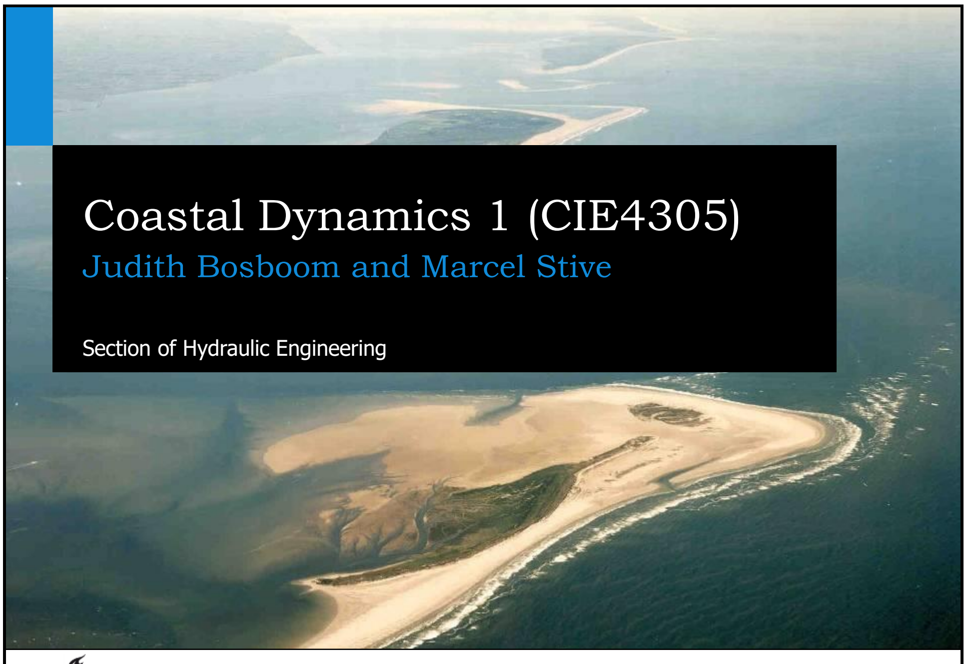


Coastal Dynamics 1 (CIE4305)

Judith Bosboom and Marcel Stive

Section of Hydraulic Engineering

TU Delft Delft University of Technology

Challenge the future

10.

Coastal protection

Jan van Overeem

Part I

29 March 2017

Coastal Dynamics 1

Contents

Coastal protection

Contents of lecture

10-A Introduction

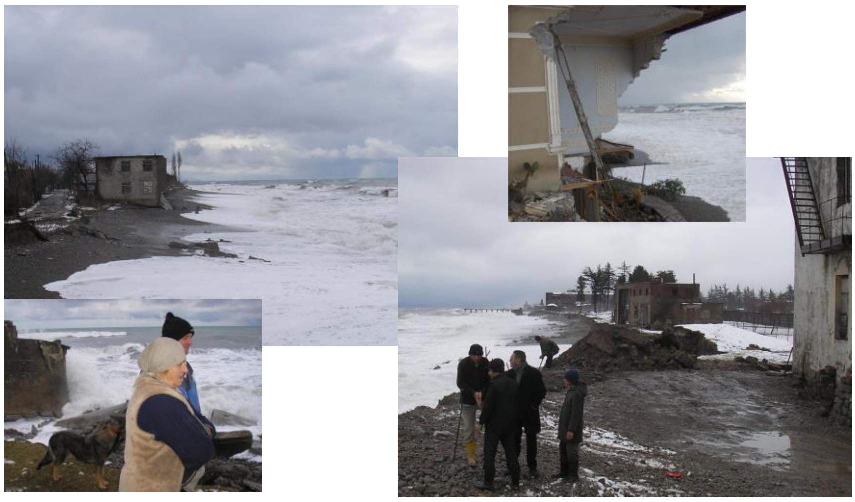
Examples of coastal erosion in UK (East coast)

10-A Introduction

Examples of coastal erosion in USA (MA, NY, AL)

10-A Introduction

Examples of coastal erosion in Georgia (Batumi)



10-A Introduction

Coastal accretion SE of Port of Salaverry, Perú

10-A Introduction

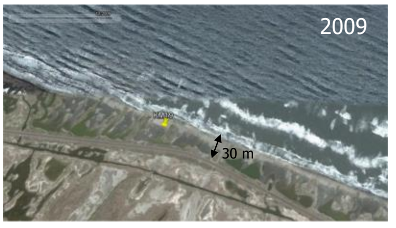
Coastal erosion NW of Port of Salaverry, Perú

10-A Introduction

Coastal erosion

10-A Introduction

Coastal erosion at road RN90 Barranquilla-Bogotá, Colombia



10-A Introduction

Focus of this lecture

- Coastal processes may generally conflict with economic interests (beach erosion, beach accretion, sedimentation access channel).
- This lecture of Chapter 10 focuses on:
  - coastal erosion problems
  - functional design aspects (= dimensions)
- Constructive design aspects:
  - Bed, Bank and Shoreline Protection (CT4310)
  - Breakwaters and closure dams (CT5308)
  - Dredging Technology (CT5300)
- Note: coastal protection here refers to protection against coastal erosion, not protection against coastal flooding.

