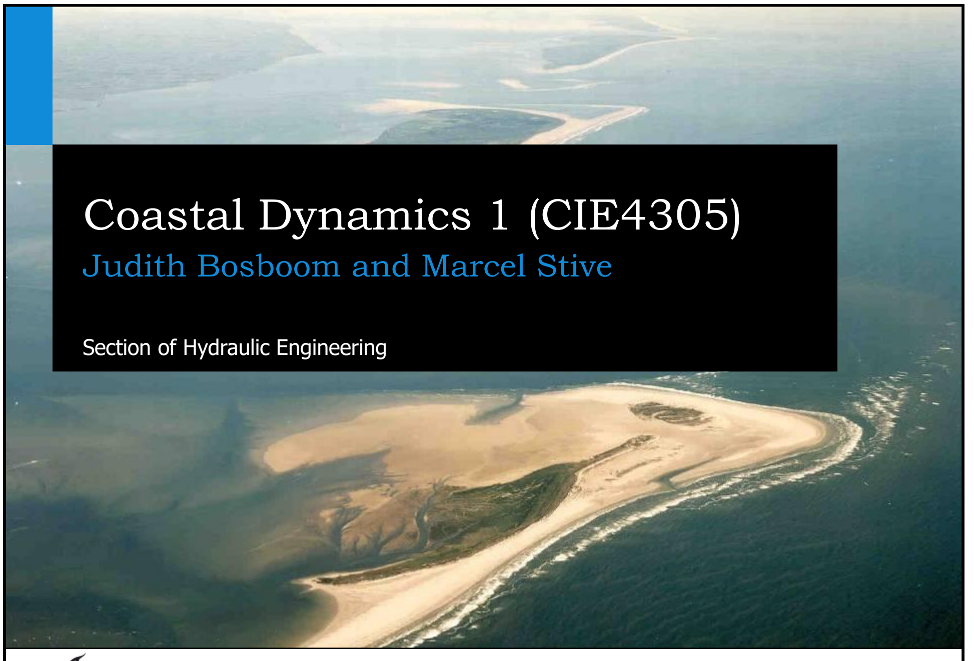


Coastal Dynamics 1 (CIE4305)

Judith Bosboom and Marcel Stive

Section of Hydraulic Engineering

10.

Coastal protection

Jan van Overeem

Part II

30 March 2017

Coastal Dynamics 1

Contents

Coastal protection

Contents of lecture

Repetition

10-B Coastal protection strategies

Selection of coastal protection method

- Important to have good insight in coastal processes
- Two basic approaches:
  1. Try to solve the cause of the erosion problem (cure the cause)
  2. Mitigate the negative effects (cure the symptoms)
- Possible solutions to mitigate coastal erosion problems:
  - "soft" (natural) measures (beach and foreshore nourishment)
  - "hard" measures (coastal structures)

Repetition

10-C Types of coastal erosion processes

Two types of erosion

See Chapter 8

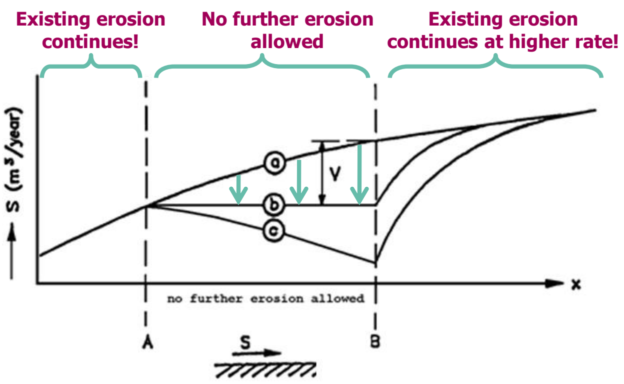
1. **Structural** erosion
   - long-term, gradual, due to 'normal' and slow processes
   - e.g. 1 m/yr or 20 m^3/m per year (if profile height is 20 m)
2. **Episodic** erosion, during severe storm (surge) events
   - i.e. dune erosion due to storm surge
   - fast process (hours)
   - e.g. 100 m^3/m in 6 hours or even 200 to 300 m^3/m (10 – 15 m) under design conditions

See Chapter 7

Repetition

10-D Modification of longshore transports

Longshore transport curve along eroding coast



- Gradient in longshore sediment transport ($S_B - S_A$) causes structural erosion in stretch A-B.
- Change curve of longshore transport such that gradient = 0 (from line a to line b).

Repetition

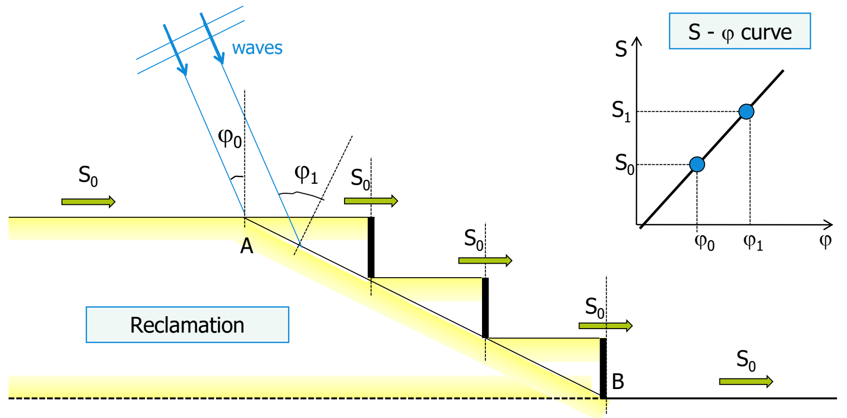
10-E 'Hard' measures influencing littoral drift

Introduction

- In order to mitigate structural erosion with structures ('hard' measures), they must interfere in sediment transports processes.
- Possible structures are:
  a) Jetties / shore-normal breakwaters;
  b) Series of groynes;
  c) Detached (offshore) breakwaters (emerged or submerged).
- Even for well-designed protection scheme, lee-side erosion is unavoidable.

