ELASTOCOAST PILOTS IN THE NETHERLANDS
2008-2009 EXTENDED MONITORING

ELASTOGRAN GMBH



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CHAPTER 1 Introduction

1.1 ELASTOCOAST PILOTS IN THE NETHERLANDS

Elastocoast is a new type of revetment system that can be applied in the wave attack-zone, run-up-zone or inner slope of dikes. It consists of granular material fixed together with a two-component polyurethane adhesive. In the Elastocoast system each individual rock is covered with a thin film of polyurethane. When cured this film bonds the rocks together only on their contact points, retaining a highly permeable, open structure.

From 2004 to 2007 several pilot tests were constructed along the North-Sea islands in the most northern part of Germany. In 2007 Elastocoast was introduced to the Dutch market. ARCADIS supervised the construction and monitoring of two prototype pilots in the Netherlands:

- September 2007: Revetment on a rudimentary sea dike called 'Zuidbout' near Ouwerkerk in the Eastern Scheldt, 490 m^2 on a 1:3-1:4 slope.
- October 2007: Refurbishment of the head of beach groyne no. 20.9 near the Pettemer Zeewering along the North Sea coast at Petten, 385 m^2 on a horizontal bed.

These prototype pilots have been subject to monitoring during the storm seasons of 2007-2008 and 2008-2009.



Figure 1.1
Dutch Elastocoast pilots 'Petten' and 'Zuidbout'.

1.2 RELATION TO PREVIOUS REPORTS

In the current report the results of the Elastocoast pilot monitoring season 2008-2009 are presented. Both hydraulic engineering and ecological aspects will be discussed. Therefore this report can be seen as a follow-up to the two reports from previous monitoring season.

- Elastocoast pilots in the Netherlands, storm season 2007/2008, 15 September 2008 [lit. 1].
  In this report the hydraulic engineering aspects of both pilots are discussed. This report gives a description of the structure build-up and an extensive analysis of hydraulic conditions that the pilots have been subjected to during the storm season of 2007-2008. A quick analysis of the loads on the structure and the possible failure mechanisms is followed by a detailed description of the damage that the pilots have suffered during that storm season.
- Early colonization of littoral communities on polyurethane coated substrates: a field and laboratory study, 23 June 2008 [lit. 2].
  This report features the ecological development on both pilots, described in terms of coverage and determination of species that have been found on the structure. This field work is backed up by laboratory tests in which the development of biomass on Elastocoast substrates is measured and compared to other substrates.

The current report is written such that it can be read without pre-knowledge of the previous reports. However, for some backgrounds and details the reader is advised to refer to these reports.

1.3 STRUCTURE OF THIS REPORT

In this chapter the reader has been introduced to the product of Elastocoast, the two Dutch prototype pilots and the relation of the current report to previous studies.

In chapter 2 a description is given of the extended monitoring plan for the season 2008-2009. Shortly, the methods from the monitoring in previous season (2007-2008) are discussed, followed by a motivation of similarities and differences with the extended monitoring.

In chapter 3 the hydraulic conditions at the Zuidbout during the storm season of 2008-2009 are analyzed. The results of damage monitoring and ecological development are then discussed separately in chapters 4 and 5. Were possible, trends over the total period of 2007-2009 are identified.

Finally in chapter 5 conclusions of the previous chapters are summarized.

CHAPTER 2 Monitoring of the pilots

2.1 GENERAL

Previous monitoring season

During the previous monitoring season (2007-2008), the Elastocoast pilots at Petten and Ouwerkerk in the Netherlands were regularly visited for monitoring. Every few weeks both pilots were investigated for damage (hydraulic engineering monitoring) and recovery of flora and fauna (ecological monitoring). Additionally, for both pilots an extensive analysis was made of the hydraulic conditions that occurred during the storm season and their effects at the pilots. Several storm events were analysed in detail.

The approach for the monitoring of the previous season is briefly discussed in Section 2.2 of this report. For a detailed description reference is made to [lit. 1] and [lit. 2].

Continuity

It is important that the data from the extended monitoring season (2008-2009) can be compared with the results from the previous season. This means that continuity in the monitoring methods is required. However, due to limited time and resources, the extended monitoring cannot be as extensive and time consuming as the previous.

Extended monitoring season

For the extended monitoring season the frequency of monitoring visits and the type of monitoring are limited, compared to the previous season. The differences are shown in Table 2.1. The choices that have been made for the extended monitoring are clarified in Section 2.3 of this report.

Table 2.1
Comparison of monitoring extent for the seasons 2007-2008 and 2008-2009.

Monitoring aspect	Previous monitoring season (2007-2008)	Extended monitoring season (2008-2009)
Pilot location Zuidbout		
- Hydraulic conditions	*quantitative, continuous*	*quantitative, continuous*
- Macro scale damage	*qualitative (7×)*	*qualitative (2×)*
- Micro scale damage	*quantitative (7×)*	*quantitative (2×)*
- Ecology	*quantitative (6×)*	*qualitative (2×)*
Pilot location Petten		
- Hydraulic conditions	*quantitative, continuous*	-
- Macro scale damage	*qualitative (5×)*	*qualitative (1×)*
- Micro scale damage	*quantitative (5×)*	-
- Ecology	*quantitative (7×)*	*qualitative (1×)*

2.2 APPROACH FOR PREVIOUS MONITORING SEASON (2007-2008)

Monitoring of hydraulic conditions

In order to analyse the hydraulic loads that the Elastocoast revetments have suffered during the storm season of 2007-2008 hydraulic data was retrieved from the following sources:

- Pilot location Zuidbout: Hydro Meteo Centrum Zeeland (HMCZ). Water levels and wind data are measured at the city of Stavenisse and wave data are measured at a nearby buoy (KEET GHr2).
- Pilot location Petten: Rijksinstituut voor Kust en Zee (RIKZ). Water levels, wind data and wave data are all retrieved from 'Pole 6' of an extensive series of measuring instruments.

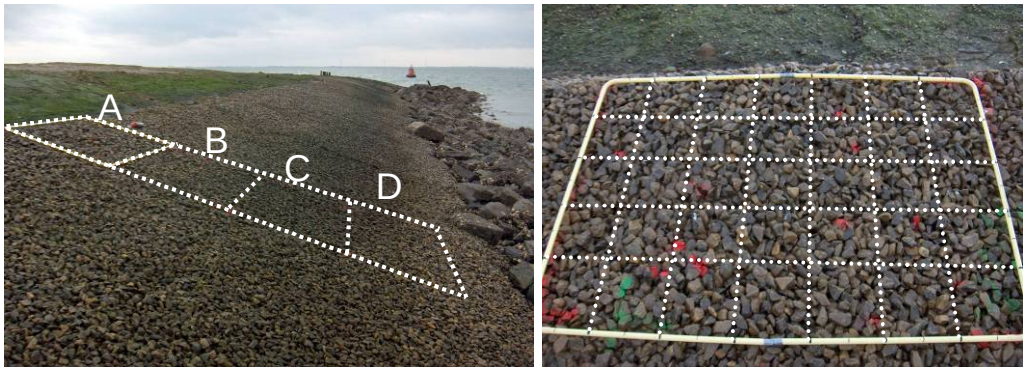
For both locations the measuring instruments are located very close to the pilots. Spatial variation in the hydraulic conditions between the measuring point and the pilot location can therefore be neglected. The measured data is a direct representation of the hydraulic effects at the pilot location.