Coastal protection

Contents of lecture

10-B Coastal protection strategies

Coastal Zone Management strategies

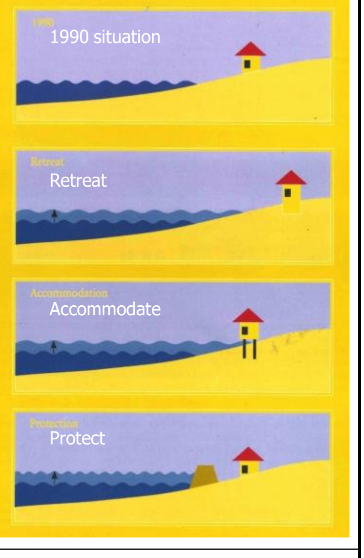
Important to have a proper CZM strategy, taking into account use of the coastal zone (social, economic and cultural) in relation to the requirements for protection.

Why?

- Increased pressures on coastal zone
- Changing conditions (climate, hurricanes, sea level rise)

CZM strategies for instance:

- Retreat (do nothing)
- Accommodate (adapt infrastructure)
- Protect (take hard or soft measures)



10-B Coastal protection strategies

Coastal zone management strategies

Actual Coastal Protection Strategy of Rijkswaterstaat (Dutch Ministry of Infrastructure and Environment)

- "Soft" if possible, "hard" if required.
- Nourishment at foreshore if possible, at beach if required.

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)

10-B Coastal protection strategies

Selection of coastal protection method

"Soft" methods: beach or foreshore nourishment

- Principle: compensate for eroded sand
- Erosion process does continue
- Must be repeated on regular basis
- If possible use sand from maintenance dredging ("make work with work")

Special "Soft" method: by-pass systems

- Re-store sediment transports from up-drift side of structure to down-drift side in an artificial way (pumping)

10-B Coastal protection strategies

Selection of coastal protection method

"Hard" methods: groynes, offshore breakwaters, revetments, seawalls

- Principle = reduce erosion by interfering in sediment transports both alongshore and cross-shore
- But …. causes impact on down-drift coast!

Sub-division of "hard" methods

- Structures influencing longshore transport under both normal and extreme conditions (groynes, dam, detached breakwaters);
- Structures preventing erosion during extreme storm events (sea wall, revetment, sea dike).

10-B Coastal protection strategies

Steps to follow for proper coastal engineering project

1. Start with making an analysis with a clear understanding of the coastal processes and the causes of coastal erosion.
2. Elaborate alternatives in terms of effectiveness, impact and cost
3. Select best alternative (using Cost-Benefit Analysis, or Multi-Criteria Analysis in framework of integrated coastal zone management project)
4. Make detailed design (engineering solutions and costing)
5. After implementation of coastal protection measure: do monitoring of actual behavior.
6. Perform maintenance, based on monitoring results.

Coastal protection

Contents of lecture

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-C Types of coastal erosion processes