10-E 'Hard' measures influencing littoral drift

Groynes to protect transition of reclamation



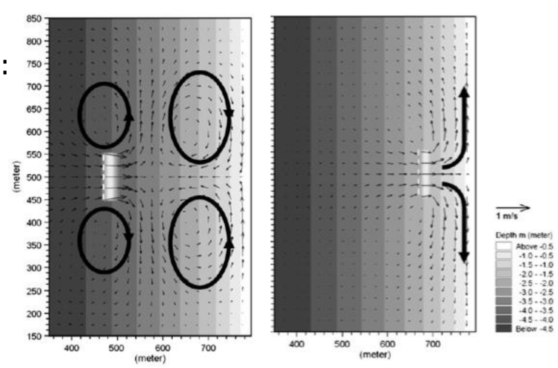
Scheme with 3 groynes used to support the beaches in the groynes bays.

E 'Hard' measures influencing littoral drift

Submerged offshore breakwaters (Rasaninghe, 2010)

Erosion or accretion based on:

- Distance of submerged breakwater from shore
- Dimensions of submerged breakwater
- Sediment characteristics
- Incident significant wave height



- far from shore: 4 cell patron => accretion
- close to shore: 2 cell patron => erosion
- Use DELFT3D type of model!

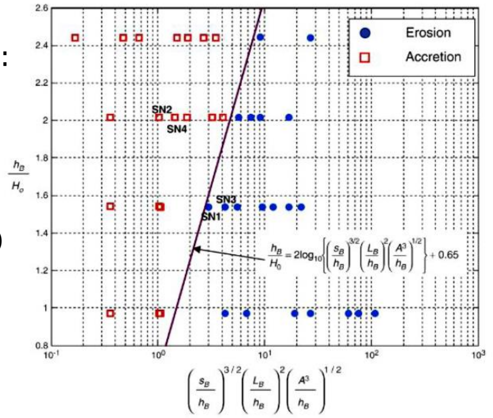
Repetition

E 'Hard' measures influencing littoral drift

Submerged offshore breakwaters (Rasaninghe, 2010 and Jos vd Baan, 2013)

Erosion or accretion based on:

- Distance of submerged breakwater from shore (h_B)
- Dimensions of submerged breakwater (L_B, s_B)
- Sediment characteristics (A)
- Incident significant wave height (H_0)



- Design graph based on DELFT3D runs

10-E 'Hard' measures influencing littoral drift

Circulation due to wave set-up differences

Coastal protection

Chapter 10 of lecture notes

10-F 'Hard' measures for storm induced erosion

Introduction

- If storm-induced erosion is unacceptably large, structures may help to reduce erosion.
- Groynes do not reduce offshore directed sediment transport
- Detached emerged or submerged breakwaters only have limited effect on reduction of extreme wave height.
- Structures that may be effective against storm-induced erosion are:
  - Seawall
  - Revetment
  - Sea-dike

10-F 'Hard' measures for storm induced erosion

Seawall at Lancashire, England, 1998

10-F 'Hard' measures for storm induced erosion

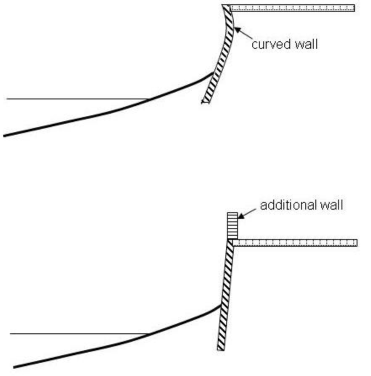
Seawall

- Seawall is vertical structure at transition between beach and dune of mainland.
- Generally smooth surface and impermeable, easy to build.
- Principle: storm erosion is prevented by cutting off supply of material from dune or mainland.
- Seawall tends to reflect incoming waves.
  Increased turbulence forms a trough along toe of seawall.
  This trough may endanger its foundation.
- This can be prevented by maintaining the sea bed in front of seawall by means of regular sand nourishment.

10-F 'Hard' measures for storm induced erosion

Seawall

- Overtopping may be reduced by applying slightly curved sea wall or additional wall.



10-F 'Hard' measures for storm induced erosion

Revetment

- Revetment is similar to seawall. Revetment has gentle slope (e.g. 1:2 or 1:4) with either rough or smooth surface.

- Slope and type of surface of revetment influences the scour depth
  - Model tests at Deltares showed that steeper slope causes deeper scour hole than milder slopes.
  - Scour depth is larger for smooth slope than for rough slope.

- Revetment for dune foot protection:
  The elevation of revetment determines volume of dune erosion and scour depth (higher revetment => less dune erosion => deeper scour hole)

10-F 'Hard' measures for storm induced erosion

Sea-dike

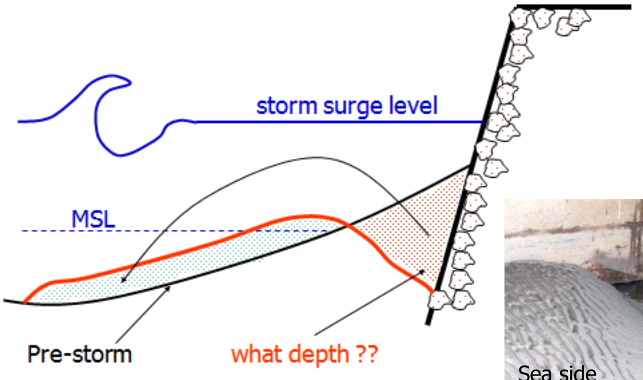
- Meant to prevent flooding (just like a river dike).
- Usually no beach in front of sea-dike.

