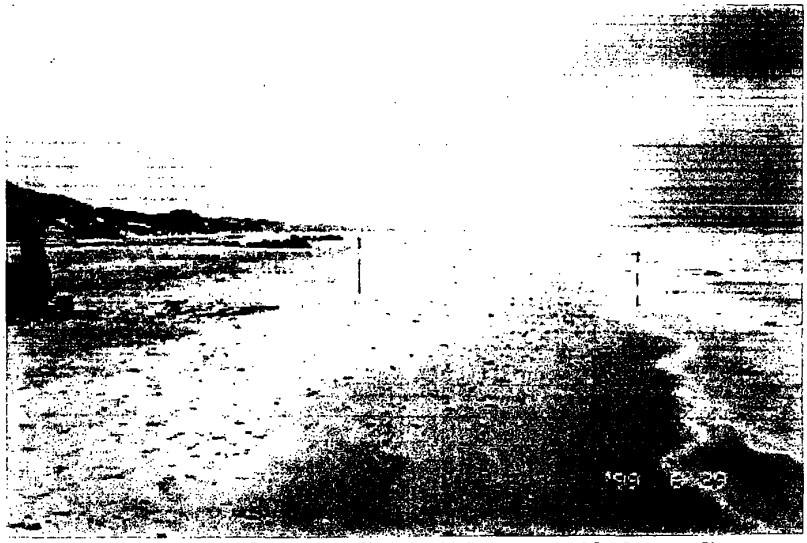
ENVIRONMENTALLY FRIENDLY COASTAL PROTECTION

By

PRESSURE EQUALISATION MODULES



Conventional groynes at Old Skagen displaced 10 metres inside the coastline.

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COST-EFFECTIVE AND ENVIRONMENTALLY FRIENDLY COASTAL PROTECTION

SIC Skagen Innovation Centre has invented the world's most efficient and environmentally friendly coastal protection system. The SIC system is based on pressure equalisation modules and fascines. The SIC system was patented world-wide in 1998.

A long-term and comprehensive test of the efficiency has been carried out on the west coast of Denmark. Furthermore, a twelve-month scientific research programme was performed in 1999.

The obtained results are no less than a global revolution within coastal protection. The system is far more efficient than conventional methods such as groynes, breakwaters and sand nourishment. Due to the well-known lee side erosion effect, groynes and breakwaters create even greater erosion in adjacent coastal areas.

Sand nourishment by dredging is in general terms a very expensive approach (about 130,000 USD / km / year in Denmark), but unfortunately enough it is also quite inefficient since usually the sand will disappear during the first spring tide.

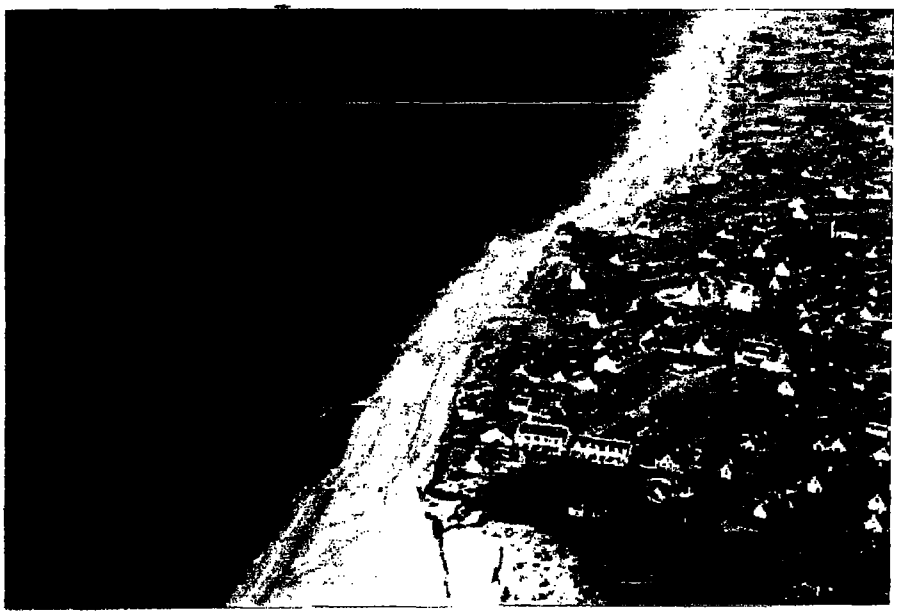
Pressure equalisation Modules.

Grounded groynes at Gammel Skagen, 3rd January 1999 after 9 months with pressure equalisation.

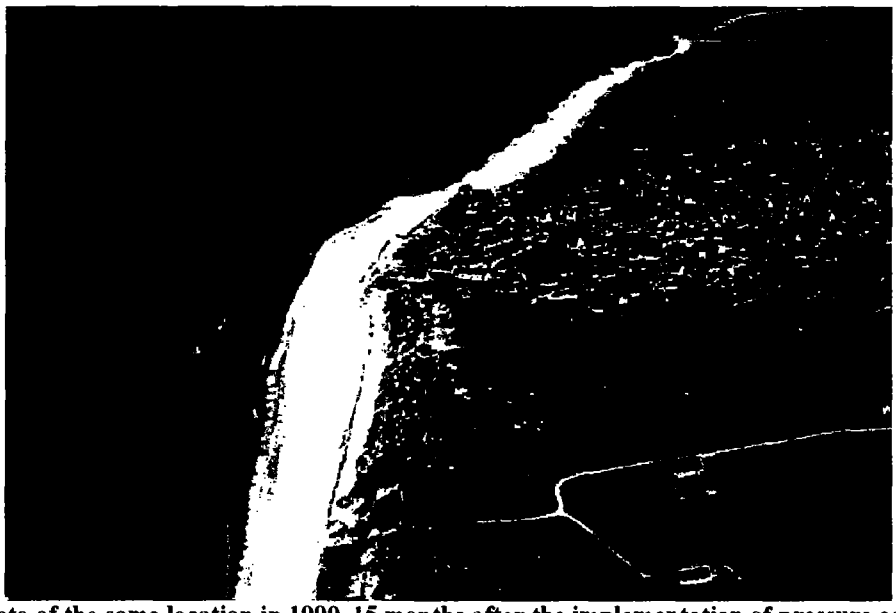
The picture above was taken during a high tide situation, were the groynes are covered with sand. The top of the wooden poles in the groynes are 48 - 61 cm over benchmark 0.

Pressure equalisation modules build up a wide balanced coastal profile. This has the significant advantage of causing the waves to loose their destructive energy while running uphill during high tide situations. Thus, the erosion of the coast profile is mitigated even in spring tide situations compounded by effects of hurricanes.

The following aerial photos of the groynes at Gammel Skagen, on the Danish west coast, illustrate very clearly the efficiency of the Pressure equalisation modules.



Aerial photo of the groynes at Old Skagen, before the implementation of pressure equalisation modules.



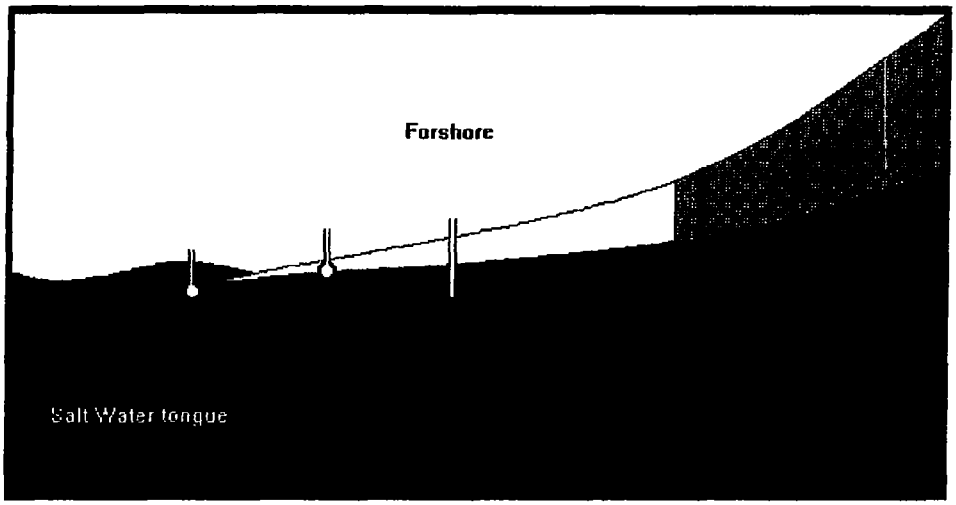
Aerial photo of the same location in 1999, 15 months after the implementation of pressure equalisation modules.

The later aerial photo from 1999 illustrates very clearly that pressure equalisation modules are far more effective than the conventional groynes from 1950. As can be seen from the photo, these groynes are now completely covered by sand on the new and sustainable beach.

The erosion Process

During the tests as carried out in Skagen it was recognised that the groundwater table was 2 metres above the sea level in a distance of only 70 metres from the coastline. Due to the gravity there is a considerable groundwater pressure from the land side. Thus, it can be illustrated that the sea water in the swash zone percolates through the sand and runs back into the sea "on top" of the

groundwater discharge area. This promote the erosion process compounded with the back run of the sea water in the swash zone.



Equilibrium Profile.

As a result of SIC's research and experiments over the last 6 years, we now experience wide equilibrium coastal profiles at locations where SIC has installed pressure equalization modules.

At the same time the local people tell us that they have never seen wider sand beaches.

Theory.

Pressure equalisation modules are vertical filters that are placed in a matrix along the coastline. The filters equalise the pressure of the ground water basin and an increased circulation of seawater in the coastal profile will take place. This will promote sedimentation of materials on the coastal profile.

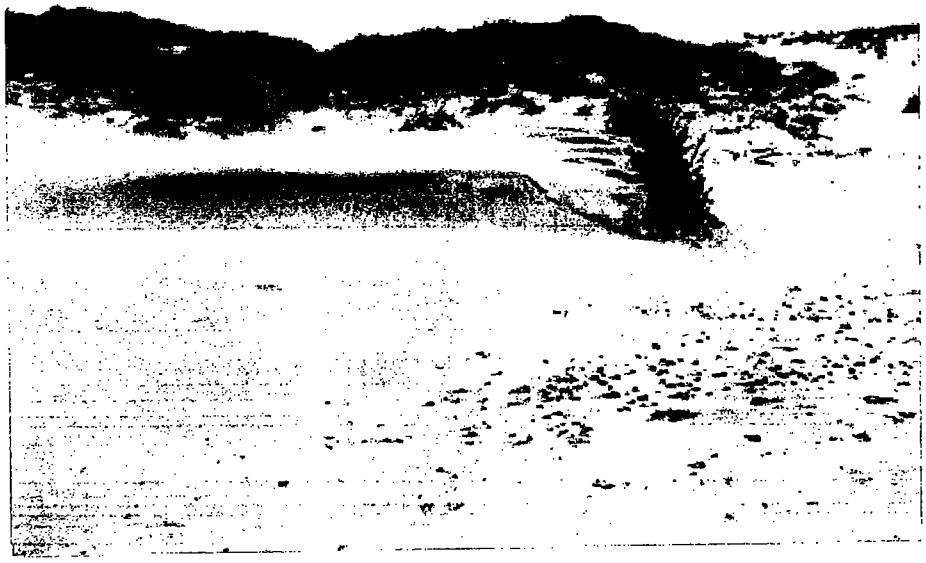
During our work we have developed the following theory (in short): The pressure equalization modules increase the drop of the water level in the coastal profile in the period from high tide to low tide. Thus, the beach will be more effectively drained of water.

When the water level is low on the coast during the period from low tide to high tide, the water circulation in the swash zone increases, which again increases the depositing of materials on the foreshore, thereby building up the beach from the sediments transported along the coast.

Over time the new materials in the coastal profile are increasingly coarse, due to a higher speed of the underlying water in the coast profile.

The result of deploying our pressure equalization modules inside a coast profile, is a strong and very wide equilibrium profile.

To build up the dunes on the beach, we use fascines to collect the sand blown along the beach by the wind.



Typical example showing the use of fascines at Skagen

MONITORED AND CONTROLLED FIELD RESEARCH

Based on the very positive experiences from Gammel Skagen, a full-scale field research programme was performed south west of Gammel Skagen.

The supervising and controlling team comprised the following persons:

Mr. Hans Falk Burcharth	Professor Dr. Tech., Aalborg University
Mr. Frede Jensen	State Forester, Northern Jutland
Mr. Bjarke Jensen	North Jutland County
Mr. John Jensen	Engineer, The Danish Coastal Authorities
Mr. Poul O. Jørgensen	Carl Bro Consulting Engineers A/S
Mr. Stig Trollebø	Teknologisk Innovation A/S
Mr. Poul Jakobsen	SIC

The research project was executed with professor Hans Falk Burcharth as research advisor for SIC, whereas the other team members were supervising the research project. The team members have participated in all conferences concerning the research project and has agreed that professor Hans Falk Burcharth, as an independent scientific expert should evaluate the procedures and the obtained data from the research programme, on behalf of the team. All measurements during the field research programme was recorded and controlled by a reputed independent consulting company; Carl Bro Consulting Engineers, Denmark.

Controlled field research.
The field research was performed along a coastline 8 km long S.W of Gammel Skagen (please se the map on the next page). Before the pressure equalising plant was implemented, a baseline measurement of the selected coastline was made with laser equipment. The distance between each of the stations/ equalisation modules is 100 metres. The total distance from station 113200 to 114250 is 1050 metres.

Flank areas.
Adjacent flank areas, without pressure equalisation modules, on either side of the test area, were monitored with the same procedures as the test area.

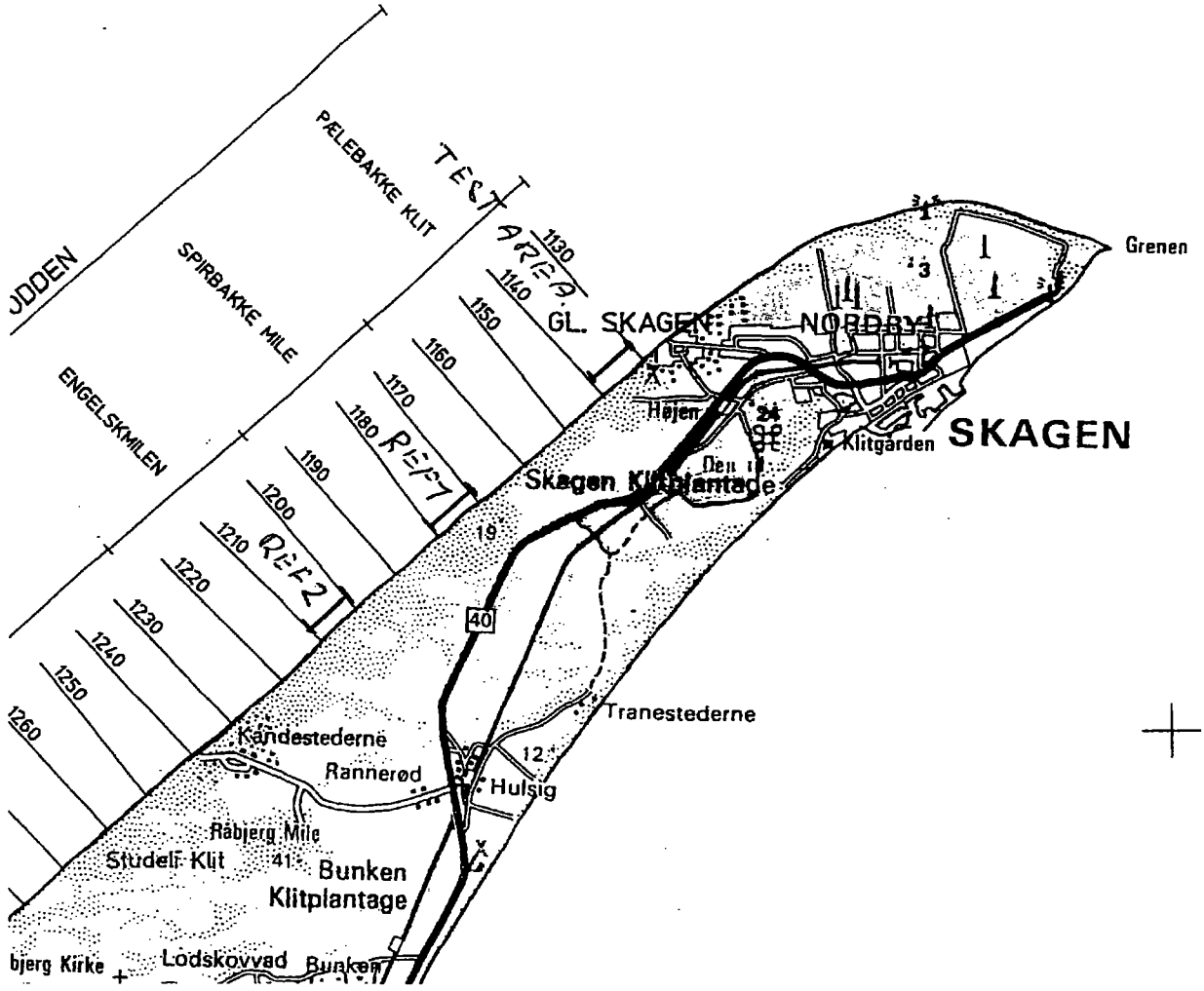
Reference area I.
Reference area I was located 4,0 km SW of the test area, ranging from station 117000 to station 118000. The objective of this reference area was to compare the development during the research period of the coastal profile in a nearby site without pressure equalisation modules.

Reference area II.
Reference area II was located 7,0 km SW of the test area, ranging from station 120131 to station 121134. The objective of this reference area was to compare development of the coastal profile in a nearby site without pressure equalisation modules during the research period

Test area, flank and reference areas are shown on the following sketch.