Two types of erosion

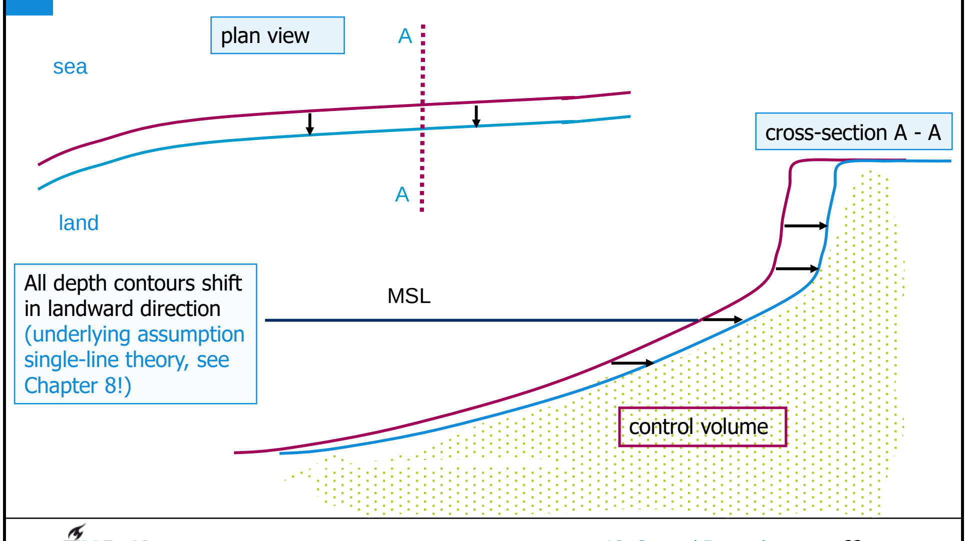
See Chapter 8

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

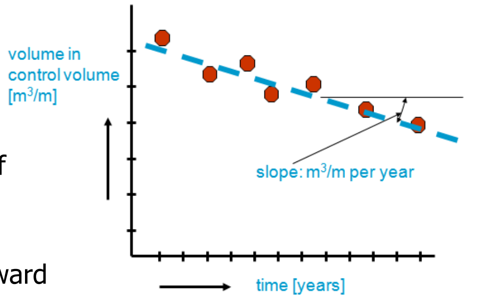
10-C Types of coastal erosion processes

Structural erosion – control volume



10-C Types of coastal erosion processes

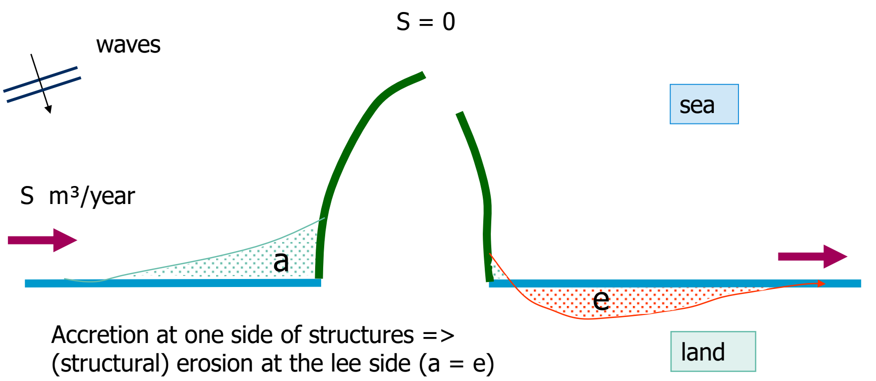
Rate of structural erosion



- Structural erosion due to loss of material out of control volume
- Permanent retreat of coast
- All depth contours shift in landward direction
- Structural erosion is often caused by gradient in longshore sediment transport

10-C Types of coastal erosion processes

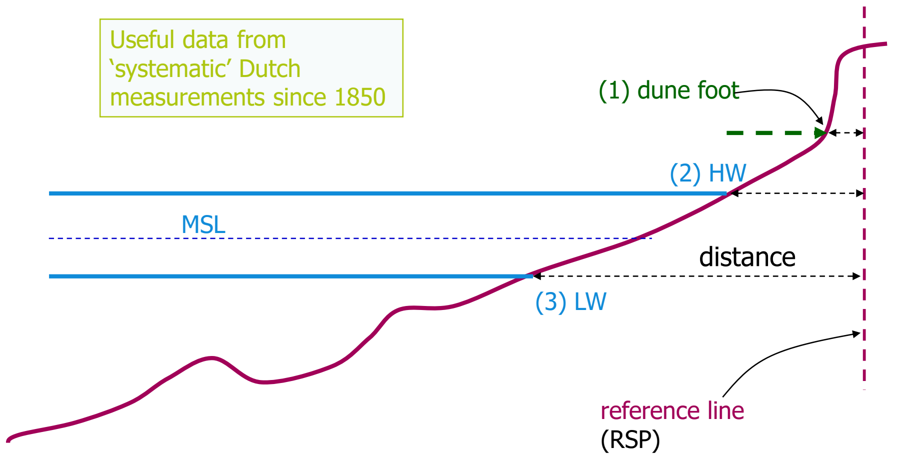
Example of structural erosion - Port



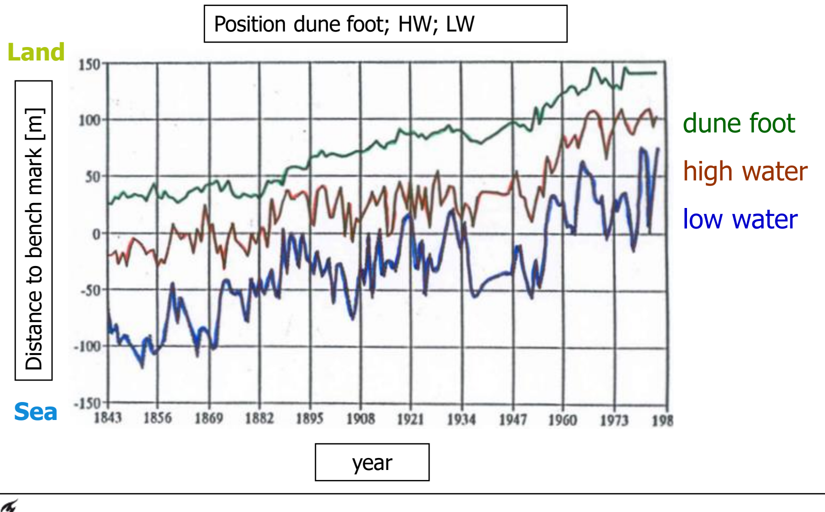
Accretion at one side of structures =>
(structural) erosion at the lee side (a = e)

