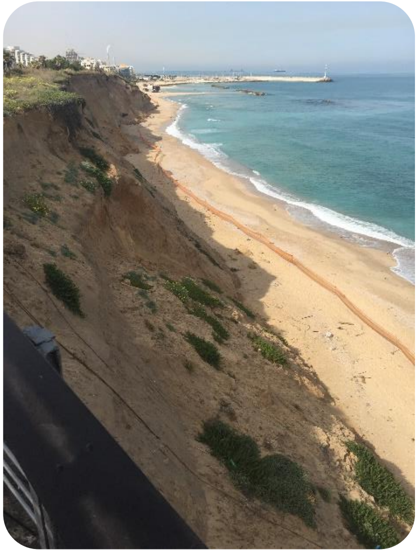

Geotextile structures for beach protection

Ashkelon, Israel

Design of the marine works

DESIGN REPORT AREA 38

DECEMBER 2016

Affaire : CORADM-73-2016

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Versions and modifications

Version	Date	Description	Modifications
0	15/10/2016	Design report	Initial version
A	21/10/2016	Modified following M&N comments	
B	12/12/2016	Modified following 29-30/11/16 meetings	

RÉSUMÉ

This report presents the design of the beach protection in Ashkelon.

This report summarize several partial report and it follows the report done by Moffatt and Nicol in May 2016: “ASHQELON URGENT PROTECTION WORKS COASTAL STABILISATION ASSESSMENT ANALYSIS FINAL REPORT”

SUMMARY

TABLES

FIGURES

1 INTRODUCTION

1.1 PREAMBLE

The Mediterranean Coastal Cliffs Preservation Government Company Ltd has welcomed proposals for design and build of coastal protection schemes in the Ashqelon area (Israel), using geotextile to build shore-parallel breakwaters.

The tender have been awarded to a Joint Venture of TAAVURA, Admir technologies and TRASOMAR.

CORINTHE Engineering is the designer of the JV.

The two sites are the Field Units 38 and 39, as described in the Policy Document and National Outline Plan 13, Amendment 9A. Field Unit 38 is immediately to the north of Ashqelon marina and Field Unit 39 is about 1.5km south of the marina.

Field Unit 38 comprises some 800m of beach, backed by hotel development on the cliff top.

Field unit 39 comprises 800m of beach, backed by the archaeological remains within the roman city of Ashqelon.

Certain segments of the above coastal cliff belt are prone to erosion of cliffs. They are mainly due to natural weathering processes triggered by a combination of various factors, including: wave erosion at ridge base, ridge slope instability, runoff erosion.

1.2 INITIAL SOLUTION SET

The tender document set the main objectives for the protection of the cliff:

- Do a nourishment to protect the cliff from the impact of the waves;
- Install a breakwater to minimize the erosion of the beach.

Taking that objectives into account, the Moffat and Nichols report present a solution for area 38 and 39. The solution for area 38 is as follow:

- Do a 211 000 m³ nourishment
- Install 120 m submerged breakwater with a gap of 50 m.

Table 1: submerged breakwater design parameters

	Area 38	Area 39
Design wave height ($H_{m0,12hrs/year}$, m)	3.2	3.2
Peak wave period (Tp, s)	11.0	11.0
1 year surge level (m)	0.3	0.3
Total length of coast (m)	1000	800
Number of breakwaters	5	5
Breakwater length per section (Ls, m)	120	120
Assumed minimum Breakwater crest width (w, m)	> 15	> 15
Gap length (G, m)	50	50
Breakwater crest level (mCD)	0.0	0.0
Seaward toe level of the breakwater (mCD)	-4.0	-4.0
Nourishment Volume (m3)	211,000	244,000
Initial berm width (width of the dry beach)	75	75
Fill slope	1V:10H	1V:10H

1.3 PURPOSE OF THE REPORT

The report aim is to extend the studies done by Moffat and Nichols for calibration and design the final solution for the beach protection of the area 38 in Ashklelon.

This report is divided in several sections:

- Metocean data analysis
- Extension of the initial calibration
- Run of several different scenarios to define the most significant parameter for the design
- Run another set of scenarios
- Define the final solution
- Study the stability of the geotube structures

It seems important to set at the beginning of the report the way the design has been performed by CORINTHE Engineering:

- The Xbeach model used by Moffat and Nichols has been used to follow the calibration set previously
- The protection of the beach is to be made with geotube structure
- The design parameter is the average shoreline position after 10 years.

The impact of specific storm on the shoreline position must be studied also to set the maintenance that will have to be performed.

2 METOCEAN DATA

2.1 WAVE DATA AND STATISTICAL APPROACH

Offshore and moreover nearshore, wave data are required to provide wave conditions to the sediment transport and coastal area morphology models, as well as extreme wave conditions to assess immediate post-storm erosion and to dimension any project.

As stated by Moffatt & Nichol in their report [1], there are no available observed (measured) wave data sets in the project vicinity of Ashqelon. MCCP has provided observed historical wave data covering a period of 23 years (Apr1992 – Mar 2015) in 3 hour intervals, recorded at a location just north of Ashdod harbor. The data includes; significant wave height (Hs), peak wave period (Tp), mean wave direction (MWD, from true north), mean wave period (Tz), directional spreading, and sea water temperature. The buoy location is -31°52.49´N, 34°38.96´E in a water depth of approximatively 24 meters.

The nearshore wave rose obtained by Moffatt & Nichol thanks to the analysis of this data is presented below. It shows that about 63% of the wave heights are higher than 0.5m, responsible for a strong littoral drift. About 62% of the waves are coming from directional sector 285 – 315 deg, responsible from a net northward littoral drift. Waves with high wave heights are having long peak periods of 10.0 – 16.0 s.

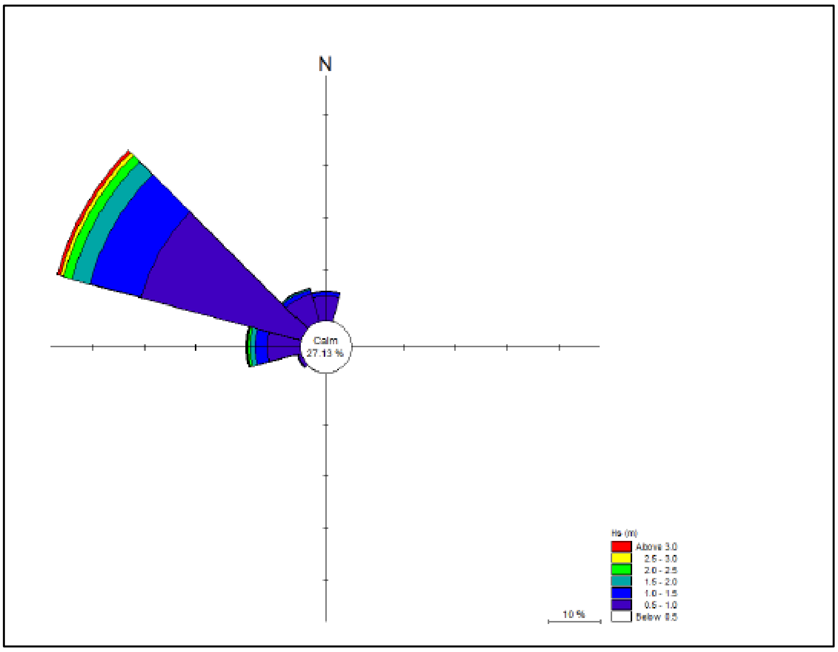


Figure 1. Wave height (Hs) rose (Apr 1992 – March 2015) north of the Ashdod harbor (approx.. 24m depth) (source : Moffatt and Nichol [1]

The Ashdod wave data were used by Moffatt & Nichol to estimate an offshore wave climate that was used as input to a wave transformation modelling approach in order undertake a statistical analysis of this data. Such data are relevant for long term beach evolution study.

For long term beach evolution purpose, a key parameter is the significant wave height exceeding 12hours per year (0.137%), used in the different formulas.

The wave exceedance curve at 5m depth provided by Moffat & Nichol is presented below. From this curve, the significant wave height exceeding 12hours per year (0.137%) was extracted
It corresponds to $H_{m0\_12hrs/year@5mdepth}$=3.2m.
And the associated Tp is 11s.

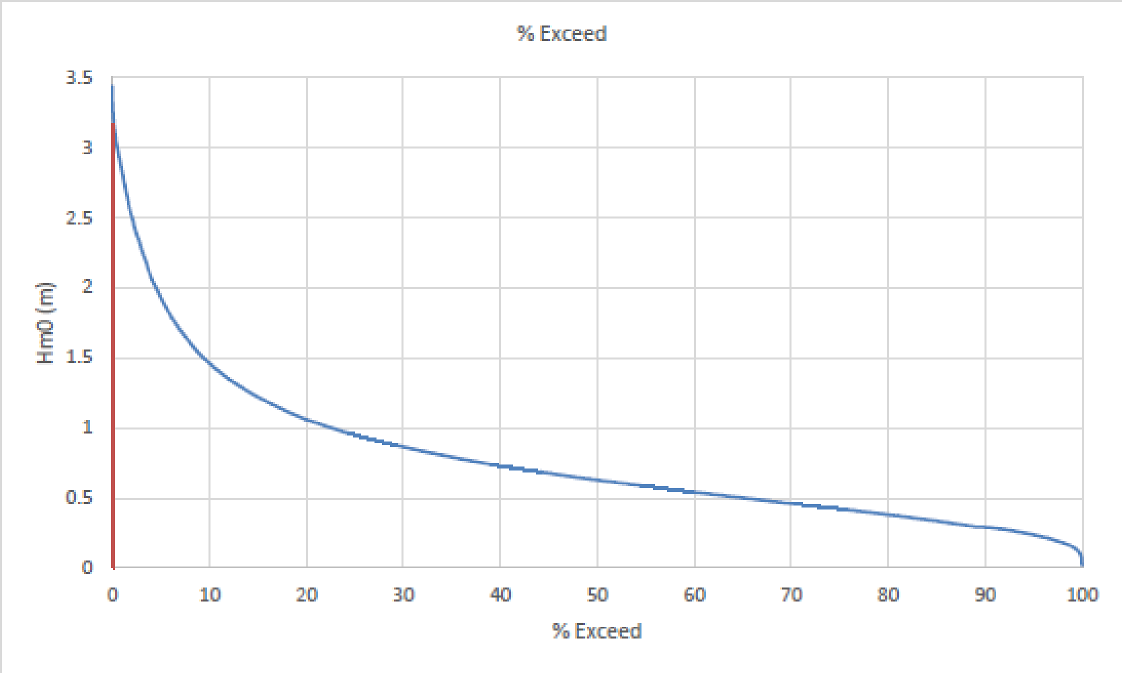


Figure 2. wave exceedance curve at 5m depth (source : Moffatt and Nichol [1])

2.2 WAVE CONDITIONS FOR STORMS

In order to assess the extreme wave climate at the site area, CORINTHE Engineering has extracted data analysis from different internal or external sources, such as:

- Internal database reports of CORINTHE Engineering
- Moffatt & Nichol report [1]
- SEATECH report from 1990 on the Ashkelon Marina design [2]
- Scientific publication by Sergiu Dov Rosen in Coastal Engineering 2012 [3].

The table below presents extreme wave data extracted from this database. It shows intensity of 4 to 6m of (significant) wave heights for "frequent" storms (1 to 5 year Return Period – RP) and 6 to more than 8m for extreme storms (10 to 100 year RP).

Table 2: comparison of extreme offshore wave conditions depending on the source

Return Period (year)	CORINTHE (2010) North of Israel		SeaTECH (<1990) Ashdod port station		Rosen(2010) Ashdod port station	
	Hs (m)	Tp (m)	Hs (m)	Tp (m)	Hs (m)	Tp (m)
1	4.4	8.7 to 10	3.7	9.6	4.8	11.5
2			5.4	11.6		
5	6	11.2 to 12.5	6.2	12.4	6.2	13
10	6.3	11.2 to 12.5	6.7	12.9	6.8	13.5
20	6.7	11.2 to 12.5			7.4	14
25			7.5	13.7		
50	7.1	12.5 to 15	8.2	14.3	8.2	15
100	7.4	12.5 to 15	8.7	14.7	8.7	15.5

Results of the analysis, undertaken on offshore wave data time series provided by M&N (generated from Ashdod port wave data) in order to determine offshore directional extreme wave data, are presented in the table below. A POT analysis was applied to estimate these values.

This shows good agreements with the above table.

Table 3: extreme wave analysis using the offshore wave provided by Moffatt&Nichol

	Significant wave height Hs (m)				
Off. wave dir. (°N)/ Return Period (year)	N195° N225°	N225° N255°	N255° N285°	N285° N315°	N315° N345°
1	0.5	1.4	3.8	4.2	2.4
10	1	2.1	5.5	6	3.7
20	1.1	2.4	6	6.7	4.1
50	1.3	2.6	6.6	7.6	4.8
100	1.4	2.8	7.1	8.2	5.2

In September 2016, MCCP provided CORINTHE Engineering with storm wave data recorded at the Ashdod port station during the period December 2015 to February 2016.

As example, the time series of wave height data is presented in the figure below for the period 27/12/2015 to 11/01/2016.

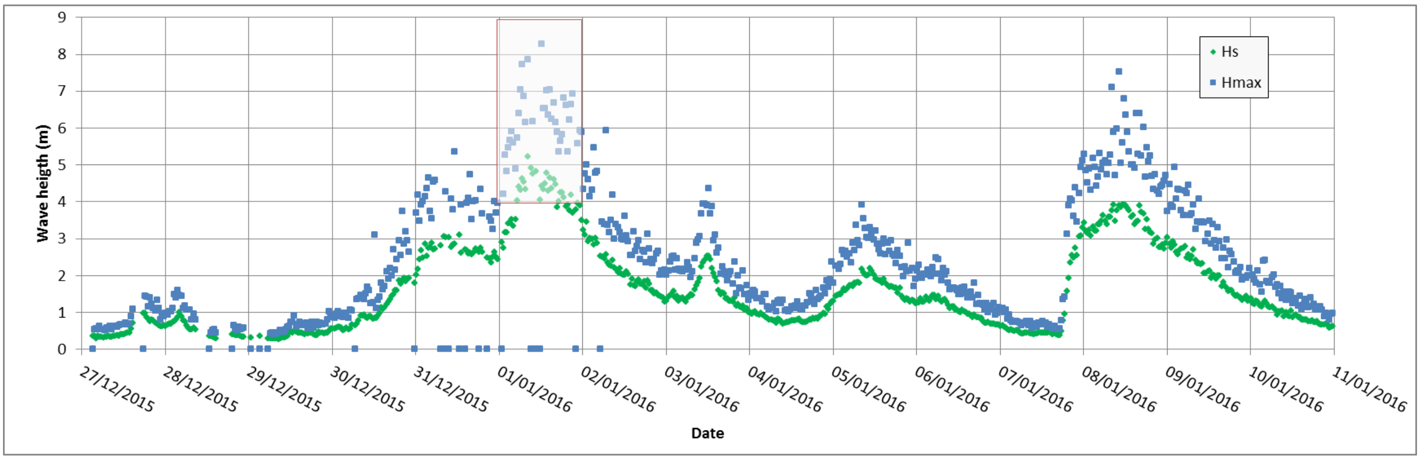


Figure 3. Wave height data recorded at Ashdod wave station

During this period, the beach experienced 5 storms with maximum significant wave heights ranging from 4m to 5m:

- This confirms the height intensity of the « frequent » storms (1 to 5 year return period).
- These records confirm the average duration of the peak storm of about 24 hours.

2.3 WATER LEVELS

As provided in the "Technical Requirement" document [4], the tide levels at Ashdod (extended in Ashkelon) are presented in the table below, with a MSL at 0.3m CD and a MHWS at 0.6m CD:

Table 4: present day Ashdod levels (source "Technical requirement" [4])

Table 2-2: Present Day Ashdod Levels

Tide	Abbreviation	Elevation (m ACD)
Highest Astronomical Tide	HAT	+0.80
Mean High Water Spring	MHWS	+0.60
Mean High Water Neap	MHWN	+0.40
Mean Sea Level	MSL	+0.30
Mean Low Water Neap	MLWN	+0.10
Mean Low Water Spring	MLWS	+0.00

Hereinafter are presented the extreme water levels extracted from different database. It shows extreme water levels from 0.6 to 1.35m depending on the intensity and the database.

Table 5: comparison of extreme water level conditions depending on the source

Return Period (Year)	CORINTHE (2010) mCD North of Israel	SeaTECH (Rosen <1981) mCD Ashdod port station	Rosen (2010) mCD Ashdod port station
1	0.55	0.9	0
5			0
10	0.65	1.15	0.1
20			0.2
25		1.25	
50	0.75	1.30	0.5
100	0.85	1.35	1.0

This data shows that, while the tendency of storm surge increase with the intensity is coherent, the values are variable between the different dataset.

In a attempt to specify the storm surge values, CORINTHE Engineering analyzed time series of water levels from the website http://ioc-sealevelmonitor.ing.org/. Extracted data at Ashkelon port station show that data is generally not available, or not exploitable, during a storm event. However, this lead to think that consequent surge might be associated with storm events. As example, the time series below correspond to the periods December 2015, January and February 2016, with storm events experienced; especially the 1st, 19th and 25th of January and the 23rd of February.

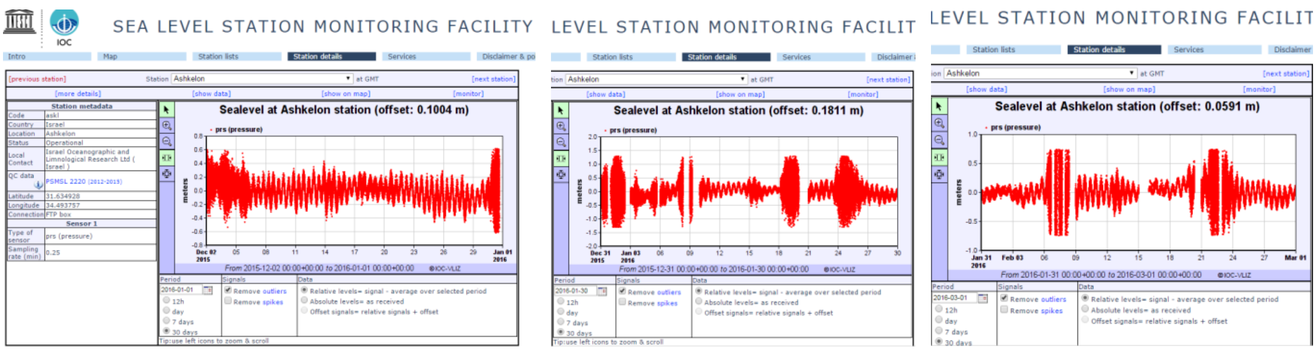


Figure 4. Recoded water levels at Ashkelon port station, period December 2015 to February 2016

Same observations (figures below) can be made from Ashdod and Hadera port station water level data, when available.