Damage monitoring

In order to quantify damage on a micro scale, on the site fixed areas on the Elastocoast protection have been marked with paint for systematic inspection. For the Zuidbout pilot, control areas with a width of 1.50 m and a length of 4.00 m have been chosen respectively on the 10 cm, 20 cm and 30 cm stretch. These areas reach from a level of approximately NAP+0.50 m to NAP+1.50 m. Each monitoring area is divided in four parts: A, B, C and D. A tube frame is used to create a grid, so that the location of damage can be noted down (Figure 2.1).

Figure 2.1

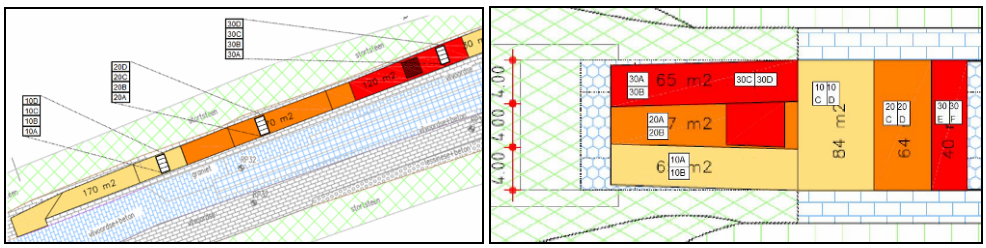
Example monitoring area of 1.50 m x 4.00 m, divided in four parts (left).
Tube frame subdivided with a grid. Damage is marked with a red paint dot (right).



The control areas are laid out on the Elastocoast structures as shown in Figure 2.2:

Figure 2.2

Control areas on the Zuidbout pilot (left) and the Petten pilot (right).



During each visit all marked areas are examined. If damage is detected, it is marked on the surface with a dot of paint and noted down on a monitoring sheet.

The rest of the Elastocoast stretches are also examined visually to detect damages on a macro scale qualitatively. If any significant damage is found in a particular area this area is marked and added to the list for periodical monitoring.

Ecological monitoring
The ecological development on the Elastocoast revetment in the first months after construction of the pilots was monitored by a marine ecologist. Species found on and close to the Elastocoast revetment were identified and the algal coverage on several control areas was quantified. Ecological monitoring took place at the same time and intervals as damage monitoring where possible.

2.3 APPROACH FOR EXTENDED MONITORING SEASON 2008-2009

Monitoring of hydraulic conditions
The hydraulic conditions for the pilot location Zuidbout have been obtained and analyzed for the storm season 2008-2009, with the same methods as were used in the season 2007-2008.

The choice has been made to perform no analysis of the hydraulic conditions for the pilot location Petten. This choice can be substantiated with the following arguments:

- The hydraulic data for Petten from the season 2007-2008 was difficult to retrieve. After the datasets had been released from the RIKZ, the process of extracting the required parameters from these extensive datasets proved to be time consuming.
- During the most extreme hydraulic conditions, the Elastocoast structure at Petten was submerged most of the time. The positioning of the structure make it difficult to translate measured hydraulic conditions to actual loads on the revetment.
- For the season of 2008-2009 the micro scale damage was not quantified. Therefore it would be difficult to relate the hydraulic data to damage development.

Damage monitoring
In previous monitoring season no macro scale damage was observed at either of the pilots. It is likely that this is due to the relatively stiff foundation of both revetment structures. A structural analysis [lit. 3] has confirmed that mechanisms such as mechanical breakage or instability of the structure at a macro scale will not occur under the combinations of hydraulic conditions and structure properties of both pilots. Nonetheless, during monitoring visits the occurrence of macro scale damage is visually assessed in case any unforeseen mechanisms take place.

At the pilot location Zuidbout micro scale damage has been quantified for the storm season of 2008-2009 using the same methods as previous storm season. Since damage development during the season 2007-2008 proved to be only minor, it has been found sufficient to perform only two damage measurements for the storm season of 2008-2009 in contrast to the seven measurements in previous season (Table 2.1). The first measurement was in December 2008, the second in April 2009. Together, these two measurements provide a good indication of the total damage that the Elastocoast pilot has suffered during the entire storm season 2008-2009.

At the pilot location Petten micro scale damage has not been measured during extended monitoring. From the results of previous monitoring it was concluded that as from April 2008 reliable measurements were no longer possible, due to weathering and plant growth on the Elastocoast surface [lit. 1]. These effects cause any signs of micro scale damage to be 'erased' from the surface. Therefore in the extended monitoring micro scale damage is no longer quantified.

Ecological monitoring

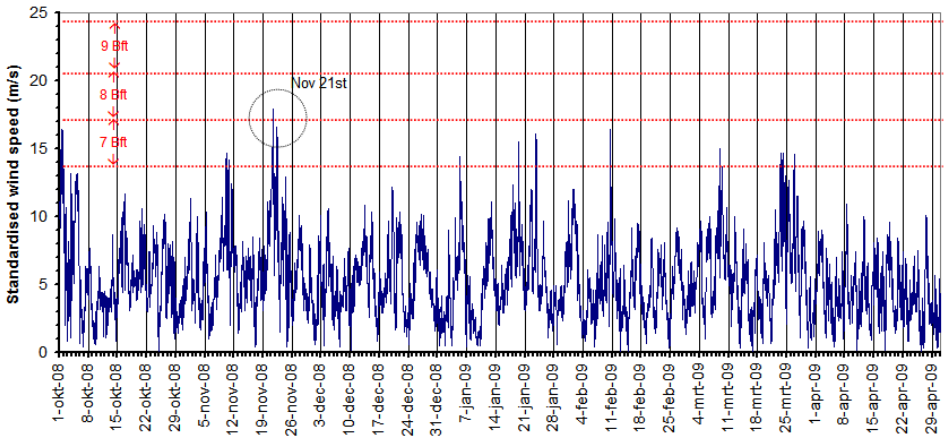
The ecological observations for the extended monitoring are less extensive than for the previous monitoring. No marine ecologist was available to visit the pilot locations. Instead, descriptions and photo material were sent to a marine ecologist off location. This has resulted in a far from complete, qualitative description of the ecological development during the extended monitoring season. Still, these observations give a good indication of the extent and diversity of the ecologic community on the Elastocoast pilots.

CHAPTER 3 Hydraulic conditions at pilot location Zuidbout

3.1 STORM SEASON 2008-2009

In the period from October 2008 to April 2009 only one storm event occurred with 10-minute average wind speeds of at least 17.2 m/s (8 Bft). The following graph shows wind speeds measured at the city of Stavenisse. The storm event of 21 November 2008 is indicated with a circle.

Figure 3.1
Wind measurements at Stavenisse; 10-minute average wind speeds at 10 m above suface.