10-C Types of coastal erosion processes
Structural erosion - data

Useful data from 'systematic' Dutch measurements since 1850



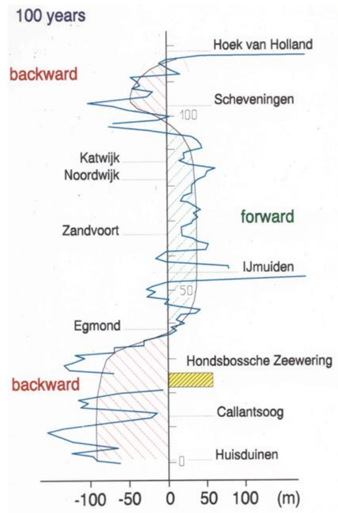
10-C Types of coastal erosion processes
Structural erosion – data ("bliksem grafieken")



10-C Types of coastal erosion processes

Data on structural erosion: 100 yr trend of HW/LW line

backward / land

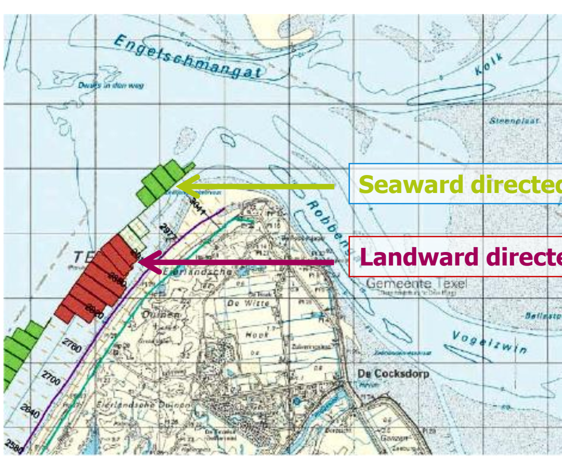


N

sea / forward

10-C Types of coastal erosion processes

Data on structural erosion. RWS "Kustlijnkaarten"

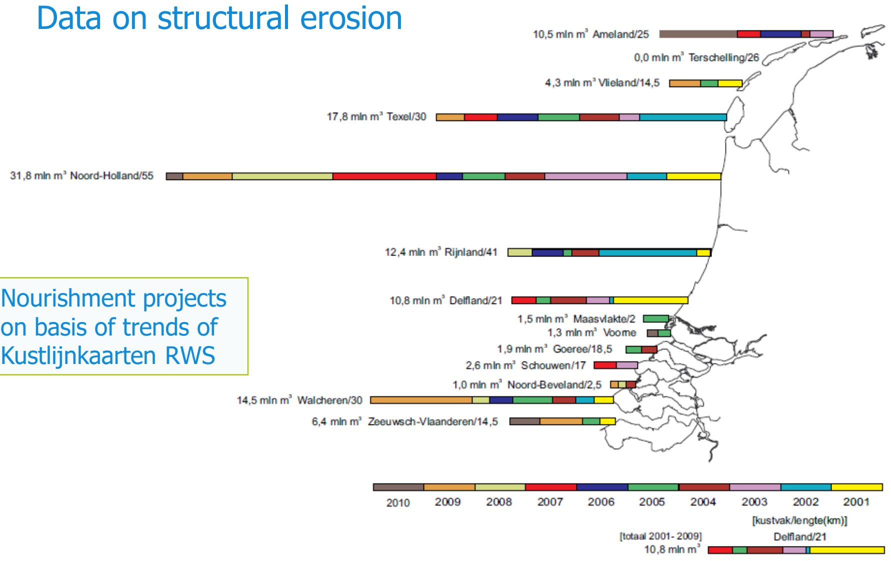


Seaward directed trend

Landward directed trend (5 m/yr)

10-C Types of coastal erosion processes

Data on structural erosion



Nourishment projects on basis of trends of Kustlijnkaarten RWS

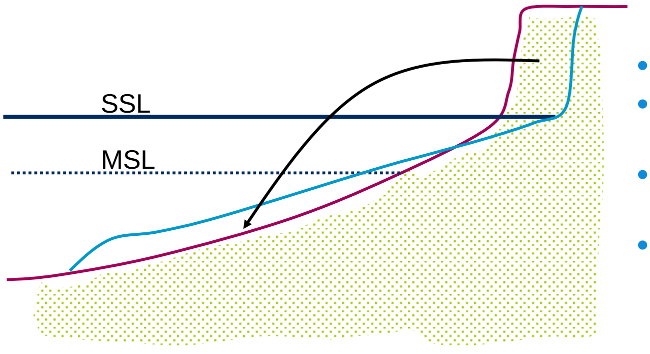
10-C Types of coastal erosion processes

Episodic erosion (dune erosion)

10-C Types of coastal erosion processes

Episodic erosion (dune erosion)

See Chapter 7



- storm event (SSL)
- redistribution over cross-shore profile
- no loss out of control volume
- return of sediments in non-storm season (in stable situations, i.e. no structural erosion)