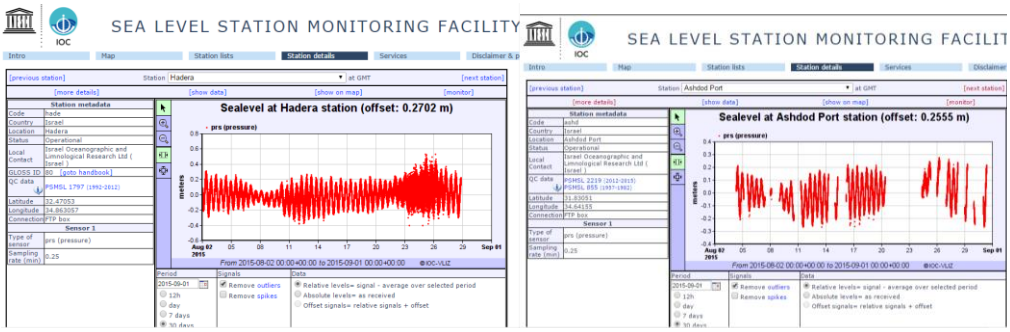


Figure 5. Recoded water levels at Hadera and Ashdod port station

2.4 EXTREME WATER LEVELS AND WAVES (PROJECT DESIGN CONDITIONS)

In order to take into account storm surge variabilities, the following water levels will be associated with the following offshore wave conditions for post storm beach erosion studies and geotextile stability calculations.

Table 6: Extreme water level and wave conditions for the project design

Return Period (Year)	Water levels (m CD)	Offshore wave conditions		
		Hs (m)	Tp (s)	Dir (°N)
1	0.6 - 0.9	4.8	11.5	290
5	0.6 - 1.0	6.2	13	290
10	0.6 - 0.8 - 1.2	6.8	13.5	290
20	0.6 - 0.8 - 1.2	7.4	14	290
50	0.6 - 1.0 - 1.3	8.2	15	290
100	0.6 - 1.0 - 1.4	8.7	15.5	290

2.5 CONSIDERATIONS REGARDING EXTREME CONDITIONS AND ASSOCIATED RISKS

In order to provide information for decision making, the table below details the percentage of risk associated with a given Return Period (RP) of a storm event. This is considering a duration of 10 years.

For a 1 year RP, it is almost certain that such a storm will happen during in 10 years and for the 10 year RP, the risk is almost 2/3.

Table 7: Extreme event and associated risks for a 10 year duration

Duration: 10 years	
Return period	Percentage of risk
1	100%
5	86%
10	63%
20	39%
50	18%
100	10%

3 EXTENSION OF THE CALIBRATION

The calibration of the XBeach model have been set by Moffat and Nichols in the report: “Ashqelon urgent protection works coastal stabilization assessment analysis final report”.

But since this report, some new data are available.

Especially on area 38, some nourishment has been performed in 2015 and several bathymetric survey allow a better understanding of the sediment transport.

CORINTHE Engineering has then performed an extension of calibration to assess the representativeness of the XBeach model.

3.1 CALIBRATION /VALIDATION USING 2015-2016 SURVEY AFTER BEACH NOURISHMENT

Based on bathymetric survey from August 2015 and April 2016 provided by MCCP, CORINTHE Engineering undertook a validation analysis in order to extend the calibration of the XBEACH model.

At first, the following assumptions shall be considered:

- The simulation ran over “1 year” to cope with the “average” wave climate, to be compared with a 9 month period for the measurements.
- The use of an “ideal” bathymetry for long term modeling stability.

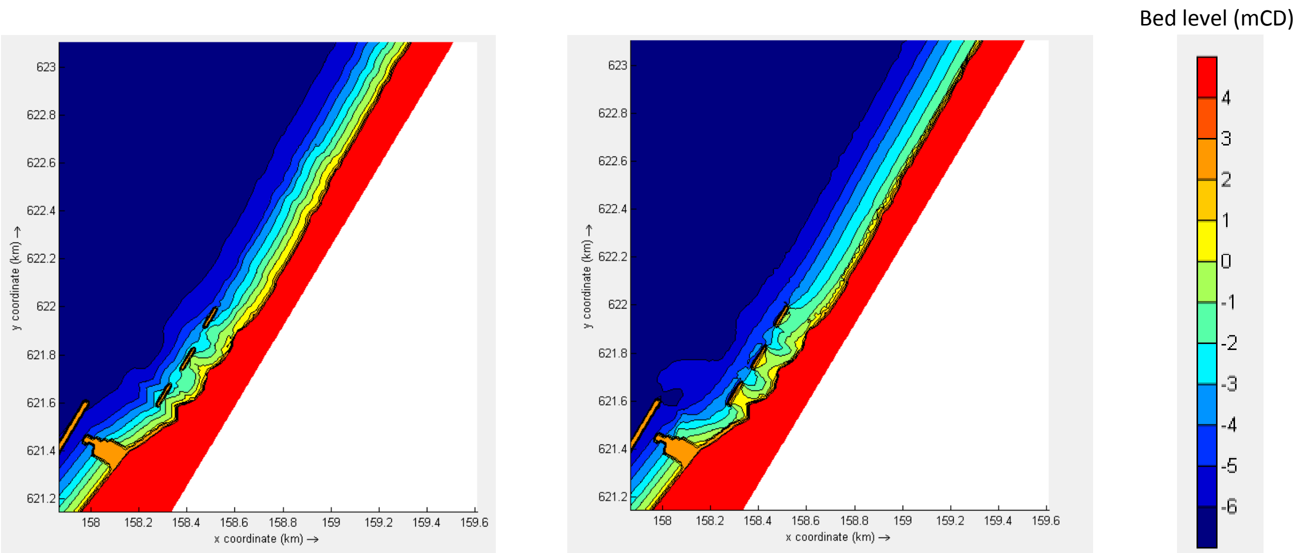


Figure 6. T=0 – beach nourishment of 65 000m3 T=1year

Comparison of survey and model results show good agreement, in general, although the offshore sediment structures growing and migration mechanism in not represented by XBEACH, as shown in the beach profiles showed hereinafter.

3.2 CROSS SECTION

On the graphics below, cross sections along the study shoreline (from north to south as shown in the figure section 4.5) for survey and numerical results are presented for comparison (Colors are similar for dates):

- **thick lines: Survey**
- thin lines: XBEACH results

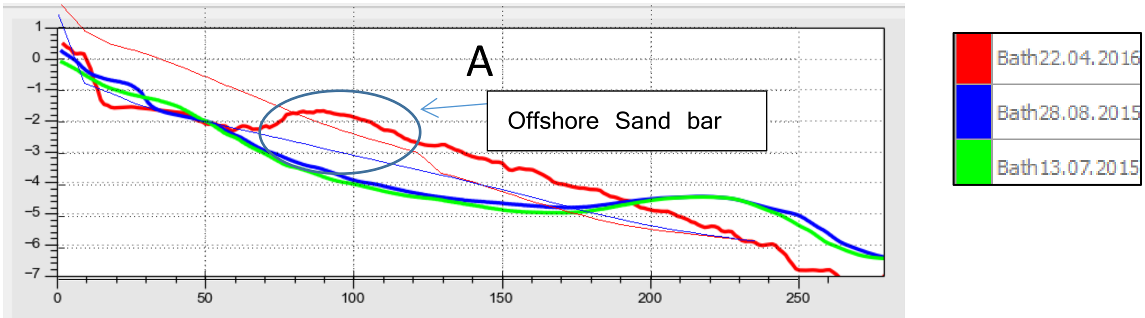


Figure 7. Beach profiles along cross section A

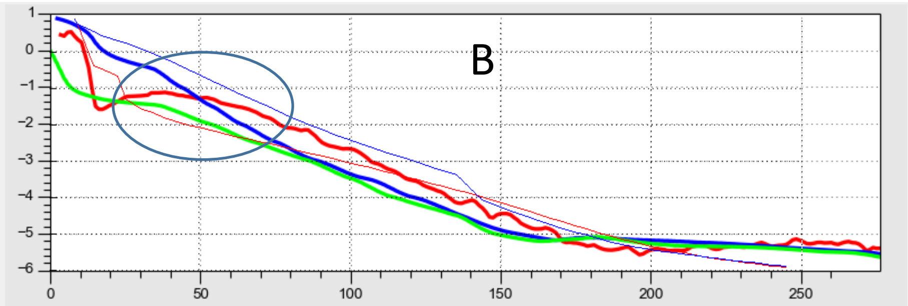


Figure 8. Beach profiles along cross section B

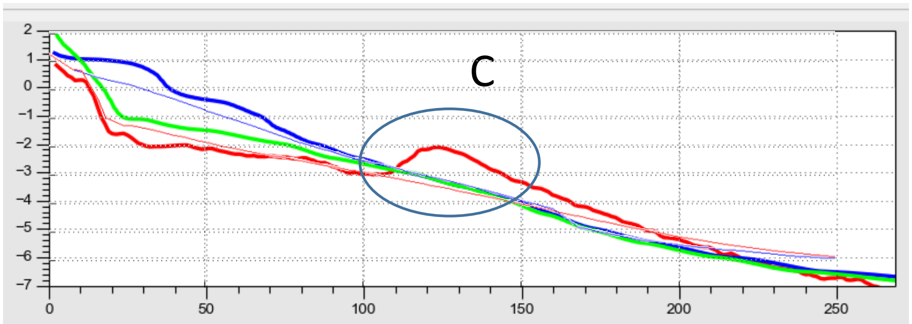


Figure 9. Beach profiles along cross section C

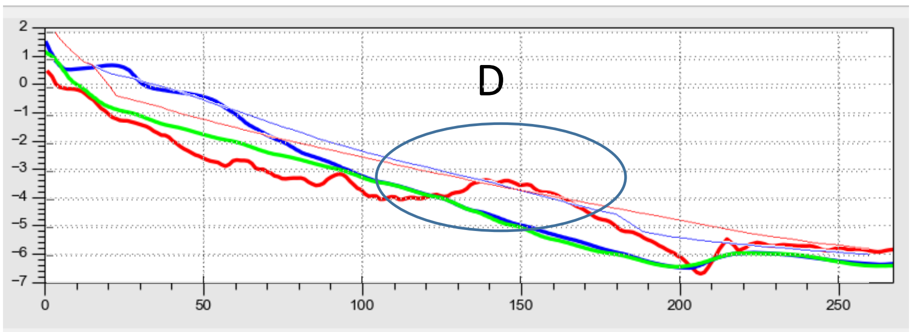


Figure 10. Beach profiles along cross section D

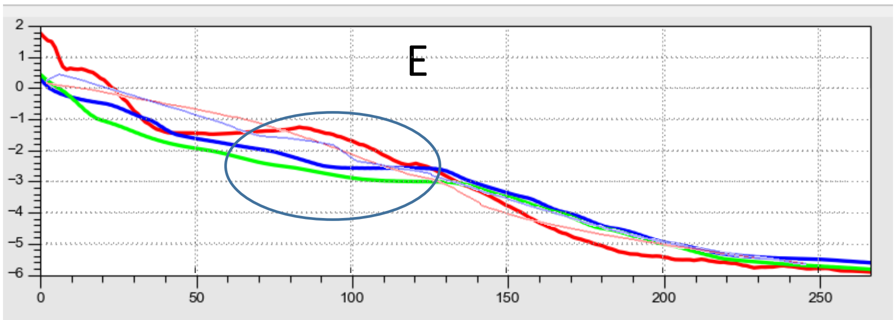


Figure 11. Beach profiles along cross section E

Nevertheless, on the 2D map of bed level difference (2016-2015) presented hereinafter, it is highlighted the capability of the model to correctly represent the offshore migration of sediment, and especially how far from the "coastline". The marks on the figures illustrate these observations, with the model's predicted areas of decomposition corresponding to those observed from the survey (offshore of the red line: red ellipse).

3.3 VOLUME CALCULATION

The table below shows the total volume gain and loss compared, 1 year after the beach nourishment. Values are of the same order of magnitude.

Table 8: comparison of beach nourishment volume between survey and modeling

(m3)	Measurement (9 months)	Xbeach (1 year)
Gain	89 000	78 000
Loss	24 000	27 700
Total	+65 000	+50 300

XBeach predict some loss of sediment over the 1 year period of about 15 000m3 but this could be explained by some dependency of the results to the extent of the selected area. Moreover, as simulation had to be run over 1 year instead of 9 months for the measurement. Over this additional period, a net northward sediment transport might be responsible from the obtained loss of 15 000m3.

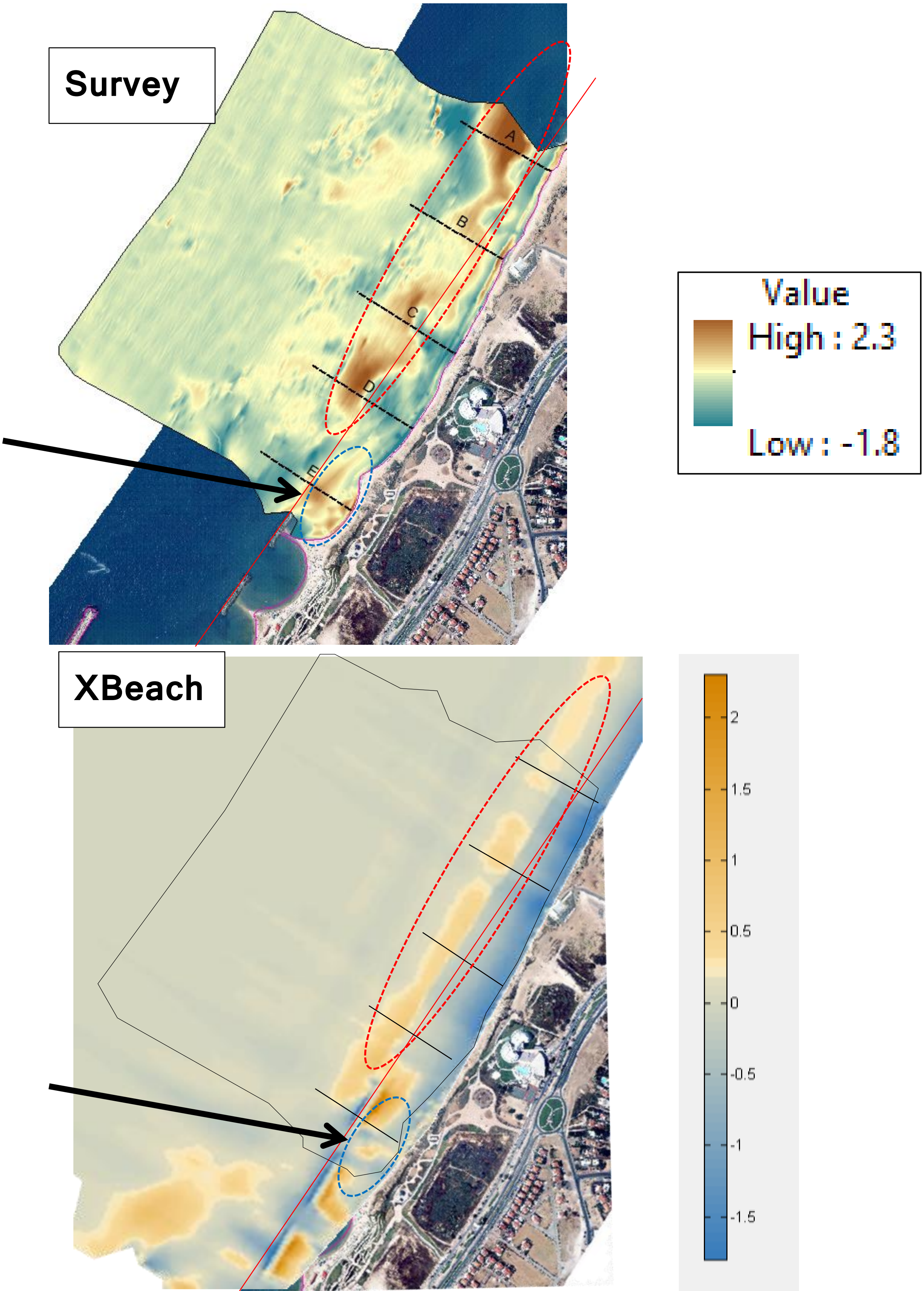


Figure 12. 2015 beach nourishment evolution – survey (up) and modelling (down)

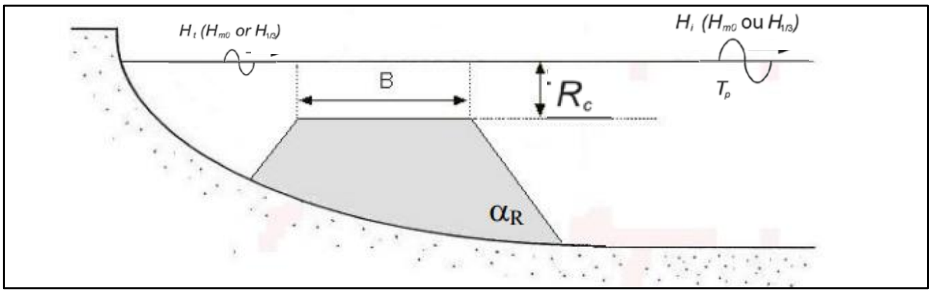
3.4 CONCLUSION

The model calibration may be considered as relatively "correct" as the global sediment movements can be represented, qualitatively as well as quantitatively.

However, there are some uncertainties in the areas sheltered by the offshore breakwater (blue ellipse). It could come from the model itself, or because of the initial "ideal" bathymetry.

4 WAVE TRANSMISSION

As a first approach, the wave transmission over the geotextile build shore-parallel breakwaters, or artificial reefs, was evaluated using the d'Angremond and al (1997), re-calibrated by Briganti and al (2004) [7]:



For B/Hs<10: $C_t = -0.4\dfrac{R_c}{H_s} + 0.64\left(\dfrac{B}{H_s}\right)^{-0.31}\left(1-\exp\left(-0.5\,\xi_p\right)\right)$

For B/Hs>10: $C_t = -0.35\dfrac{R_c}{H_s} + 0.51\left(\dfrac{B}{H_s}\right)^{-0.65}\left(1-\exp\left(-0.41\,\xi_p\right)\right)$

With:

Ct: wave transmission coefficient

Rc: water column height above the breakwater (m)

B: breakwater width (m)

Hs: incident significant wave height (m)

ξ_p: Irribaren number

Research works were realized about wave transmission through geotextile made artificial reef. Comparisons between empirical formulas, such as d'Angremond (1997), numerical modelling and physical modeling, showed good agreements. For example, one can cite refer to works from JARRY N. (2009) [8] or CHARRIERE A. (2013) [9].

Similar approach was undertaken here: incident and transmitted wave heights were extracted from the numerical modeling in order to estimate the coefficient of transmission associated to the studied submerged breakwaters. A typical profile is shown on the figure below.

Comparisons of this data with results from empirical formulae calculations were undertaken:

- For long term modelling: extraction from time series along the 10 years
- For short term: wave conditions extracted during a storm

The figures hereinafter present the results, showing on average, as expected, good agreements.