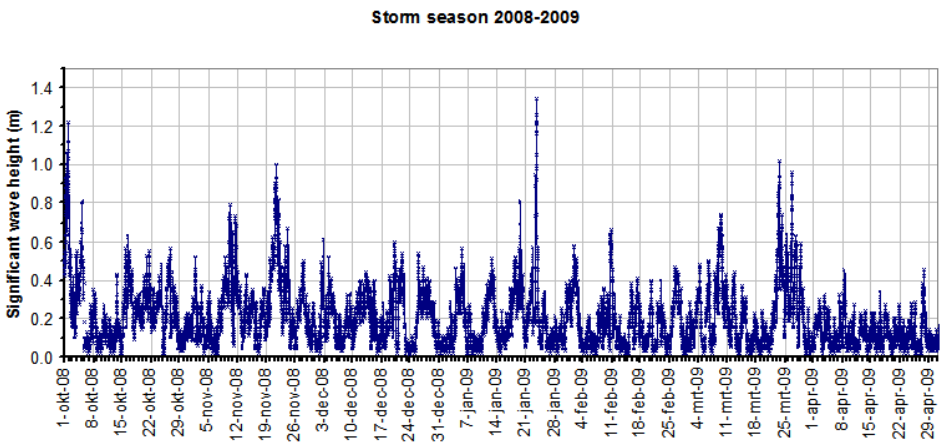
The storm season of 2008-2009 has been quite mild, compared to the same period in 2007-2008. In the previous storm season a total of 6 storm events could be identified, the most extreme having wind speeds reaching 9 Bft.

3.2 HYDRAULIC EFFECTS AT THE STRUCTURE

The following graph shows the significant wave heights at measuring buoy Keeten during the period of October 2008 to April 2009. It shows that the largest significant wave heights were not measured during the abovementioned storm event of 21 November 2008, but under milder wind conditions on 23 January 2009.

Figure 3.2

Significant wave heights at measuring buoy Keeten.



In the next section the hydraulic loads on the Elastocoast structure are analysed in detail for the following two events:

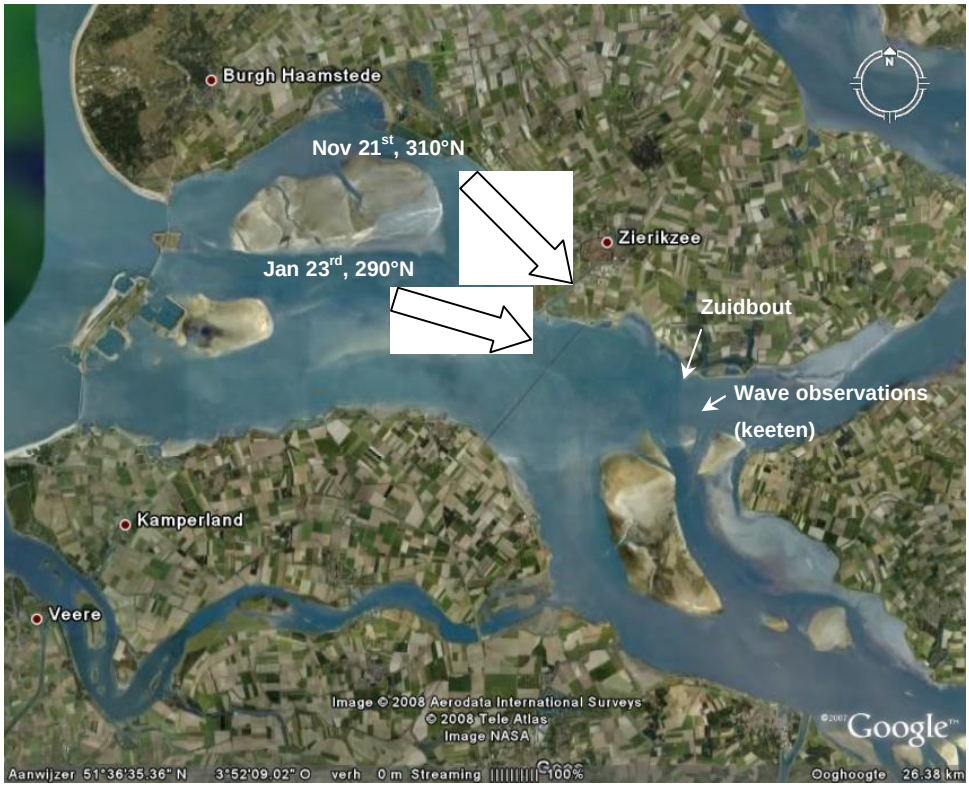
§ 21 November 2008 – highest measured wind speeds

§ 23 January 2009 – highest measured significant wave height

The position of the Zuidbout in the Eastern-Scheldt estuary is such that it is expected that most extreme wave conditions will occur with a wind blowing from the West. From this direction the distance over which the wind blows over the water surface before reaching the prototype pilot is longest. This is illustrated in the figure below. The Elastocoast structure is located on the North West face of the dike and is therefore exposed to direct wave attack from the West.

Figure 3.3

Eastern-Scheldt with the locations of the prototype pilot and the measuring buoy Keeten. Also, the wind directions of the events of 21 November 2008 and 23 January 2009 are indicated.



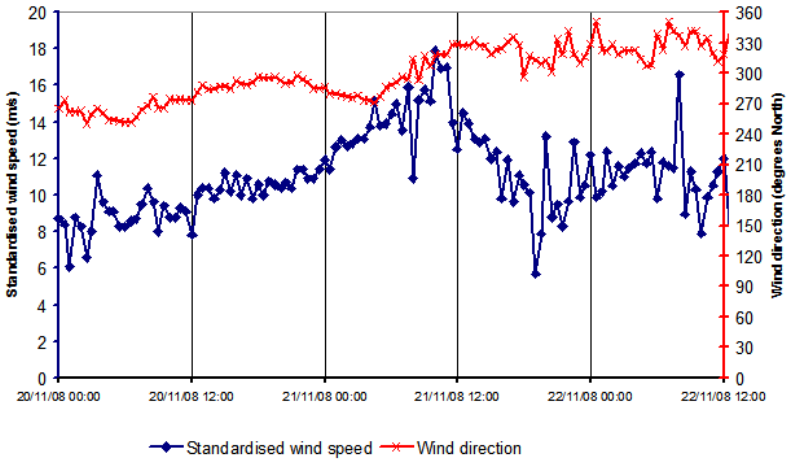
3.3 LOADING OF THE ELASTOCOAST STRUCTURE

Loading of the Elastocoast structure during the storm of Nov 21st, 2008

The following graph shows the wind conditions as measured at Stavenisse in the period in which the storm occurred.

Figure 3.4

Wind speeds and direction during the storm of 21 November 2008.

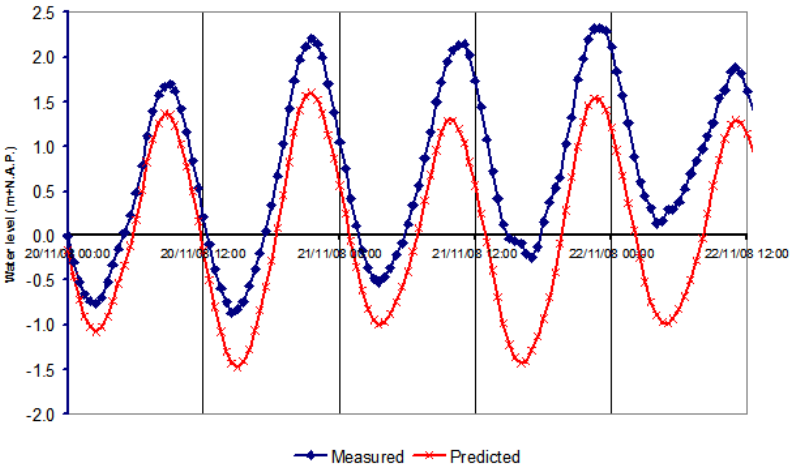


Disregarding the somewhat erratic behaviour of the observations, wind speed peaked around 17 m/s, with a sustained direction around 310ºN.