Hondsbossche Zeewering

- Crest height must be high enough to prevent overtopping
- Flat and smooth slopes causes high wave run-up => high dike.
- Point of concern: erosion just in front of sea-dike (larger water depth results in higher wave at toe and higher wave run-up.

10-F 'Hard' measures for storm induced erosion

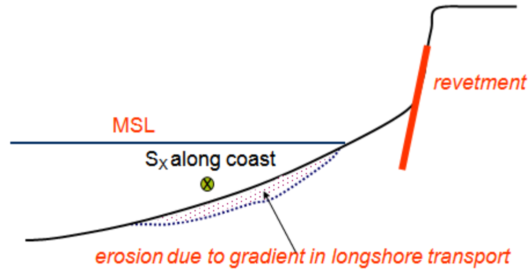
Sea-dike: development of scour hole!



Test in Delta flume at Deltares

10-F 'Hard' measures for storm induced erosion

Do shore-parallel structures prevent structural erosion?



- No!
- These structures do not influence longshore transport gradients!
- Structural erosion continues in the area below MSL.

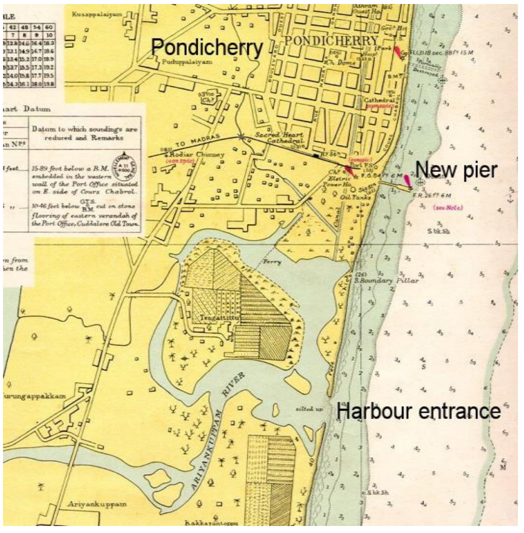
10-F 'Hard' measures for storm induced erosion

Example of Pondicherry, India

Pondicherry

10-F 'Hard' measures for storm induced erosion

Example of Pondicherry



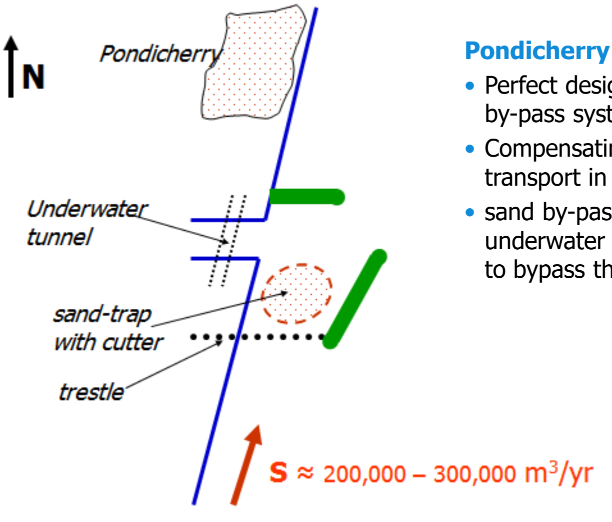
Pondicherry

- old French colony
- loading/unloading along open pier
- small harbour for barges
- nice beaches in front of city center

- Project
  Use existing tidal inlet for small boats => build breakwaters at entrance in inlet.

10-F 'Hard' measures for storm induced erosion

Example of Pondicherry



Pondicherry

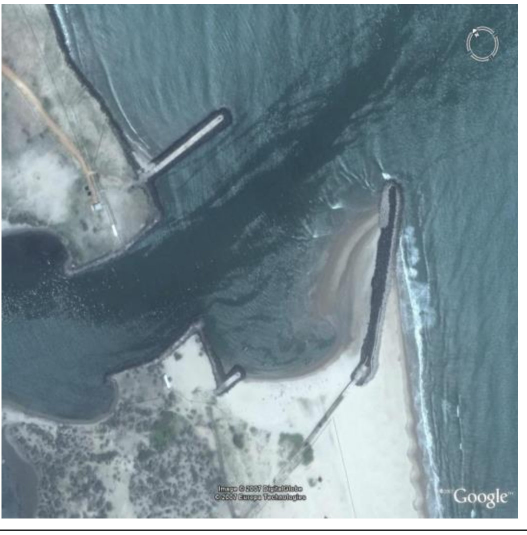
- Perfect design, including sand by-pass system!
- Compensating for net transport in Northern direction
- sand by-pass system with underwater tunnel for pipeline to bypass the sand.

10-F 'Hard' measures for storm induced erosion

Cutter dredge for sand by-pass system at Pondicherry

10-F 'Hard' measures for storm induced erosion

Pondicherry's sand by-pass system **failed**



Effects:

- Accretion at the South side
- Structural erosion at the North side

Applied solution:

- **Revetment** along coast, 6 km long
- Is extended from time to time
- No beaches left

This revetment is good example of bad solution for structural erosion!