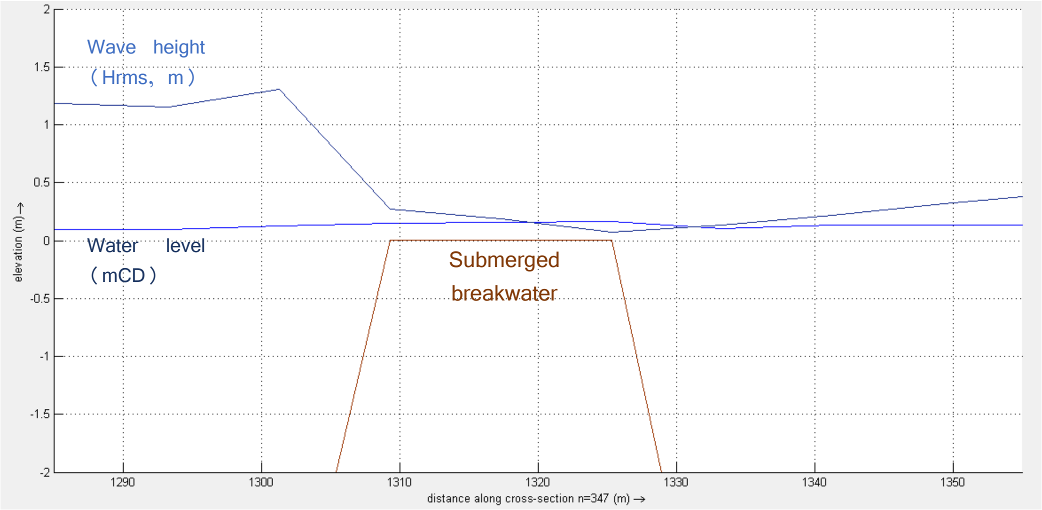


Figure 13. Typical profile of data extraction for wave transmission analysis of submerged breakwaters

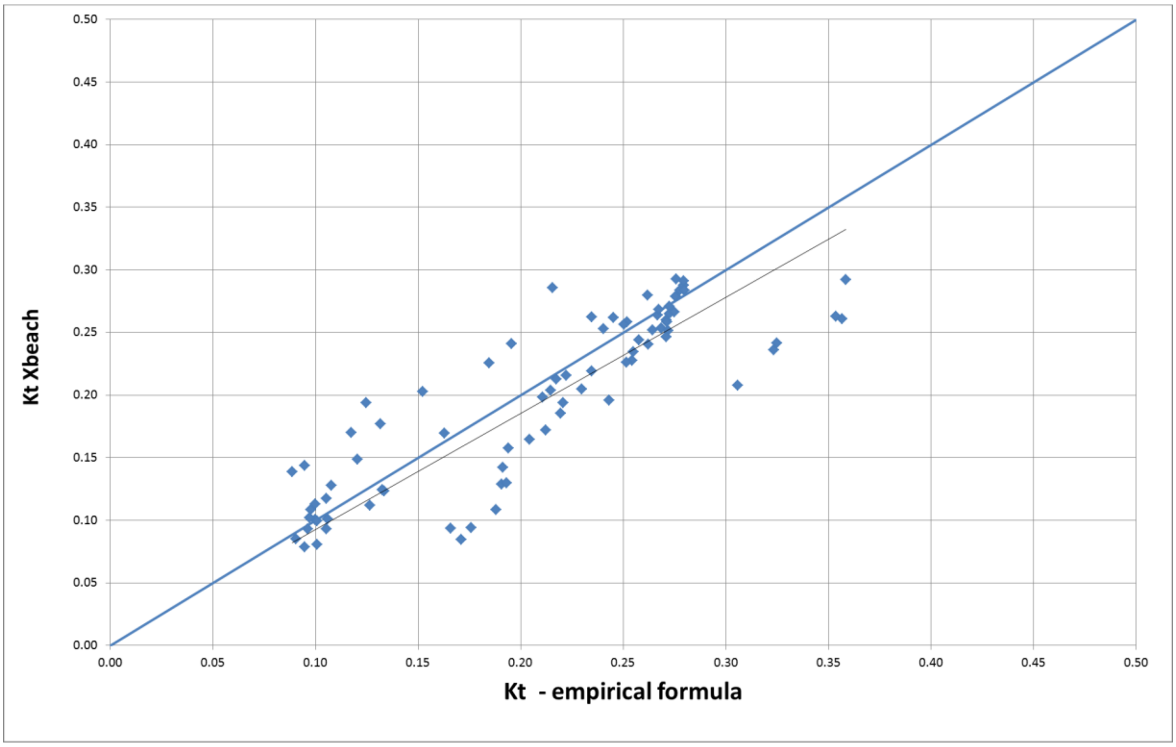


Figure 14. Transmission coefficient (wave height) from extracted XBeach results compared to empirical formulae: long term

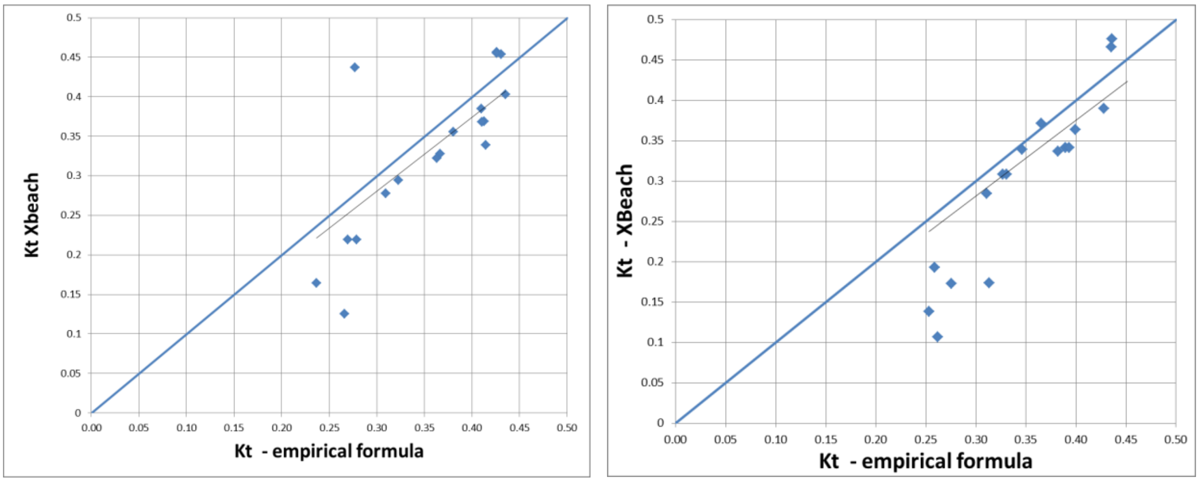


Figure 15. Transmission coefficient (wave height) from extracted XBeach results compared to empirical formulae, storm conditions (1 year – left, 10 years – right).

5 INITIAL SCENARIOS

After assessing the calibration, we had to run several scenarios of protection in the XBeach model.

In the following sections, the shoreline is linked to the 0mCD line.

5.1 PRESENTATION (SOLUTIONS RUN IN THE MODEL)

At first to get a good view on the design of the breakwater, we run scenarios for the geotubes structures in order to determine the most relevant parameters.

Therefore, we first simulated the following solutions:

Table 9: characteristics of initial studied solutions

	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Breakwater length per section (m)	120	105	120	105	105
Assumed breakwater crest width (m)	15	15	15	15	15
Gap length (m)	50	90	50	90	75
Breakwater crest level (mCD)	0	-1	-1	-0.5	-1
Seaward toe level of the breakwater (mCD)	-4	-4	-4	-4	-4
Initial berm width (width of the dry beach)	75	75	75	75	75

For all those solutions, we keep the D50 determined in the calibration studies: 0.25 mm. We then run those simulations with d50 = 0.36 mm as per the sand specification (given by the sand supplier).

The purpose of those simulations was to see the influence of all the parameters.

With those solutions, we saw the influence of the following parameters:

- Size of sediment (D50=0.25mm or =0.4mm)
- Length L of the breakwaters and gap G between the breakwaters
- Crest level C (or height) of the geotubes.

We added some other modeling to see the influence of two other parameters:

- Width W of the geotubes
- Depth D of the geotubes location

For this study, the different configurations are as follow, indicating the different parameters values used for the sensitivity analysis.

Table 10: characteristics of studied configurations for sensitivity analysis purpose

Configuration	1	2
Breakwater length per section (m)	120	105
Assumed breakwater crest width (m)	10 , 15	15
Gap length (m)	50	90, 75
Breakwater crest level (mCD)	0 , -0.2, -1	0 , -0.2, -0.4 , -1
Seaward toe level of the breakwater (mCD)	-4	-4, -5
Initial berm width (width of the dry beach)	≈75	≈75

5.2 RESULTS AND SUM-UP

Different configurations were studied in order to evaluate the impact of a change in one of the following parameters, on the shoreline evolution (0mCD line):

- Size of sediment (d50=0.25mm or =0.36mm)
- Length L of the breakwaters and gap G between the breakwaters
- Crest level C (or height) of the geotubes
- Width W of the geotubes
- Depth D of the geotubes location

5.2.1 Size of sediment

As a comparison, the table below shows the result of the shoreline evolution in the same model with different grain size.

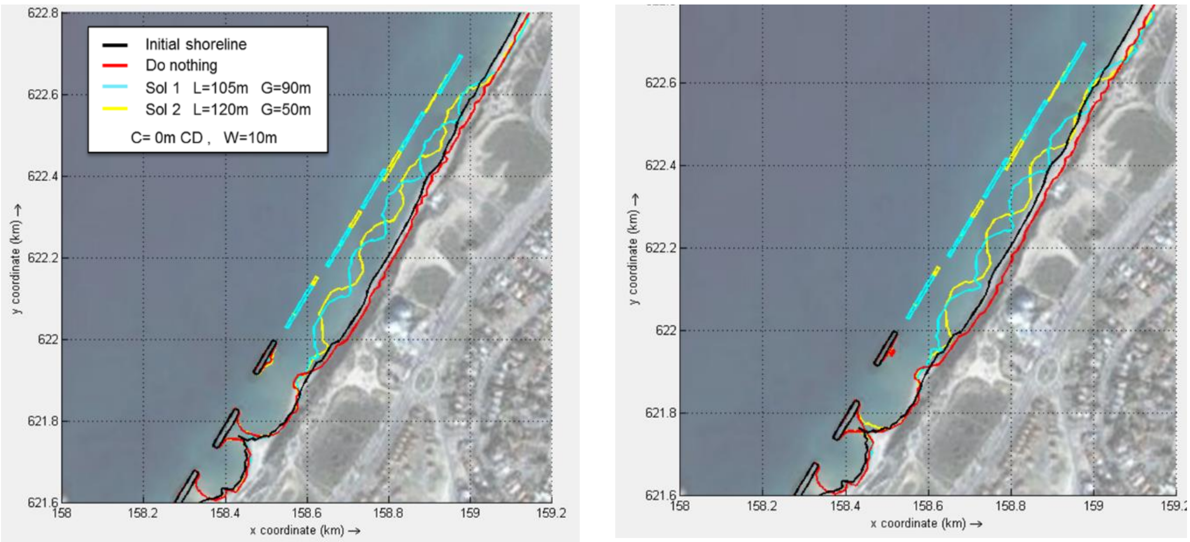
Table 11: Shoreline (OmCD) location depending on the sand size used for the initial beach nourishment

	Present	D50=0.25mm	D50=0.36mm
T = 0	0	87	87
T = 2 years	-13	25	27
T = 4 years	-14	9	11
T = 10 years	-22	-19	-13

This parameter does not influence the design of the breakwater but only the stability of the sand.

5.2.2 Length L of the breakwaters and gap G

Considering different breakwater lengths and gaps between, the numerical model predicts relatively few differences, regarding the beach evolution for the different configurations.



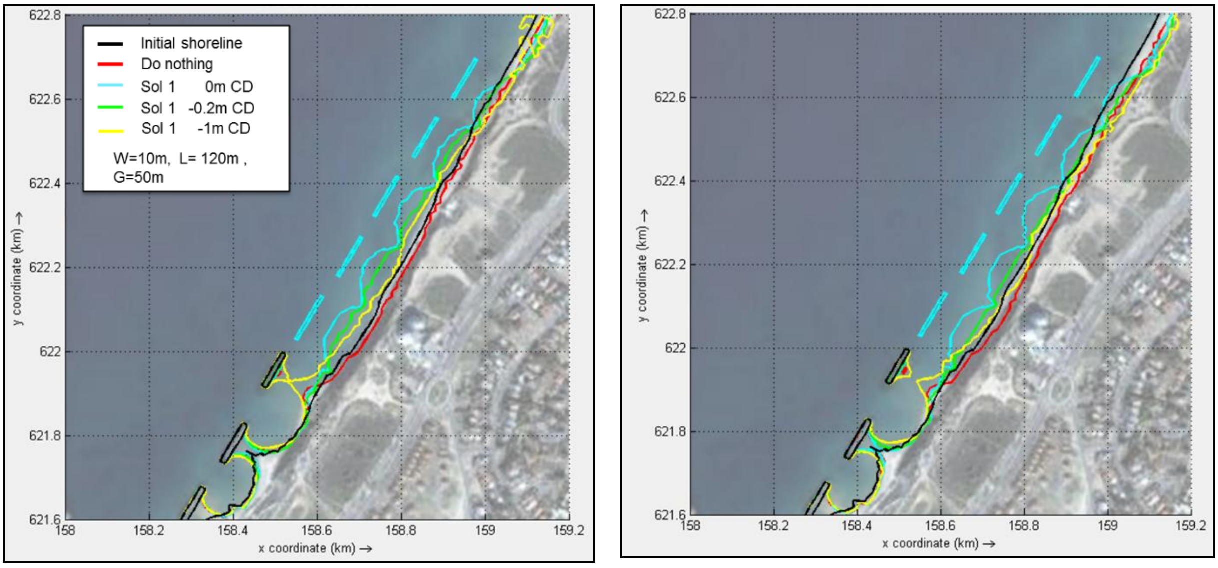
T = 2 years

T= 4 years

Figure 16. Shoreline (OmCD line) evolution after 2 years (left) and 4 years (right) for solution 1 and 2 (gap and length variation analysis)

5.2.3 Crest level C (or height of the geotubes)

Shoreline response is highly dependent on the breakwater crest level C. C=0m CD resulting in the most stable shoreline according to the model results.



T = 2 years

T= 4 years

Figure 17. Shoreline (OmCD line) evolution after 2 years (left) and 4 years (right) for configuration 1, for different crest levels

Such a sensitivity to this parameter is rather surprising so we compare the shoreline evolution with two models :

- Xbeach (2DH)
- SBeach (1DH):

Table 12: Comparison of predicted storm induced beach, by XBeach and SBeach

Xbeach

Sol1, 0m CD

Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD	Cliff reached? (to be confirmed)
1	0.6	4.7	1	24	No effect on the cliff
5	0.6	6.1	4	35	No effect
10	0.6	6.7	7	40	No effect
20	0.6	7.3	7	44	No effect
50	0.6	8	9	44	yes
100	0.6	8.4	11	48	yes

Sol1, -0.2m CD

Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD	Cliff reached? (to be confirmed)
1	0.6	4.7	4	36.5	No effect on the cliff
5	0.6	6.1	10	37.5	No effect
10	0.6	6.7	9	45	slightly
20	0.6	7.3	12	48	slightly
50	0.6	8	17	49	yes
100	0.6	8.4	17	49.5	yes

Sbeach

Sol1, 0m CD

Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD	Cliff reached? (to be confirmed)
1	0.6	4.7	12	35.8	No effect
5	0.6	6.1	14.3	38.7	No effect
10	0.6	6.7	16.4	39.8	No effect
20	0.6	7.3	17.2	40.7	No effect
50	0.6	8	17.5	41.1	yes
100	0.6	8.4	18.5	41.3	yes

Sol1, -0.2m CD

Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD	Cliff reached? (to be confirmed)
1	0.6	4.7	13.3	36.6	No effect
5	0.6	6.1	15.2	38.8	No effect
10	0.6	6.7	17.2	39.9	No effect
20	0.6	7.3	18	40.3	No effect
50	0.6	8	18.1	40.9	yes
100	0.6	8.4	18.9	40.7	yes

In the columns "Erosion", + is for values of erosion, - is for values of accretion.

Results are consistent between both models, however SBeach is more conservative.

For SBeach, results of the erosion <u>are similar</u> if we compare solution 1 at 0mCD and at -0.2mCD.

For XBeach, a clear difference of beach erosion between the two configurations can be noticed for storms of return period event from 1 to 10 years.

However the SBeach model is more conservative than the XBeach model, he predicts a smoother impact on the crest level than the XBeach model for a minor difference (20cm).

We then decide to go for a Crest level at -0.2 mCD as it allows a freeboard of 50cm on top of the breakwater at MSL.

5.2.4 Width W of the geotubes

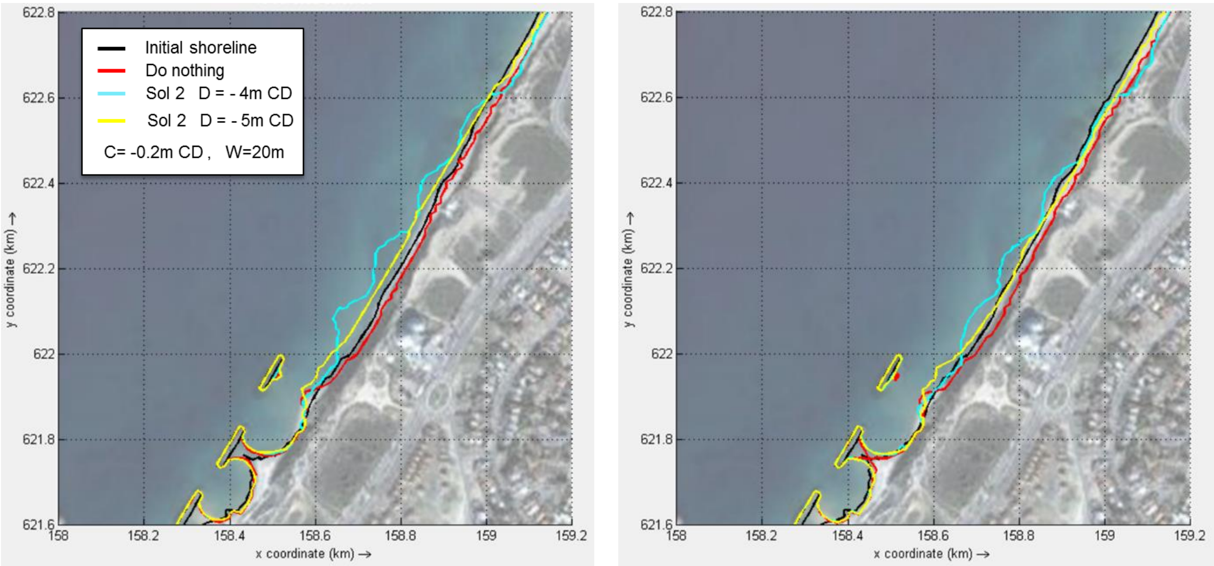
Shoreline response is dependent on the breakwater width, but note really on the average shoreline must most essentially on the height of the salient.

This result might be due to the wavelength of the swell which is really important for Ashkelon beaches. So as the wavelength is up to 100 m, the influence of a breakwater of 8-24 m is not really significant.

However a too short breakwater will result in several problems including external stability. The range define is then between 10-15 m.

5.2.5 Depth D of the geotubes location

Relocating the breakwaters further offshore, while maintaining the same sand volume of initial beach nourishment, might result in a reduction of the beach protection effect. However, the predicted shoreline is more "linear" (smoothed).