The following graph shows the water levels and forecasted tides at Stavenisse during the storm. The effect of the wind on the water level is clearly visible.

Figure 3.5

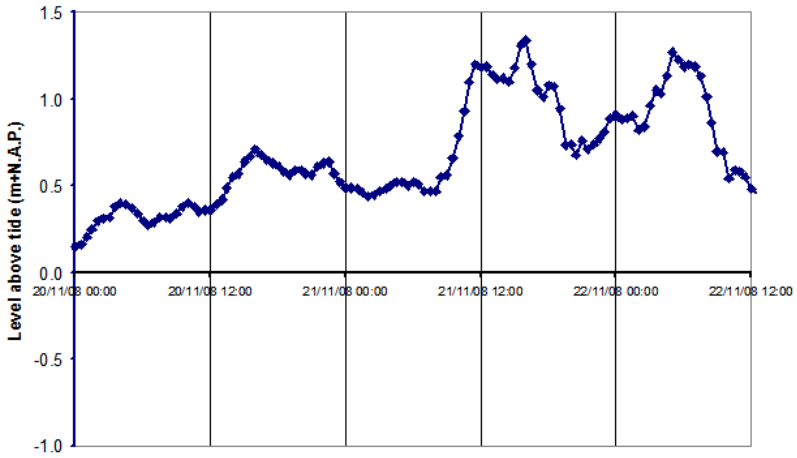
Predicted and actually observed water levels at Stavenisse.



The following graph shows the wind setup, calculated as the difference between forecasted (tidal) water level and actually observed water level.

Figure 3.6

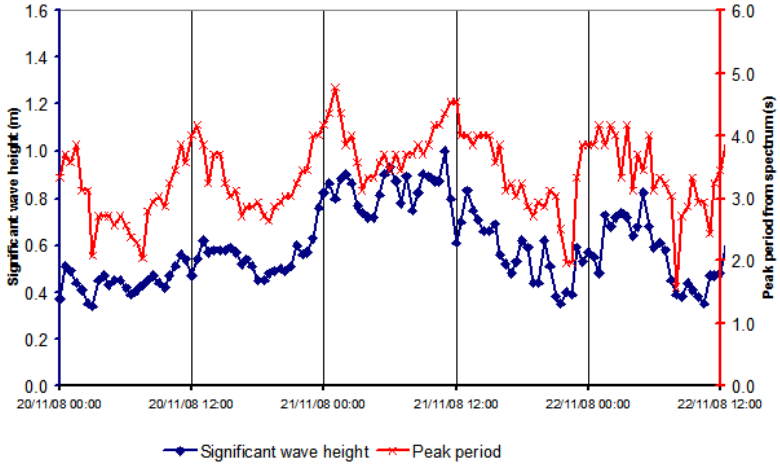
Wind setup.



The wave conditions in the Eastern-Scheldt, measured at the location Keeten are shown below.

Figure 3.7

Significant wave height and peak period.

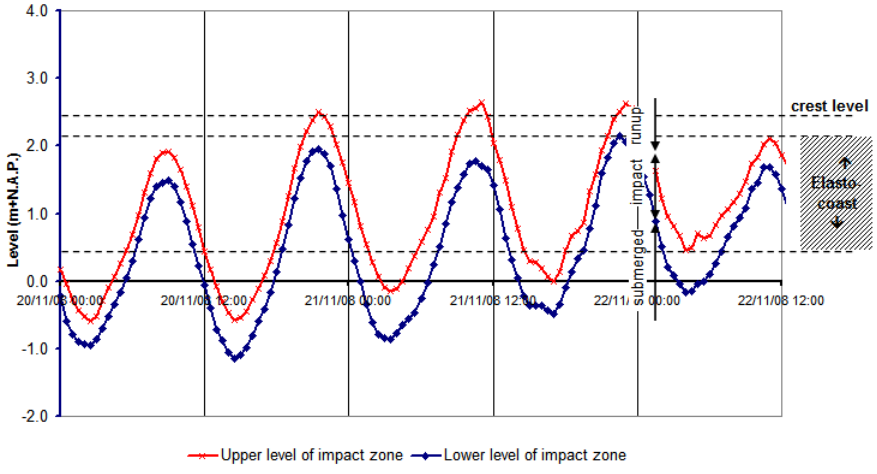


The significant wave height at Keeten peaked around 0.9 m. At the same time the peak period peaked around 4 s.

The following graph shows the upper and lower level of the wave impact zone in comparison to the level of the Elastocoast structure.

Figure 3.8

Position of upper and lower level of the impact zone.

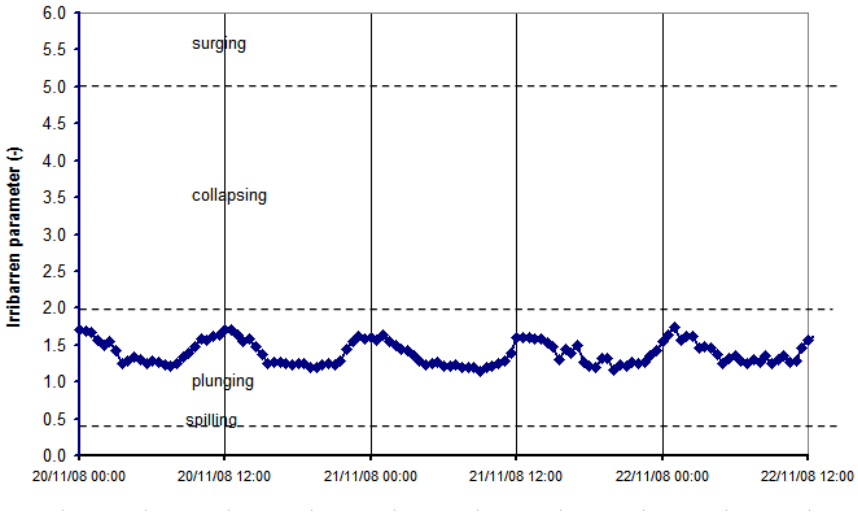


The graph shows that the Elastocoast structure has suffered from all load cases during the storm. Comparison to observed wave conditions show that a persistent wave attack was present from 21 November 0:00 AM to 12:00 AM. Therefore, all load cases have occurred in combination with heavy wave attack.

The graph below shows the Irribarren-parameter at the Zuidbout during the storm and the corresponding breaker type. During the storm, the Elastocoast layer was persistently subjected to breaking waves in the plunging regime.

Figure 3.9

Breaker types that occurred at the Zuidbout during the storm of 21 November 2008.