10-F 'Hard' measures for storm induced erosion

Pondicherry's beaches disappeared

10-F 'Hard' measures for storm induced erosion

Pondicherry: end of 6 km long revetment (right side) (March 2002)

10-F 'Hard' measures for storm induced erosion

Pondicherry: end of 6 km long revetment, August 2002

TUDelft 10. Coastal Protection 29

10-F 'Hard' measures for storm induced erosion

Pondicherry: end of 6 km long revetment, October 2002

TUDelft 10. Coastal Protection 30

10-F 'Hard' measures for storm induced erosion

Pondicherry, 2007

- Revetment extended till last buildings of Pondicherry
- Erosion continues

Coastal protection

Chapter 10 of lecture notes

A. Introduction
B. Coastal protection strategies
C. Types of coastal erosion processes
D. Modification of longshore transports
E. 'Hard' measures influencing littoral drift
F. 'Hard' measures for storm induced erosion
G. Artificial sand nourishment ('soft' measures)

10-G Artificial nourishment ('soft' measures)

Introduction

- Compensation for structural erosion
- Protection of beach and dunes against storm erosion.
- Creation of new beaches
- Reclamation of new land.

- Must be repeated regularly (only treating symptoms).
- Leaves coast in natural state, without lee-side erosion.
- Flexible: scheme can be modified if results are not as expected.
- Good for coastal system: sediment is added to it.

10-G Artificial nourishment ('soft' measures)

Introduction

- Nourishment can "never" go wrong (except for bad designed nourishment scheme)

- Nourishment is often an economic solution due to its cost structure (no capital cost, only maintenance cost).

10-G Artificial nourishment ('soft' measures)

Design aspects - Origin of sand

Borrow sand

- Land sources (river beds or sand deposits)
- Marine sources (estuaries or sea bed)
- Maintenance dredging
  (Dutch: make work with work)

Borrow pit

- At sufficiently large distance from shore
  (in NL: 20 km) to prevent coastline erosion;
- Small and deep versus large and shallow?
  - Deep => stagnant water with poor quality
  - Large => environmental disturbance of surface layer
  - No clear recommendation. Perform EIA for each project

10-G Artificial nourishment ('soft' measures)

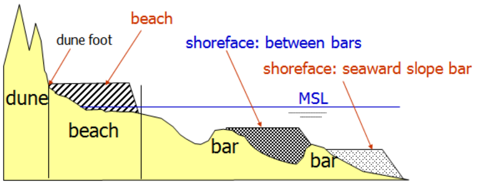
Design aspects - Quality of sand

- Use preferably borrow sand that is similar to native material (same behavior)
- Sometimes coarser material is used to reduce losses (steeper slopes).
- Borrow material contains silt (2%-5% is normal), which may have negative impact on marine environment (during overflow).
- If necessary wash out silt before placing sand on beach.

10-G Artificial nourishment ('soft' measures)

Design aspects - Location of nourishment

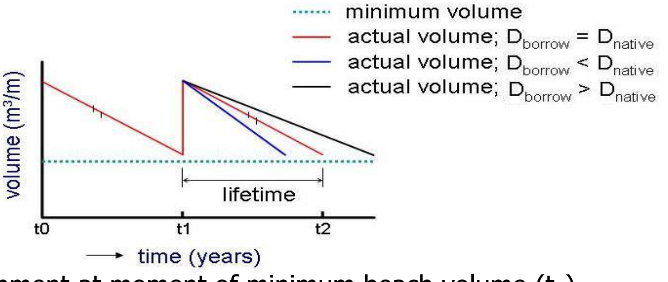
- Location of nourishment:
  - Landward, seaward or on top of dunes
  - Dry beach
  - Shoreface



- Sand for (landward) dune nourishment is often from land sources, because marine sand may cause salt problems for dune vegetation.
- Placing sand on beach requires dredging equipment to cross breaker zone. Rainbowing is alternative solution (shallow water).
- Shoreface nourishment is placed at the seaward edge of the surf zone with sufficient depth for the hopper dredge to navigate.
- Effectiveness of shoreface nourishment is lower than that of beach nourishment. At the other hand unit cost are lower.

10-G Artificial nourishment ('soft' measures)

Re-nourishment for structural erosion



- Start re-nourishment at moment of minimum beach volume (t_1).
- Generally lifetime is 5 to 10 years (due to high mobilization costs).
- Borrow sand coarser => loss decreases => lifetime increases (black)
- Borrow sand finer => loss increases => lifetime decreases (blue)

10-G Artificial nourishment (‘soft’ measures)

Example nourishment project

- Assume coastline retreat is 2 m per year => sand loss over total profile height (20 m) is ΔV = 40 m^3/m' per year.
- Assume period between nourishments is 5 year => volume to be nourished is 200 m^3/m' every 5 years.
- Assume stretch of coast is 5 km long => total volume to be nourished is 1,000,000 m^3 every 5 years.
- Volume is increased with 10% to 20% to account for additional losses of the fine fraction.
- Contract with dredging contractor:
  - Long term contract for regular nourishment of stretch of coastline
  - Combine foreshore with beach nourishment (flexibility contractor)
  - Control method (hopper volume measurements or as built survey)

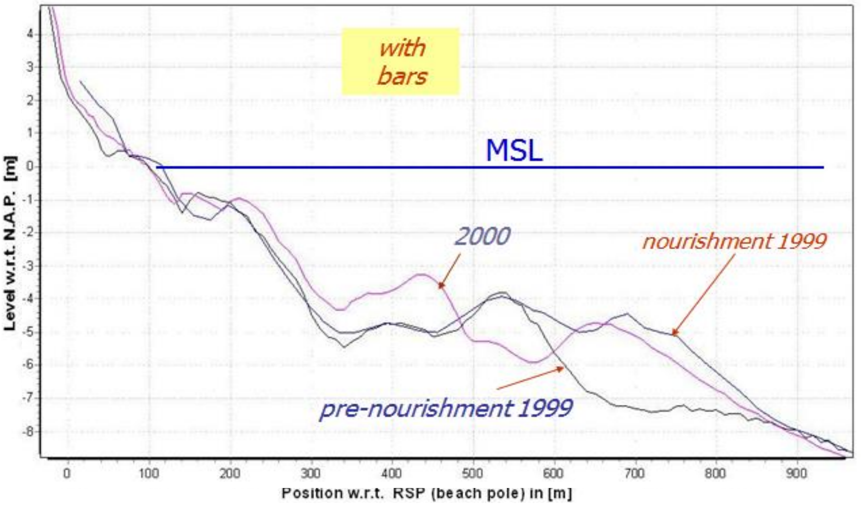
10-G Artificial nourishment (‘soft’ measures)