T = 2 years T= 4 years

Figure 18. Shoreline (OmCD line) after 2 years (left) and 4 years (right) for configuration 2 and two depth implantations of breakwater

The depth of the geotubes structure are therefore set at - 4mCD.

5.3 CONCLUSION

To sum up, here is the influence of each parameter in the overall erosion process

- D50 : some impact but this is not a parameter for the breakwater design
- Length L and gap G in between : **minor effect** as it stay reasonable
- Crest C (or High) of the geotubes: **major impact** on the result. We then add some other software modelling which allow us to moderate this affirmation (section4.2.3)
- Width W of the geotubes : **minor effect** on average shoreline
- Depth D of the geotubes location: **major effect**

According to that information, we decided to focus on two solutions set in the following paragraph.

6 ALTERNATIVE SOLUTIONS

Therefore we actually focused on two solutions for the model and try to see the major differences.

Table 13: Description of alternative solutions studied

	Tender solution	Solution studied
Breakwater length per section (m)	120	105
Assumed breakwater crest width (m)	10-15	10-15
Gap length (m)	50	75
Breakwater crest level (mCD)	-0.2	-0.2
Seaward toe level of the breakwater (mCD)	-4	-4
Initial berm width (width of the dry beach)	75	75

6.1 DETAILED COMPARISON OF SOLUTION 1 AND SOLUTION 2 ON LONG TERM CONSIDERATIONS

Below are presented results of simulations after 4 years. The "average" shorelines (0m cd line) for both configurations show a similar position compared to the "present shoreline+50m offshore" line.

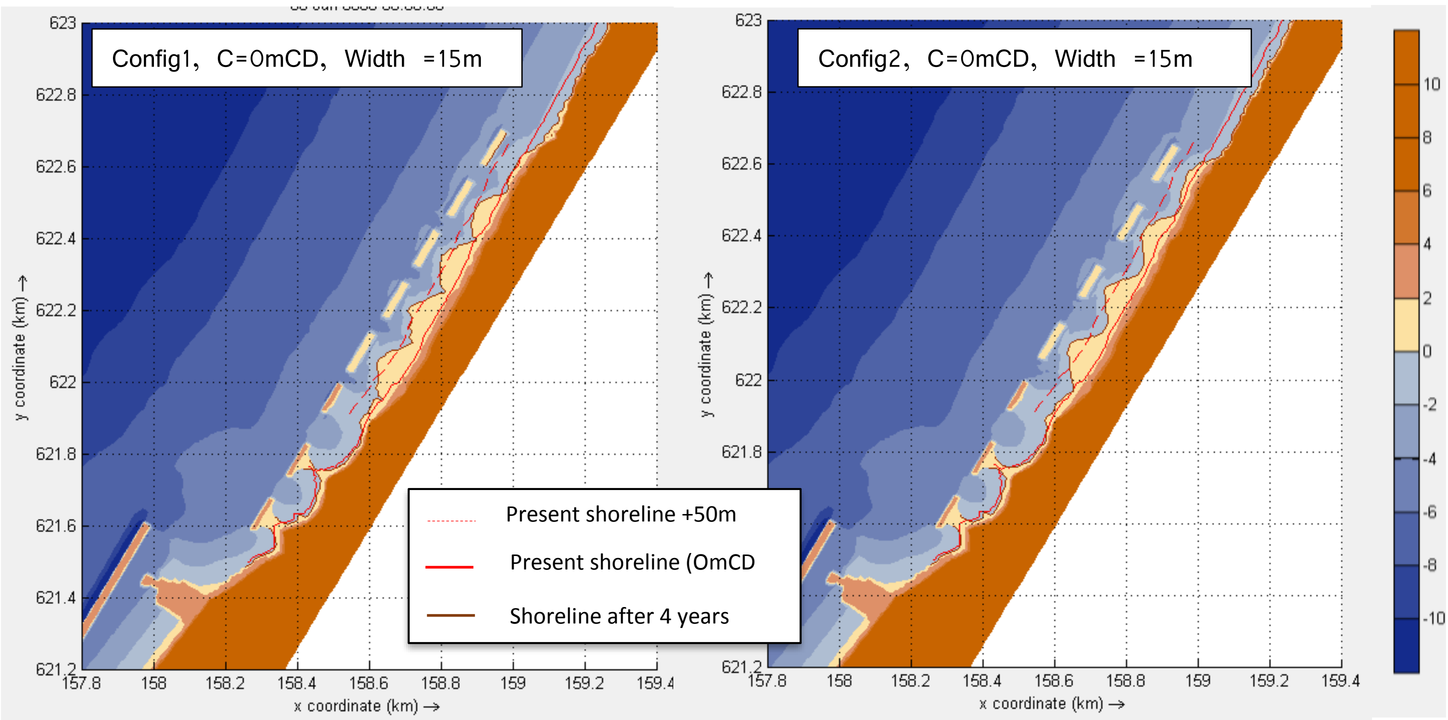


Figure 19. Seabed evolution after 4 years of simulation

Below are presented the evolutions, for the different configurations (solutions 1 and 2 and two width of breakwater), of the sediment volumes of initial beach nourishment, for the area located between the shoreline (the beach) and the future breakwaters. Starting from an initial beach nourishment of 172 000m3 (to sweet an initial 75m beach width), the segment volume reduces quickly for all configurations after 2 years (100 000m3). Half of the initial is lost after about 2 to 3 years for all configurations. For configurations 2, the total volume of additional sand volume is lost after about 6 to 7 years, and for configurations 1, after 8 to 9 years.

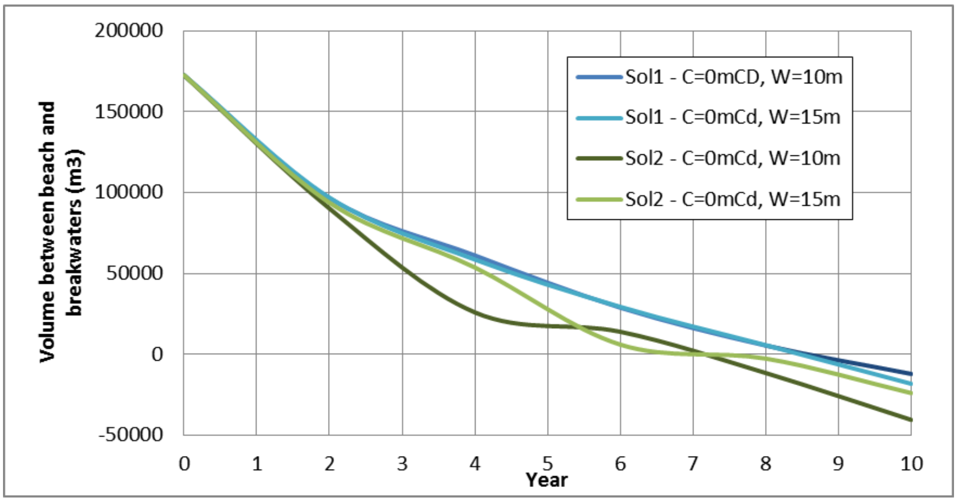


Figure 20. Time evolution of the volume of the initial beach nourishment (172 000m3)

6.2 CONCLUSION ON AVERAGE SHORELINE POSITION

As a reminder, it seems important to bear in mind the logical connection between the structures:

- The beach prevents the cliff from erosion
- The geotubes minimize the erosion.

According to this point, we proved that both solutions are working properly and will reduce the long term nourishment of sand.

If we want to maintain an average beach width of 50m, nourishment will be needed after 4 to 5 years with no major differences in the amount of sand to be replaced.

It seems important to bear in mind that while reducing the erosion on a specific area will stop the sediment transport and might induce bigger erosion process downstream.

Therefore, we study the erosion process downstream in order to cap the erosion in the northern part of area 38.

But as set previously, it is also important to have a look of the retreat of the shoreline after a major storm event.

6.3 EFFECT OF STORM EVENTS

6.3.1 Detailed Comparison for Configuration 1 and Configuration 2 regarding storm effects

6.3.1.1 Configuration 1 at t=0year

The figure below presents the effect of a 1 year return period storm (0.6m storm surge) on the bathymetry/topography for configuration 1. It shows the location of the present shoreline, shifted 50m offshore (dashed red line), the location of the proposed shoreline for configuration 1 (dashed light brown line, equivalent to 0mCD) and the location of the 2mCd line for configuration 1 (dashed brown line) to evaluate the potential impact on the toe of the cliffs. The thick lines represent the post storm location of the 0mCD line (light brown) and 2mCD line (brown).

This figure illustrates how the waves modify the bathymetry-topography, creating "immediate" erosion, especially into the gaps between the breakwaters. With these storm conditions, the beach recession is limited, less than 25m, **allowing for a remaining post storm beach width of minimum 50m. Moreover, the toe of the cliff is not impacted by the storm.**

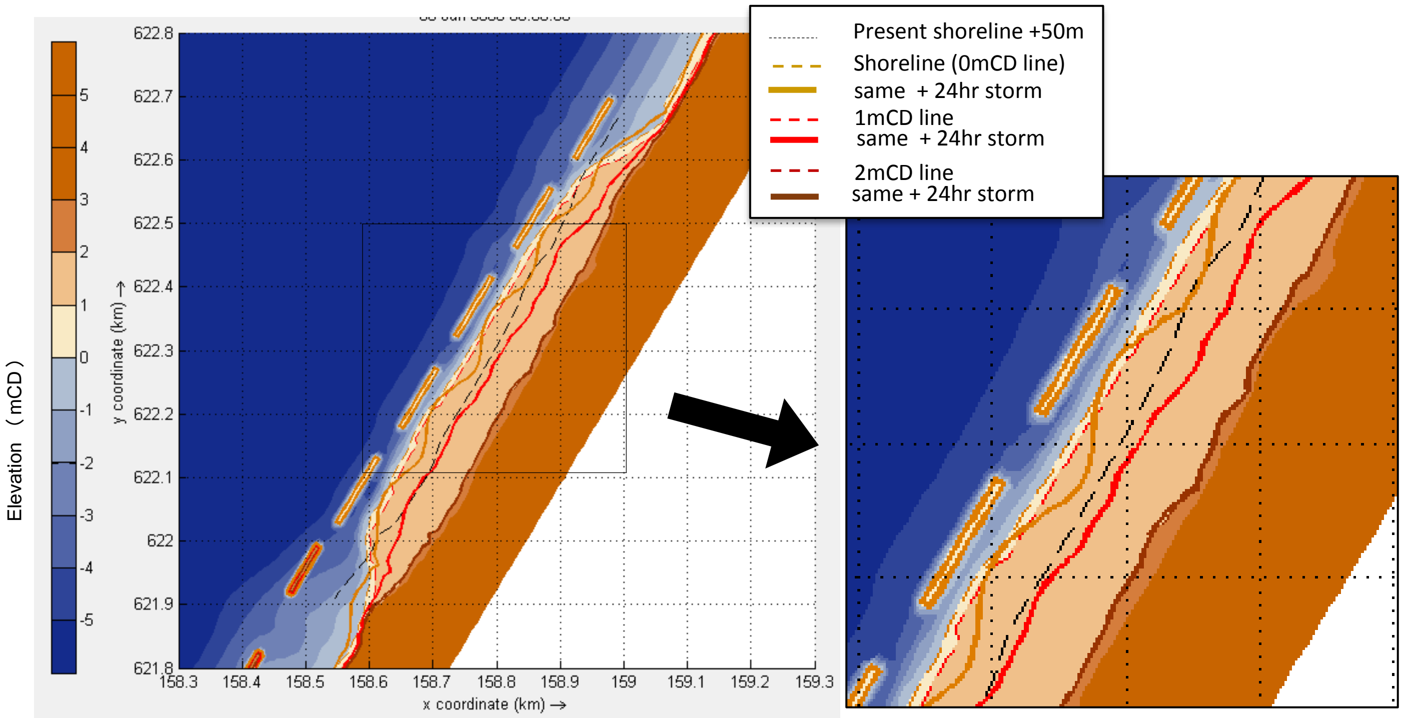


Figure 21. Effect of storm: 1 year return period storm, water level 0.6m CD, for configuration 1 at t=0year

The figure hereinafter presents the effect of a 10 year return period storm (1.2m storm surge) on the bathymetry/topography for configuration 1. With these storm conditions, the beach recession is "uniform" along the study shoreline but remain less than 25m, **allowing for a remaining post storm beach width of minimum 50m. Nevertheless, due to high storm surge, the water level might reach the cliff toe as well as small waves.** This is what is obtained with the XBeach model, which predicts an evolution of the 2mCD line (see the enlarged icon above). But this impact is limited as the model shows accretion instead of erosion at this elevation.

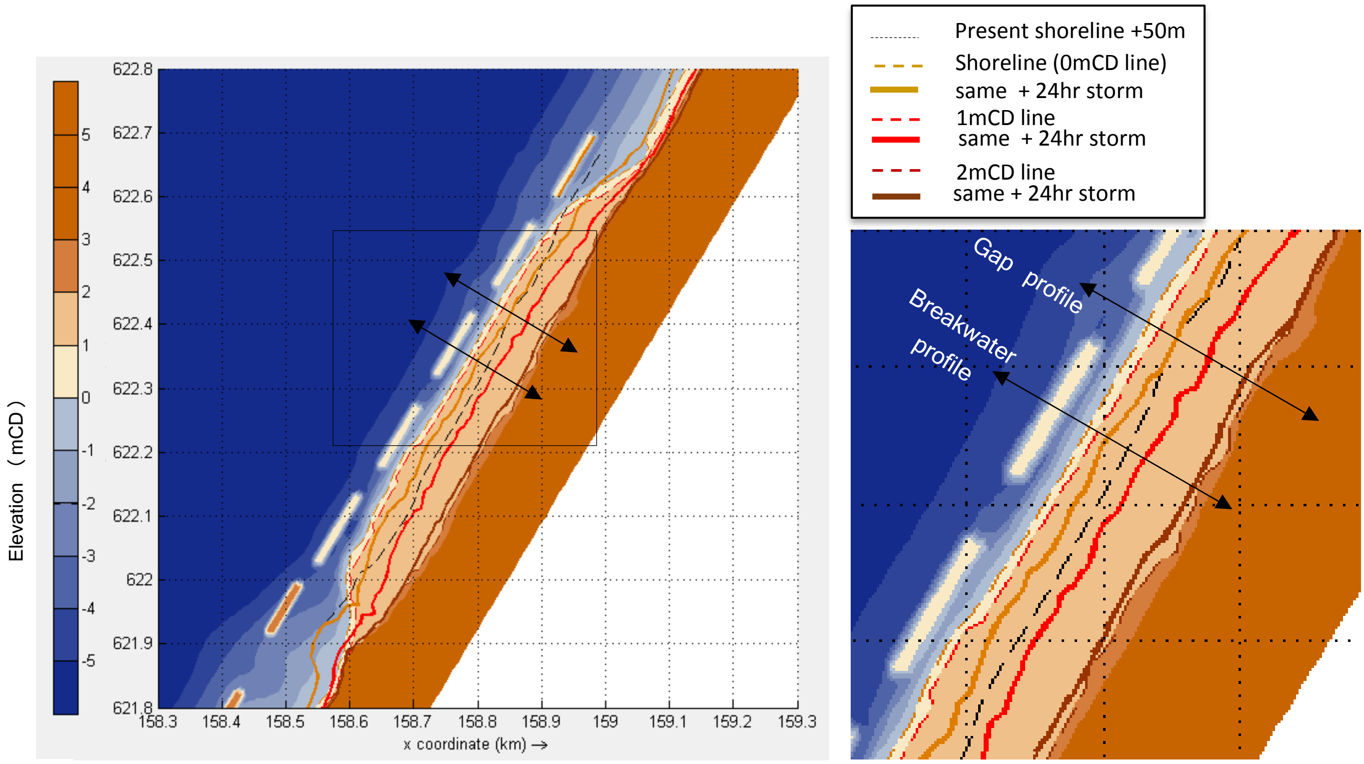


Figure 22. Effect of storm: 10 year return period storm, water level 1.2m CD, for configuration 1 at t=0year

The figures below present the results of the modeling along the profiles shown on the above figure (black arrows), located at the lee of the central breakwater ("breakwater profile") and in a gap ("gap profile") for the present case and configuration 1 for two storm intensities (1 year RP and water level 0.6mCD, 10 year RP and 1.2mmCD). It shows that for configuration 1, even if for extreme storm surges the toe of the cliff is reached by sea water level and wave, the impact is negligible or very weak and has nothing compared with the impact in the present case.

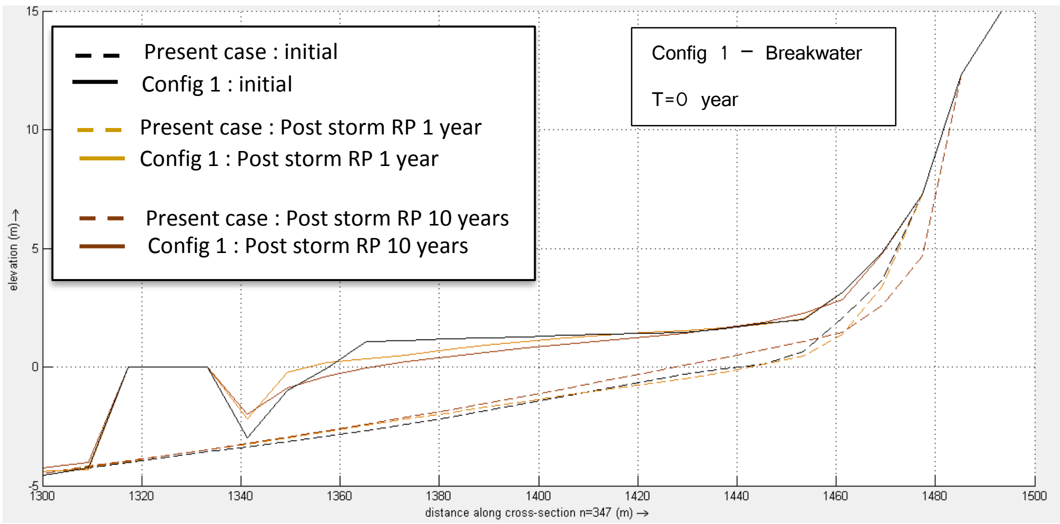


Figure 23. Effect of storm along a "breakwater" profile: 1 and 10 year return period storm, water level respectively 0.6mCD and 1.2m CD, for present case and configuration 1 at t=0year

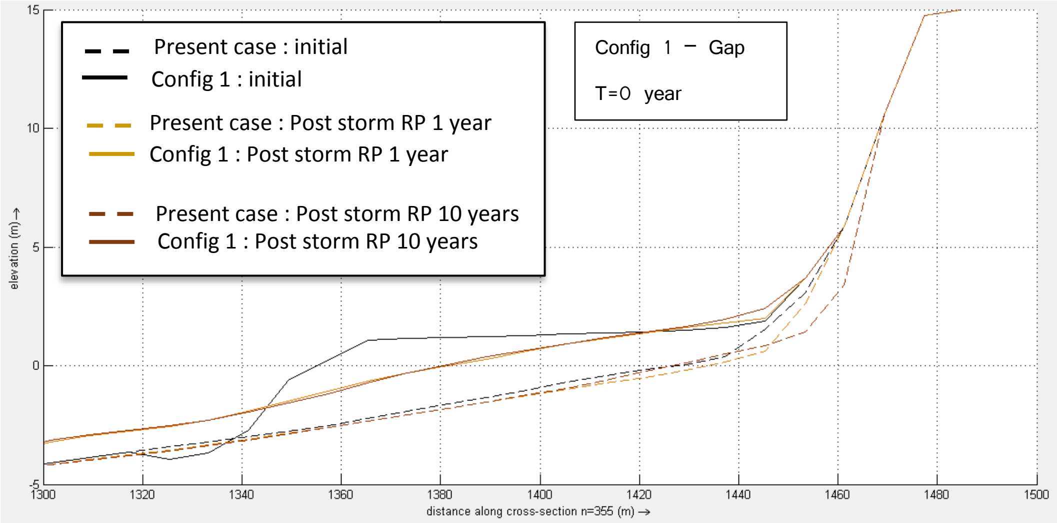


Figure 24. Effect of storm along the gap profile: 1 and 10 year return period storm, water level respectively 0.6mCD and 1.2m CD, for present case and configuration 1 at t=0year

Erosion at the elevation 0mCd and 1mCD are detailed in the table below for different storm intensity and water levels. Values are extracted from simulation results along the profile shown on the above figure (black arrow), located at the lee of the central breakwater of configuration 1. It shows the intensity of erosion of the beach (0mCD, +1mCD) depending on the storm intensity and water level sensitivity.