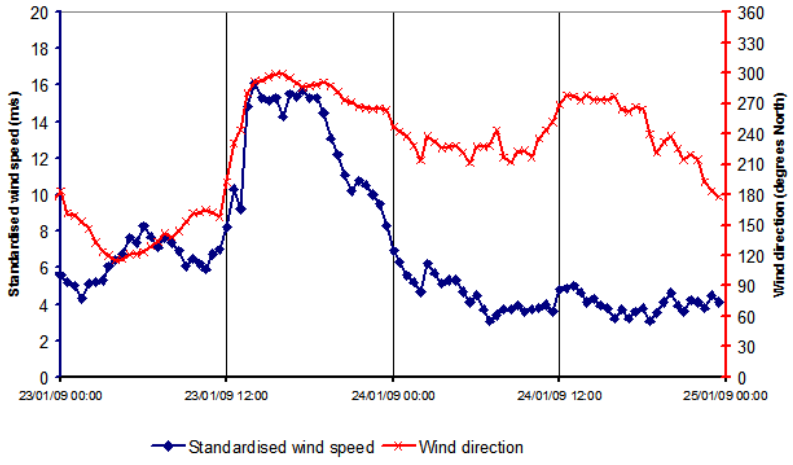


Loading of the Elastocoast structure during the event of Jan 23rd, 2009

The following graph shows the wind conditions as measured at Stavenisse in the period around 23 January 2009.

Figure 3.10

Wind speed and direction during the event of 23 January 2009.

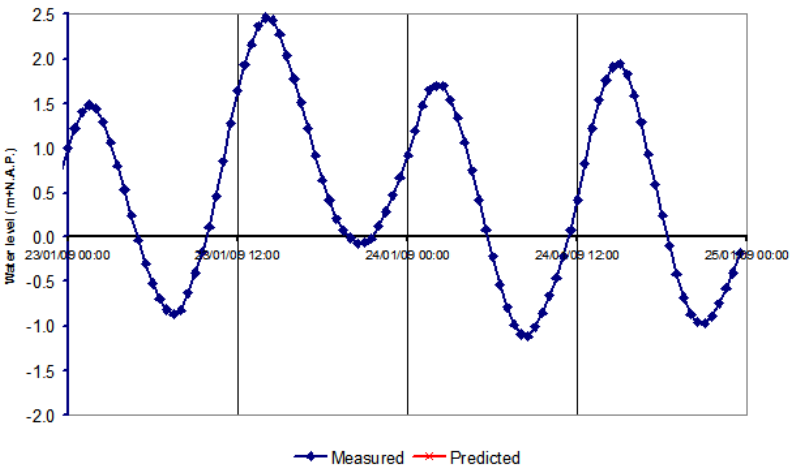


Disregarding the somewhat erratic behaviour of the observations, wind speeds peaked around 16 m/s, with a sustained wind direction around 290ºN. This situation persists for approximately 5 hours, resulting a stronger effect on the hydraulic conditions than were measured during the storm of 21 November 2008.

The following graph shows the water levels that were observed at Stavenisse. Although the predicted tide was not readily available during the event, the effect of the persistent high wind speeds is still clearly visible from the observed water levels.

Figure 3.11

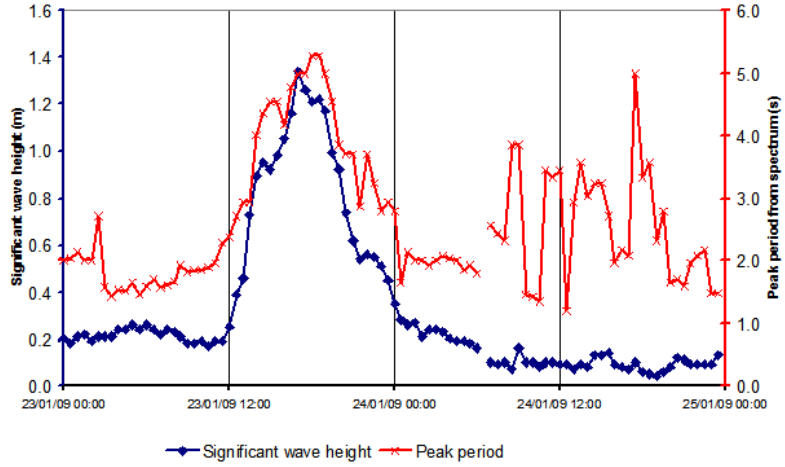
Observed water levels at Stavenisse.



The wave conditions in the Eastern-Scheldt, measured at Keeten are shown below.

Figure 3.12

Significant wave height and peak period.

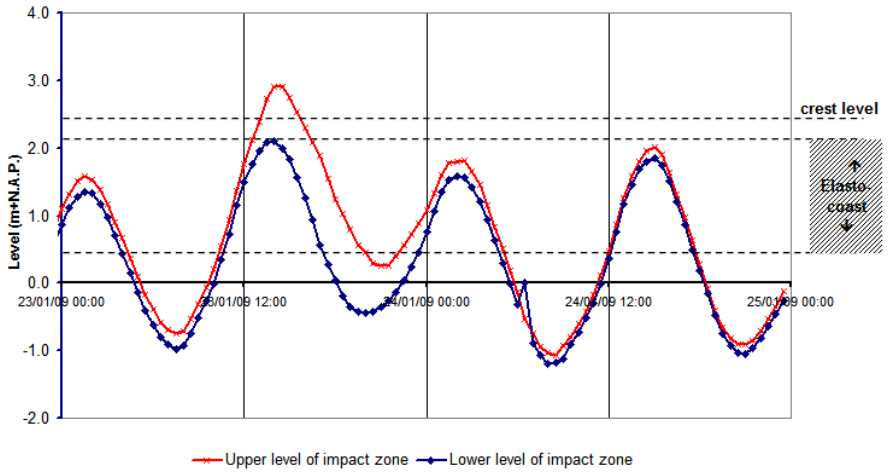


The significant wave height at Keeten peaked around 1.3 m. At the same time the peak period peaked around 5 s.

The following graph shows the upper and lower level of the wave impact zone in comparison to the level of the Elastocoast structure.

Figure 3.13

Position of upper and lower level of the wave impact zone.

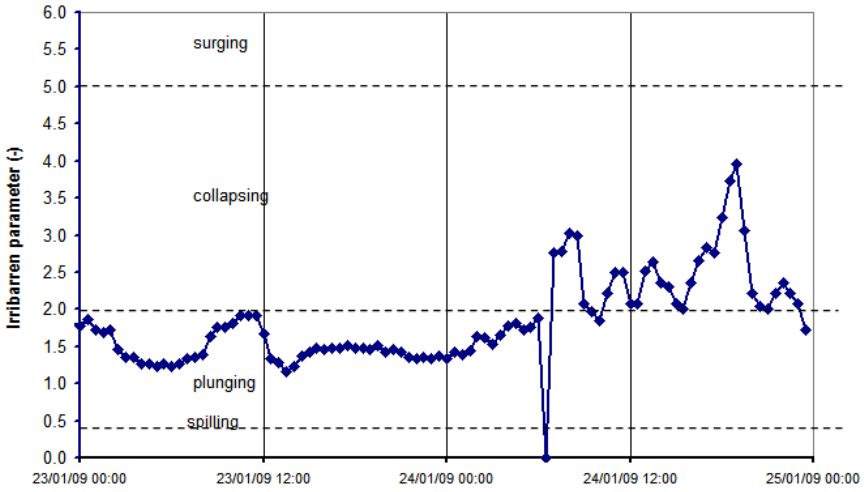


The graph shows that the Elastocoast structure has suffered mostly from the impact and submerged load cases during the event. Comparison to the observed wave conditions shows that a persistent heavy wave attack was present from 21 November 13:00 PM to 18:00 PM. Due to the high water level, most of the time the loading by wave run-up took place above the Elastocoast structure.