7-C Cyclic profile and bar behaviour

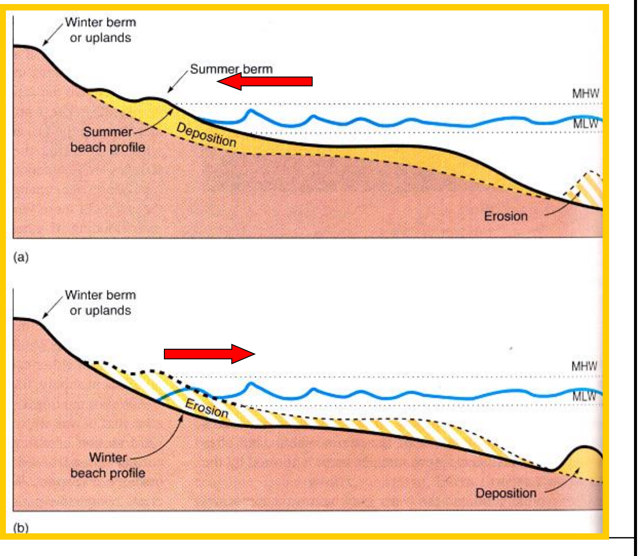
Storm and seasonal changes (see Chapter 7)

Summer: beach rich in sediment

(resembling reflective beach)

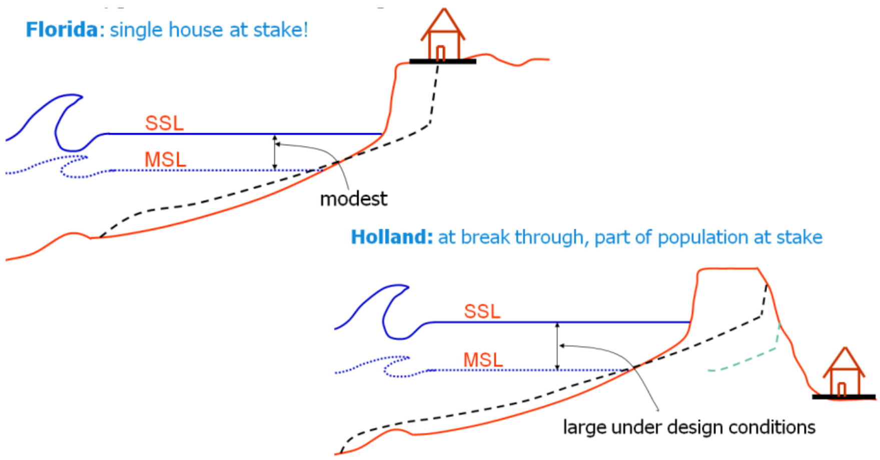
Winter and/or after storm: beach poor in sediment

(resembling dissipative beach)



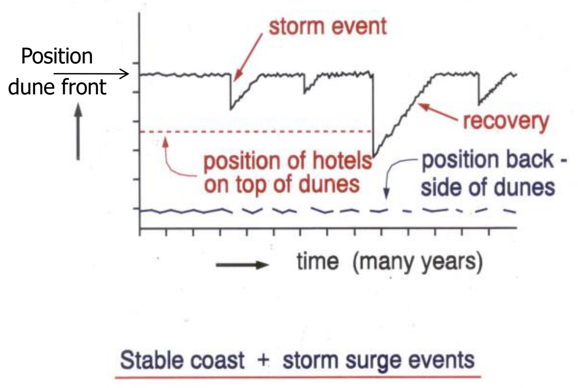
10-C Types of coastal erosion processes

Dune erosion (episodic erosion)



10-C Types of coastal erosion processes

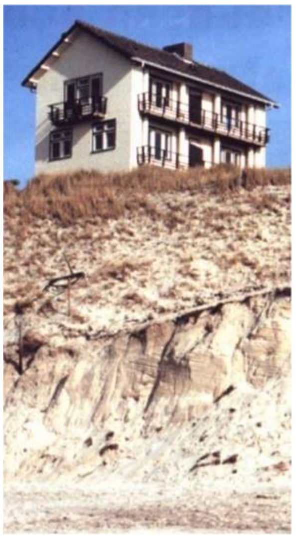
Episodic erosion along a stable coast



10-C Types of coastal erosion processes

Conflict of interest in the coastal zone

- **Coastal Zone Manager:**
  - Keep dunes free from structures
  - Allow space to the sea (flexibility)
- **Hotel owner:**
  - Be as close as possible to sea (attraction)
  - Government takes care for possible damage



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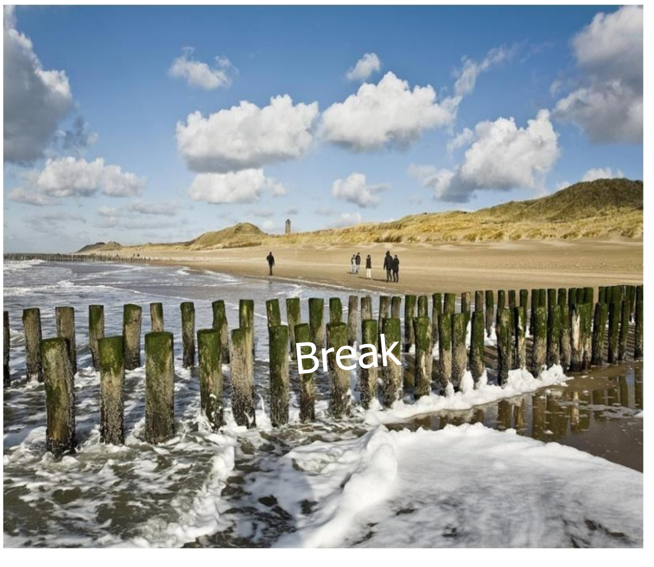
10. Coastal protection