Shoreface nourishment

- Larger nourishment volumes are required as only 30% to 50% of nourishment volume will reach the beach.
- Costs per m^3 for shoreface nourishment is 50% to 70% less than for beach nourishment
- Total cost in balance: 100 m^3 x € 10/m^3 = 200 m^3 x € 5/m^3

10-G Artificial nourishment ('soft' measures)

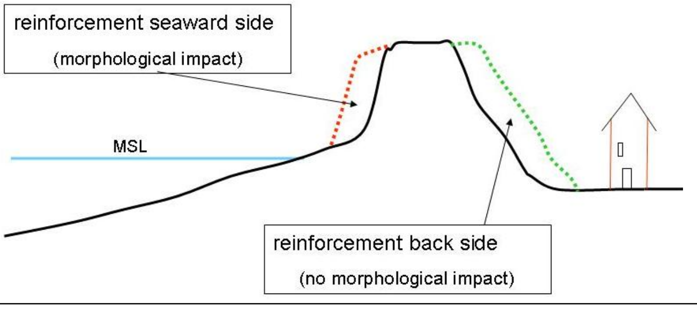
Shore face nourishment: movement of sand towards beach



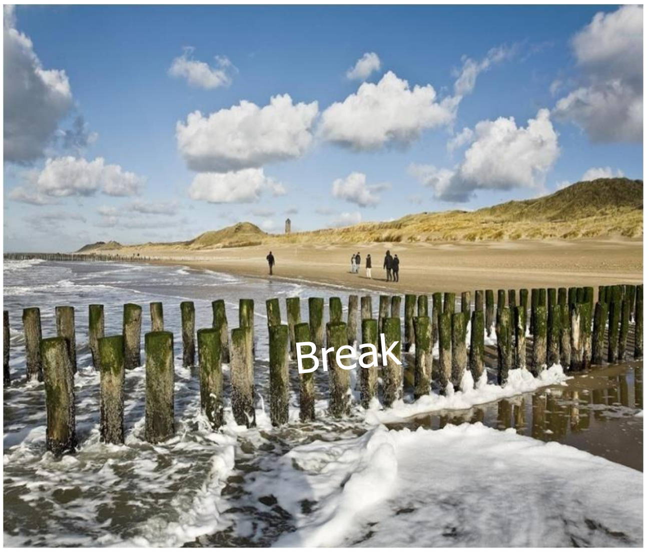
10-G Artificial nourishment ('soft' measures)

Dune nourishment

- Dune nourishment required if volume of dune is insufficient to cope with dune erosion during design storm.
- Nourishment at landward side is most effective (infrastructure?)
- Nourishment at seaward side or on top of dune interferes with the coastal dynamic system (effective but sand may be "lost" for dune)



10. Coastal protection



10-G Artificial nourishment ('soft' measures)

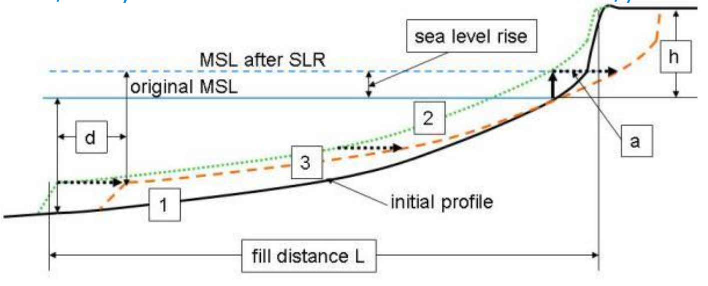
Possible to counteract sea-level rise with nourishment?

How to determine equilibrium profile with sea level rise (profile 3)? (Chapter 7)

- Profile 2 is obtained by vertical shift of initial profile 1 over distance *SLR*.
- Profile 3 is obtained by horizontal shift of profile 2 over distance *a*.

  $(SLR \times L) = a \times (d+h)$ => $a = (SLR \times L)/(d+h)$

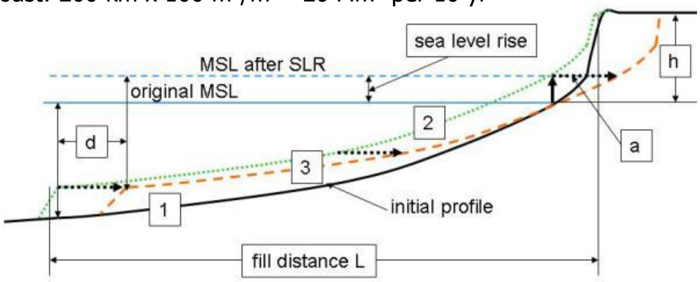
  a = (1 m/100 yr x 1000 m)/(10 m + 10 m) = 0.5 m/yr
- SLR of 1 m / 100 yr results in structural coastal erosion of 0.5 m/yr!



10-G Artificial nourishment ('soft' measures)

Possible to counteract sea-level rise with nourishment?