The graph below shows the Irribarren-parameter at the Zuidbout during the event and the corresponding breaker type. During the event, the Elastocoast layer was persistently subjected to breaking waves in the plunging regime.

Figure 3.14

Breaker types that occurred at the Zuidbout during the event of 23 January 2009.



3.4 CONCLUSION

Overall, the storm season of 2008-2009 was considerably milder than the storm season of 2007-2008. The loading conditions during two events have been analysed in detail. During the most extreme conditions a significant wave height of 1.3 m was measured and a peak wave period of around 5 s.

During the most extreme conditions, the Elastocoast revetment was persistently subjected to the most unfavourable form of wave loading on a dike slope; namely plunging waves.

CHAPTER 4 Damage development

4.1 INTRODUCTION

In this chapter the results from damage monitoring are presented and discussed. To get a complete view of the damage that the prototype pilots have suffered since their construction in September-October 2008 the following results are presented for each of the pilots in Section 4.2 and Section 4.3:

- Results from previous monitoring season
- Changes in between monitoring seasons
- Results from extended monitoring season

Then, the results will be discussed in Section 4.4 Here possible trends over the seasons are identified with their relation to the hydraulic loading of the structure.

4.2 PILOT LOCATION ZUIDBOUT

4.2.1 RESULTS FROM PREVIOUS MONITORING SEASON

Macroscopic failure

The following observations were made:

1. No visible deformations;
2. No cracks or fissures in the surface of the Elastocoast layer;
3. No visible movement or sliding of the structure.

Other observations regarding macroscopic failure:

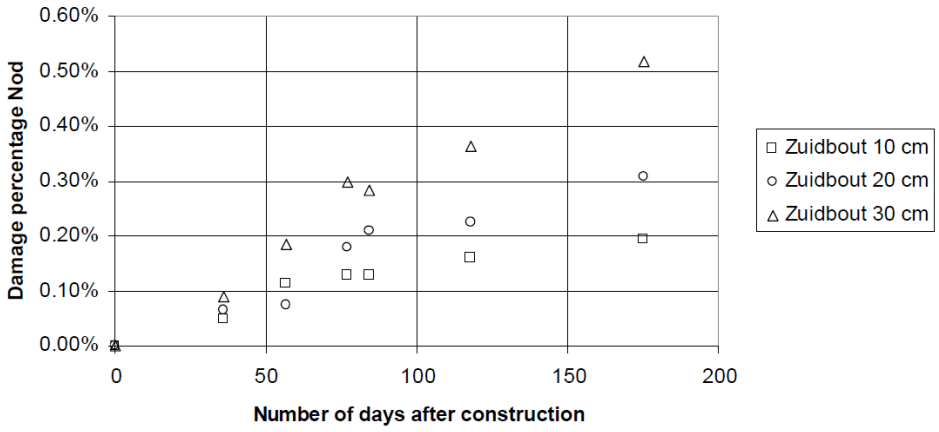
4. Dirt in the form of plants and debris carried in by waves collect on the surface, but do not clog the open structure of the Elastocoast revetment.

Microscopic failure

The following graph shows the observed damage development during the storm season of 2007-2008. The damage is expressed as a damage percentage N_{od}.

Figure 4.1

Damage development during the storm season of 2007-2008 [lit. 1].



4.2.2 CHANGES IN BETWEEN MONITORING SEASONS

Macroscopic failure

On a macroscopic scale there have been no changes since the last observations in March 2008.

Microscopic failure

During previous monitoring season the control areas on the Zuidbout were set out on the dike slope with red paint markings. Also, the signs of microscopic damage were marked with red dots. During the last visit, on March 13th 2008, all markings were extra accentuated. 9 months later, on December 19th 2008, the paint marks indicating the location of the control areas and the 'old' damage signs were still clearly visible.

It is therefore assumed that, with some caution, the observations from December 19th can be seen as an extension of the set of observations made during last season. The next table gives the results from the last monitoring visit from previous season (March 13th, 2008) and the results from the first monitoring for the storm season of 2008-2009.

Table 4.1

Comparison of damage at the end of season 2007-2008 and the beginning of season 2008-2009.

Layer thickness	Reference area	13 Mar (day 175)		19 Dec (day 456)
10 cm	Z10A	12		14
	Z10B	4		5
	Z10C	4		4
	Z10D	4		6
	Total	24		29
20 cm	Z20A	11		20
	Z20B	10		12
	Z20C	10		13
	Z20D	7		4
	Total	38		49
30 cm	Z30A	14		18
	Z30B	27		24
	Z30C	10		10
	Z30D	13		11
	Total	64		63

From the table above it can be seen that the overall correspondence between the two sets is reasonable. Only in the upper part of the 20 cm area a significant increase with 9 dislocated

rocks is observed. The rest of the measurements differ no more than 3 rocks. Overall it can be concluded that there is only a small increase in erosion damage, since the last measurement in March.

4.2.3 RESULTS FROM EXTENDED MONITORING SEASON

On 19 December 2008 and 28 April 2009 the pilot location Zuidbout has been visited for extended monitoring.

Macroscopic failure

Regarding macro scale damage the following observations were made:

- No visible deformations;
- No cracks in the surface of the Elastocoast top layer;
- No visible movement or sliding of the structure;
- The open structure of the Elastocoast top layer is not clogged by sand or debris.

Microscopic failure

Micro scale damage over the monitoring area is quantified in the table below.

Table 4.2
Damage development during storm season 2008-2009.

Layer thickness	Reference area	19 Dec (day 456)	28 Apr (day 586)
10 cm	Z10A	14	17
	Z10B	5	9
	Z10C	4	10
	Z10D	6	10
	Total	29	46
20 cm	Z20A	20	28
	Z20B	12	18
	Z20C	13	15
	Z20D	4	15
	Total	49	76
30 cm	Z30A	18	22
	Z30B	24	37
	Z30C	10	18
	Z30D	11	17
	Total	63	94

4.3 PILOT LOCATION PETTEN

4.3.1 RESULTS FROM PREVIOUS MONITORING SEASON

On 27 April 2009 the pilot location Petten has been visited for monitoring.

Macroscopic failure

Regarding macro scale damage the following observations were made:

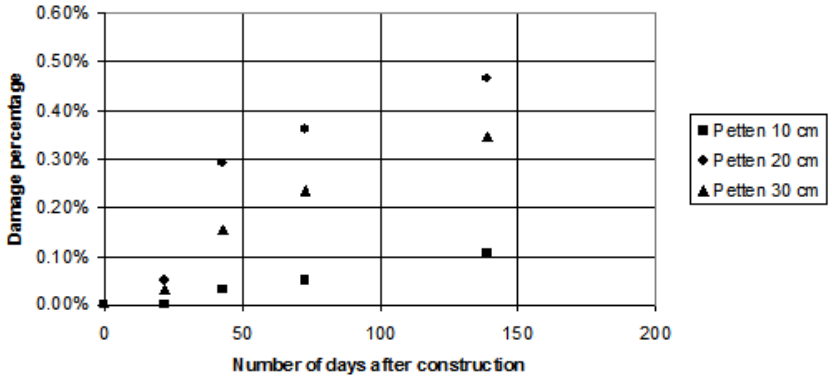
1. No visible deformations;
2. No cracks or fissures in the surface of the Elastocoast layer;
3. No visible movement or sliding of (parts of) the structure.