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Coastal protection

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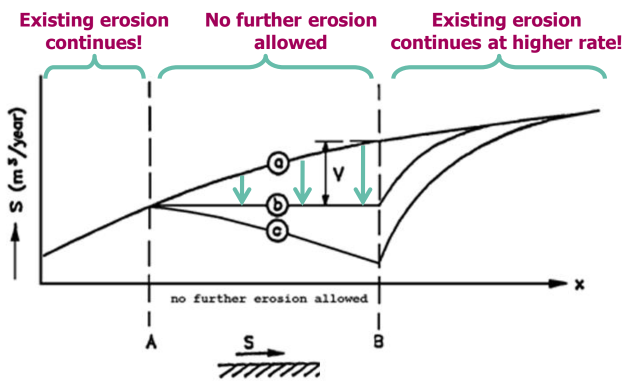
10-D Modification of longshore transports

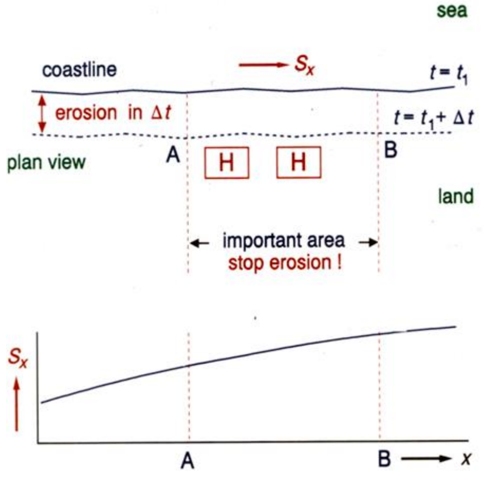
Longshore transport curve along eroding coast



- 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).

10-D Modification of longshore transports

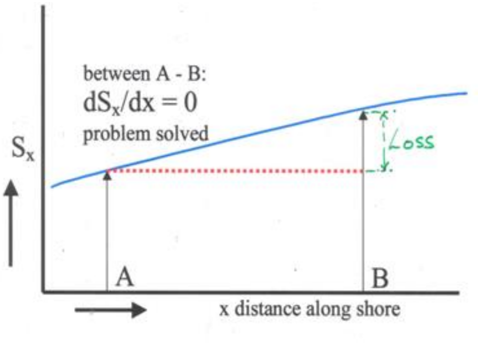
Example erosion problem: from $dS_x/dx > 0$ to $dS_x/dx = 0$!



- stretch of coast = 5 km
- gradient in longshore transport say: S_A = 200,000 m^3/yr
  S_B = 300,000 m^3/yr
- annual loss is 100,000 m^3/yr
- assume evenly distributed over 5 km along coast => loss of 20 m^3/m per year
- closure depth = MSL -10 m en dune height = MSL +10 m => yearly retreat: 20/20 = 1 m/yr

10-D Modification of longshore transports

Example erosion problem: from $dS_x/dx > 0$ to $dS_x/dx = 0$!

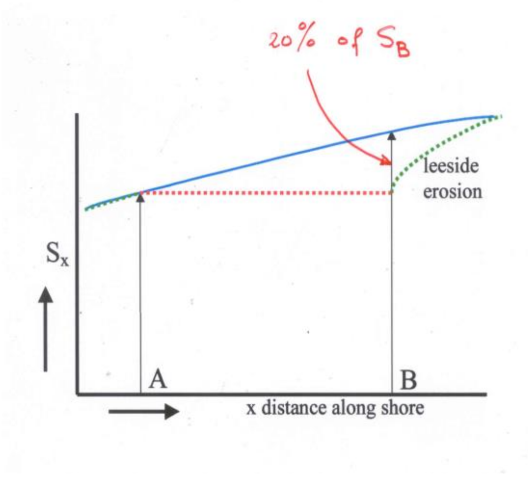


E.g.
- S_A = 200,000 m^3/yr
- S_B = 300,000 m^3/yr

- If gradient = 0 then S_B must be reduced with 33%.
- If groynes are applied, they should interfere with the longshore transport and reduce S_B with 33%.
- **What happens right of B?**

10-D Modification of longshore transports

Higher transports, same erosion, lower reduction



E.g.

- S_A = 400,000 m^3/yr
- S_B = 500,000 m^3/yr

- If gradient = 0 then S_B must be reduced with 20%.

- If groynes are applied, they should interfere with the longshore transport and reduce S_B with only 20% (less than in the previous case).

Coastal protection

Contents of lecture

10-E 'Hard' measures influencing littoral drift

Coastline at Sitges, Spain

- groyne cells with a spacing of about 500 m
- Various types of hard measures: groynes, L-head and T-head groynes, detached breakwaters

See Chapter 8

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) Groynes;
  c) Detached / shore parallel / offshore breakwaters (emerged or submerged).
- Even for well-designed protection scheme, lee-side erosion is unavoidable.
- Seawalls or revetments are not a good solution for structural erosion!
  Seawalls do not interfere in the littoral drift. They do not reduce the littoral drift so they do not take away the cause of erosion. Erosion of under-water profile will continue and may cause failure of structure.