For comparison, same parameters are extracted for the present case, showing a net modification of the profile.

Table 14: Predicted erosion for configuration 1, breakwater profile

Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD
1	0.6 / 0.9	4.7	-4 / -3	28 / 36
5	0.6 / 1.0	6.1	-2 / 7	38 / 38
10	0.6 / 1.2	6.7	0 / 10	38 / 43
20	0.6 / 1.2	7.3	4 / 15	42 / 40
50	0.6 / 1.3	8	3 / 21	47 / 46
100	0.6 / 1.4	8.4	11 / 22	45 / 46

Table 15: Predicted erosion for configuration 1, gap profile

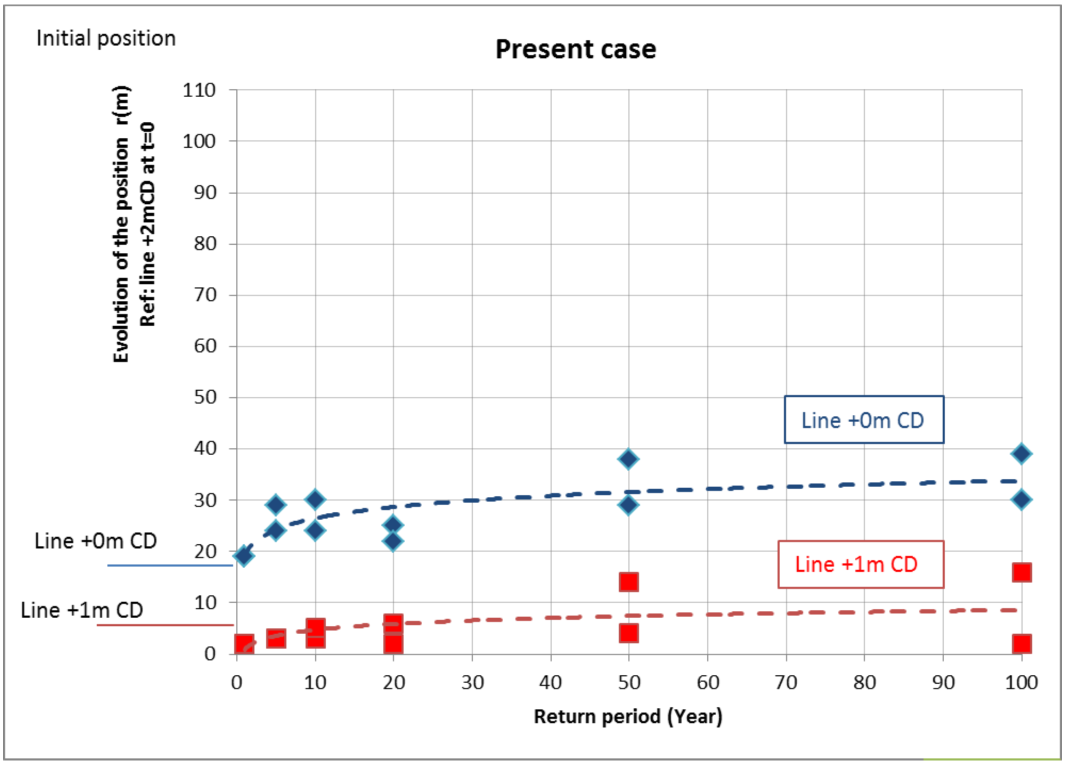
Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD
1	0.6 / 0.9	4.7	20 / 19	41 / 41
5	0.6 / 1.0	6.1	23 / 21	47 / 47
10	0.6 / 1.2	6.7	22 / 24	50 / 46
20	0.6 / 1.2	7.3	27 / 25	50 / 46
50	0.6 / 1.3	8	26 / 26	50 / 46
100	0.6 / 1.4	8.4	29 / 26	49 / 45

Table 16: Predicted erosion for the present case

Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD	Erosion at +1m CD
1	0.6 / 0.9	4.7	0 / 0	3 / 3
5	0.6 / 1.0	6.1	-5 / -10	2 / 2
10	0.6 / 1.2	6.7	-5 / -11	2 / 0
20	0.6 / 1.2	7.3	-6 / -3	3 / -1
50	0.6 / 1.3	8	-10 / -19	1 / -9
100	0.6 / 1.4	8.4	-11 / -20	3 / -11

In the columns "Erosion", + is for values of erosion, – is for values of accretion.

The figures below illustrate the value on the above tables. A minimum beach width is conserved, even after strong storms for configuration 1.



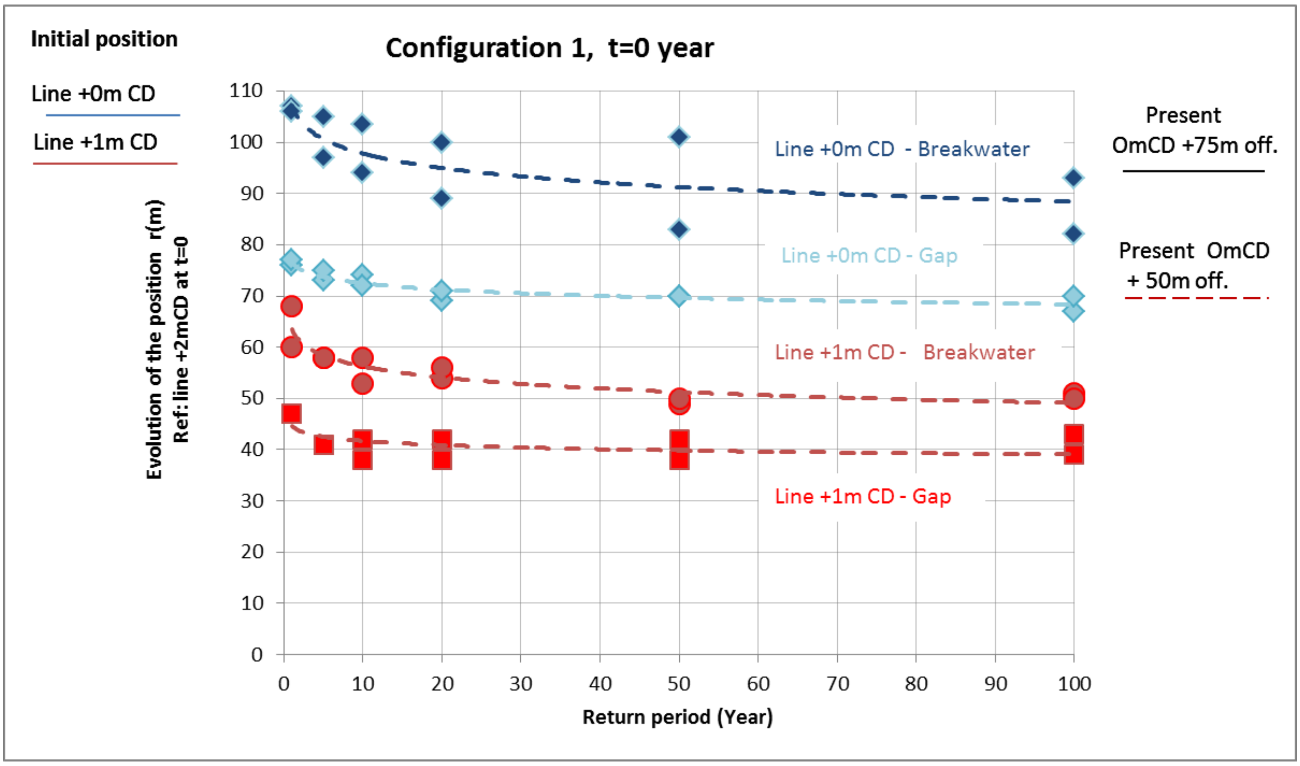


Figure 25. Beach evolution (erosion) depending on the storm intensity (return period) for the present case (top) the configuration 1 (down)

6.3.1.2 Configuration 1 and 2 at t=4years

As in the previous paragraph, the figure below presents the effect of a 1 year return period storm (0.6m storm surge) on the bathymetry/topography but for configuration 1 and configuration 2, **after 4 years of long term simulation.**

For both configurations, the beach recession is limited, less than 25m, however, due to long term 4 year erosions, the post storm beach width is less than 50m along the all stretch of study shoreline. **But the toe of the cliff is not impacted by the storm.**

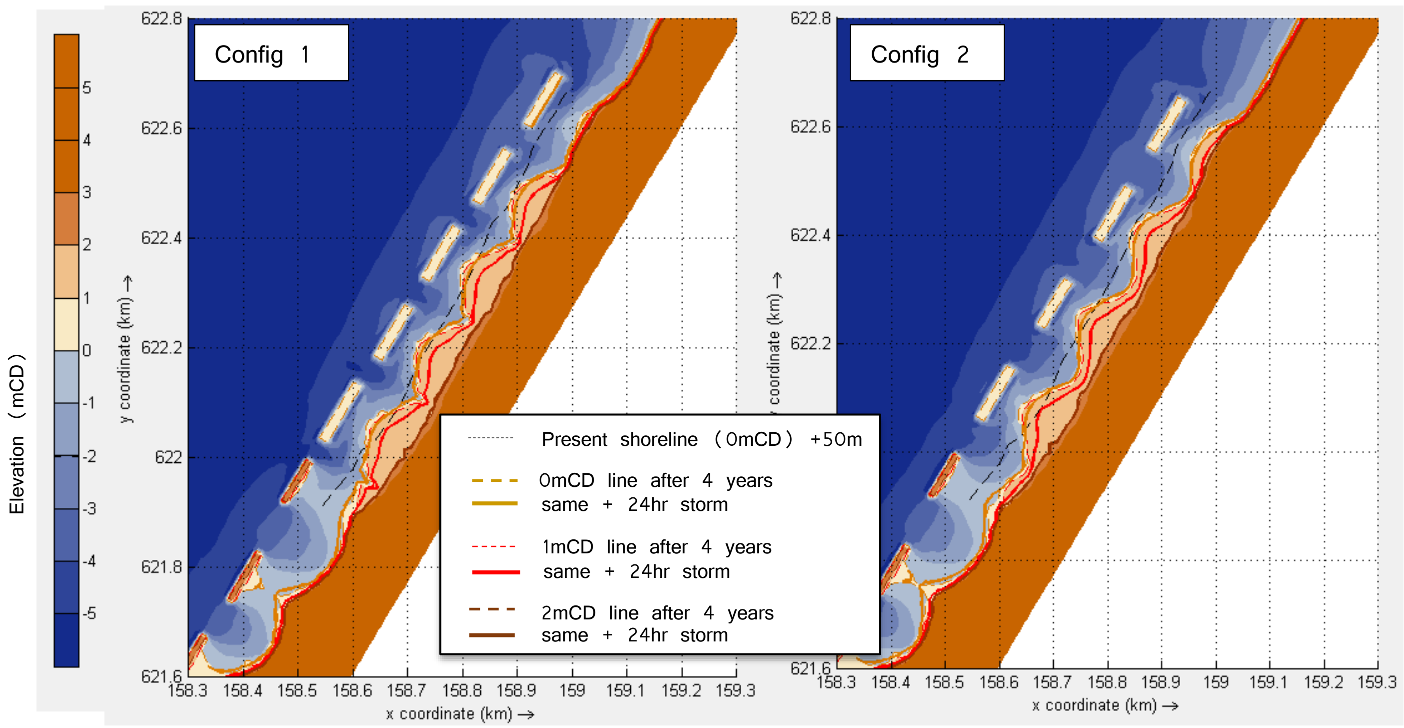


Figure 26. 1 year return period storm, water level 0.6m CD, for config 1 (left) and config 2 (right) after 4 years of long term simulation

The figure hereinafter presents the effect of a 10 year return period storm (1.2m storm surge) on the bathymetry/topography for configuration 1 and configuration 2.

Similar results are obtained. **Nevertheless, due to high storm surge, the water level might reach the cliff toe as well as small waves.** This is what is obtained with the XBeach model, which predicts an evolution of the 2mCD line (see the enlarged icon above). But this impact is limited compared to the present case.

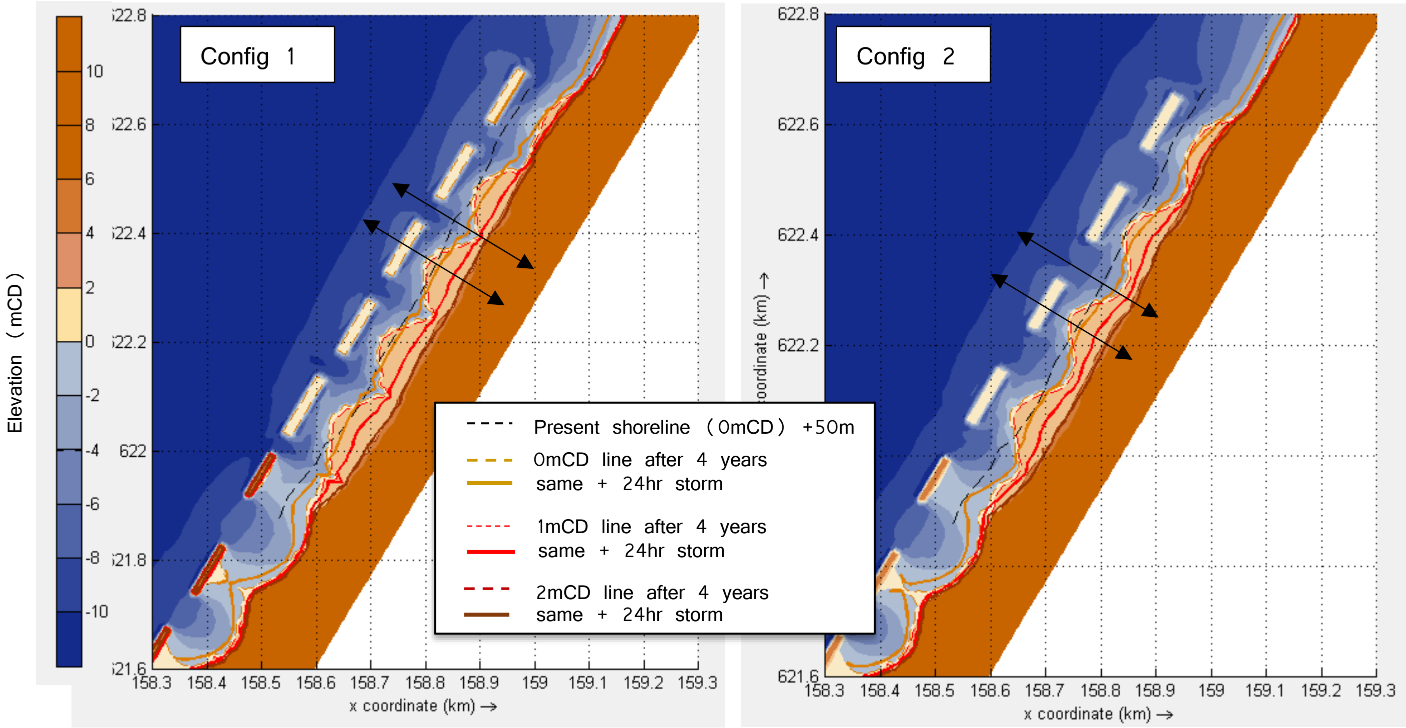


Figure 27. 10 year return period storm, water level 1.2m CD, for config 1 (left) and config 2 (right) after 4 years of long term simulation

The figure below presents the results of the modeling along the profiles shown on the above figure (black arrow), for configuration 1 and configuration 2.