Other observations regarding macroscopic failure:

4. Significant amounts of dirt (mostly sand and shell material) have collected in the pores of the open structure. There seems to be no difference in amount of dirt between the different layer thicknesses. In time, the structure is clogged by sand, shells and vegetation. Water remains in puddles on the structure after a wave has passed.

Microscopic failure

The following graph shows the observed damage development during the storm season of 2007-2008. The damage is expressed as a damage percentage N_{α}. As from April 2008 (day 139) damage monitoring was ceased because reliable quantification was no longer possible.



4.3.2 CHANGES IN BETWEEN MONITORING SEASONS

Macroscopic failure

No observations have been made at the beginning of the storm season of 2008-2009.

Microscopic failure

No observations have been made at the beginning of the storm season of 2008-2009.

4.3.3 RESULTS FROM EXTENDED MONITORING SEASON

Macroscopic failure

At the end of the monitoring season of 2008-2009, the following observations were made:

1. No visible deformations;
2. No cracks or fissures in the surface of the Elastocoast layer;
3. No visible movement or sliding of (parts of) the structure.

Other observations regarding macroscopic failure:

4. There is still a significant amount of clogging material present. Advanced growth of algae seaweed indicate that this material is not washed out during extreme conditions. Water remains in puddles on the structure permanently (Figure 4.2).
5. Large quantities of mussels have covered the entire surface of the Elastocoast revetment.

Figure 4.2

Water remains permanently in puddles on the clogged structure at Petten.



Microscopic failure

No observations have been made regarding microscopic damage during the storm season of 2008-2009.

4.4 DISCUSSION OF RESULTS

Macroscopic failure

Corresponding to expectations no macro scale damage has been observed at both of the pilots. However, the clogging phenomenon that had already been observed during the previous monitoring season has intensified with the growth of algae and mussels. Now, clogging can be expected to have two effects on the macro scale behaviour of the structure:

- Permeability of the structure is strongly reduced.
- Surface roughness of the structure has reduced.

The first effect may have influence on the macro stability of the structure; it has become more vulnerable to potential uplift pressures. However since the structure build-up of the prototype pilot does not allow the development of high overpressures under the Elastocoast revetment this does not result in instability of the structure.

The reduction of surface roughness will lead to slightly increased flow velocities over the structure and increased wave run-up. Since the structure is orientated horizontally, wave run-up does not play a role in this situation.

So far, the clogging phenomenon has only been observed at the pilot location Petten. Some aspects can be identified that contribute to the susceptibility of this pilot to clogging:

- High concentrations of sand and organic material in the sea-water.
- Horizontal orientation of the revetment, water flow under gravitational force is limited.
- Low vertical position of the revetment (under the mean water level).

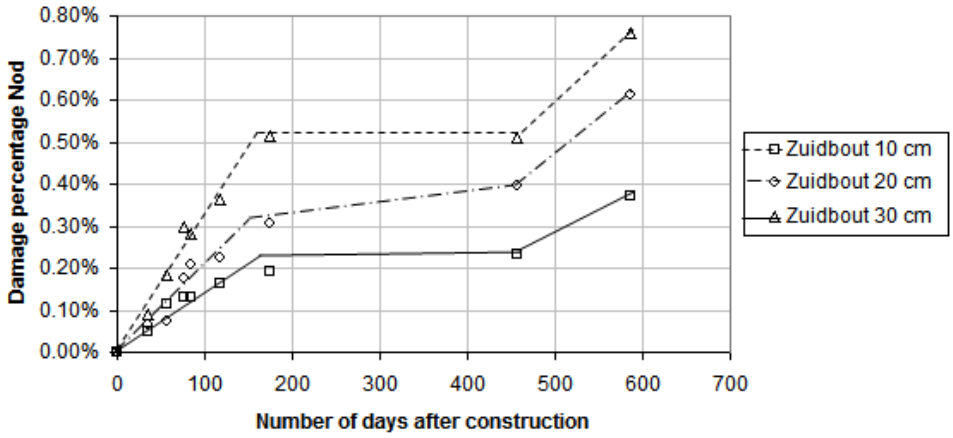
Microscopic failure

Figure 4.3 shows the micro scale damage development over the control areas starting from the construction of the pilot Zuidbout on 20 September 2008 to the end of the extended monitoring season in April 2009. Trend lines for the 10 cm, 20 cm and 30 cm stretches have been determined visually.

It can clearly be seen from Figure 4.3 that the bulk of the damage has occurred only during the storm seasons and a stable situation is present during the summer season. It should be noted that the damages shown in Figure 4.3 are all very small; they are expressed in the damage percentage, which has been determined over the top two layers of stone [lit. 1]. The 20 cm layer consists of approximately 7 layers of stone. Over a period of two years, the total damage of the Elastocoast revetment is still very low.

Figure 4.3

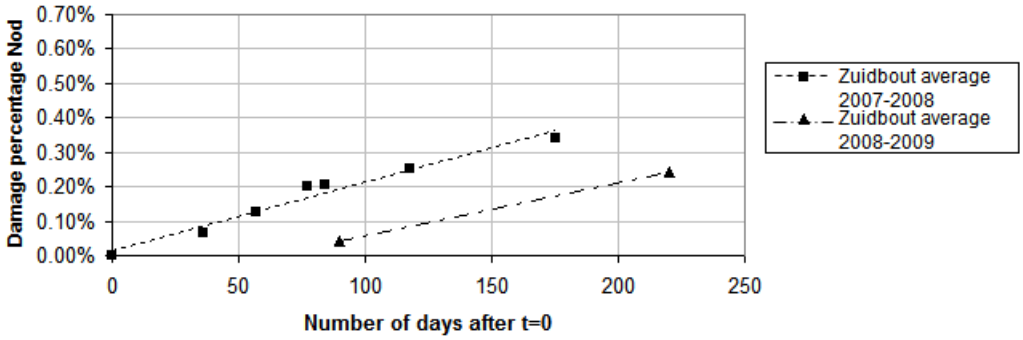
Damage development at pilot location Zuidbout over the period September 2007 to April 2009.



The slopes of the damage progression in Figure 4.3 are approximately equal for the two storm seasons. This can also be seen in Figure 4.4 which shows the normalized and averaged damage for the two storm seasons. In this figure the damage on 20 September of each year has been defined as zero-point (t = 0). The amount damage from the extended monitoring has been reduced by the amount damage at the end of previous monitoring.

Figure 4.4

Normalized and averaged damage development.



Relation to hydraulic conditions

Figure 4.4 shows that the average damage over the storm season of 2007-2008 is roughly between 0.30 – 0.40%, and the damage over the storm season of 2008-2009 is between 0.20 – 0.30 %. The fact that the Elastocoast structure suffered less damage in the second storm season can be attributed to:

§ Burn-in of the structure, 'weakest' rocks are removed first.

§ Hydraulic loading during the storm season 2008-2009 is less than previous season.