10-E 'Hard' measures influencing littoral drift

a) Jetties or shore-normal breakwaters

Function 1: Blocking transport to avoid sedimentation in access channel

Port of Scheveningen

10-E 'Hard' measures influencing littoral drift

a) Jetties or shore-normal breakwaters

Function 2: Constricting river entrance to avoid sedimentation

Tweed River, Australia (with sand-by-pass system)

10-E ‘Hard’ measures influencing littoral drift
a) Jetties or shore-normal breakwaters

Function 3: Protecting coast near tidal inlet, preventing sediments to disappear into the tidal basin.

Dutch Island of Texel with 800 m long dam

10-E ‘Hard’ measures influencing littoral drift
a) Jetties or shore-normal breakwaters

Intermezzo

Prediction of effectiveness of 800 m long dam at Northern tip of Texel

10-E ‘Hard’ measures influencing littoral drift

b) Groynes - series

10-E ‘Hard’ measures influencing littoral drift

b) Groynes - sheet pile

10-E 'Hard' measures influencing littoral drift

b) Groynes – wooden plates

10-E 'Hard' measures influencing littoral drift

Groynes - wooden piles

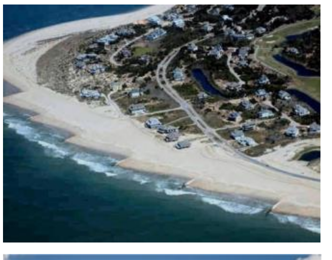
10-E 'Hard' measures influencing littoral drift

Groynes - wooden piles

10-E 'Hard' measures influencing littoral drift

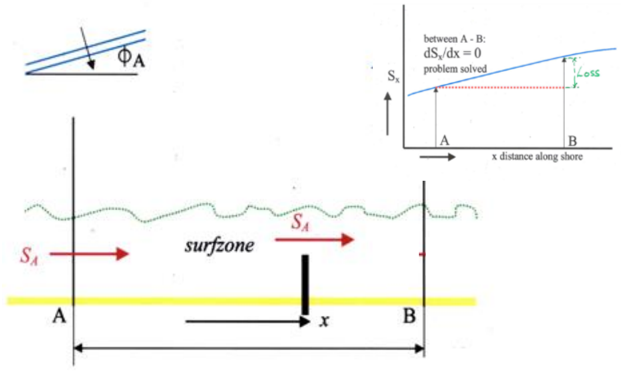
Type of groynes

1. **Impermeable groynes**
   - Rock with crest just above MSL (+1m).
   - Keep the sand within compartment between groynes.
   - If sand by-pass is 0, shoreline within each compartment parallel to dominant wave crests (saw-tooth effect).
2. **Permeable groynes**
   - Wooden piles with crest level between MLW and MHW
   - (Slightly) reduce the littoral drift in the inner surf zone and create a more regular shoreline (without saw-tooth effect). Always by-pass of sand.



10-E 'Hard' measures influencing littoral drift

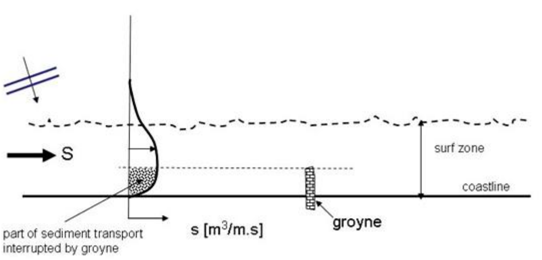
Desired situation for sediment transport along groyne



- Natural situation: sediment transport increases from S_A to S_B.
- Choose length of groyne such that sediment transport at tip of groyne is $S = S_A$

10-E 'Hard' measures influencing littoral drift

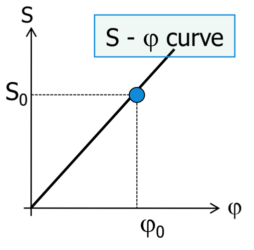
Groyne interrupts (part of) the longshore transport



- Reduction depends of groyne length, height and permeability.
- cross-shore distribution of longshore sediment transport gives idea of reduction.
- Use coastline model (UNIBEST LT-CL/ Genesis) to account for shoreline orientation inside groyne bays in relation to longshore sediment transport (S - φ curve)

10-E 'Hard' measures influencing littoral drift

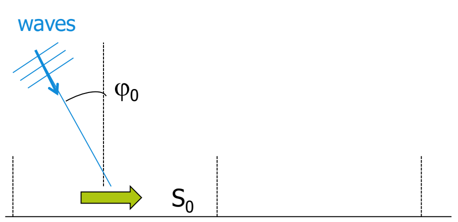
Groyne interrupts (part of) the longshore transport

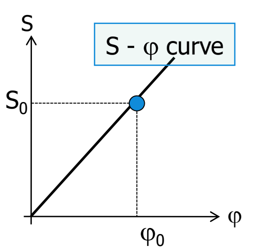


- Theoretical case with straight coastline.
- Transport S_0 can be determined from S - φ curve.
- S_0 can be reduced by implementing a series of groynes along coastline.
- Length of groyne determines the reduction.