Overview map

Test, flank and reference areas



Flank 1	112800 - 113200
Test area	113200 - 114250
Flank 2	114250 - 114650
Reference area I	117000 - 118000
Reference area II	120134 - 121134

FIELD RESEARCH REPORT

Issued by	**SIC** Skagen Innovation Center Østre Strandvej 33 a, DK - 9990 Skagen Denmark
Subject	Coastal Protection
Method	Pressure Equalisation modules
Location	Old Skagen.
Duration of research	27th January 1999 - 18th January 2000
Executing Consultants	Professor Dr. Tech. Hans Falk Burcharth Carl Bro Consulting Engineers, Denmark

SIC, Skagen Innovation Centre has established a demonstration/research pressure equalisation module plant at Old Skagen (Gammel Skagen), a small town on the West Coast of Jutland. The town is located in the extreme north of Denmark by the North Sea, at the position 10° 32,38' E - 57° 44,22' N. The site is recognised as a generally very windy location with heavy lateral currents.

The objective of the research program was to demonstrate, monitor and examine the efficiency of the SIC Pressure Equalisation System as a feasible solution to control coastal erosion.Profesor Dr. Tech. Hans Falk Burcharth and Carl Bro, Consulting Engineers, Denmark carried out the research programme, during an all-season period of twelve months (27 January 1999 – 18 January 2000).

Summary

The efficiency of the pressure equalisation modules is unambiguous. After 12 months with 4 spring tide situations and 4 hurricanes, the average increase of the coastal profile in the 1000 metre long research area, was measured as 6,54 cubic metres per metre.

In reference area 1 (4 km SW of the research area), without pressure equalisation modules, a loss of 10,3 cubic metres (average) per metre was measured.

In reference area 2 (7 km SW of the research area), without pressure equalisation modules, a loss of 3.45 cubic metres (average) per metre was measured.

The function of the pressure equalisation modules has created a wide balanced coastal profile, with the significant advantage that the waves are losing their destructive energy while running uphill during high tide situations. Thus, the erosion of the coast profile is mitigated even in high tide situations combined with hurricanes.

Methodology

1.0 The current situation after twelve months of research is shown in diagram 1. It should be recognised that during this period 4 events with spring tide and hurricanes had taken place at this location.

2.0 The efficiency of the pressure equalisation modules is shown in diagram 2, which illustrates the efficiency and density of the coastal profile, compared to the adjacent reference areas.

3.0 The dynamics of each of the monitored coastal profiles during the twelve months research period is shown in diagram 3.

4.0 Comparison of conventional nourishment by dredging and the SIC pressure equalisation module system is shown in diagram 4. The Danish Coastal Authorities have back-filled a 3 km long coastline with 20 cubic metres of sand per metre at a cost of several million DKK.

The results of the twelve-month research programme.

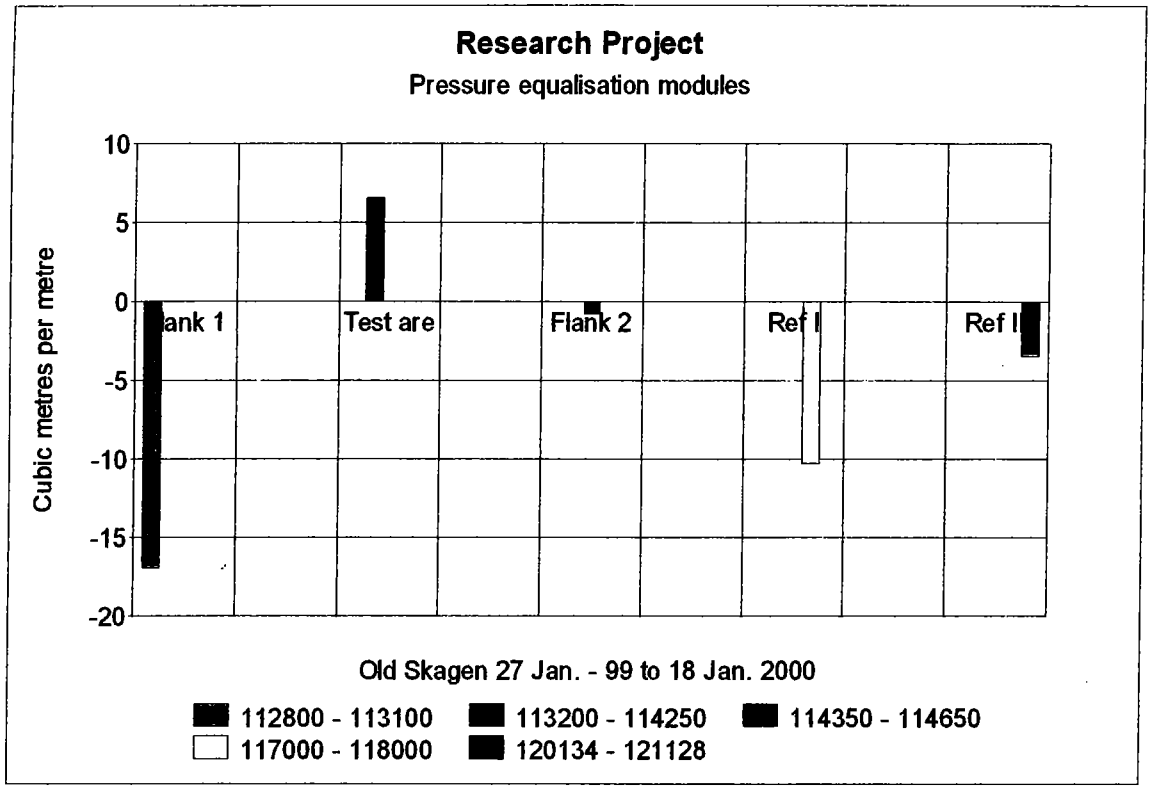


Diagram 1. The current situation after twelve months research.

The current situation after twelve months research is shown in diagram 1. It should be recognised that during this period 4 events with spring tide and hurricanes took place at this location.

After one year with heavy hurricanes the following results were observed.

Area	Measured impact	result
Flank 1	-16,95 cubic metre per metre	Erosion
Test area with modules	+ 6,54 cubic metre per metre	**Increase**
Flank 2	- 0,75 cubic metre per metre	Erosion
Ref. area I	-10,30 cubic metre per metre	Erosion
Ref. Area II	- 3,45 cubic metre per metre	Erosion

Table 1. Situation after twelve months research (including hurricanes).

The results of the test are unambiguous, but it is of greater importance that the density in the pressure equalised profile is significantly higher, compared with the adjacent areas.

Efficiency of the pressure equalisation modules.

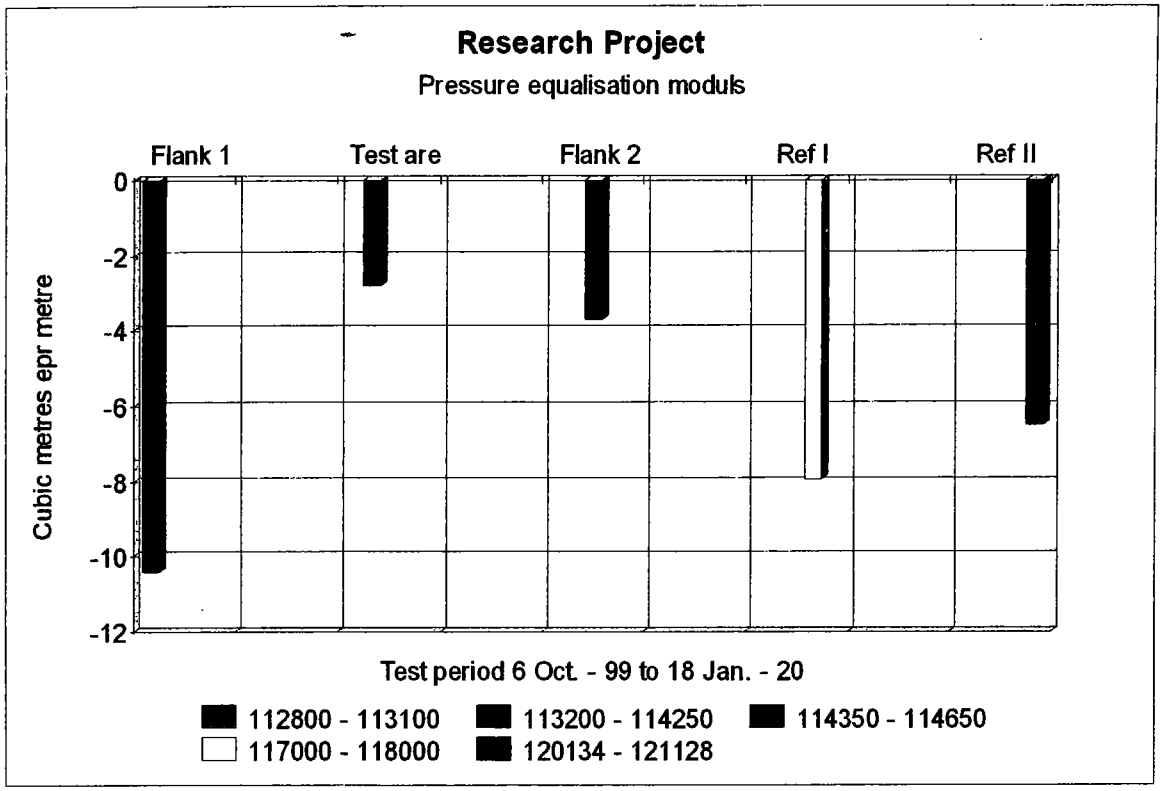


Diagram 2. The efficiency of pressure equalisation compared with the adjacent reference areas

The efficiency of the pressure equalisation modules is shown in diagram 2 which illustrates the efficiency and density compared with the adjacent reference areas.

The average erosion per metre caused by the two hurricanes in December 1999

Area	Measured impact	result
Flank 1	-10,41 cubic metres per metre	Erosion
Test area with modules	- 2,8 cubic metres per metre	Erosion
Flank 2	- 3,8 cubic metres per metre	Erosion
Ref. area I	- 7,93 cubic metres per metre	Erosion
Ref. Area II	- 6,48 cubic metres per metre	Erosion

Table 2. Erosion impact from hurricanes in 1999

Note:
The efficiency and density in the pressure equalised area with modules is more than 100 % higher than in the adjacent areas without modules when disregarding the upstream effect in Flank 2.

Development of the profiles during twelve months

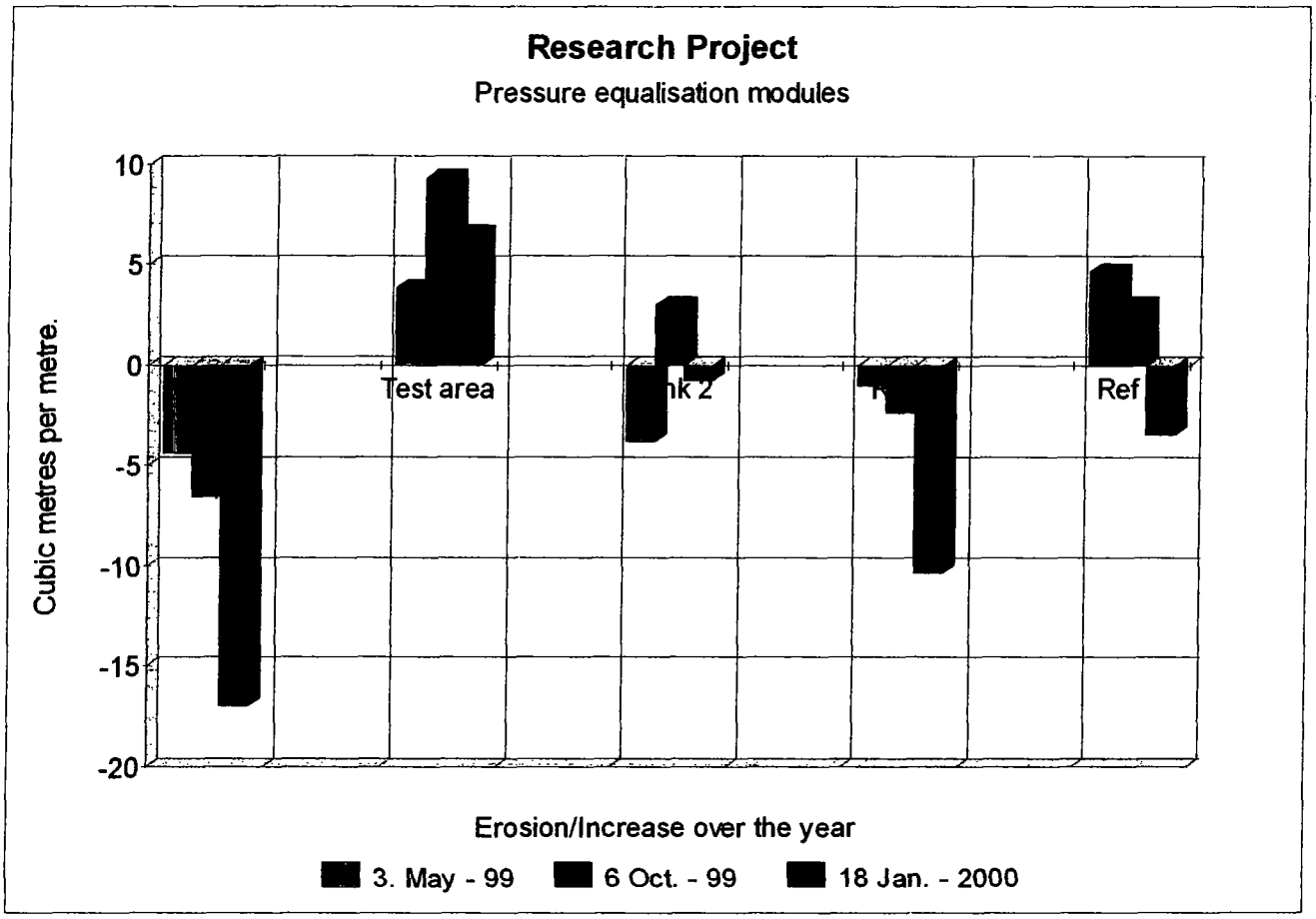


Diagram 3. The development of each of the monitored profiles over the twelve-month period.

The measurements were made between January and October of 1999 and January 2000 and comprise the test area with pressure equalisation modules as well as the nearby reference areas, each 1 kilometre long. The following results were observed:

Site	Results	Quantity	Unit
Test area	accumulation	9350.00	cubic metres
Reference area I	erosion	2363	cubic metres
Reference area II	accumulation	3035	cubic metres

Table 3. Erosion and accumulation over twelve months

Gain and loss factors immediately after the hurricanes:

Site	Results	Quantity	Unit
Test area	Remaining	6543 *	cubic metres
Reference area I	Loss / erosion	10295 *	cubic metres
Reference area II	Loss / erosion	3446 *	cubic metres

Table 4. Gain and loss of coastline after the hurricanes

* (The observed measurements from 27th January 1999 are used as base line values).

It can be concluded that the pressure equalisation modules have not only mitigated the erosion, but also created a balanced coastal profile.

Comparison of efficiency between systems

The efficiency comparisons are made between; (i) the SIC environmentally friendly system based on pressure equalisation modules and (ii) the conventional approach as executed by the Danish Coastal Authorities with dredging/nourishing of a 3 kilometre coastline with 20 cubic metres of sand per metre, at a cost of several million DKK.

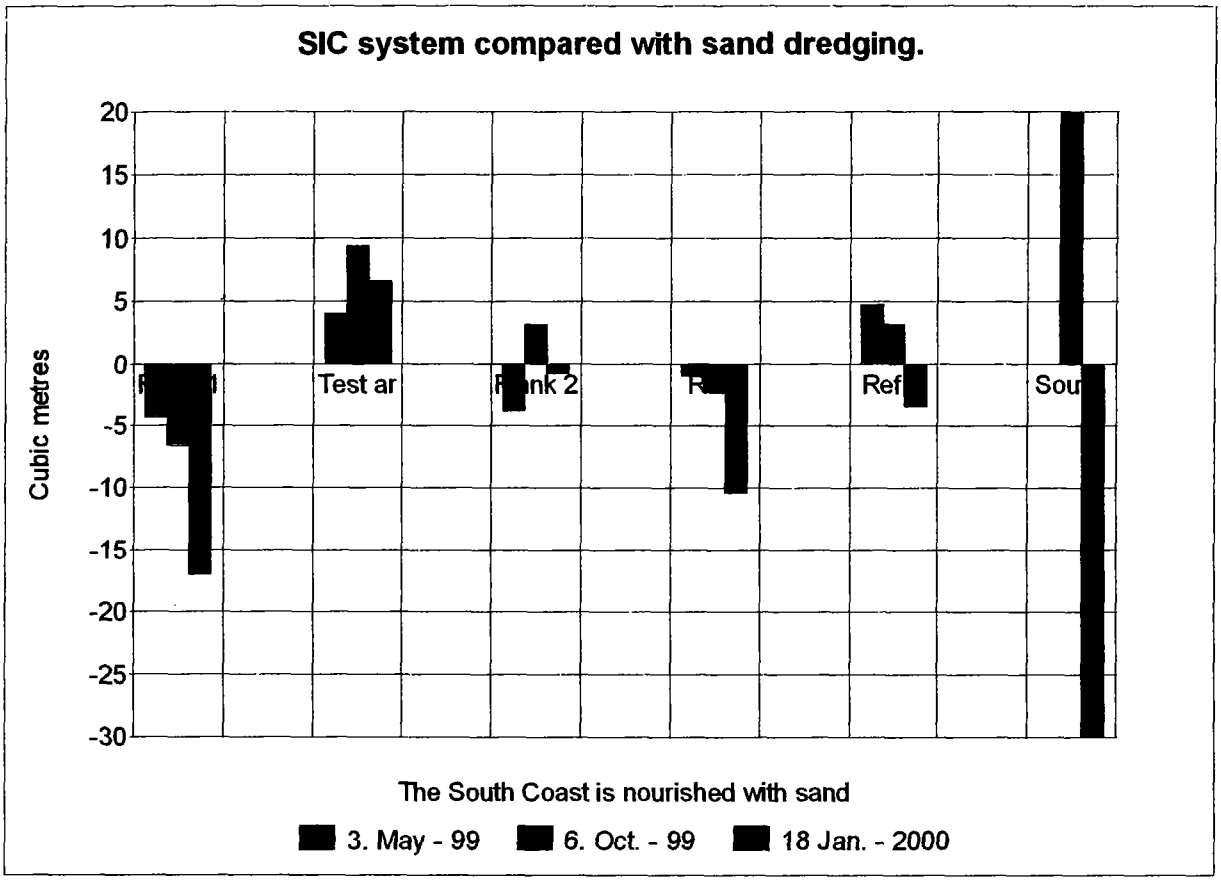


Diagram 4. Comparison of the SIC System and conventional dredging.