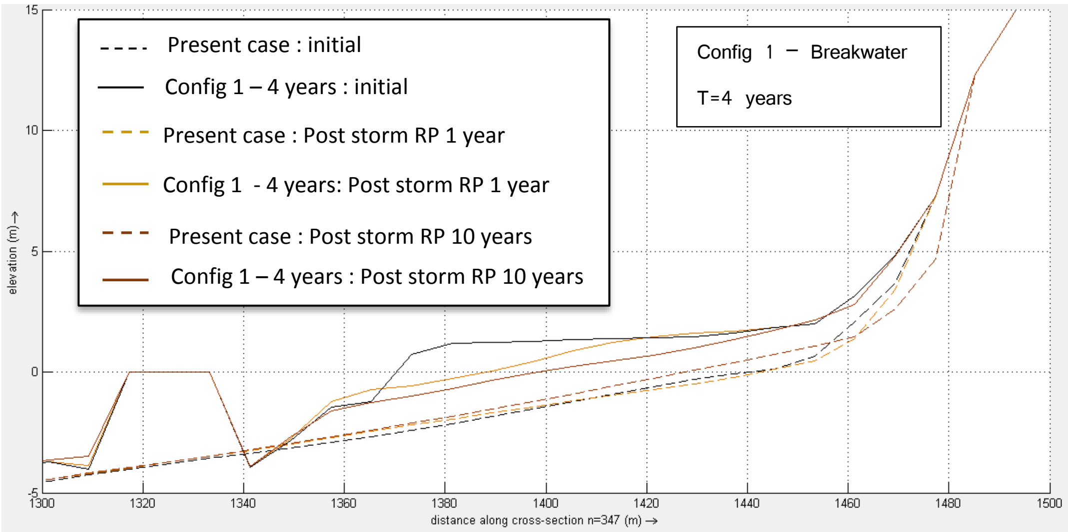


Figure 28. Effect of storm along the breakwater profile: 1 and 10 year return period storm, water level respectively 0.6mCD and 1.2m CD, for present case (t=0year) and configuration 1 at t=4years

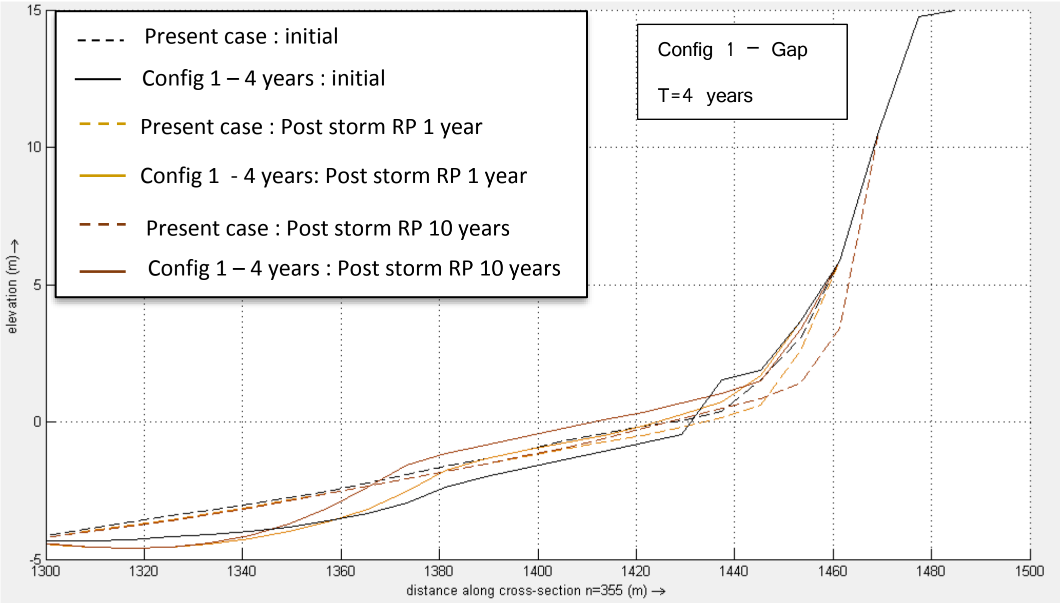


Figure 29. Effect of storm along the gap profile: 1 and 10 year return period storm, water level respectively 0.6mCD and 1.2m CD, for present case (t=0year) and configuration 1 at t=4years

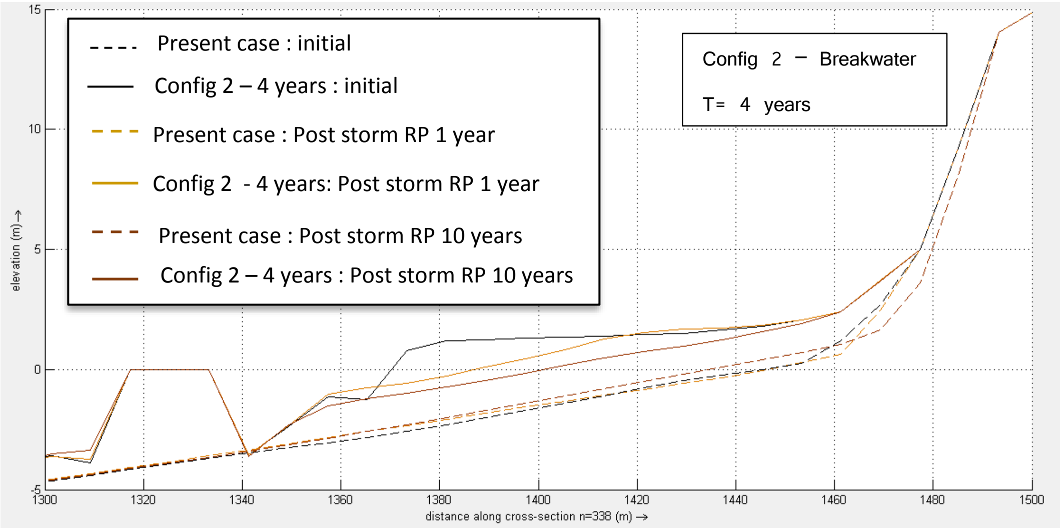


Figure 30. Effect of storm along the breakwater profile: 1 and 10 year return period storm, water level respectively 0.6mCD and 1.2m CD, for present case (t=0year) and configuration 2 at t=4years

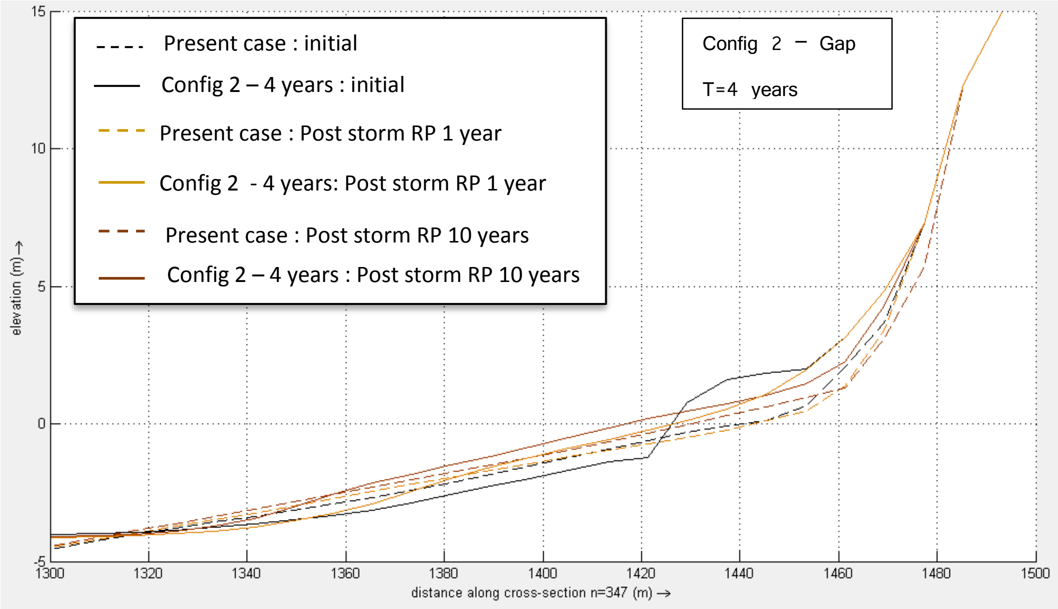


Figure 31. Effect of storm along the gap profile: 1 and 10 year return period storm, water level respectively 0.6mCD and 1.2m CD, for present case (t=0year) and configuration 1 at t=4years

6.3.2 Detailed Comparison for the effect of the crest level regarding storm effects

Figure below show the effect of a 10 year storm for configuration 1 and different breakwater characteristics:

- 10m width and crest elevation at 0mCD (figure on the left)
- 10m width and crest elevation at -0.2mCD (central figure)
- 15m width and crest elevation at 0mCD (figure on the right)

We can notice that for the 15m width breakwater, the protection is slightly better. However, the protective effects are similar when comparing the three figures.

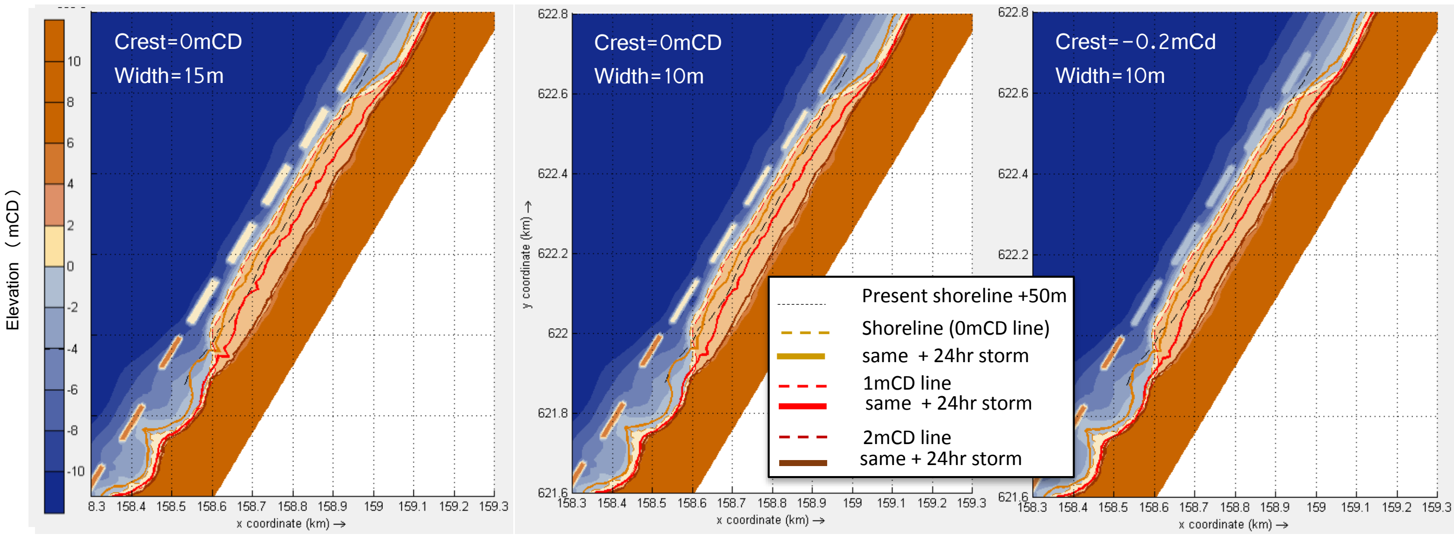


Figure 32. Effect of width and crest elevation on beach erosion induced by a 10 year return period storm, water level 1.2m CD, config 1.

7 FINAL SCENARIO

7.1 SOLUTION DESCRIPTION

Considering the results and analysis of the different modeling for the configurations described in section 5, an alternative scenario, configuration A, is proposed. This configuration consists in combining elements from configuration 1 and 2. Breakwater length is 120m for the southern breakwater and 105m for the 4 others. From South to North, the gaps increase from 50m to 75m. Between the existing breakwater and the proposed breakwater located just beside, the gap is about 30m. The initial associated beach nourishment is about 190 000m3.

Table 17: Characteristics of solution A.

Configuration	A
Breakwater length per section (m)	120 to 105 from south to north
Assumed breakwater crest width (m)	15
Gap length (m)	50 to 75 from south to north
Breakwater crest level (mCD)	0 , -0.2
Seaward toe level of the breakwater (mCD)	-4
Initial berm width (width of the dry beach)	≈75

The initial seabed view for configuration A is presented in the figure on the right, showing the location of the breakwaters and the initial nourishment. The red line indicates the present shoreline location, the dashed red line indicate the estimated shoreline position (0mCD) for an additional 50m width of the present beach, and the black line corresponding to an additional 75m width.

Such configuration was implemented in the aim to offer a better protection south of the study site and "smoothing" the likely erosive effect north of the study site.

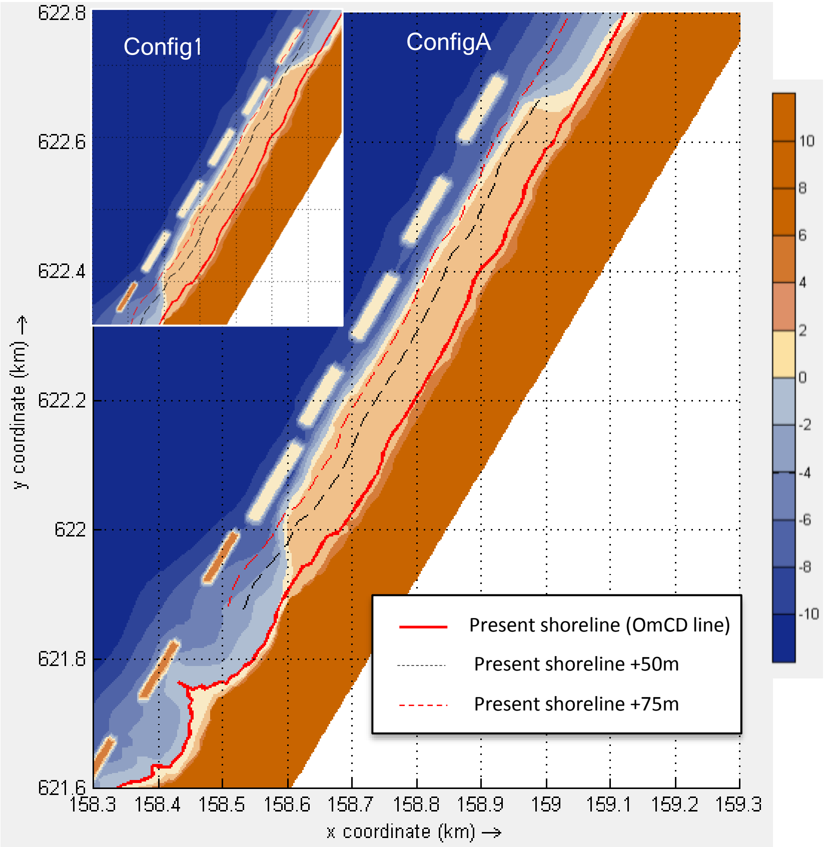


Figure 33. Seabed at T=0 for configuration A (and 1 in icon)

7.2 LONG TERM (CREST LEVEL AT 0MCD)

Results of simulations, every 2 years and up to 10 years, compared to configuration 1, are shown on in the figure below.

As a result, the protective effect along the study shoreline looks as expected.

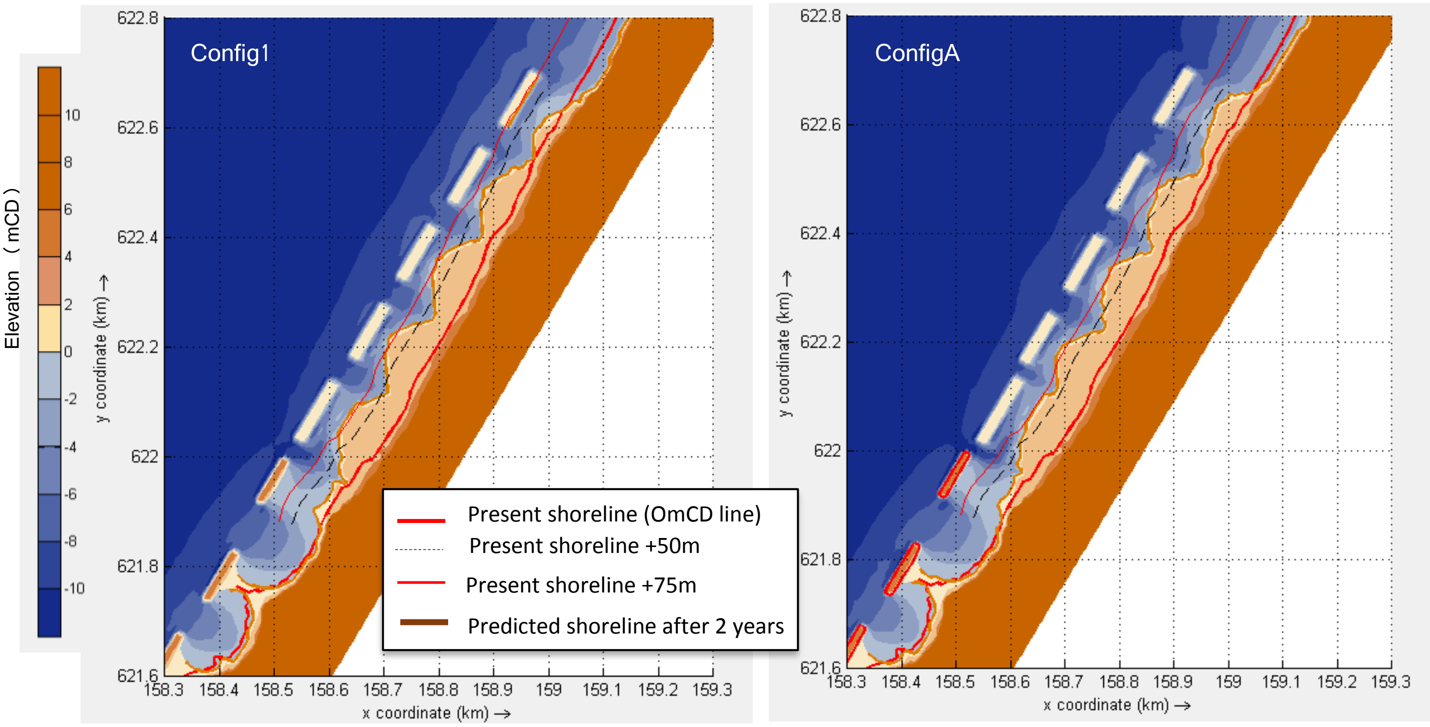


Figure 34. Seabed evolution after 2 years of simulation for configuration 1 and A

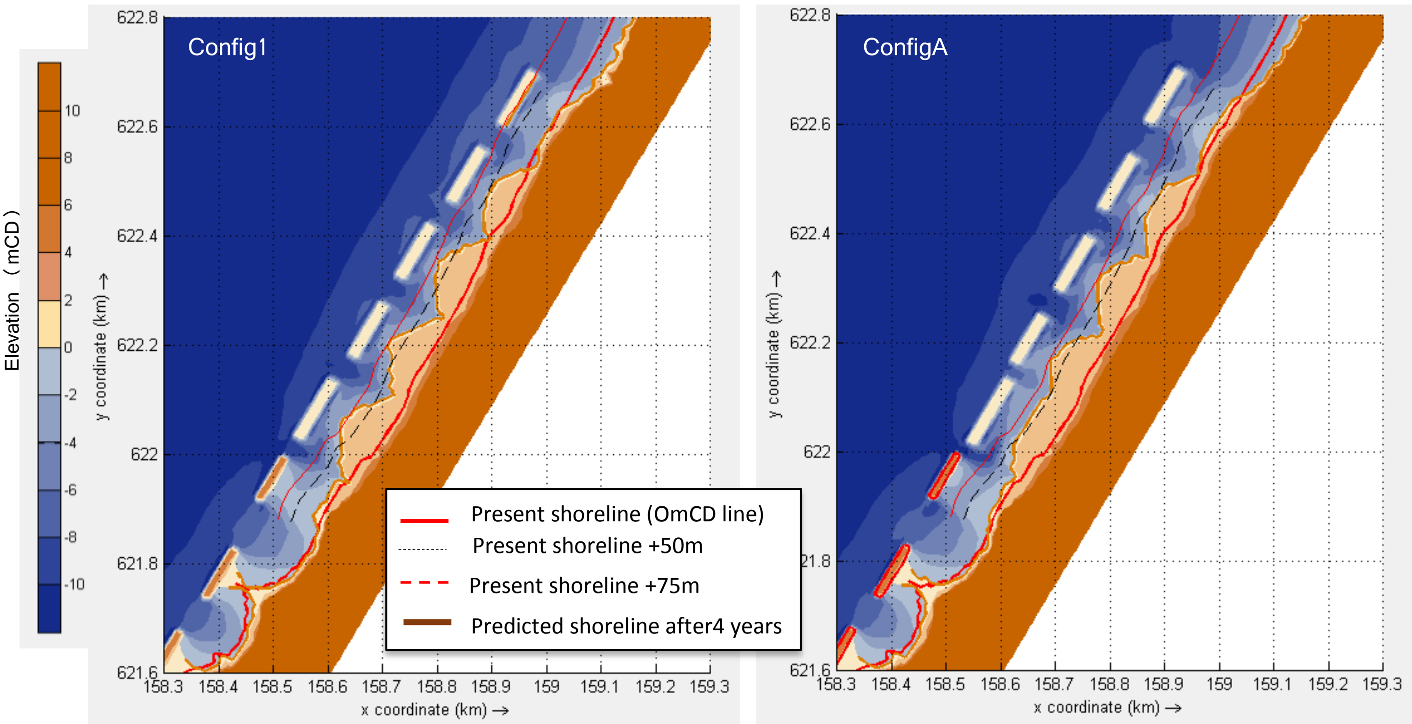


Figure 35. Seabed evolution after 4 years of simulation for configuration 1 and A