4.5 CONCLUSION

At both pilots there has been no damage on a macroscopic scale. At the Petten pilot the clogging phenomenon that was observed during the previous monitoring season has intensified with growth of algae and mussels. This has a negative influence on structure permeability and surface roughness.

On a microscopic scale, after being stable during the summer period, damage has increased further during the second storm season. The damage during the second storm season is less than the first season. This is probably attributable on the one hand to the so called burn-in effect and on the other hand to the relatively mild hydraulic conditions of the second storm season. Total damage to the structure after two storm seasons is still very low.

CHAPTER 5 Ecological development

5.1 INTRODUCTION

The status of ecological development on the Elastocoast pilots has been observed during the same visits as the damage monitoring. Observations have been performed qualitatively. Determination of species has been performed in a later stage and based on photographic material by a marine ecologist.

5.2 PILOT LOCATION ZUIDBOUT

5.2.1 FLORA

Some species that were found and identified on 19 December 2008 and 28 April 2009 are:

- Brown algae (Fucus spiralis)
- Green algae (Enteromorpha compressa)
- Green algae (Blidingia minima)

Figure 5.1
Brown and green algae on pilot location Zuidbout.

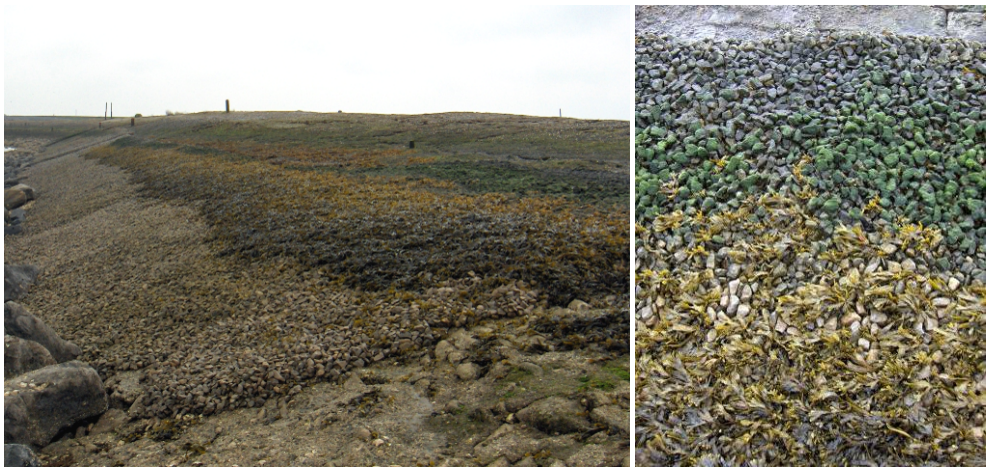


Strong zonation

During previous monitoring season a strong zonation was observed. Algae (mostly green) were present mainly above a certain level on the dike slope. After the summer period, this zonation is still present. The zonation seems to have become more distinct and has even subdivided. The zonation is clearly visible in Figure 5.2. On this part of the Zuidbout the green algae seem to have yielded from the bottom up for brown algae. These brown algae (mostly Fucus spiralis) are present in different stadiums from young to fully developed.

Figure 5.2

Strong vertical zonation at pilot location Zuidbout.



The zonation is not only present in a vertical direction, but also horizontally over the revetment surface. Figure 5.3 shows that further to the north mainly green algae are present, whereas Figure 5.2 showed also brown algae. Figure 5.3 shows patches of different sizes of bright green and dark green algae.

Figure 5.3

Horizontal zonation at pilot location Zuidbout.



There was no change observed in zonation during the winter period (between 19 December 2008 and 28 April 2009).

5.2.2 FAUNA

Some species that were found and identified after the two visits are (see also Figure 5.4):

- Acorn barnacle (Semibalanus balonoides)
- Common periwinkle (Littorina littorea)
- Dog whelk (Nucella lapillus)
- Common limpet (Patella vulgata)
- Sea mite (Halacaridae)
- Springtail (Anurida maritima)
- Sand hopper (Talitrus saltator)



Figure 5.4
Common limpet (top left), sea mite (top right), springtail and acorn barnacle (bottom left) and sand hopper (bottom right).

5.3 PILOT LOCATION PETTEN

5.3.1 FLORA

Some species that were found and identified after visit on 27 April 2009 are:

- Brown algae (possibly Sugar Weed, Laminaria saccharina)
- Green algae (possibly Gut Weed, Enteromorpha intestinalis)
- Sea lettuce (Ulva lactuca)



Figure 5.5
Brown and green algae on pilot location Petten.

Zonation

Like on the Zuidbout, the pilot location Petten shows a zonation in algae growth. The zonation in Petten is less distinct, because the height differences over the revetment are only small. Figure 5.5 shows several patches of green algae on the structure, there seems to be no particular pattern or relation to the position on the Elastocoast revetment.

Figure 5.6

Zonation at pilot location Petten.



5.3.2 FAUNA

Mussels everywhere

Sometime between June 2008 and April 2009 the entire surface (80-90%) of the Elastocoast revetment at pilot location Petten has been covered by mussels (Mytilus eludes). Figure 5.7 shows that the mussels occupy every open space between the rocks on the surface. Strangly some spots remained completely bare for unknown reasons (Figure 5.8).

Figure 5.7

Mussels have covered 80-90% of the Elastocoast revetment at pilot location Petten.



Figure 5.8

Some spots remained completely free of mussels.





Other species

Some other species that were found and identified after two visits are:

- Seagulls (Laridae)
- Acorn barnacle (Semibalanus balonoides)
- Sand hopper (Talitrus saltator)

Figure 5.9

Seagulls (top left), leftovers of a crab which has probably been left behind by a seagull (top right) and a sand hopper (bottom).



5.4 CONCLUSION

On both pilot locations a dynamic and abundant ecological community has developed on parts of the Elastocoast revetment, though strongly zonated and leaving some other parts of the structure bare. At pilot location Petten mussels have found a suitable settling place on the Elastocoast surface.

CHAPTER 6 Conclusion

The main conclusions from chapters 3, 4 and 5 are summarized below:

Hydraulic conditions at pilot location Zuidbout

§ During the storm season of 2008-2009 only one event was observed during which 10 minute average wind speeds reached a strength of 8 Bft. During a second event wind speeds were less high, but maintained for a longer period, resulting in higher waves.
§ The storm season of 2008-2009 was considerably milder than that of 2007-2008.
§ During the most extreme conditions a significant wave height of 1.3 m was measured and a peak wave period of around 5 s. The Elastocoast revetment was persistently subjected to the most unfavourable form of wave loading on a dike slope; namely plunging waves.

Damage development

§ At both pilots there has been no damage on a macroscopic scale.
§ At the Petten pilot the clogging phenomenon that was observed during the previous monitoring season has intensified with growth of algae and mussels. This has a negative influence on structure permeability and surface roughness.
§ Microscopic damage was monitored only at the Zuidbout pilot. After being stable during the summer period, damage has increased further during the second storm season.
§ The micro scale damage at the Zuidbout during the second storm season is less than that from the first season. Total damage to the structure after two storm seasons is still very low.

Ecological development

§ On both pilot locations a dynamic and abundant ecological community has developed.
§ Ecological growth is strongly zonated and some other parts of the structure are left bare.
§ Pilot location Petten has been covered for 80-90% by mussels.

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