Conclusion

With reference to the above-mentioned observations during the research period, it has been proved that conventional dredging / nourishing with sand as performed by The Danish Coastal Authority during the past 17 years is inefficient.

Furthermore, it can be seen that the SIC environmentally friendly system based on pressure equalisation modules is a feasible and sustainable solution for coastal protection.

Driftsrapport

Ribersborg Strand - Malmö

2005

Ribersborg Strand efter et år med trykudligning

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Ribersborg Strand Malmö.

Etableringsdato 27 oktober 2001

Evaluering August 2004.

Kommune: Malmö Kommune

Kunde: Gatukontoret Malmö

Totalentreprenør:

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Dr. Alexandrinesvej 75
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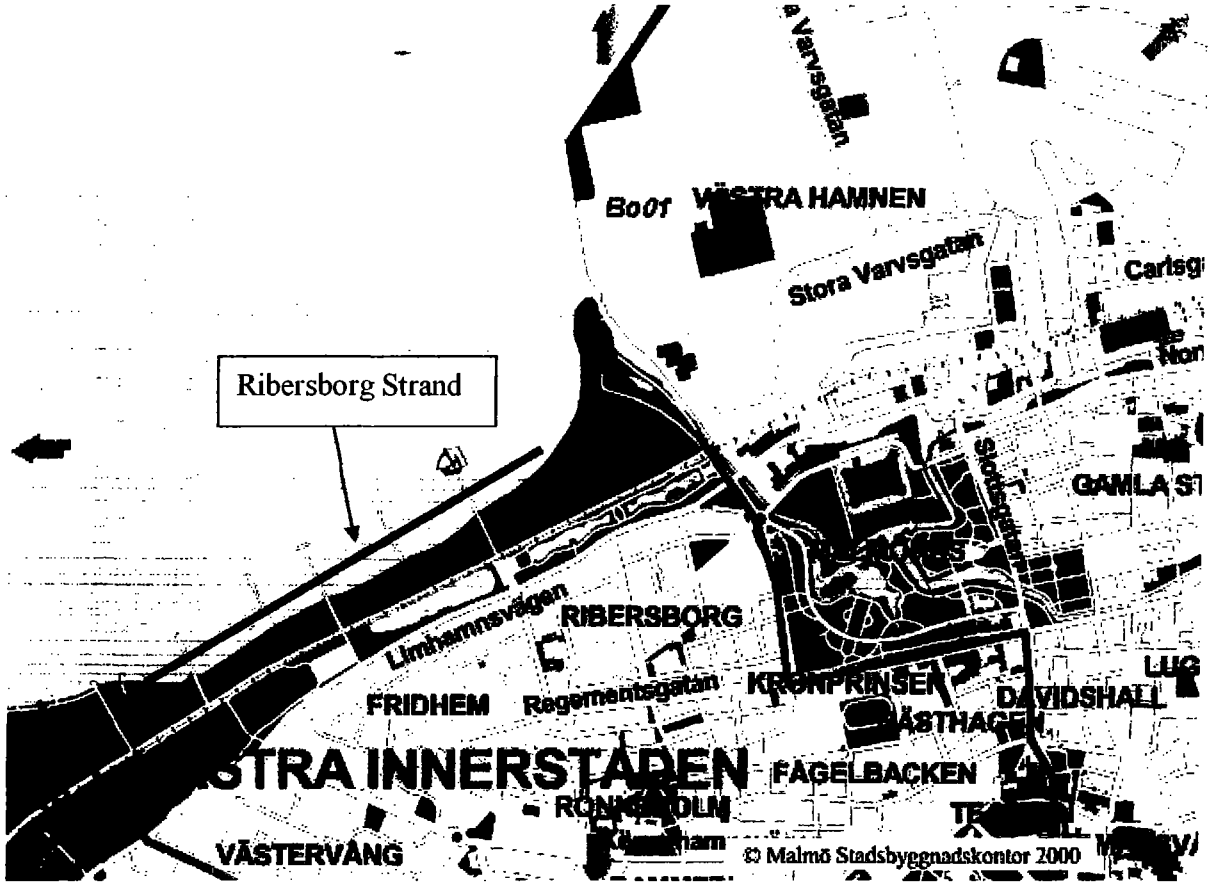
Ribersborg Strand.



Stranden er beliggende i midten af Malmö og benyttes af tusindvis af badegæster over sommeren, samt som et meget aktivt fritidsområde i den øvrige del af året.

Den kysttekniske undersøgelse dækker området fra hundebadet til handikapbadet.

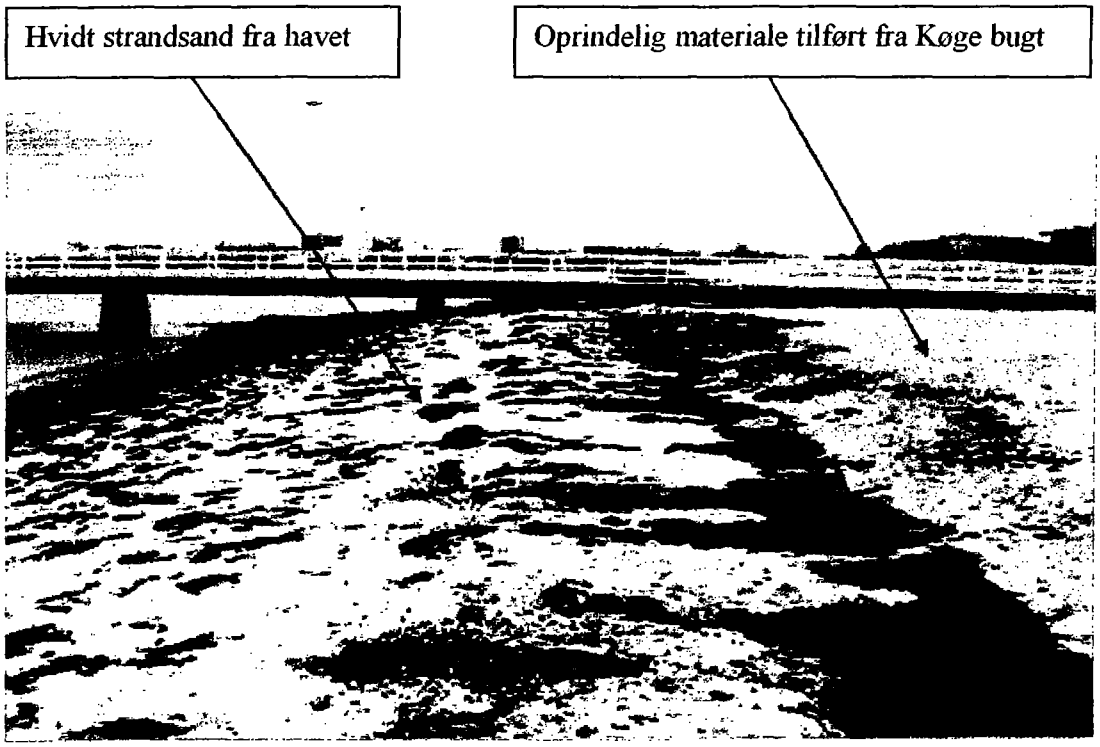
Området er markeret med blåt på ovenstående bykort.

Anlægget blev etableret d. 27 oktober 2001 med en afstand mellem modulerne i længdeprofilet på mellem 50 og 100 meter og ca. 10 meter mellem modulerne i tværprofilet.

Modulerne er 1,75 meter lange og er nedgravet i plan med stranden, hvor det er muligt, så modulerne er næsten usynlige i stranden.

De enkelte moduler består af 1,0 meter 60 mm filterrør og 0,75 meter stålrør, som er lukket i toppen med et låg med ventilationsfilter.

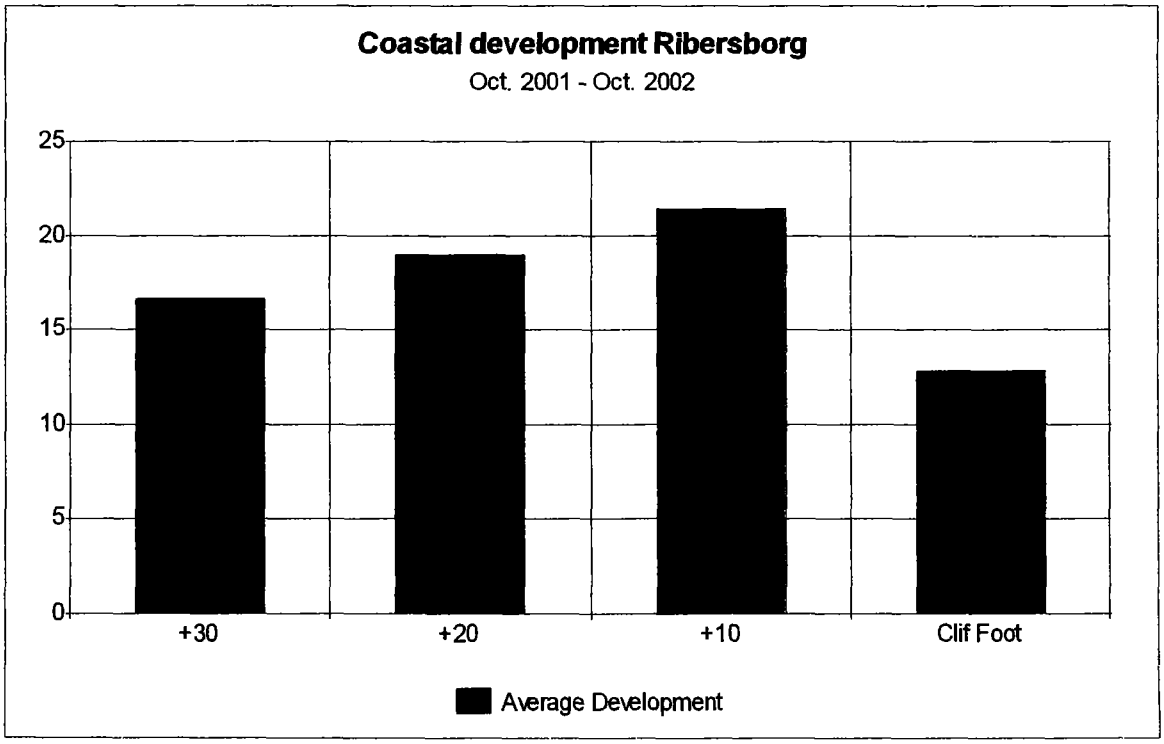
Som det ses på efterfølgende billede fra d. 30 november 2001 skete der meget hurtigt en opbygning af stranden med hvidt strandsand ude fra havet, som aflejrede sig på stranden så stranden blev konveks.



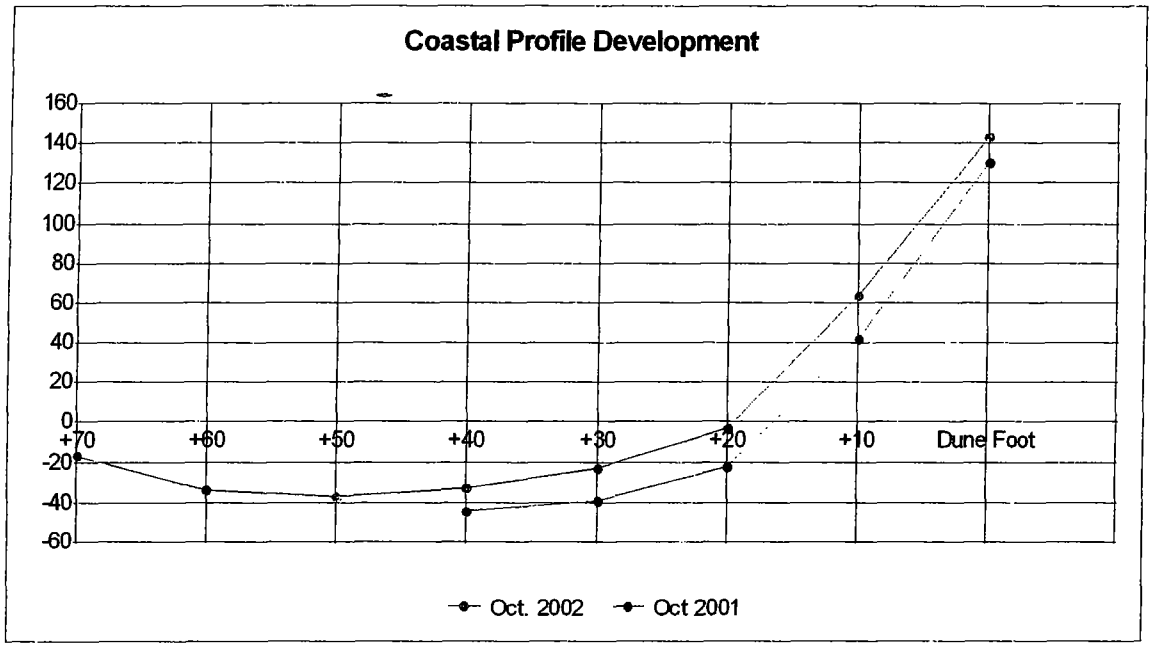
Billede fra Ribersborg strand d. 30 november 2001

Det ses meget tydeligt at der sker en opbygning i stranden med hvidt sand, som kommer ind fra havet.

Det hvide sand er efterfølgende også føget op i baglandet, så man ikke længere ser en farveforskel på sandet i stranden.



Der er et gennemsnitligt kysttillæg på Ribersborg strand på 6,1 kubikmeter pr. meter det første år baseret opmålingen i et 35 meter bredt kystprofil.



Der er et gennemsnitligt kysttillæg på kystlinien over det første år på ca 3,0 meter, samtidig med at vi har registreret at havbunden har hævet sig10 – 20 cm uden for kystlinien.

Anbefaling.

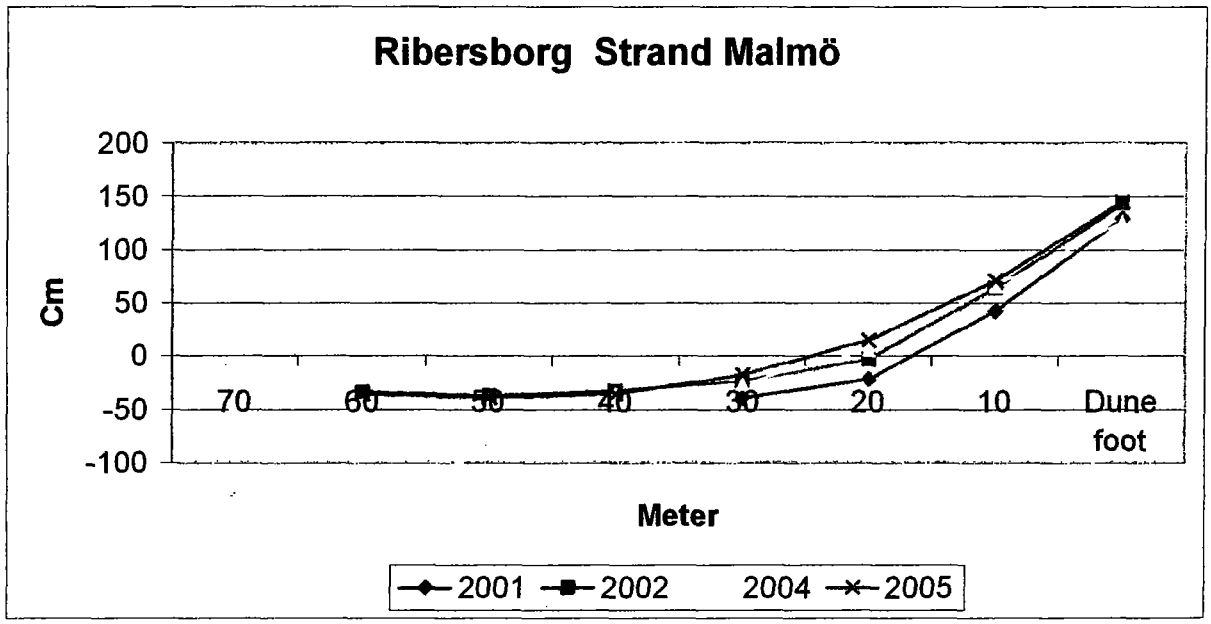
Vi kan derfor på det foreliggende grundlag anbefale fortsat drift af anlægget idet kystprofilet efter trykudligning er inde i en meget positiv udvikling med en generel opbygning af kystprofilet.

Skagen d. 23 oktober 2002.