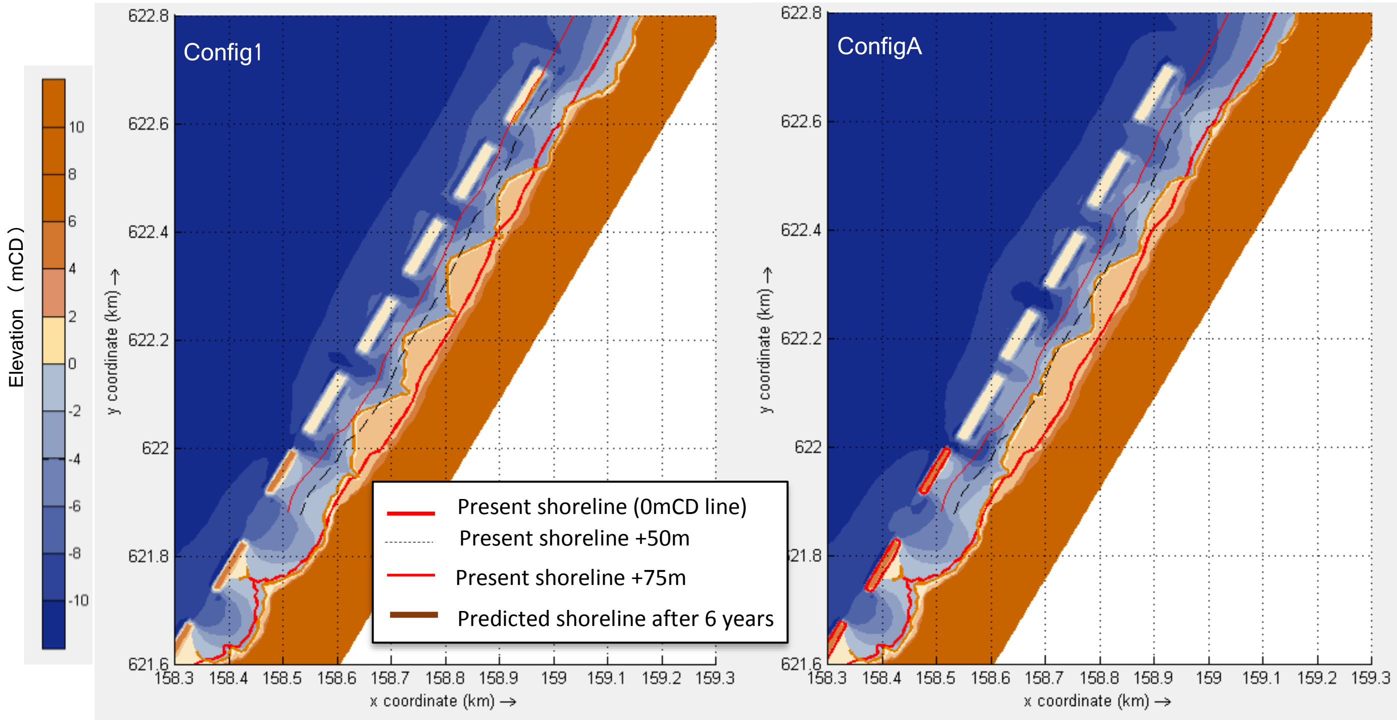


Figure 36. Seabed evolution after 6 years of simulation for configuration 1 and A

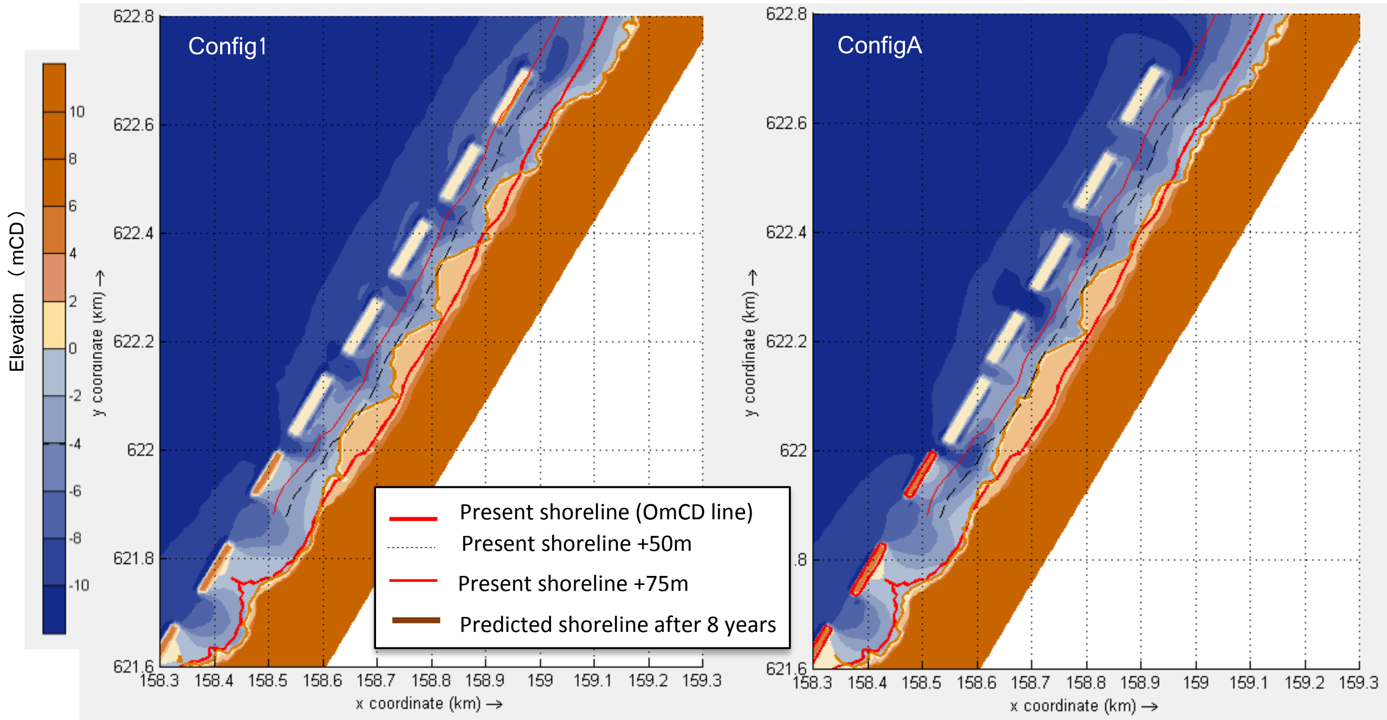


Figure 37. Seabed evolution after 8 years of simulation for configuration 1 and A

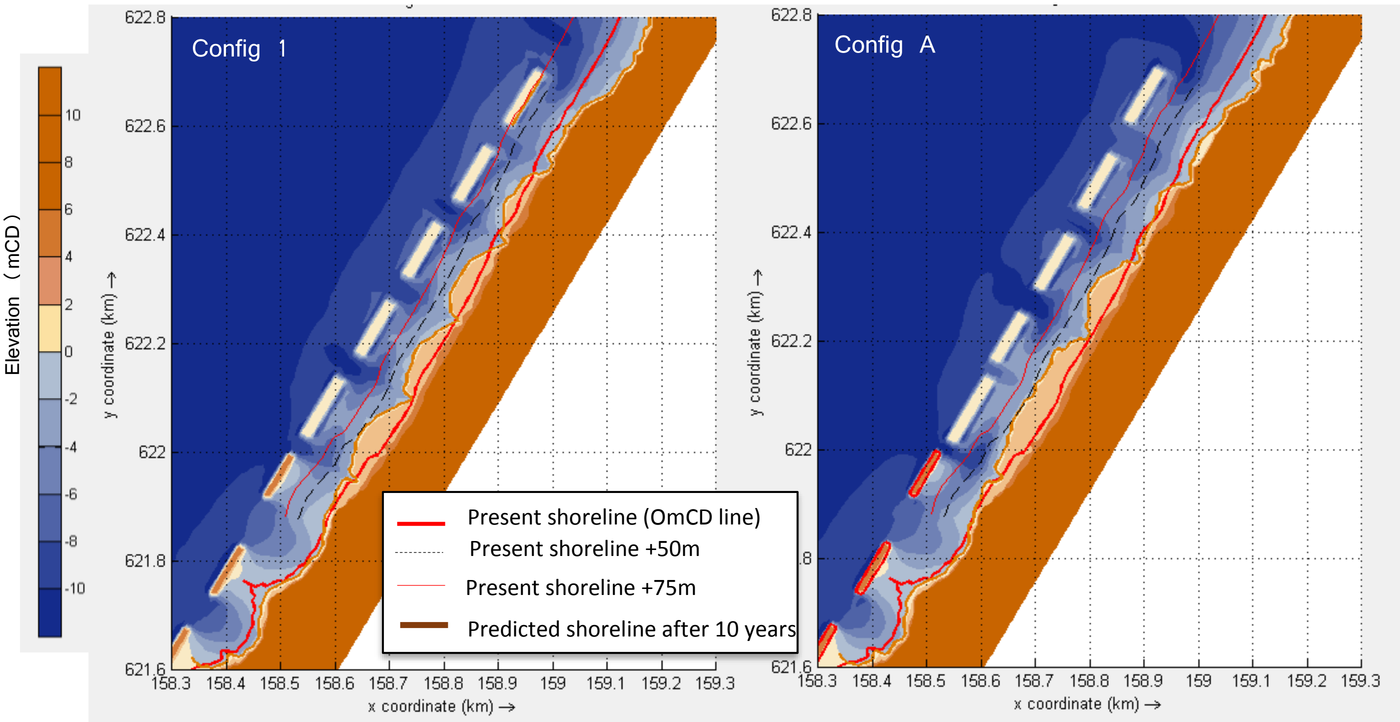


Figure 38. Seabed evolution after 10 years of simulation for configuration 1 and A

Below are presented the evolutions, for configuration 1 and A of the sediment volumes of initial beach nourishment, for the area located between the shoreline (the beach) and the future breakwaters. As expected, both curves are similar.

For configuration A, starting from an initial beach nourishment of 190 000m3 (to sweet an initial 75m beach width), the volume reduces quickly for after 2 years (120 000m3). Half of the initial volume is lost after about 3 to 4 years and the total volume of additional sand is lost after 9 to 10 years.

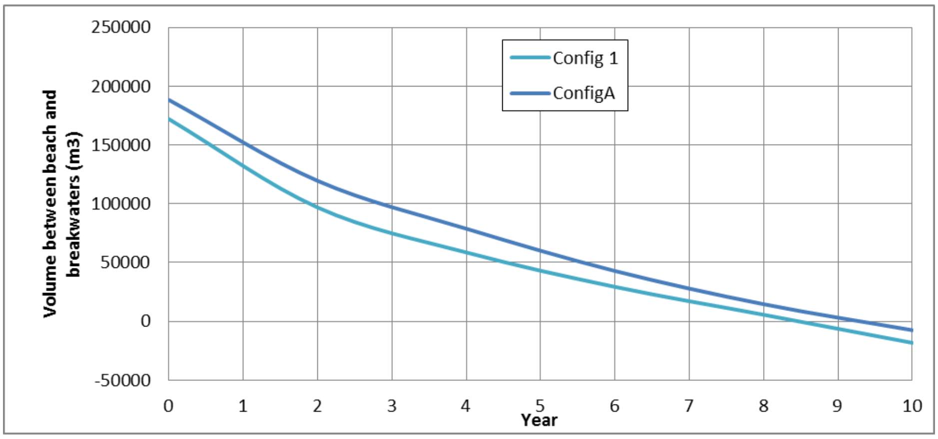


Figure 39. Time evolution of the volume of the initial beach nourishment (172 000m3 for config 1 and 190 000m3 for config A)

The two simulations are consistent and allow an appropriate of the beach against erosion issues.

This solution A allows then to reduce the erosion downstream compared to the solution 1.

7.3 LONG TERM SENSITIVITY TO CREST ELEVATION

In reference to section 4.2.3, a simulation was undertaken considering a crest elevation at -0.2mCD. Comparisons of results are made with the 0mCD line (green line on the figure) configuration 1, with crest elevation at -0.2m.

As the evolution of 0mCD lines are similar for config1 and config A, same comments as in section 4.2.3 can be made regarding the (too?) high sensitivity of the XBeach model to the breakwater crest level parameter.

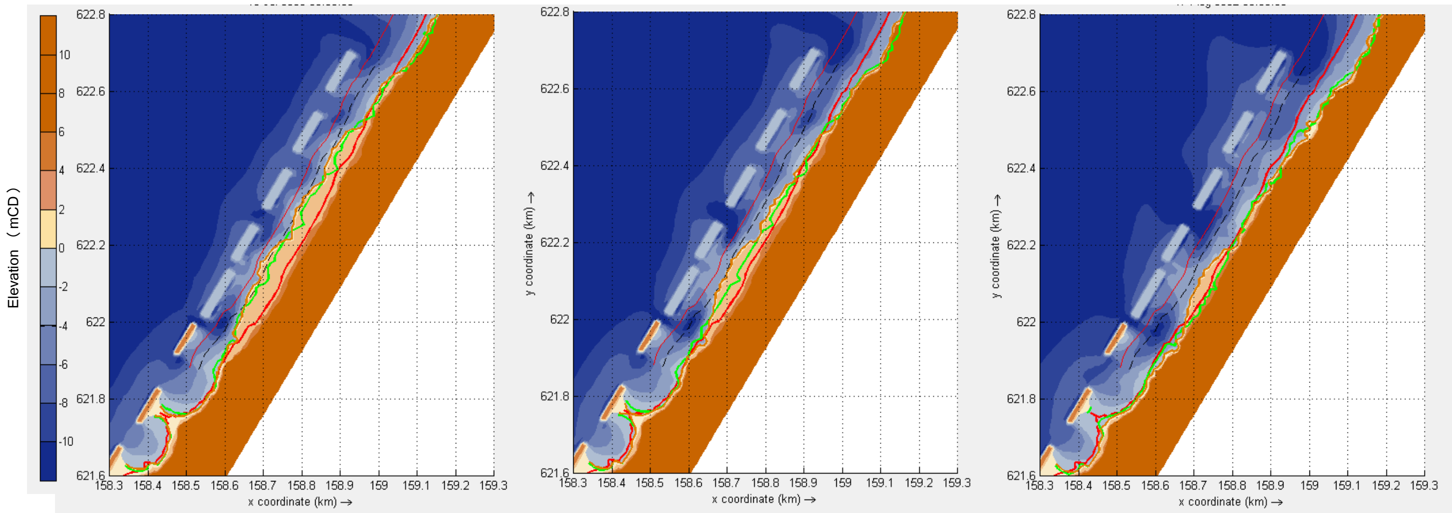


Figure 40. Seabed evolution for configuration A with breakwaters crest level at -0.2mCD

7.4 SAND HOLES FOR GEOTUBE FILLING OPERATION

To fill in the geotubes, sand will be dredged offshore of each proposed breakwaters, generating holes in the present bathymetry. Diameter of the holes is assumed to be about 50m, for a depth (difference with the present bathymetry) of about 1.5m. In a conservative approach, a 2m depth is considered for the modeling.

Figures below show the initial bathymetry including the sand holes and the results of modeling for 2 years and 4 years. The hole locations are presented on the figures.

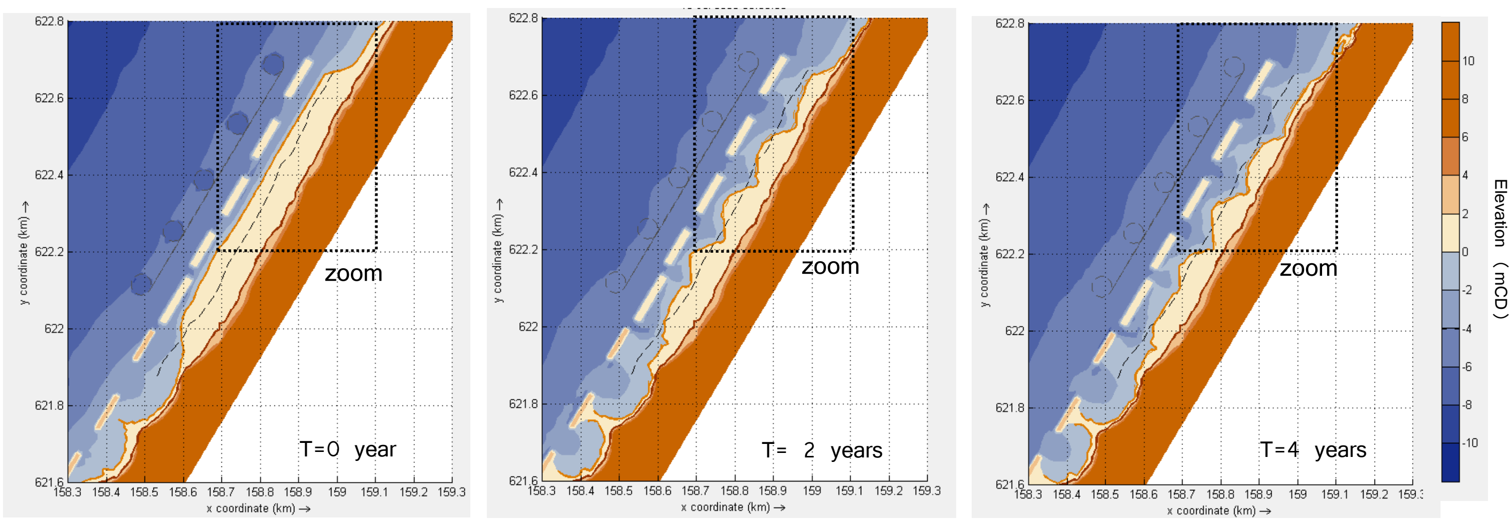


Figure 41. Seabed evolution for configuration A (crest level 0mCD), considering sand holes

Results predict very little differences between simulation take into account the hole or not. Differences can be noticed only for the northern part of the study area. The figures below, which are a zoom of the previous figures on the concerned area, show that, taking into account the holes, the 0mCD line is only affected by few meters of erosion after 2 years, and these differences are negligible after 4 years and more.