- Nourishment can be used to compensate space between profile 1 and 2 created by the sea-level rise.
- Required volume = *SLR* x distance *L*
- E.g. *SLR* = 1 m per century and *L* = 1000 m => volume is 10 m^3/m per yr.
- Nourishment of 100 m^3/m per 10 year is a standard job to do!
- Dutch coast: 200 km x 100 m^3/m = 20 Mm^3 per 10 yr



10-G Artificial nourishment ('soft' measures)

Scheveningen: example of beach nourishment with pipeline

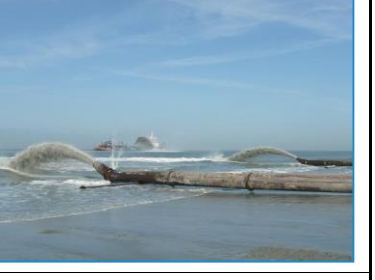
10-G Artificial nourishment ('soft' measures)

Scheveningen: beach nourishment by pipeline

Much attention is given to informing the general public!

10-G Artificial nourishment ('soft' measures)

Delfland: nourishment by rainbowing and pipeline

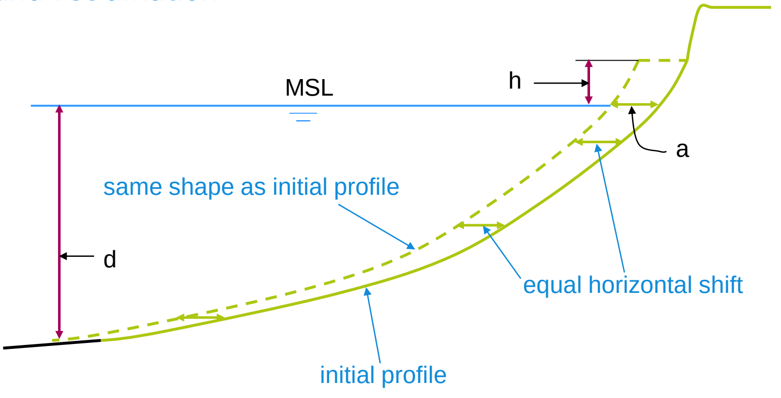


10-G Artificial nourishment ('soft' measures)

Land reclamation

10-G Artificial nourishment ('soft' measures)

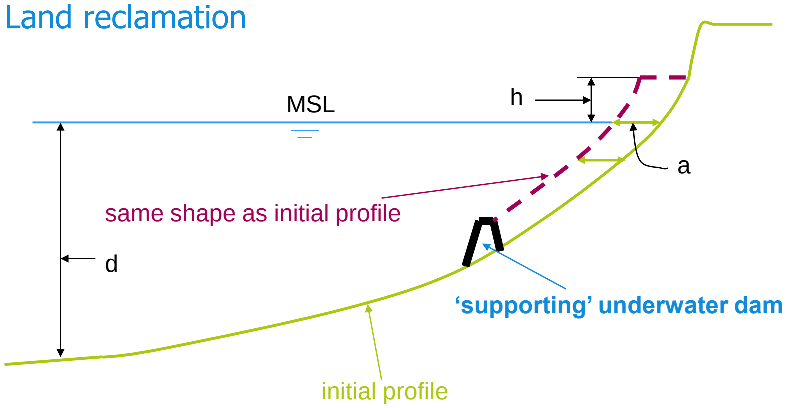
Land reclamation



d = 15 m; h = 10 m ---> 1 m^2 of 'new' land: 25 m^3; costs?

10-G Artificial nourishment ('soft' measures)

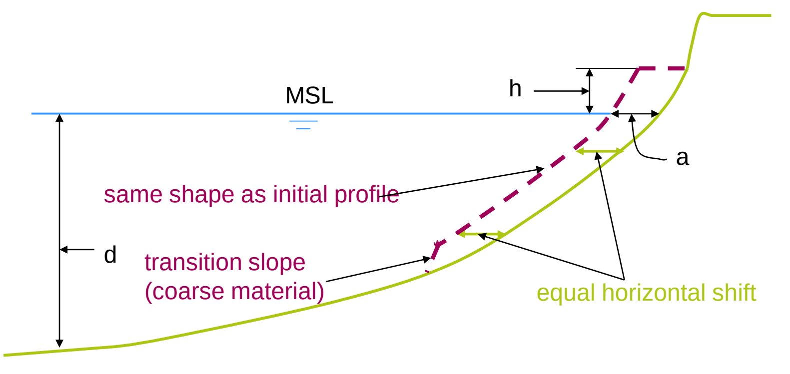
Land reclamation



"Perched" beach

10-G Artificial nourishment ('soft' measures)

Land reclamation



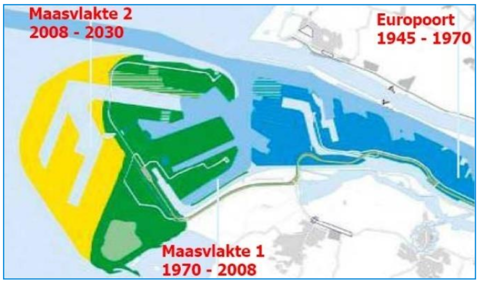
Other methods?

10-G Artificial nourishment ('soft' measures)

Land reclamation for new port at Maasvlakte 2

10-G Artificial nourishment ('soft' measures)

Maasvlakte 2: necessary extension of Port of Rotterdam



- Extension 20% with 2,000 ha:
  - at water depth of NAP -18 m.
  - located seaward of existing port at Maasvlakte 1.
- In particular for container vessels of 12,500 TEU (nautical depth 20 m).
- PUMA (JV Van Oord and Boskalis) won DCM (design, construct and maintenance) contract, with maintenance till 2018.
- Total volume of sand is 240 million m³ (of which 30 million m³ obtained from deepening basins and channels).
- First vessel used the port in 2013.