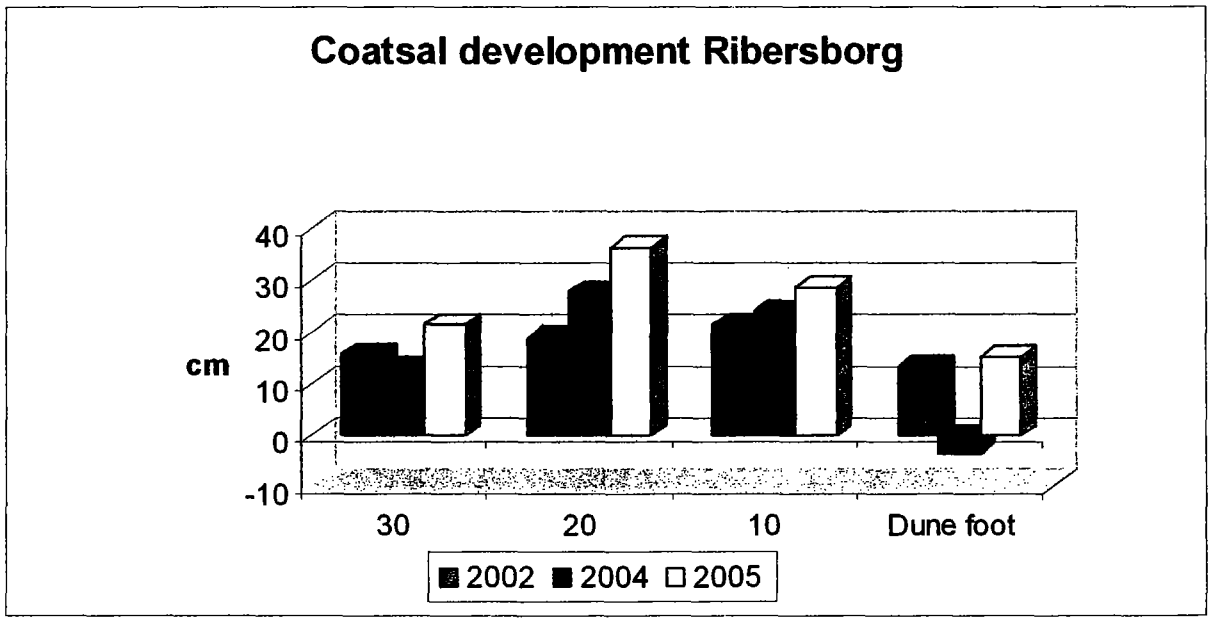
Poul Jakobsen

Status November 2005

Alle moduler er fortsat dykket i stranden og står dybere i stranden, idet stranden er hævet i forhold til 2004.



Strandbredden er forøget med ca. 3 meter i gennemsnit og stranden er nu ca. 8 meter bredere i forhold til etableringstidspunktet i 2001.



	Average	Delta
Gennemsnitlig strandudvikling i 30 meters brede 2002	18,8 cm	
Gennemsnitlig strandudvikling i 30 meters brede 2004	21,7 cm	2,9 cm
Gennemsnitlig strandudvikling i 30 meters brede 2005	28,8 cm	7,1 cm.

Driften af anlægget forløber helt som forventet i relation til de kontrollerede forsøg i Danmark og andre steder i udlandet.

SIC anbefaler fortsat drift af anlægget, idet driftsresultaterne er meget tilfredsstillende på lokaliteten.

Der er i det forløbne år gennemført et feltforsøg med SIC systemet på den jyske vestkyst med det resultat, at der var et kysttillæg på 265.000 kubikmeter i testområdet 5,6 km, mens tillægget i referenceområderne 5,4 km kun var 27.000 kubikmeter.

Resume af resultaterne er vedlagt som bilag.

Skagen d. 10 november 2005.

Poul Jakobsen

Oct	2002									
		+70	+60	+50	+40	+30	+20	+10	Dune Foot	
0					-83	-64	-32	13	78	
50			-77	-67	-27	1	-3	84	156	
100			-68	-40	-12	-17	-6	60	143	
150			-67	-49	-21	-17	-2	56	142	
200				-69	-50	-23	3	55	124	
250			-40	-57	-36	-18	-7	39	119	
300		-31	-33	-41	-9	-36	-8	53	134	
350		-53	-35	-44	-28	-20	-2	61	112	
400		-42	-35	-45	-42	-14	4	56	144	
450		-47	-48	-44	-24	-21	0	70	115	
500			-50	-44	-41	-31	17	83	152	
600		-37	-31	-27		-33	2	53	155	
700			-38	-34	-21	-24	18	78	182	
800				-34		-6	0	79	138	
900			-35	-28	-3	-21	12	81	139	
1000		-27	-18	-37	-34	-26	-6	55	141	
1050		-32	-28	-26	-27	-17	1	60	145	
1100		-36	-18	-20	-30	-20	-4	59	163	
1150		-24	-27	-22	-31	-14	-5	53	164	
1200		-24	-25	-29	-29	-18	-15	52	131	
1250		-23	-26	-32	-29	-15	5	63	133	
1300			-31	-16	-28	-22	5	76	130	
1350			-27	-21	-26	-20	4	72	149	
1400		-41	-42	-33	-32	-16	-8	37	156	
1450			-44	-42	-42	-37	-36	64	106	
1500				-41	-46	-38	-12	66	113	
Average level		-16,68	-33,72	-37,68	-32,65	-23,48	-3	63,12	142,6	

Oct	2001									
		+70	+60	+50	+40	+30	+20	+10	Dune Foot	
0							-29	4	81	
50							-43	-2	80	
100					-47	-24	-14	26	139	
150						-45	-15	14	66	
200						-46	-8	32	124	
250						-48	-30	24	90	
300					-50	-29	-11	39	110	
350						-48	-23	45	100	
400						-37	-7	59	100	
450						-52	-6	40	136	
500						-44	2	37	100	
600						-41	-7	30	126	
700						-44	-28	40	138	
800						-34	-32	45	130	
900						-33	-21	45	128	
1000						-39	-37	45	128	
1050						-41	-32	56	145	
1100					-38	-18	-19	43	164	
1150						-31	-21	37	162	
1200						-41	-28	41	128	
1250						-32	-33	37	134	
1300						-32	-3	55	172	
1350						-30	-8	59	175	
1400						-32	-28	52	120	
1450						-40	-39	59	129	
1500						-46	-29	81	140	
	0	0	0	0	-45	-39,43	-21,96	41,72	129,8	

July
2004

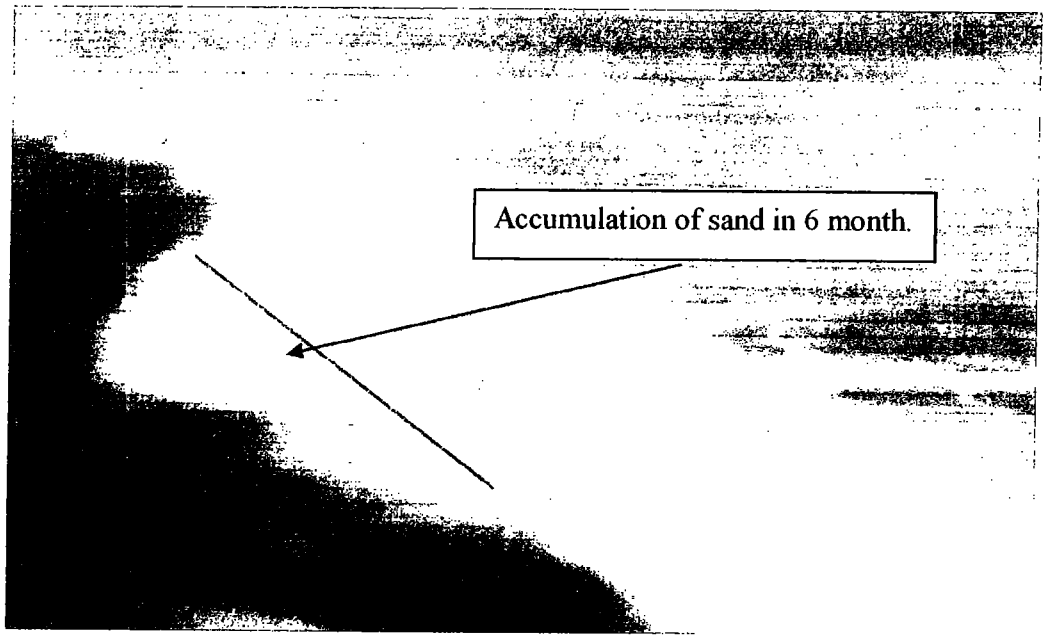
July	70	60	50	40	30	20	10	Dune foot
0				–	-83	-54	46	119
50				-66	-40	-7	50	163
100		-77	-56	-29	-25	-13	52	147
150	-74	-67	-42	-18	-7	1	63	130
200	-74	-42	-40	-38	-32	2	78	130
250	-57	-54	-71	-49	-31	5	79	116
300	-28	-56	-51	-55	-35	-11	38	104
350	-38	-49	-50	-58	-41	-25	47	107
400	-61	-63	-49	-34	-21	15	77	127
450	-42	-50	-47	-45	-25	17	82	116
500	-56	-43	-39	-29	17	74	112	167
600	-45	-41	-44	-18	10	73	94	131
700	-47	-50	-47	-24	-3	57	89	152
800	-36	-35	-45	-38	-11	11	81	136
900	-44	-40	-28	-36	-36	-3	52	133
1000	-27	-37	-33	-41	-34	-7	56	120
1050	-50	-50	-28	-26	-37	-12	56	125
1100	-39	-38	-35	-37	-27	-3	55	119
1150		-35	-42	-41	-21	10	55	110
1200	-40	-27	-39	-40	-31	-2	50	113
1250		-48	-26	-34	-30	10	51	111
1300	-38	-30	-37	-20	-3	55	98	134
1350	-35	-39	-35	-22	-25	-21	52	97
1400	-41	-38	-32	-25	-25	-15	65	114
1450	-45	-48	-43	-37	-43	-23	66	121
1500		-55	-43	-37	-37	-13	68	124
								125,6154

Oct 2005

July	70	60	50	40	30	20	10	Dune foot
0			-61	-47	-31	-15	53	147
50				-60	-49	3	52	163
100			-55	-53	-45	-11	58	192
150			-59	-44	-23	-7	65	172
200			-60	-37	-17	-15	72	132
250				-65	-39	-17	41	121
300			-48	-42	-66	-10	39	101
350		-54	-33	-45	3	64	104	141
400		-55	-56	-44	-4	37	62	151
450		-34	-39	-29	-1	25	73	134
500		-31	-35	-42	-6	31	90	152
600		-38	-32	-5	14	82	127	162
700		-37	-38	-19	-1	27	96	162
800		-27	-34	-26	1	16	104	145
900		-32	-47	-45	-33	6	39	148
1000		-46	-35	-31	-14	-11	26	148
1050		-29	-24	-22	-6	-3	46	156
1100		-22	-31	-31	-22	2	59	135
1150		-34	-33	-44	-18	-4	49	109
1200		-30	-31	-34	8	10	62	130
1250					-16	5	67	111
1300		-26	-30	-34	-16	31	98	138
1350		-32	-21	-20	7	85	116	148
1400		-40	-21	-6	-21	5	76	149
1450		-39	-33	-25	-33	29	50	149
1500		-43	-51	-42	-39	12	104	160
		-36,1	-39	-35,7	-18	14,5	70,31	144,4615

Environmentally Friendly Coastal Protection Pilot Project

Southern Holmsland Barrier on the Danish West Coast



Test area 2

The **beach width** has increased up to 65 metre, 34 Metres average in test area 2

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Mob +45 40 40 14 25

Web: www.shore.dk
Mail : sic@shore.dk

Project area.

The Project is situated between Hvide Sande and Nymindegab on the Holmsland Barrier at the Danish West Coast.

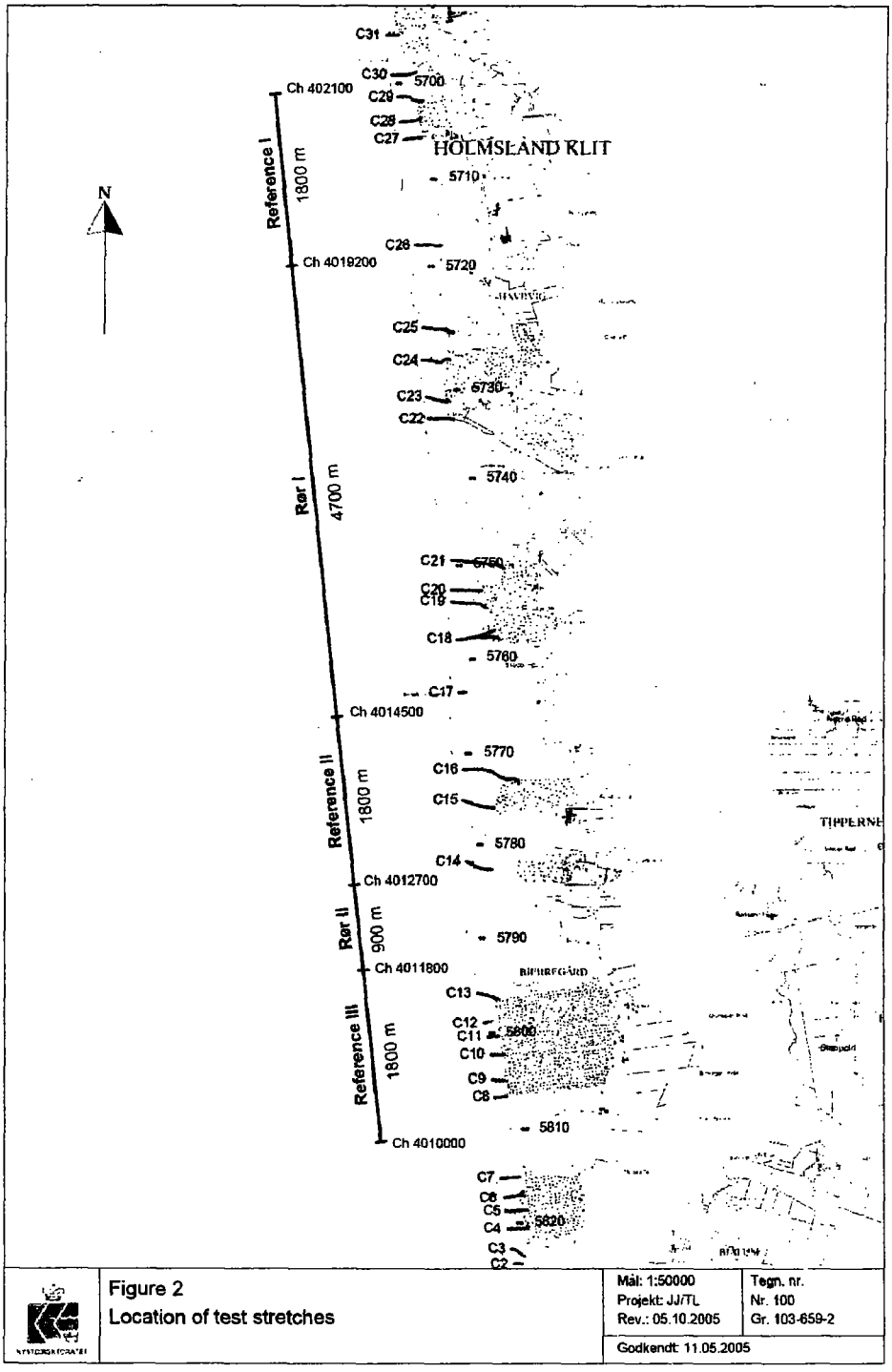


Fig. 1

Reference area 1	st. 9200 – 11000
Project area 1	st. 4500 – 9200
Reference area 2	st. 2800 – 4400
Project area 2	st. 1800 – 2700
Reference area 3	st 0 – 1700

As illustrated in fig. 1 , the Project is divided in areas with PEM modules (5600 Metres total) and reference areas (5400 Metres total).

The purpose is to measure and document the effect of the SIC System in comparison with the areas without the modules.

Results of surveys January, April and July, 2005.

The survey and data in this project are done by the independend consulting ingeneering company Carl Bro A/S.

The results shows, that the sand accretion where the beach is drained by the SIC System is 10 times greater, than the areas with no modules.

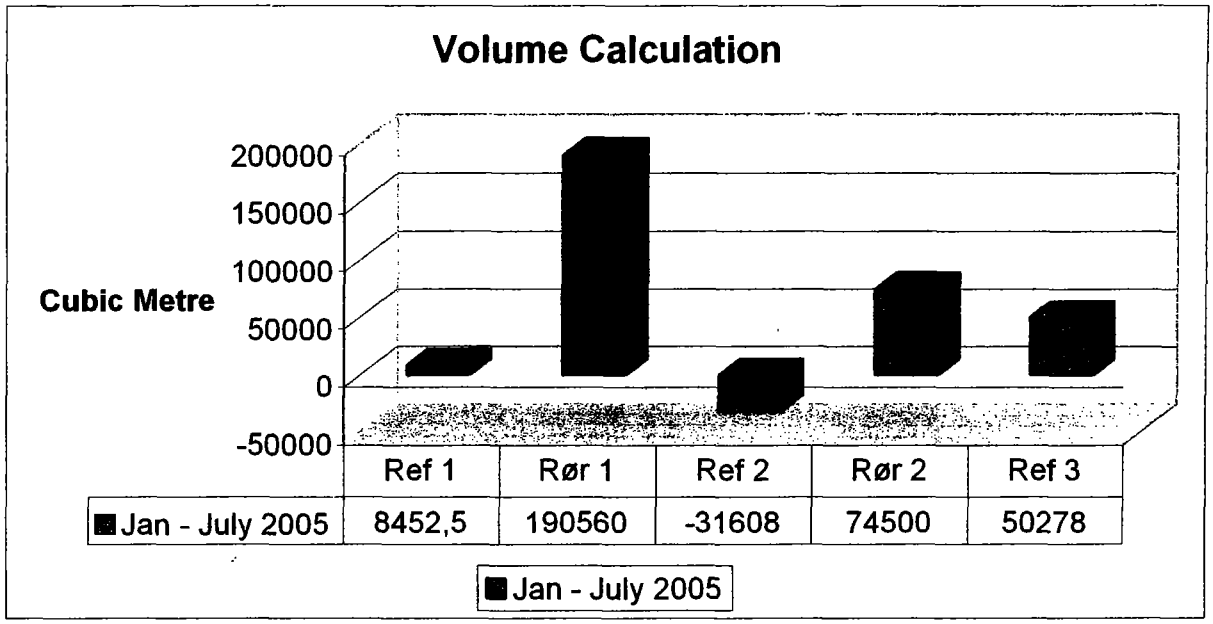
The increase of sand in the pressure equalized areas was 265.000 m3 (5.600 Metres) , compared with the reference areas (5.400 Metres), where the sand accretion only was 27.000 m3.

However, these results will not appear in the first 6 month official evaluation report, as all data has to be recalculated, so volume the calculations shows the total volume accretion of sand on the test areas where there has been accumulation .

