.10	22.1	0.0049	0	0						
P21	Hs-Water level (high)	20	1.8	6.5	J	4.70	24.7	0.0273	0	0						
P22		20	2	8.5	J	4.70	24.7	0.0177	0	0						
P23		20	3	10.5	J	4.70	24.7	0.0174	0	0						
P24		20	4.5	12	J	4.70	24.7	0.0200	0	0						
P25		20	5	13.5	J	4.70	24.7	0.0176	0	0						
P26		20	2.5	18	J	4.70	24.7	0.0049	0	0						
P31	Wave steepness	20	4	7	J	2.10	22.1	0.0523	0	0						
P31		20	4	9	J	2.10	22.1	0.0316	0	0						
P32		20	4	12	J	2.10	22.1	0.0178	0	0						
P33		20	4	14	J	2.10	22.1	0.0131	0	0						
P41	Wave steepness; WL high	20	4	7	J	4.70	24.7	0.0523	0	0						
P42		20	4	9	J	4.70	24.7	0.0316	0	0						
P43		20	4	12	J	4.70	24.7	0.0178	0	0						
P44		20	4	14	J	4.70	24.7	0.0131	0	0						
P51	Double peaked	20	4	12	Double; Tp2=6	2.10	22.1	0.0178	0	0						
P52		20	4	12	Double; Tp2=8	2.10	22.1	0.0178	0	0						
P53		20	4	12	Double; Tp2=10	2.10	22.1	0.0178	0	0						
	Directional															
P61	Hs-Water level (high)	20	1.8	6.5	J	4.70	24.7	0.0273	10	0						
P62		20	2	8.5	J	4.70	24.7	0.0177	10	0						
P63		20	3	10.5	J	4.70	24.7	0.0174	10	0						
P64		20	4.5	12	J	4.70	24.7	0.0200	10	0						
P65		20	5	13.5	J	4.70	24.7	0.0176	10	0						
P66		20	2.5	18	J	4.70	24.7	0.0049	10	0						
P71		20	1.8	6.5	J	4.70	24.7	0.0273	20	0						
P72		20	2	8.5	J	4.70	24.7	0.0177	20	0						
P73		20	3	10.5	J	4.70	24.7	0.0174	20	0						
P74		20	4.5	12	J	4.70	24.7	0.0200	20	0						