10-G Artificial nourishment ('soft' measures)

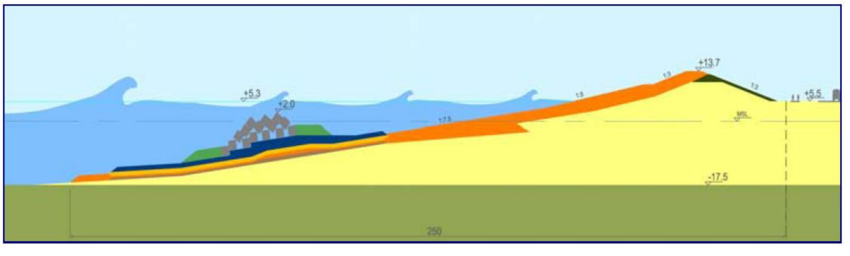
Maasvlakte 2 with 11 km long sea defence

- 3.5 km hard sea defence with cobble beach and emerged reef
- 8 km soft sea defence with coarse sand

10-G Artificial nourishment ('soft' measures)

Maasvlakte 2 - Sea Defence

- Thick layer of crushed cobbles (10 cm) over a sand core (0.35 mm) with foreshore reef of re-used concrete blocks (40 t).
- S-shaped cross-shore profile to absorb wave energy (deformation, porosity)
- Physical and numerical modelling was done to optimize design.
- Solution with lowest Total Cost of Ownership (TCO)



10-G Artificial nourishment (‘soft’ measures)

Maasvlakte 2 - Program of requirements

System-oriented way of design, without reference design of client (design freedom).

Requirements:

- No sedimentation in Maasgeul, so northern section of the sea defence must be hard. Southern section may be soft. Position of boundary between hard and soft is free to define as long as all other requirements are fulfilled.
- Cross-currents should meet nautical criteria for safe navigation in the adjacent Maasgeul.
- Design storm for sea defence once every 10,000 years (H_s = 7.9 m, T_p = 13.5 s from NW and SSL = MSL +5.1 m)
- Lowest TCO (Total Cost of Ownership): sum of present value of construction costs and present value of 50 years of maintenance costs.

10-G Artificial nourishment (‘soft’ measures)

Maasvlakte 2 - Model testing – Cross-shore dynamics

Movable bed model 2D at scale 6 (1:6)

Old Delta flume (240 m x 5 m x 7 m):

- Cross-shore deformation
- Wave overtopping
- Check movement of sand into cobble layer!
  Possible effect of intruded sand on cross-shore deformation and wave overtopping (less erosion of lower slope => less deposition near crest => more wave overtopping).

10-G Artificial nourishment ('soft' measures)

Maasvlakte 2 - Model testing – Longshore dynamics

Movable bed model 3D at scale 20 (HRW, 31 m x 24 m x 0.9 m)

- Shoreline deformation for annual maintenance and design condition
- Definition of alongshore buffer for cobble

10-G Artificial nourishment ('soft' measures)

Maasvlakte 2 - Model testing – longshore dynamics

Numerical modelling DELFT3D (flow, wave, STONE)

- Cobble transport is estimated making use empirical bed-load formula of Bijker (originally developed for gravel rivers).
- Calibrated with results of scale model test (HRW)
- Validated for two cases (Shoreham, UK and Lake Coleridge, NZ).
- Alongshore cobble drift was calculated for design storm and for year-round conditions.
- Very much computational effort

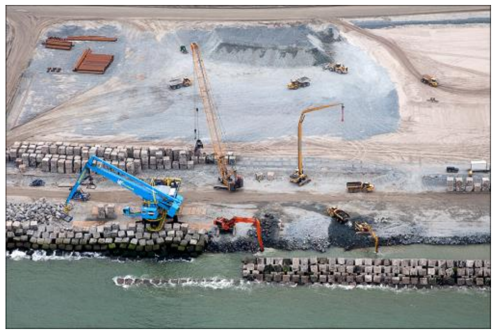
Parametric 1D model (alongshore component of radiation stress)

- Relation S_{xy} - alongshore cobble drift (similar to CERC formula).
- Including threshold (initiation of motion) of cobble.
- Calibrated using results of DELFT3D runs.
- Strong reduction of computational effort!

10-G Artificial nourishment ('soft' measures)

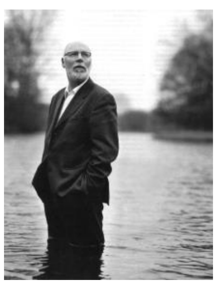
Maasvlakte 2: construction started in 2010

- Started with creation of small banana-shaped island at location of future sea defence
- Suction Hopper dredges of different size dredge coarse sand at distance between 7 and 20 km off the coast.
- After preparing coble profile 20,000 blocks of existing block dam have been placed at foreshore of hard sea defense.



10-G Artificial nourishment ('soft' measures)

Mega nourishment: The sand motor at Delfland



Founder of the Sand Motor

10-G Artificial nourishment ('soft' measures)

Mega nourishment: The sand motor at Delfland

- Delfland has vulnerable coastline.
- Dutch are continuously looking for new methods to protect The Netherlands against flooding and to gain land from the sea.
- Mega nourishment is unique in the world.
- Initially 21.5 Mm^3 of sand was nourished from March 2011 to March 2012.