SIC do not agree in the statement, which says, that the beaches will build up during the summer period. We can prove it by the results in reference area 1 and 2. In Ref 2, there has been an erosion of 31.000 m3 on the beach during the summer period, which resulted in a decrease in beach height of -24 cm in Ref 2.

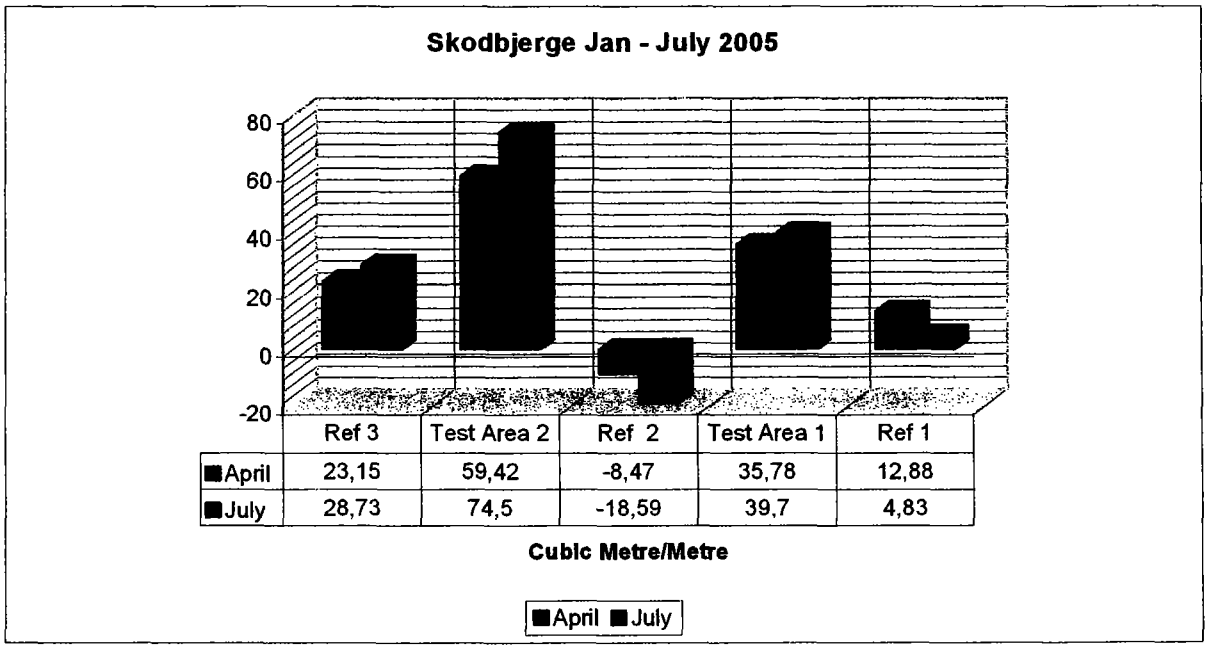
Therefore we can expect damages on the dunes in reference area 1 and 2 during winter 2005/6, like the erosion damages we have seen on the Søndervig Beach during winter 2004/5.

SIC Field test Holmsland Barrier
6 month result 2005



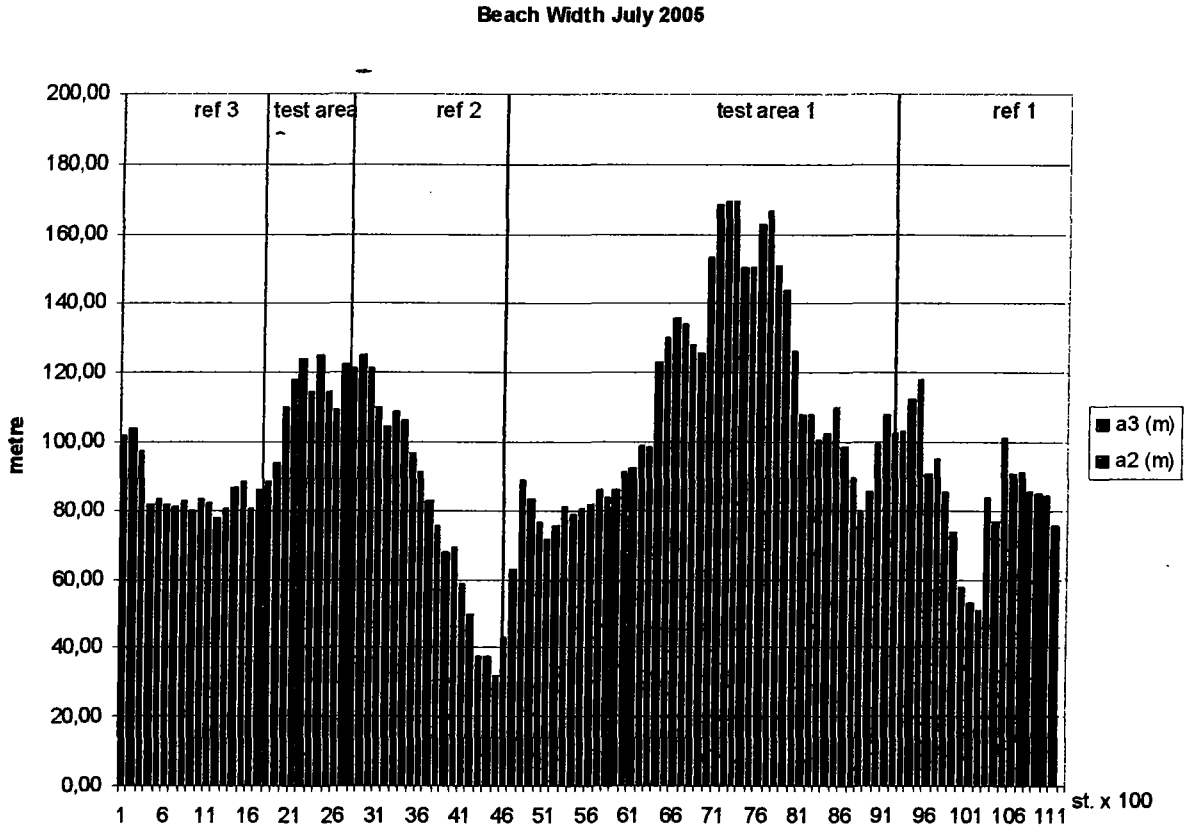
The increase of sand in the pressure equalized areas was 265.000 m3 , compared with the reference areas where the sand accretion only was 27.000 m3.

The Project is divided in areas with PEM modules (5600 Metres total) and reference areas (5400 Metres total).



The figure shows the sand accretion/erosion in m3 along the beach.
The result are significant.

Beach Width.



The beach width is between 80 and 120 Metres in test area 1 and 2 and the beach is elevated avarage by 38 cm in the test area 1, and 66 cm in test area 2.

In test area 2 is the average beach width increased from 78 Metres to 112,4 Metres from January to July 2005.

In contrast to the test areas, reference area 2 beach elevation has decreased by -24 cm.

We can expect damages to the dune in reference area 1 stn. 10000 , where the beach width only is 50 Metres.

We can expect huge damages to the dune in reference area 2 stn. 4100-4300 , where the beach width is only 20 Metres.

SIC is now briefing the Minister of Transport about the risk of severe damage in the reference areas 1 and 2, and we are recommending that the SIC System is implemented in these areas.

It has been decided in the project group, that a new calculation model will be used in the project , because the current models can not be used on advancing beaches in the test areas.

Skagen d. 11 October 2005.

Poul Jakobsen

COASTAL PROTECTION
AND
BEACH CONSERVATION
GHANA

Christiansborg built by Danes 1621

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Evaluation of Coastal Engineering Test
Accra Beach - Ghana

Donor:

Danish Ministry of Foreign Affairs Copenhagen
Program PSDP

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FIELD TEST ACCRA BEACH GHANA

Poul Jakobsen Skagen Innovation Centre, Dr. Alexandrinesvej 75, DK-9990 Skagen, Denmark
Enor Homiah NDA Construct, Dansoman, Accra, Ghana.

Abstract
Land-based activities and natural physical processes have resulted in significant modifications of the shorelines in many countries, with drastic effects on the coastal geomorphology as well as on the coastal infrastructures. There is an urgent need to introduce new and cost-effective measures that can reduce and mitigate the impacts on the shorelines.
SIC Skagen Innovation Centre has invented an environmentally friendly coastal protection system. The SIC system is based on pressure equalisation modules and fascines. A long-term and comprehensive test of the efficiency has been carried out on the West Coast of Denmark. Furthermore, a twelve-month scientific research programme was performed in 1999. The results obtained show that the system is far more efficient than conventional methods such as groynes, breakwaters and sand nourishment. Due to the well-known lee side erosion effect, groynes and breakwaters create even greater erosion in adjacent coastal areas. Sand nourishment by dredging is in general terms a very expensive approach (about 130,000 USD / km / year in Denmark), but unfortunately it is an inefficient solution since usually the sand will disappear during the first spring tide.

Summary
With background in the above SIC established in July 2000 in cooperation with ABC Hansen A/S and NDA Construct an environmental friendly pressure equalisation plant in Ghana. The plant was established on a 1,000 m stretch on Accra Beach west of Independence Square.

The purpose was to explain the possibility to achieve positive results under very different conditions than tried before.

The test is very successful indeed. The final result from the measurements carried out during the period shows an increase of 17.76 m^3 per running metre of new sand on the coastline. Compared to the successful plant in Old Skagen, monitored by Carl Bro, Denmark, where the increase is 6.5 m^3 per running metre, the plant in Ghana is without any doubt the most successful plant installed so far.

The test area at Accra Beach is considered rather difficult with four freshwater outflows mainly rainwater and sewage from the hinterland. This combined with lee side erosion from the Accra harbour mole causes heavy erosion on the beach.

During the test period we experienced a very heavy storm in October 2000 which caused severe erosion and lowered the coastal profile by up to 1.10 m.

We find the final result very satisfactory, as a new and wide beach is now visible as can be seen from the following pictures from Accra Beach. The pictures before and after are not technically photographic directly comparative but show the development on the beach and documented with levelling carried out before and after.

The measurements from the engineering company Rudan/Carl Bro are attached as enclosure 19 and 20.

Christiansborg Accra 1999

Christiansborg Accra 1 year later

Photo Accra Beach Jan. 2001 direction east

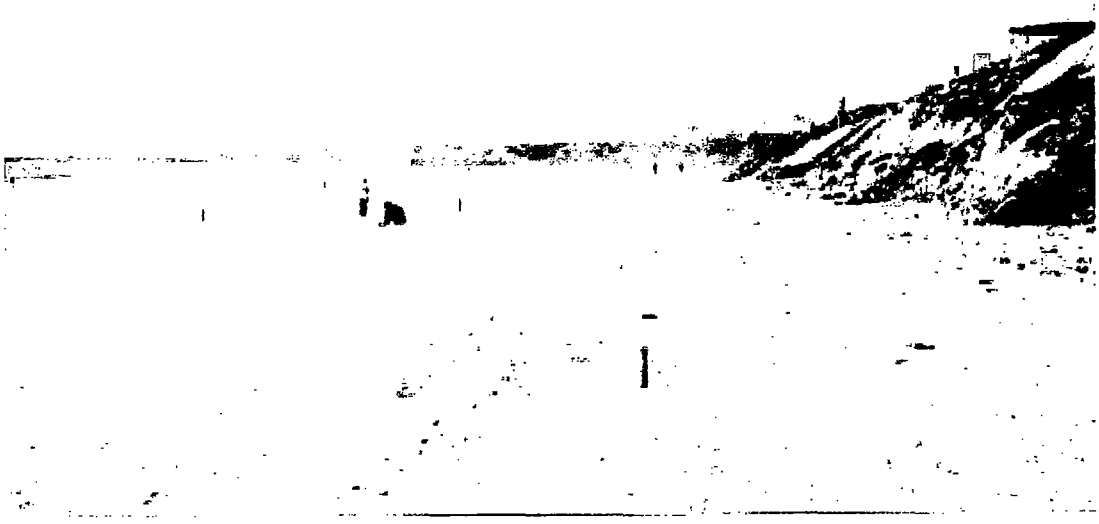


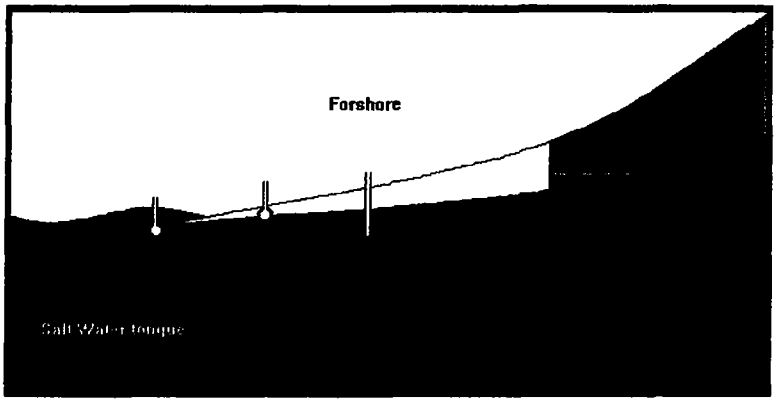
Photo Accra Beach Jan. 2001 direction west

INTRODUCTION

The SIC system is radically different to the dredging, sand nourishment and groynes building methods hitherto being employed. The SIC System makes the lowest impact on the aesthetic beauty of the beach area without disfiguring it with boulders etc. It also precludes sand nourishment activities since it basically traps the sediment transported by the sea on to the beach and thus starts the beach rehabilitation process by extending the beach further into the sea. The basic principle of the SIC system is pressure equalisation of the hydrodynamic forces along the coastal stretch it is being implemented on.

Pressure equalisation modules build up a wide balanced coastal profile. This has the significant advantage of causing the waves to loose their destructive energy while running uphill during high tide situations. Thus, the erosion of the coast profile is mitigated even in spring tide situations compounded by effects of hurricanes.

During the tests as carried out in Skagen it was recognised that the groundwater table was 2 metres above the sea level in a distance of only 70 metres from the coastline. Due to the gravity there is a considerable groundwater pressure from the land side. Thus, it can be illustrated that the sea water in the swash zone percolates through the sand and runs back into the sea "on top" of the groundwater discharge area. This promotes the erosion process compounded with the back run of the sea water in the swash zone.



Equilibrium Profile

As a result of SIC's research and experiments over the last 6 years, we now experience wide equilibrium coastal profiles at locations where SIC has installed pressure equalisation modules. At the same time the local people tell us that they have never seen wider sand beaches.

Theory

Pressure equalisation modules are vertical filters that are placed in a matrix along the coastline. The filters equalise the pressure of the ground water basin and an increased circulation of seawater in the coastal profile will take place. This will promote sedimentation of materials on the coastal profile.

During our work we have developed the following theory (in short): The pressure equalisation modules increase the drop of the water level in the coastal profile in the period from high tide to low tide. Thus, the beach will be more effectively drained of water. When the water level is low on the coast during the period from low tide to high tide, the water circulation in the swash zone increases, which again increases the depositing of materials on the foreshore, thereby building up the beach from the sediments transported along the coast. Over time the new materials in the coastal profile are increasingly coarse, due to a higher speed of the underlying water in the coast profile. The result of deploying the pressure equalisation modules inside a coast profile, is a strong and very wide equilibrium profile. To build up the dunes on the beach, fascines are used to collect the sand blown along the beach by the wind.

MONITORED FIELD RESEARCH

On this background it was agreed with The Ministry for Works and Housing to carry out a field research on Accra Beach. This is shown on drawing No. TL101 and the aerial photo from the Accra Beach.

The plant was installed using pressure equalisation modules build from galvanized steel pipes, 1.5 m in lengths. The pipes are fitted with 0.5 m or 1.0 m special filter.

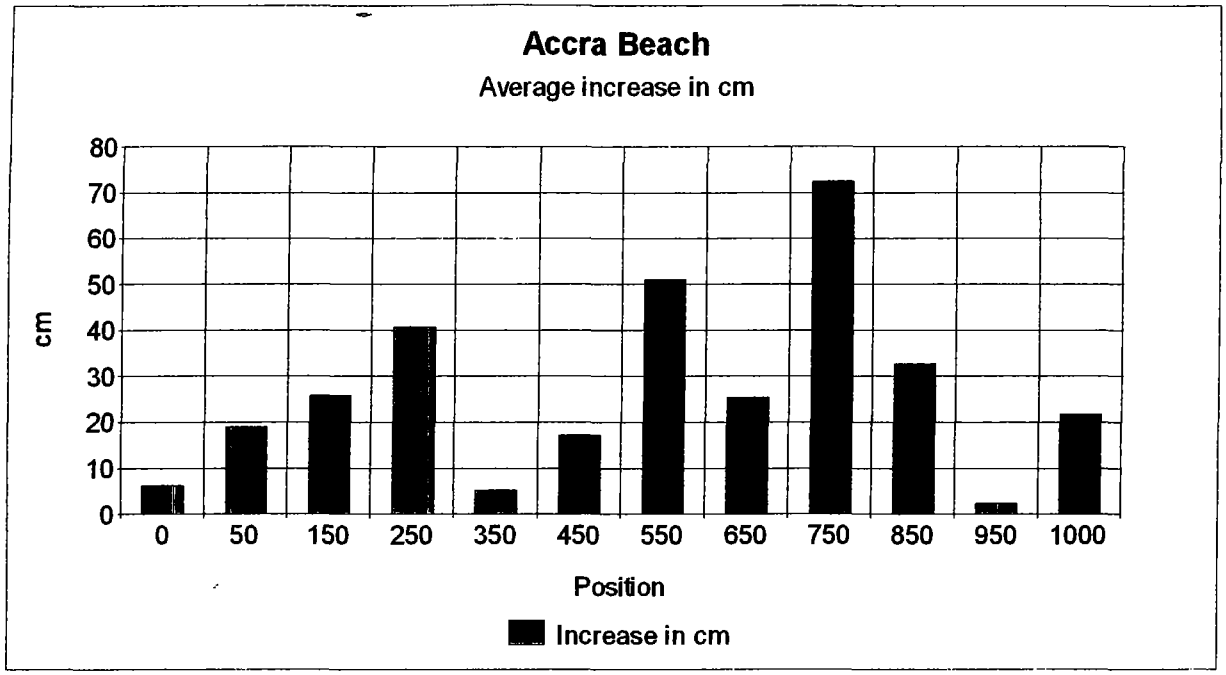
The modules are closed at both ends by ventilated screwcaps.