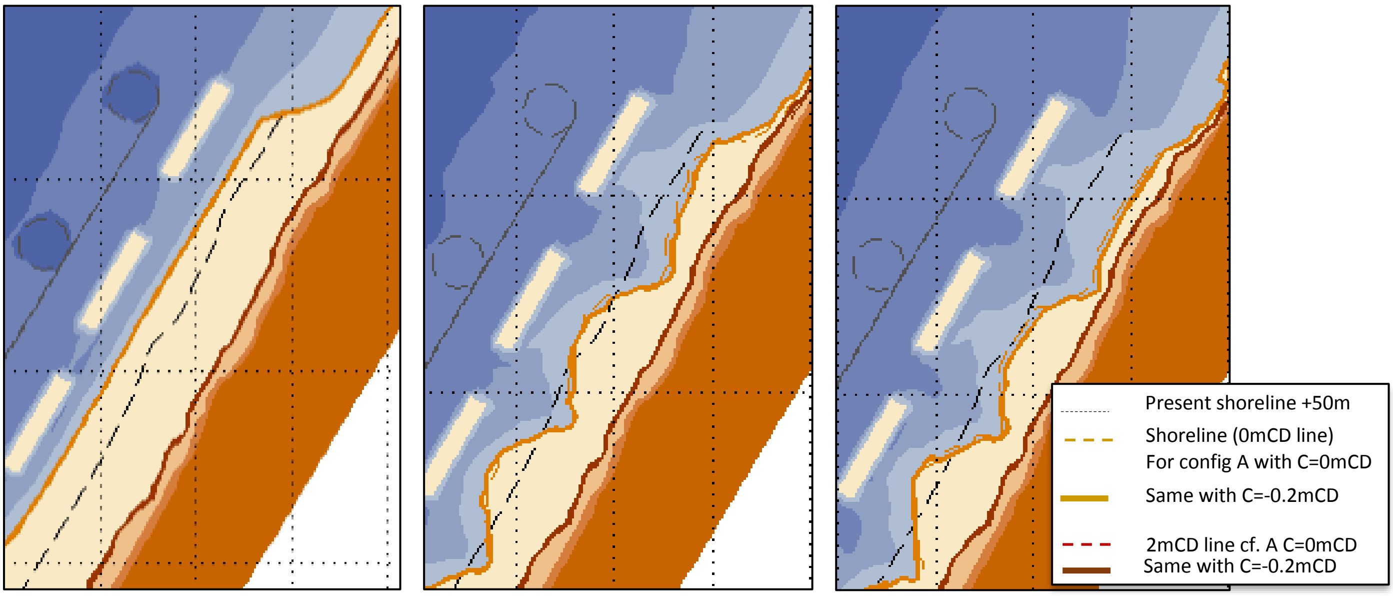


Figure 42. Zoom: Seabed evolution for configuration A (crest level 0mCD)

As shown on the graphic below, a crossection including the north hole and breakwater, after 2 years, the sand holes are filled. In reality, the process of filling should be really fast and after few weeks, the bathymetry should have recovered.

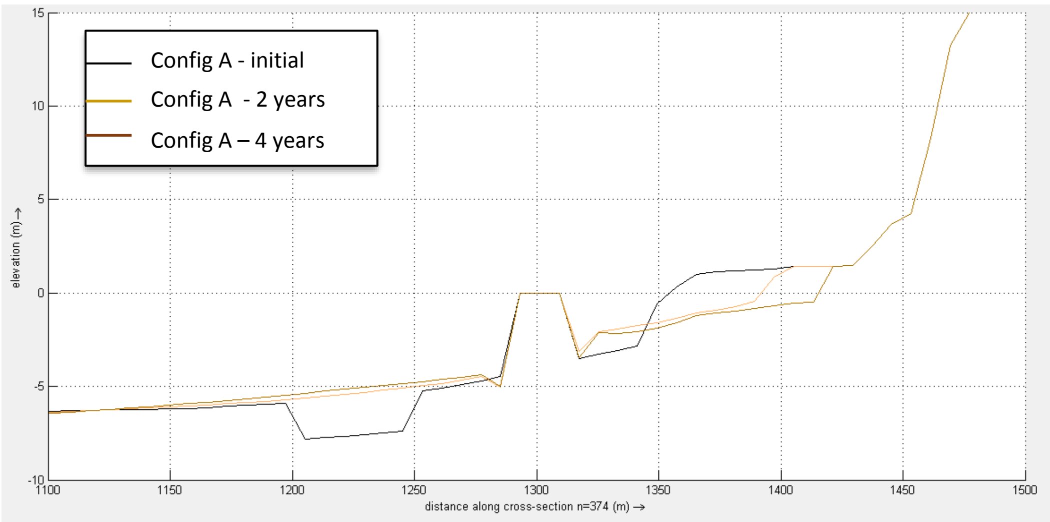


Figure 43. Zoom: Seabed evolution for configuration A (crest level 0mCD)

Therefore, no impact on the shoreline should be noticed due to the offshore sand holes in the bathymetry generated by the geotube sand filling operation.

7.5 DOWNSTREAM EROSION

The potential erosion generated downstream (north of the study site) was studied in order to anticipate on mitigation methods to avoid potential damages on the cliffs.

A conservative approach was considered; the model only considers sand along the coast, resulting in stronger shoreline erosion prediction than can be expected in reality with cliffs.

The figure below presents a comparison of the shoreline position after 10 years of simulation for "configuration A+ initial nourishment" (green line) and the case "do nothing" (grey line). It shows that, after 10 years, submerged breakwaters should prevent cliff erosion along, at least, half the protected area, and reduce significantly the potential erosion north of the site compared to the "do nothing" case.

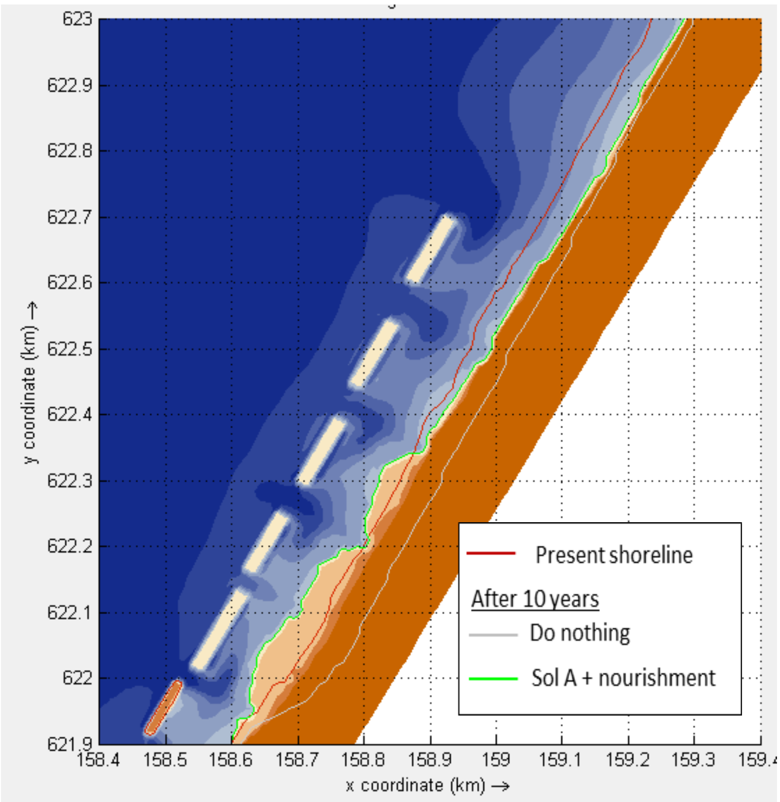


Figure 44. Comparison of 10 year shoreline evolution for configuration A (crest level 0mCD) and "do nothing" case.

The figure hereinafter presents a comparison of the 10 year shoreline evolution for configuration A, "do nothing" case, "nourishment only" case and configuration 1. It allows comparing the downstream erosion effects and shows that configuration A is the most adapted configuration to reduce potential downstream erosion while protecting the cliffs along the study area.

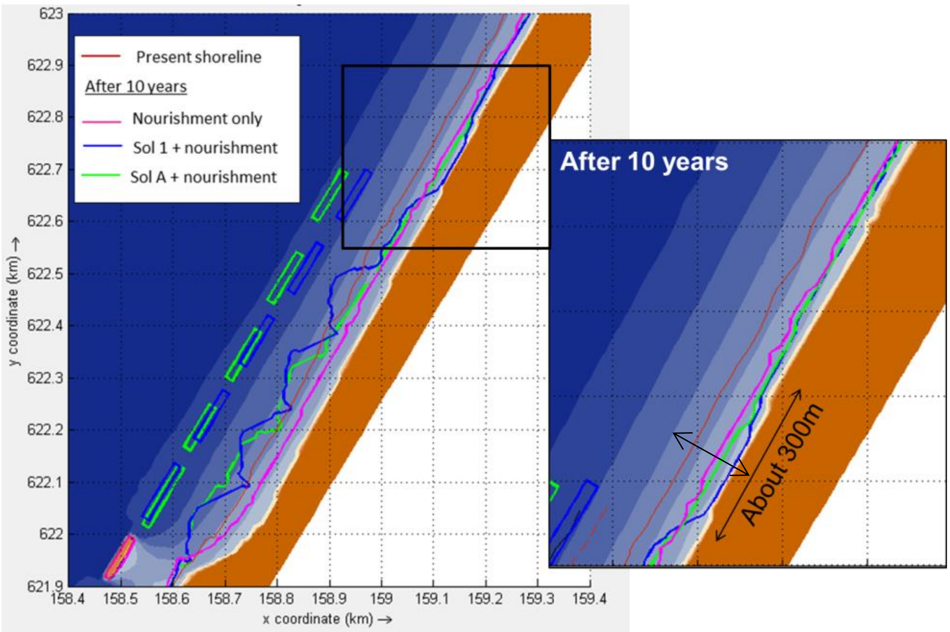


Figure 45. Details of 10 year shoreline evolution for configuration A (crest level 0mCD) and “do nothing” case, “nourish only” case and configuration 1.

In order to quantify the potential downstream erosion, beach profiles were extracted along the beach section the most impacted (arrow on the above figure) after 2 years of simulation. They are presented on the figure below.

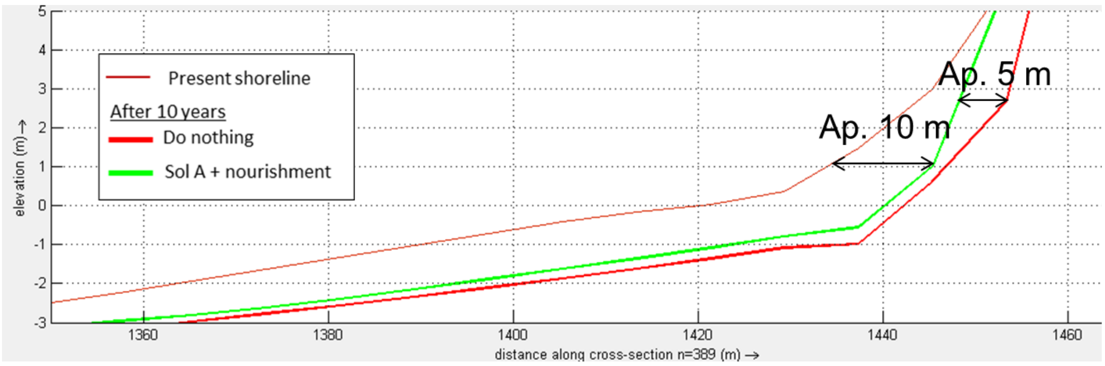


Figure 46. Beach profile after 2 years for configuration A (crest level 0mCD) and “do nothing” case.

Therefore, potential downstream erosion shall be limited to a shoreline stretch of about 300m, north of the protected site. Considering a conservative approach, about 10 m erosion was obtained after 2 years of simulation.

It is recommended to undertake beach survey twice a year in order to evaluate the evolution of the shoreline north of the site and to anticipate a local nourishment of about 10 000m3 to 20 000m3 to prevent this potential erosion.

7.6 LAYOUT AND CROSS SECTION

The plan and cross-section are given as appendix to this document.

Below a quick view at the drawing.

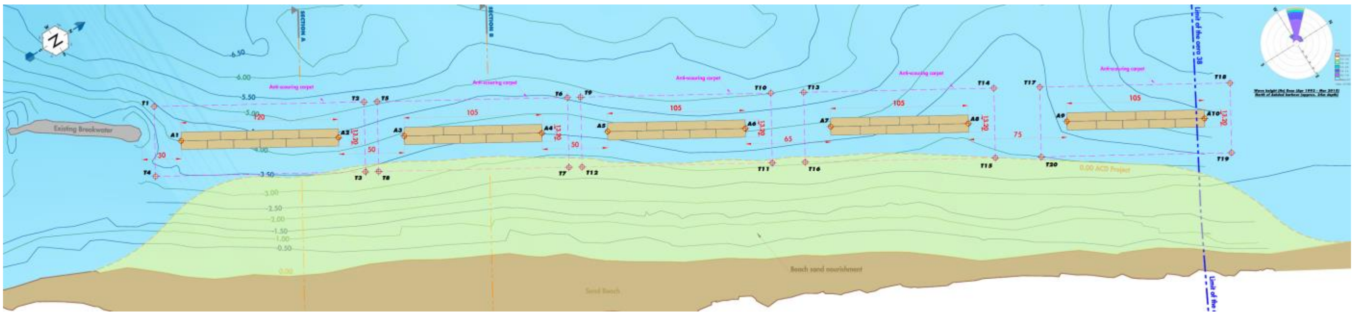
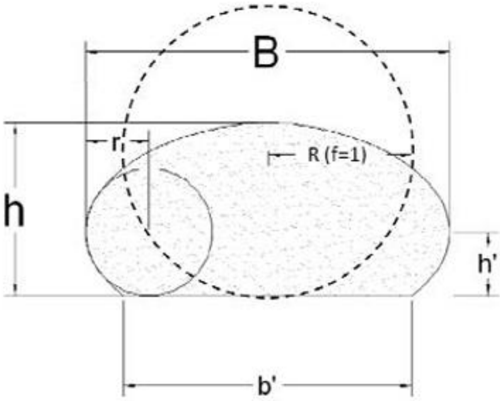


Figure 47. Plan view of the final scenario

Assuming a water depth of -4mCD for the breakwater implantations, as set by Moffat and Nichol, and a crest level of -0.2mCD, the Geotube® dimensions are determined considering the Bezuijen and Vastenburg 2012 formulae [5]:

$$h \geq \left(1-\sqrt{1-f}\right) \cdot D$$

$$B \leq h + \frac{1}{2} \cdot \pi \cdot (D-h)$$



With:

h: height of the Geotube®

B: width of the Geotube®

f: porosity or percentage of sand filling

h being imposed as 3.8m and f being 90%, B=6.6m.

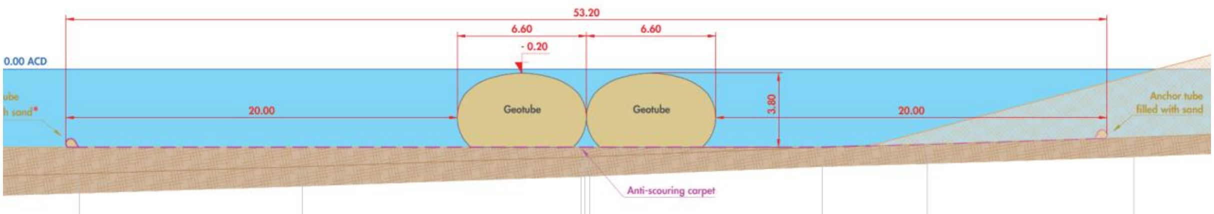


Figure 48. Typical cross-section of the geotube breakwater of the final scenario

8 GEOTEXTILE STRUCTURE STABILITY ASSESMENT

According a geotextile breakwater design life of 10 years and considering a conservative approach, a project design Return Period of 50 years is considered, using a high range storm surge for the associated water level.

Wave propagation modeling (SWAN and XBEACH) provides the following results, in term of wave and water level conditions, at the geotextile breakwater locations (-4mCD).

Table 18: considered extreme wave and water level conditions at the proposed breakwater locations

RP (Year)	Inshore wave conditions (bk location)			Water level at breakwater location (mCD)		
	Hs (m)	Tp (s)	Dir (°N)	Storm WL	Setup (m)	Max WL
1	3.4	11.6	306	0.9	0.13	1.0
5	3.6	13.2	306	1	0.23	1.2
10	3.8	13.6	306	1.2	0.27	1.5
20	3.8	13.8	306	1.2	0.31	1.5
50	3.9	15.2	306	1.3	0.35	1.7
100	4	15.5	306	1.4	0.41	1.8

Shape of geotube and formula for stability under wave action were mainly sourced from "Geosystems Design, rules and applications" from Tencate [5].

Assuming a crest level of the breakwater at -0.2mCD (breakwater height of 3.8m), three formulas were applied to assess the breakwater stability under storm wave actions:

- **PILARCZYK (2000) [6]**

Chapitre III les propositions des dispositifs de défense avec une vision d'aménagiste

c. Vérification de stabilité du géotube

Pilarczyk (2000) a présenté l'équation suivante de stabilité des géotubes :

$$\frac{Hs}{\Delta . b} < 1 \quad (10)$$

Avec :

- H_s : étant la hauteur significative des vagues incidentes,
- b : la largeur du géotube
- n : la porosité

$$\Delta = (1 - n)\frac{\gamma s - \gamma w}{\gamma w} \quad (11)$$

- **Van Steeg and Vastenburg [5]**

$$\frac{\chi H_s}{\Delta_t \sqrt{BD}(f\cos\alpha + \sin\alpha)} \leq 0.65$$

Avec les paramètres suivants :

Hs= la hauteur significative de la houle incidente (m)

Δt= La densité relative du géotube= $\frac{\rho s - \rho w}{\rho w}$ avec ρ_s=1480kg/m³

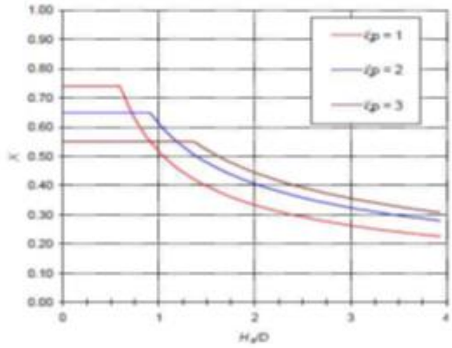
B= la largeur du géotube (m)

D = la hauteur du géotube (m)

F= le coefficient de friction entre le géotextile et le support

α = la pente du fond

χ= le facteur de réduction dû à l'énergie perdue par subversement (nota : pour ce coefficient, les modélisations physiques supposaient que le niveau de l'eau au repos correspondait à l'arase du récif)



Facteur de réduction dû au déversement de la houle sur le récif artificiel. Ɛp= paramètre de déferlement

- **Morison formula** : $\boldsymbol{P_w > F_l + (F_D + F_I)\frac{C_x}{\mu}}$

$$Fd = \frac{1}{2}\rho_e Cd \cdot D \cdot u(t)^2 \qquad Fi = \rho_e Cm \cdot S \cdot a(t) \qquad Fl = \frac{1}{2}\rho_e Cl \cdot D \cdot u(t)^2$$

As shown in the table below, the following results parameter are obtained for the proposed geotube breakwaters (central column), to be compared with the associated stability criteria (right column).

Table 19: stability criteria analysis

50 year Return Period event		
Formulation	Parameter	Stability criteria
PILARCZYK (2000)	**0.7**	**<1**
Van steg et Vastenburg (2010)	**0.65**	**<0.65**
Morison formula	**19.2**	**> 18.2**

One can conclude in the stability of the proposed geotube, considering a 50 year return period event associated with a 10 year design life.

9 REFERENCES

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