10-G Artificial nourishment ('soft' measures)

Future approach: mega nourishment The sand motor at Delfland (0 – 20 yrs)

- Total surface area is 100 ha (1 km^2) eventually resulting in 35 ha of new beach (65% moved alongshore)
- Morphological behaviour will be monitored to calibrate and improve our prediction models.
- Sea currents are constantly monitored for public safety.
- Project of Rijkswaterstaat and Province of Zuid-Holland.
- Executed by JV Van Oord and Boskalis

10-G Artificial nourishment ('soft' measures)

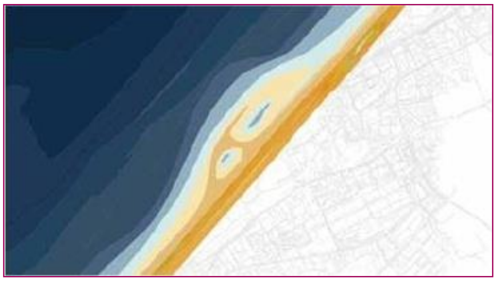
Future approach: mega nourishments
The sand engine (t = 0 yr) – diffusion process

10-G Artificial nourishment ('soft' measures)

Future approach: mega nourishments
The sand engine (t = 5 yr) – diffusion process

10-G Artificial nourishment ('soft' measures)

Future approach: mega nourishments
The sand engine (t = 10 yr) – diffusion process



10-G Artificial nourishment ('soft' measures)

Future approach: mega nourishments
The sand engine (t = 20 yr) – diffusion process

10-G Artificial nourishment ('soft' measures)

Mega nourishment: The sand motor, Delfland 13 Oct 2011

10-G Artificial nourishment ('soft' measures)

Mega nourishment: The sand motor, Delfland 10 Jan. 2012

10-G Artificial nourishment ('soft' measures)

Mega nourishment: The sand motor, Delfland 2 July 2012

10-G Artificial nourishment ('soft' measures)

Mega nourishment: The sand motor, Delfland 31 Oct. 2012

10-G Artificial nourishment ('soft' measures)

Movie "The sand motor" from VPRO (NL van Boven, 2011)

10-G Artificial nourishment ('soft' measures)

The Tweed River Entrance Sand Bypassing Project

10-G Artificial nourishment ('soft' measures)
The Tweed River Entrance Sand Bypassing Project

- Joint initiative of New South Wales and Queensland State Governments.
- DCO contract to McConnell Dowell to operate project for 25 years.
- Operation started in 2001.

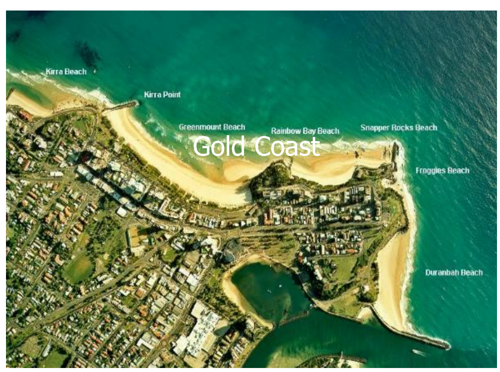
Background:

- Training walls at Tweed River from 1960's to improve navigation.
- Sediment transport is 500,000 m^3/yr northwards.
- Training wall blocked transport causing accumulation at Letitia Spit South of entrance.
- Beaches at Gold Coast eroded due to cutting of natural sand supply.

10-G Artificial nourishment ('soft' measures)
The Tweed River Entrance Sand Bypassing Project

Aim of sand bypass system:

- To move sand past Tweed River entrance.
- To improve navigation conditions at the river mouth.
- To provide the Southern Gold Coast beaches with a constant supply of sand in order to bring them back to the state of before the 1960's.



10-G Artificial nourishment ('soft' measures)

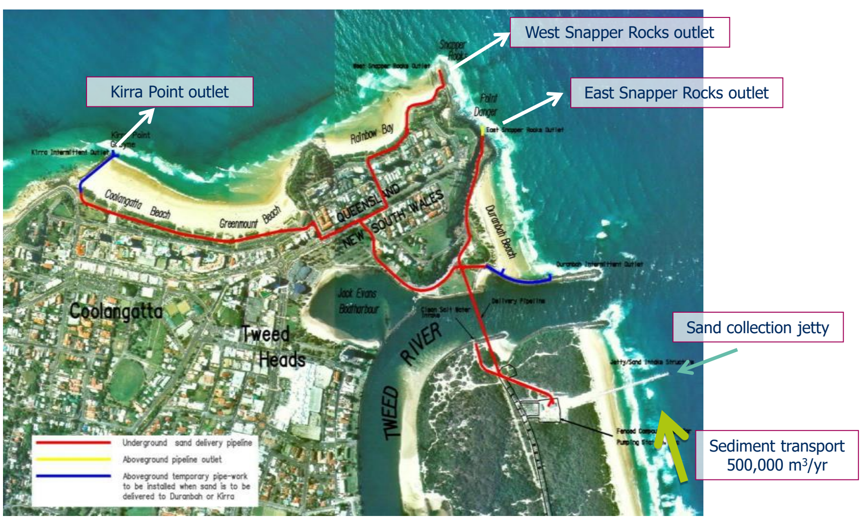
The Tweed River Entrance Sand Bypassing Project

The sand bypass system consists of:

- a 450 m long jetty south of the Tweed River entrance
- 10 submersible jet pumps at jetty located under the sea bed
- control building and deposition basin from where sand slurry is pumped northwards under river
- 3 km of underground pipeline to transport sand to the outlets at East Snapper Rocks, West Snapper Rocks and Kirra Point.

10-G Artificial nourishment ('soft' measures)

The Tweed River Entrance Sand Bypassing Project



10. Coastal protection

10.

Coastal protection

Jan van Overeem

Part II
30 March 2017