The modules were initially installed at the beach with only 40-60 cm above the sand.

As can be seen on the drawings the modules are placed in a matrix with 50 or 100 metres between the rows along the beach and 10 metres between the pipes in the cross-section.

The plant was installed July 14, 2000 and the only equipment used was a JCB digger on crawler tracks.

Survey

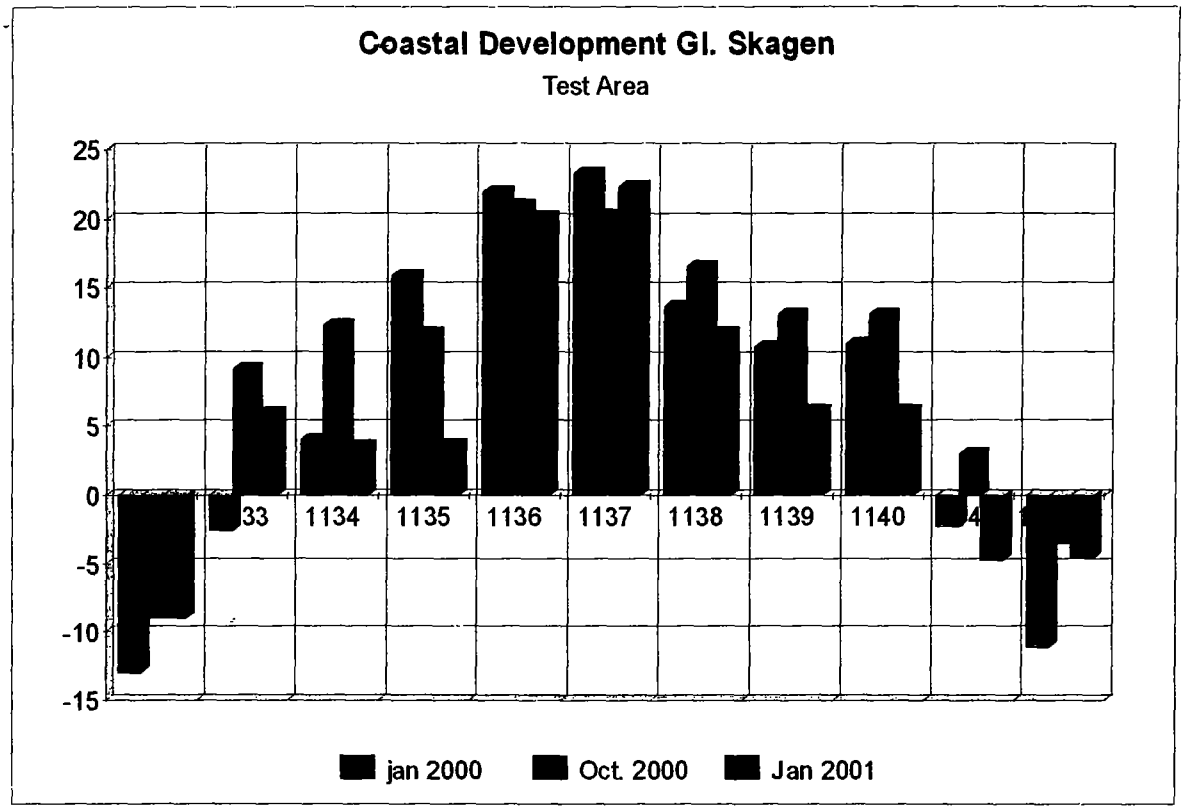


The coastline was measured July 18, 2000 by Rudan in cooperation with Carl Bro. It is important that an impartial control body carried out the measurement.

It was decided that the test period was to be six months, and the coast profile was measured again January 19, 2001 with the abovementioned result. It is also important to mention that during the six months test period, an engineer employed by SIC/ABC HANSEN A/S measured all modules every day.

The average raise in the profile on the 66,600 m^2 was 26.66 cm, which shows an increase of 17.76 m^3 per running metre along the pressure equalised coastal profile on Accra Beach.

Old Skagen - Denmark



For comparison reasons it can be mentioned that the increase in the monitored research project south west of Old Skagen is 5.6 to 6.5 m^3 per running metre.

The coastal profile is, however, only 35.33 m wide in average in contrast to the profile on Accra Beach with 66.66 m in average in the measured area. The plant south west of Old Skagen has been in permanent use for more than two years, and the profile is now stable.

Conclusion
After a test period of six months with a very heavy storm in October 2000, a very significant and positive development in the coastal profile is seen and similar to other plants installed at other locations.

The wind directions on the coast of Ghana are generally south west. Only in January 1992 and 1993 the wind direction turned to north west for a short period. The wind direction has no special influence on the build-up of the beach.

The average increase (supply of new sand) is measured to 17.76 m^3 per running metre and the raise in the coastal profile is measured to 26.66 cm in average.

Of all the plants installed, the plant in Ghana is showing the most positive result. The result is very satisfying, and on this basis we intend to continue our activities in Ghana within the field of coastal protection using the SIC pressure equalisation modules.

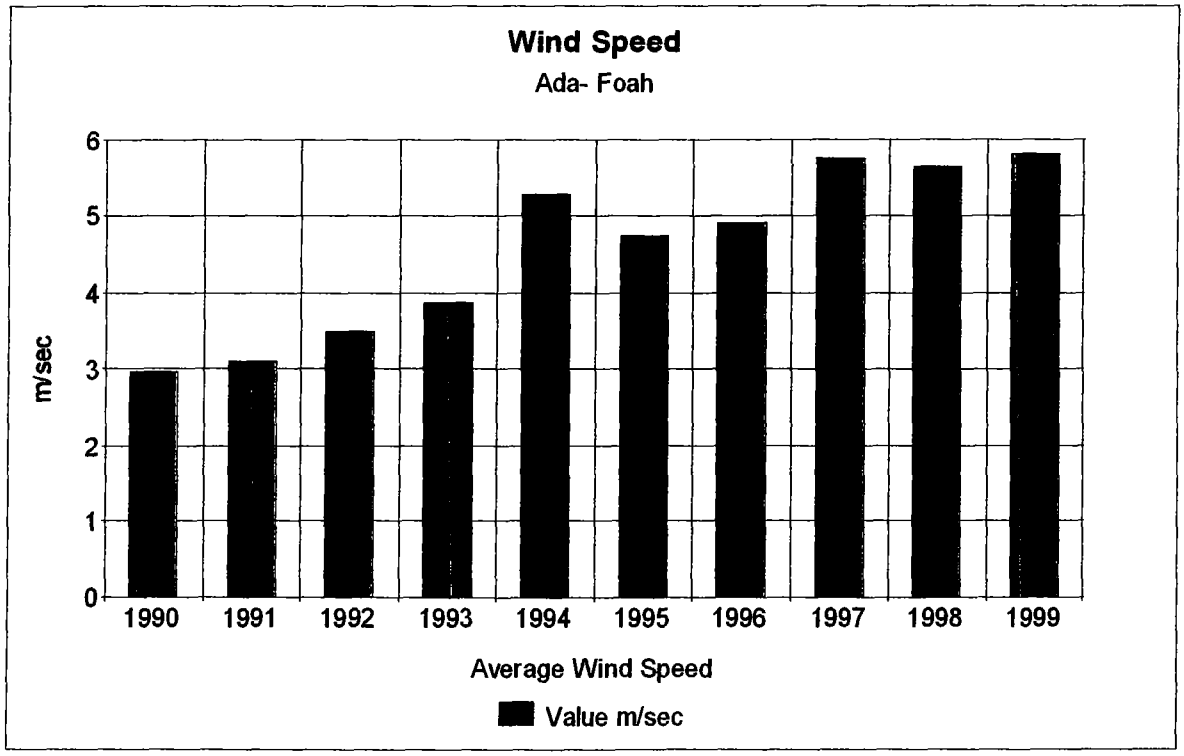
Weather

	jan.	feb.	mar.	apr.	maj.	jun.	july.	aug.	sep.	oct.	nov.	dec.
1990	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1991	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1992	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1993	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1994	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1995	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1996	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1997	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1998	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
1999	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW

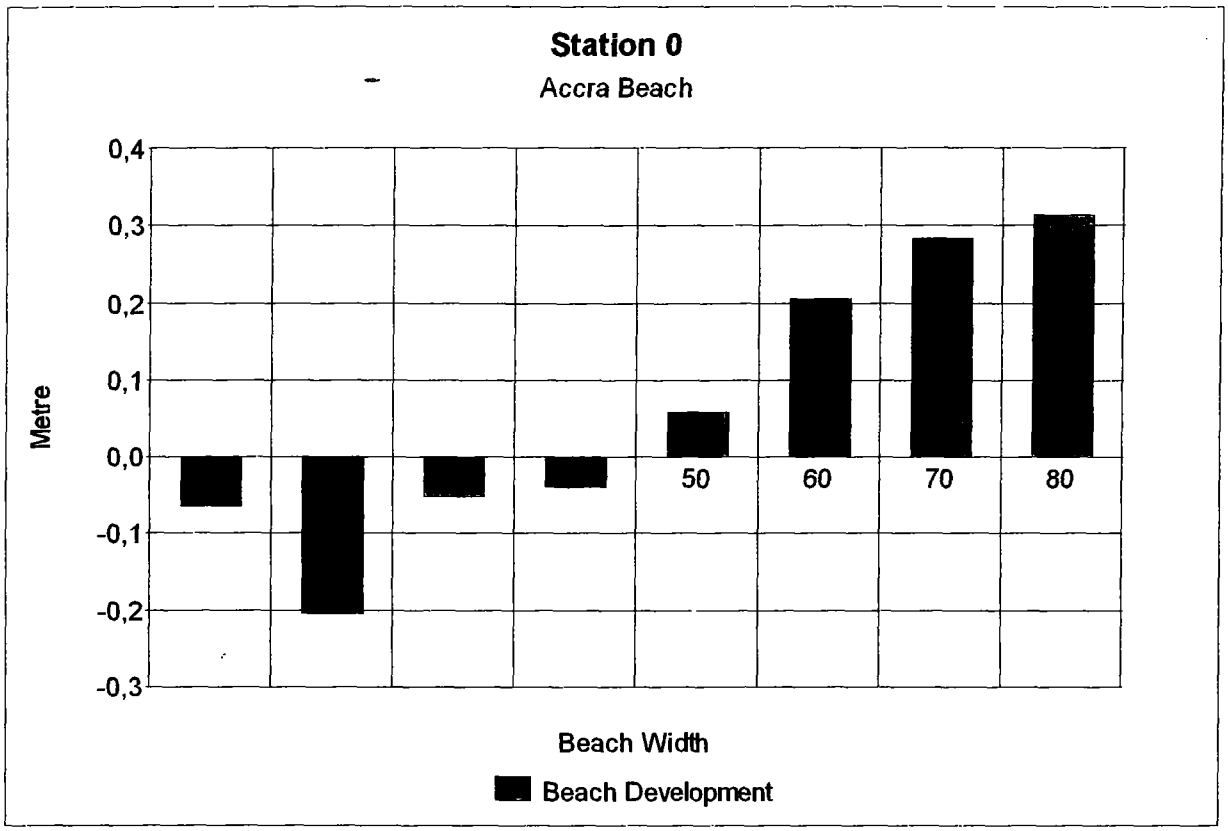
Wind direction

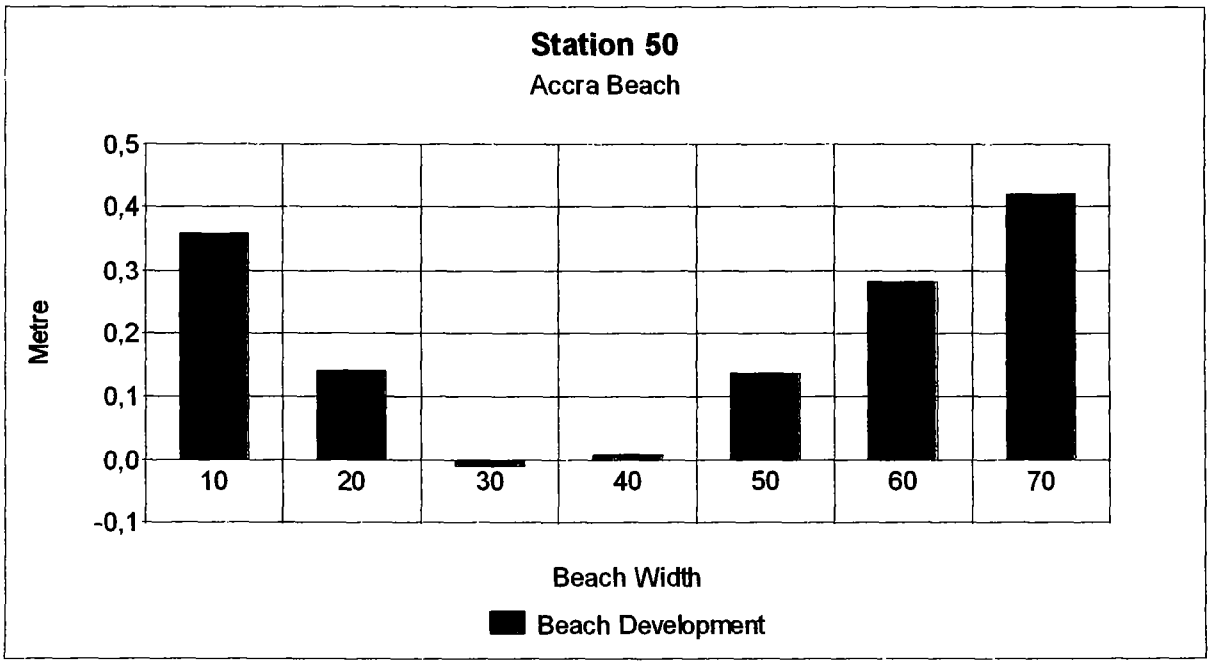
	jan.	feb.	mar.	apr.	maj.	jun.	july.	aug.	sep.	oct.	nov.	dec.	Avera
1990	2,6	3,4	3,3	3,7	2,8	3	4,2	2,8	2,6	2,6	2,3	2,4	2,98
1991	3	4,4	3,6	3	2,5	2,4	3,6	2,6	3,3	3,5	2,6	2,8	3,11
1992	3,5	2,7	3,3	2,6	2,6	3,7	3,9	4,1	4,8	4,5	2,8	3,4	3,49
1993	3,3	4,5	4	4	3,7	3,4	3,8	4,4	4	3,7	3,7	4	3,88
1994	5,2	7	6	5,6	5,4	4,5	3,1	4,5	6,2	5,9	4,7	5,4	5,29
1995	4,8	6,8	5,4	5,8	5	4,3	3,4	4,1	4,4	5,2	3,9	3,8	4,74
1996	3,8	5,5	3,8	5,1	4	3,1	4,9	4,6	5,8	6,8	5,8	5,6	4,9
1997	4,9	5,4	5,7	5,6	4,5	5,5	5,9	6,4	7,2	5,8	6,5	5,7	5,76
1998	4,3	5,4	5,3	5,3	4,7	5	5,7	6,5	7,1	6,9	6,1	5,5	5,65
1999	6	6,4	7,3	6,7	5,5	4,2	4,7	5,5	6,1	7,4	5,3	4,6	5,81
	4,14	5,15	4,77	4,74	4,07	3,91	4,32	4,55	5,15	5,23	4,37	4,32	4,56

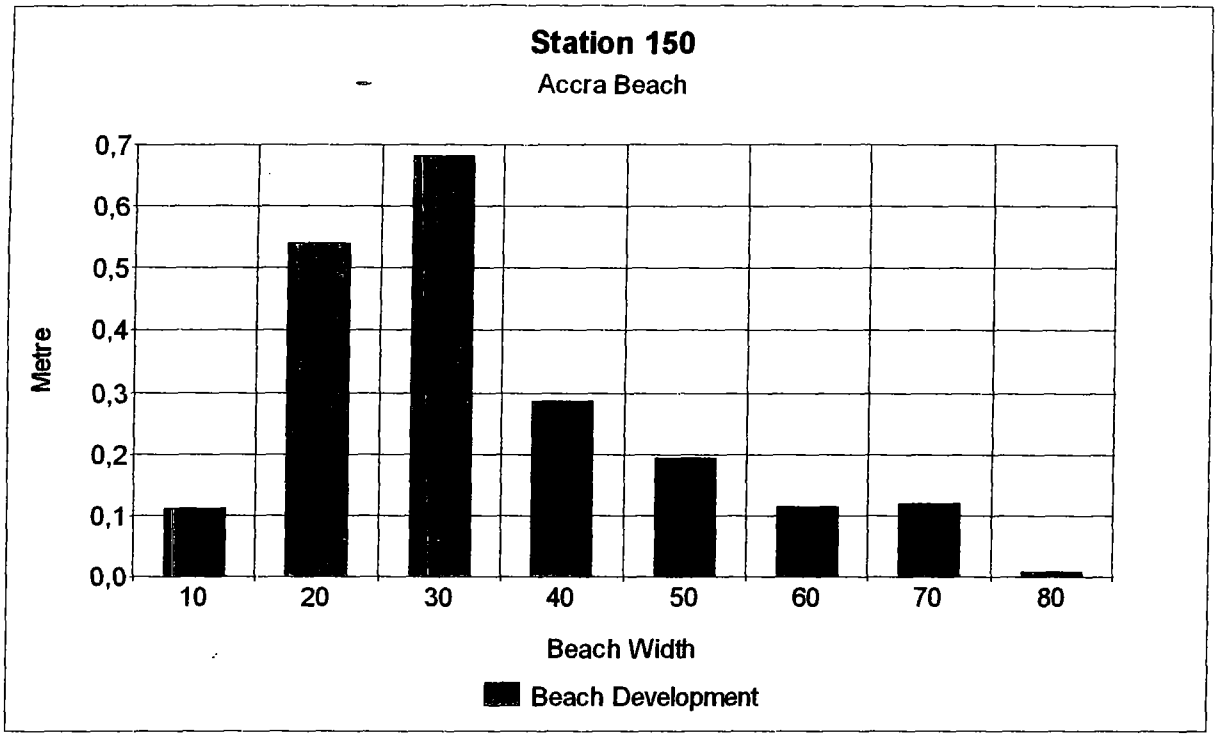
Wind speed over 10 years

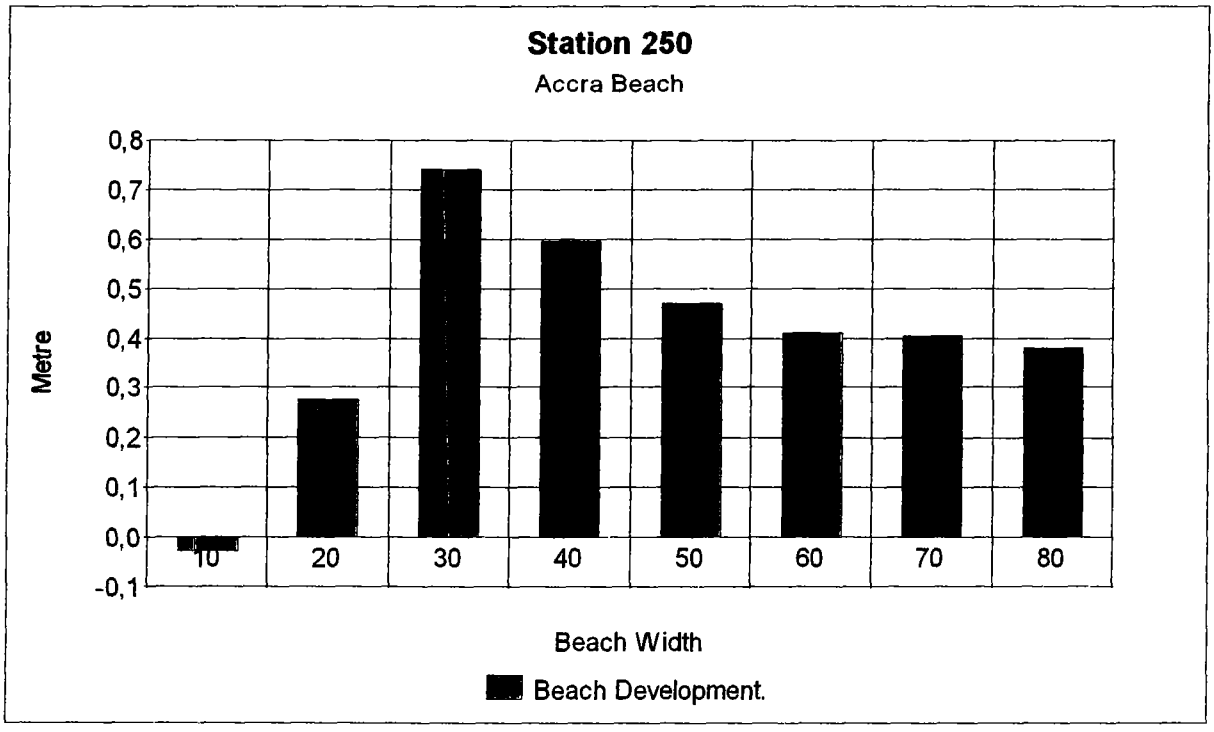


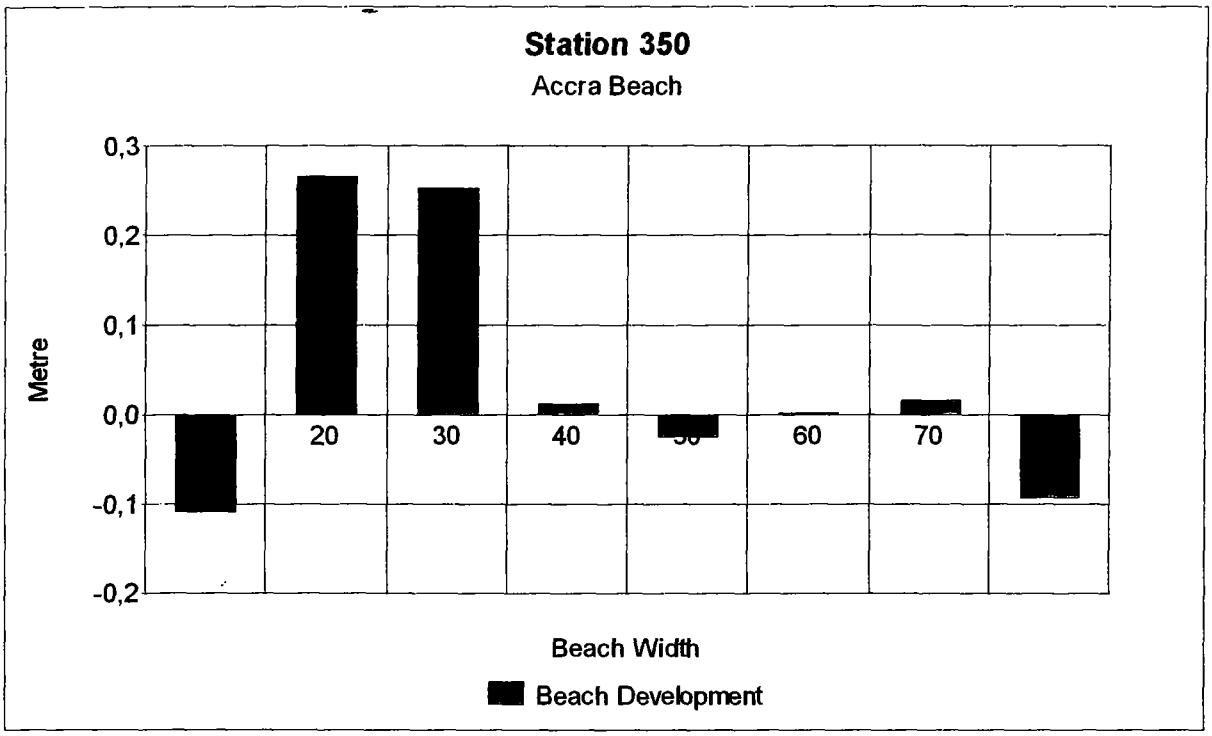
The measurements show that the wind speed has doubled over a period of 10 years, but need to be reconfirmed.

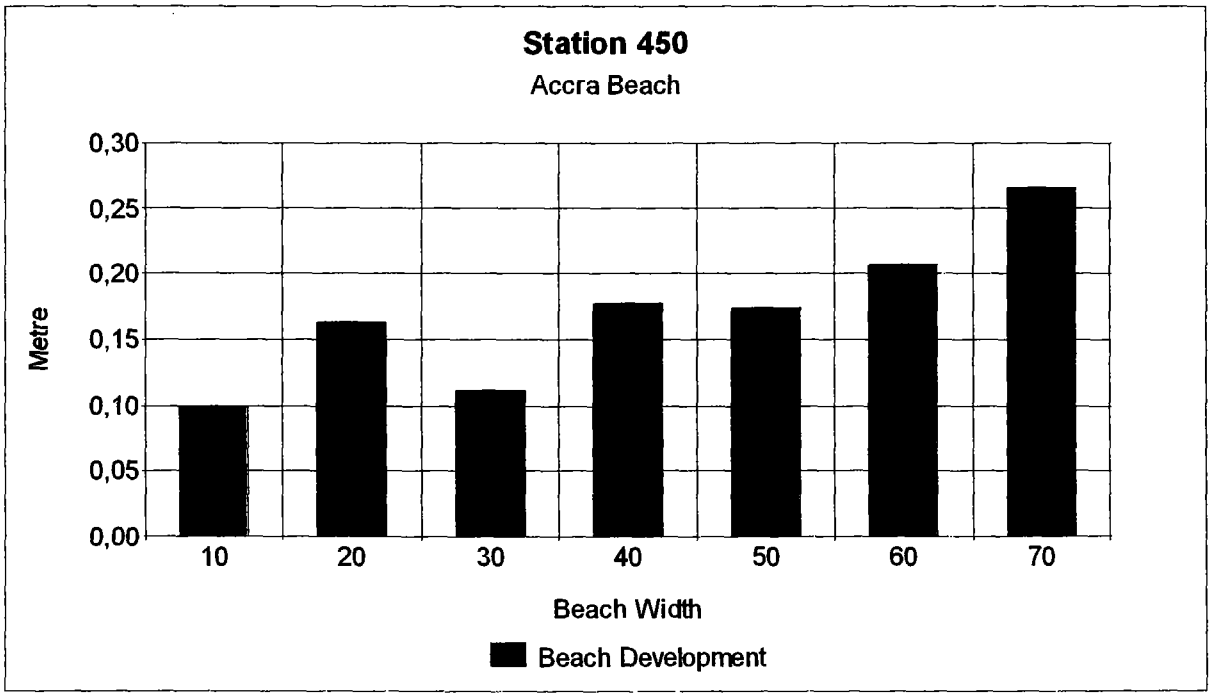

Station 0
Accra Beach
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
-0,3
Metre
50
60
70
80
Beach Width
Beach Development

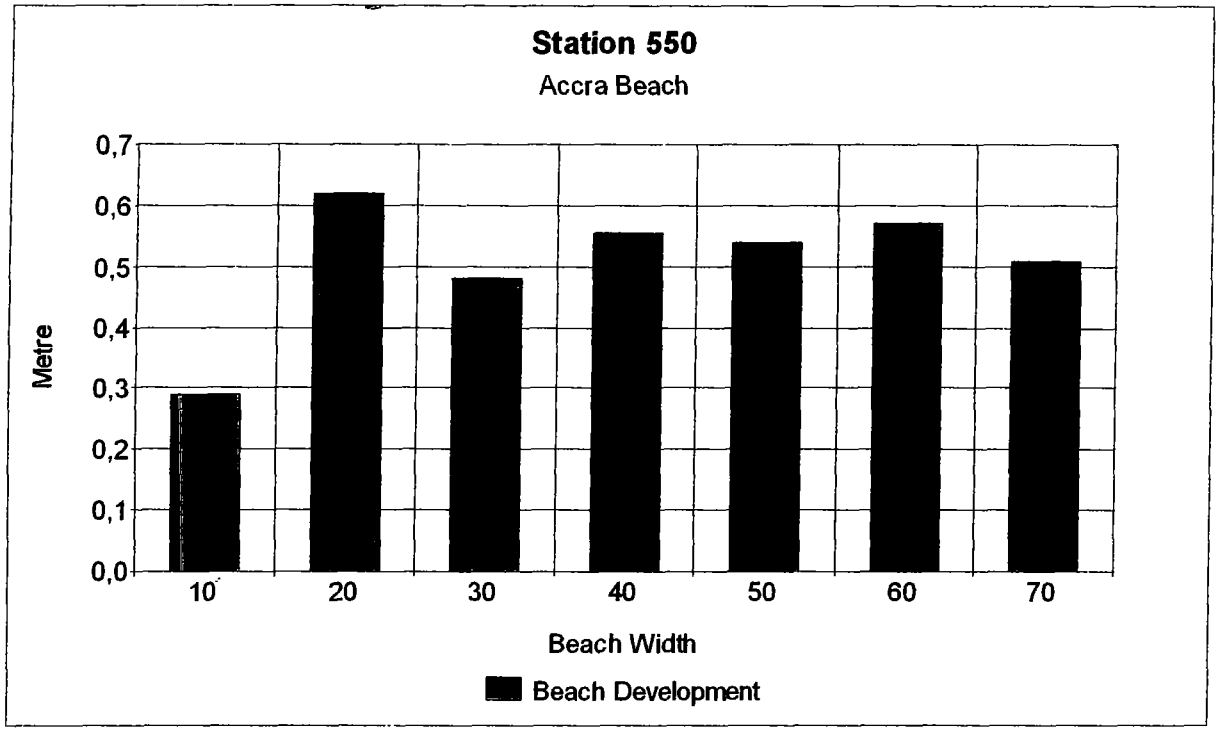

Station 50
Accra Beach
0,5
0,4
0,3
0,2
0,1
0,0
-0,1
Metre
10
20
30
40
50
60
70
Beach Width
Beach Development

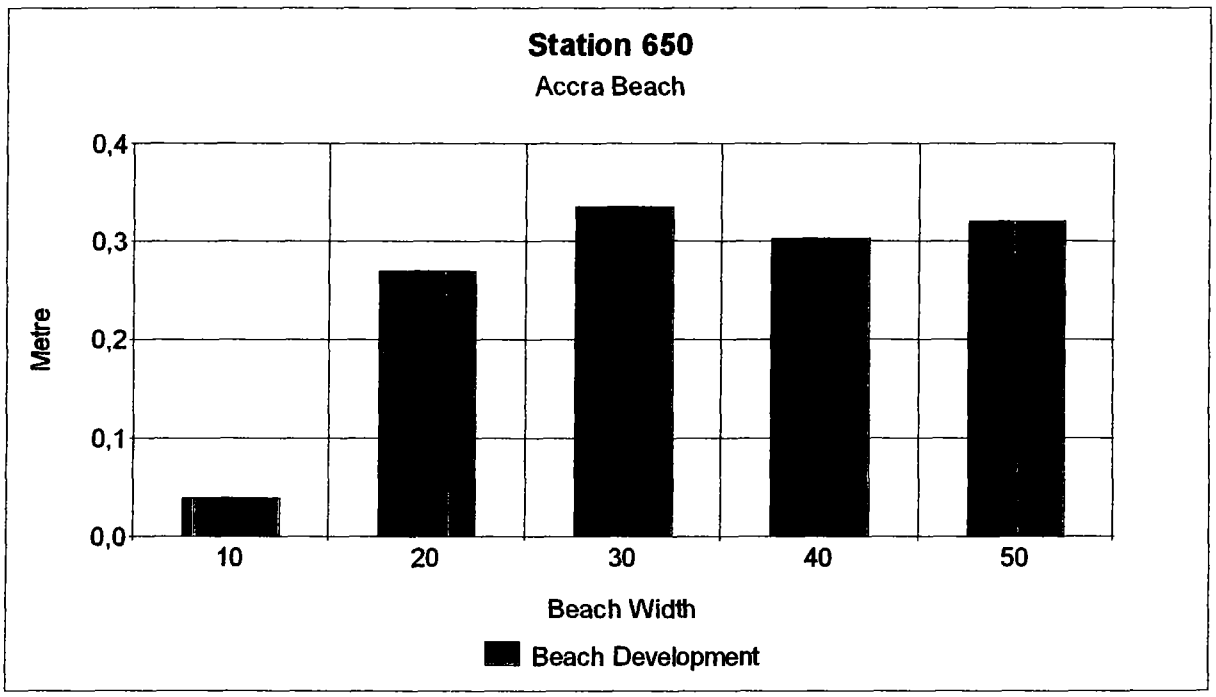

Station 150
Accra Beach
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Metre
10
20
30
40
50
60
70
80
Beach Width
Beach Development

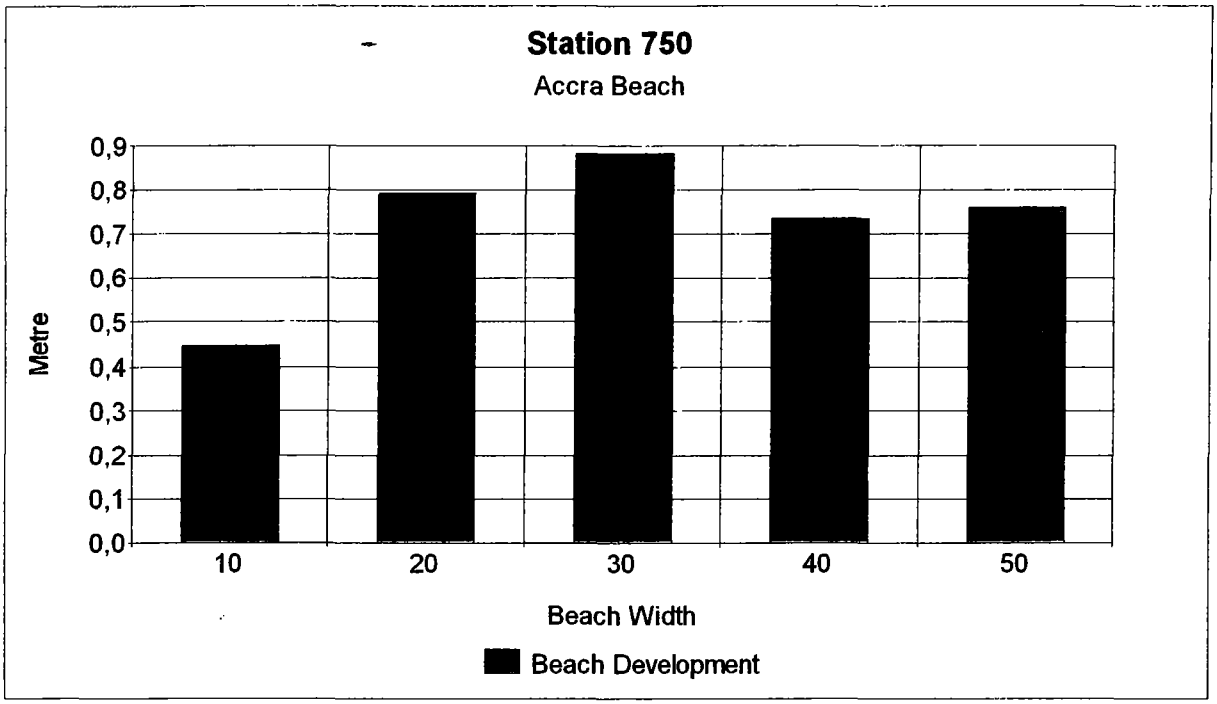

Station 250
Accra Beach
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
-0,1
Metre
10
20
30
40
50
60
70
80
Beach Width
Beach Development.

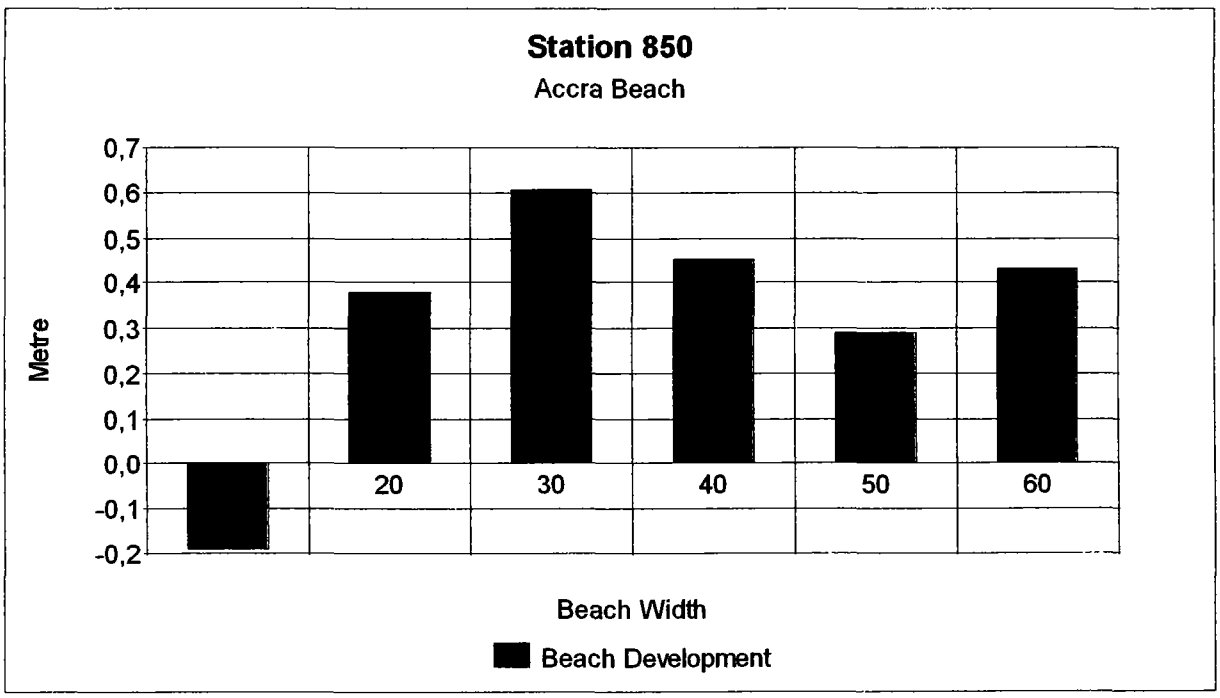

Station 350
Accra Beach
0,3
0,2
0,1
0,0
-0,1
-0,2
Metre
20
30
40
60
70
Beach Width
Beach Development

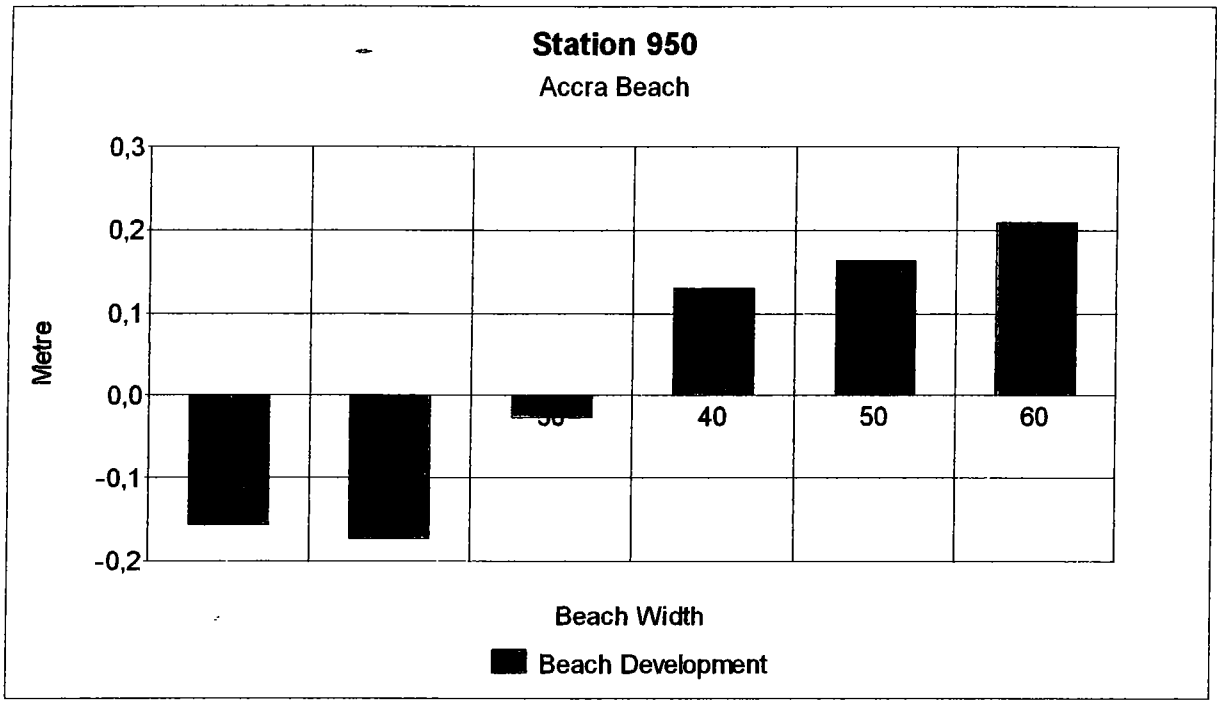

Station 450
Accra Beach
0,30
0,25
0,20
0,15
0,10
0,05
0,00
Metre
10
20
30
40
50
60
70
Beach Width
Beach Development

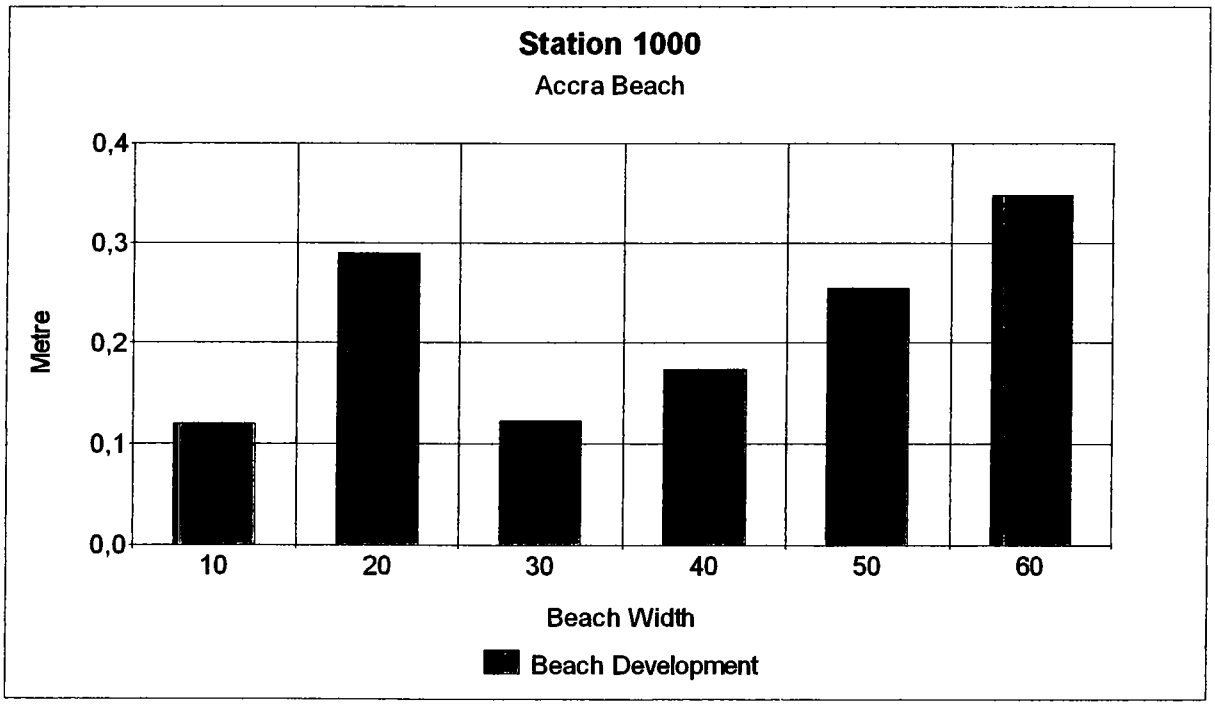

Station 550
Accra Beach
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Metre
10
20
30
40
50
60
70
Beach Width
Beach Development

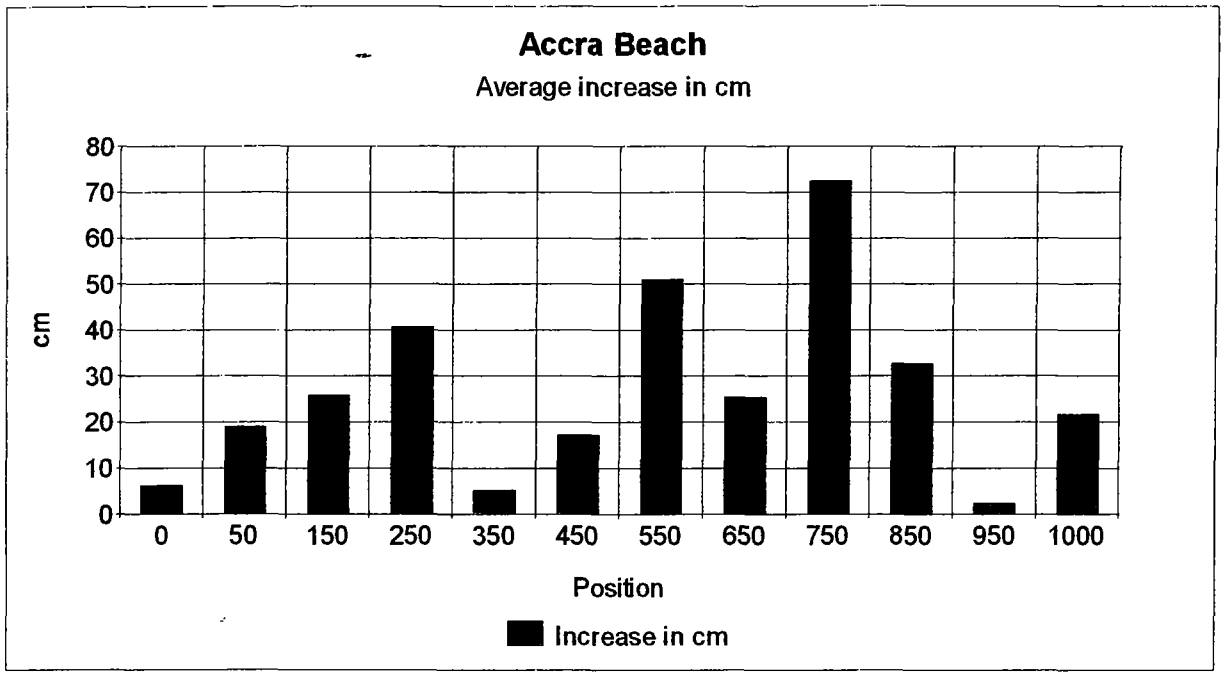

Station 650
Accra Beach
0,4
0,3
0,2
0,1
0,0
Metre
10
20
30
40
50
Beach Width
Beach Development


Station 750
Accra Beach
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Metre
10
20
30
40
50
Beach Width
Beach Development


Station 850
Accra Beach
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
Metre
20
30
40
50
60
Beach Width
Beach Development


Station 950
Accra Beach
0,3
0,2
0,1
0,0
-0,1
-0,2
Metre
40
50
60
Beach Width
Beach Development


Station 1000
Accra Beach
0,4
0,3
0,2
0,1
0,0
Metre
10
20
30
40
50
60
Beach Width
Beach Development



Calculation of profile development Accra Beach
July 2000 - jan 2001

	Average	Profile	Profile		
Station	increase	Width m.	Length m.		
0	6,2	80			
50	19,1	70			
150	25,7	80			
250	40,6	80			
350	5,3	80			
450	17,1	70			
550	51	60			
650	25,4	50			
750	72,4	50			
850	32,9	60			
950	2,5	60			
1000	21,8	60			
Total	320	800			
Average	26,666667	66,66	1000	17776	Cubic metre.
Increase 17,78 Cubic meter pr. meter.					

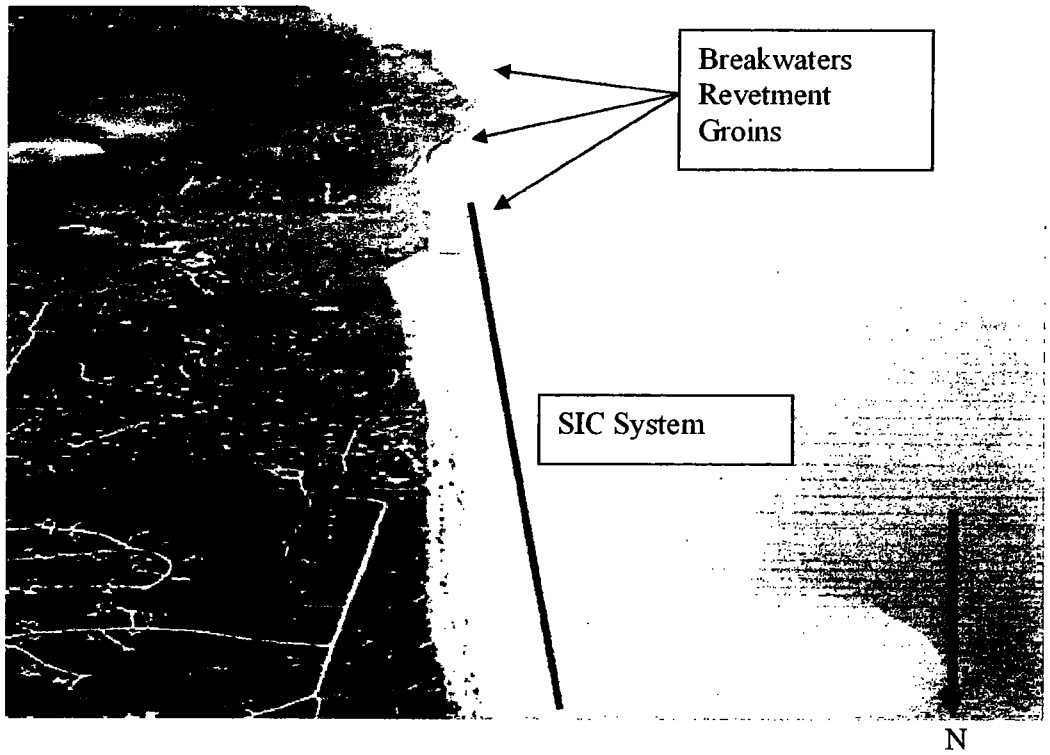
Test Area Accra Beach
1000 meter

SIC vertical drain system compared with groins and breakwaters combined with beach nourishment.

Poul Jakobsen, Skagen Innovation Center, Dr. Alexandrinesvej 75, DK 9990 Skagen, Denmark

SIC carried out a field test on the west coast of Jutland, Denmark together with council Hjørring from 2000 – 2003.

The objective of the project was to compare the SIC pressure equalisation system with groins and breakwaters combined with beach nourishment at Lønstrup. Laustrup C 1988



Introduction.
The SIC system of Pressure Equalising Modules (PEM) is a vertical drain system placed in a matrix along the coastline with a distance between the rows of 100 metre along the coastline, and 10 metre between the modules (in the cross) Burcharth H. F. April 2000

The SIC system was installed on a 3700 meter long beach from the groin's in south to the Hirtshals county border in north.

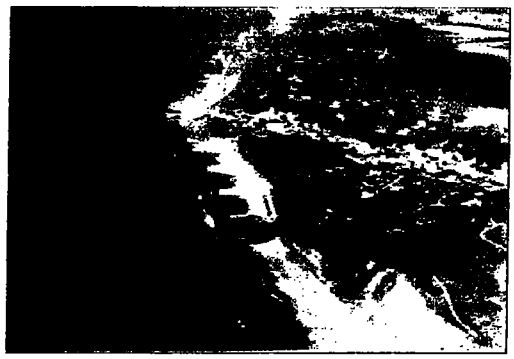
Monitoring.
The beach profile was controlled by an independent survey company before the installation of the SIC system in June 2000, and yearly until June 2003.

PEM system from SIC
The sand loss from level 2.5 meter in the dune foot to the shoreline is over three years 740 cubic metre per kilometre.

Groin's
In the area with groin's the erosion on 1150 metre over 15 years has been 33.000 cubic metre per year incl. dune erosion. The groins have tripled the erosion in relation to the natural erosion rate in this place.

Breakwaters

Lønstrup with the SIC system
July 1999



Lønstrup with beach nourishment.
July 2002

The beach with breakwaters at Lønstrup was protected with the SIC system in 1999 and the breakwaters were placed passive inside the beach.

The Coast Authority in Denmark insisted to have the SIC system removed, so they could continue the yearly beach nourishment with 22 000 cubic metre per year, but lost the beach.

Leaside erosion caused by breakwaters at Lønstrup.
July 2002

The breakwaters have resulted in extreme leaside erosion, and the beach is totally lost, and the owners of the land try to protect their property with rocks on the cliff.

Conclusion.

In the test area over 3700 metre with the SIC system, the erosion was limited to 740 cubic metre per km over 3 years or 250 cubic metre per Year.
In relation to the West coast of Jutland (100 km) the yearly need of beach nourishment will only amount to 25.000 cubic metre per year, ***if most of the groins and breakwaters are removed*** and the west coast of Jutland is stabilised with the SIC system.

Christian Laustrup estimated in his summary in 1988, that the need for beach nourishment combined with breakwaters on the west coast of Jutland, would be 620.000 cubic metre a year, but the erosion is now 4.1 mill cubic metre per year or 700 % more than estimated.