10-E 'Hard' measures influencing littoral drift

Groyne interrupts (part of) the longshore transport





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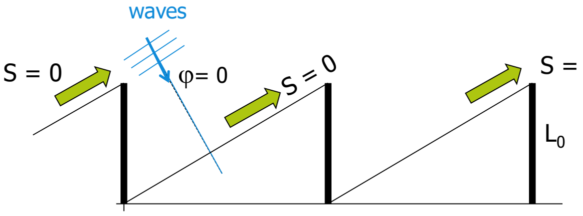
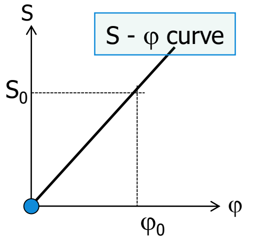
10-E 'Hard' measures influencing littoral drift

Groyne interrupts (part of) the longshore transport

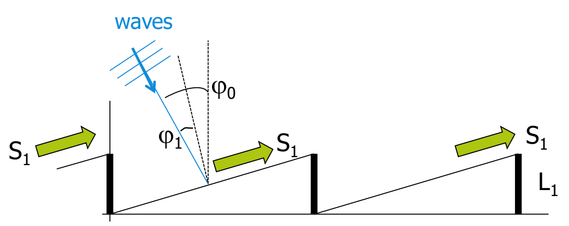


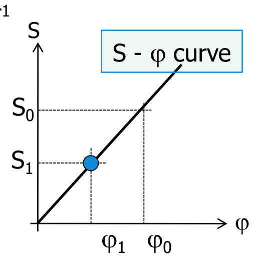


- Groyne length L_0 results in orientation of beach parallel to wave crests.
- By-pass of sediment along tip of groyne depends on the orientation of beach in groyne bay (S - φ curve) => S = 0.
- In this case full blockage!

10-E 'Hard' measures influencing littoral drift

Groyne interrupts (part of) the longshore transport

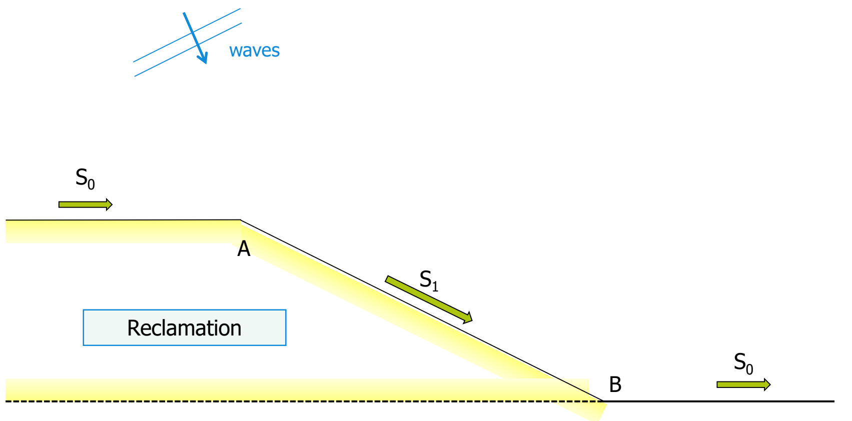




- Groyne length $L_1 = 0.5\ L_0$
- Orientation of beach not parallel to waves
- By-pass of sediment along tip of groyne depends on the orientation of beach in groyne bay (S - φ curve) => S_1
- In this case S_1 = 50% S_0 (reduction 50%)

10-E 'Hard' measures influencing littoral drift

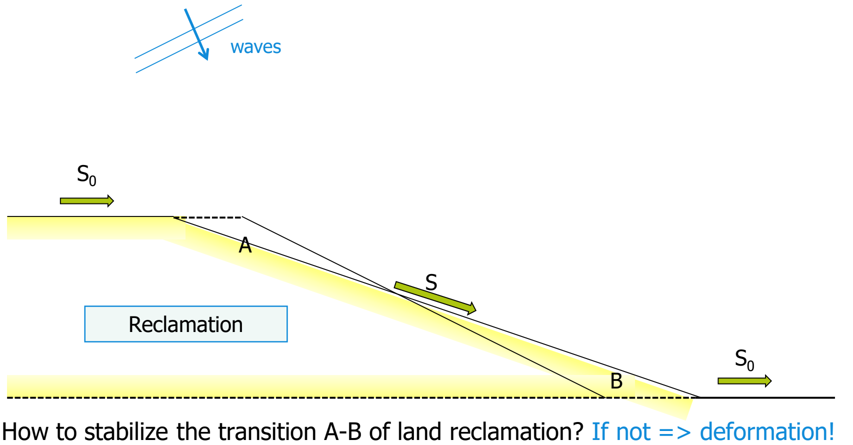
Groynes to protect transition of reclamation



How to stabilize the transition A-B of land reclamation?

10-E 'Hard' measures influencing littoral drift

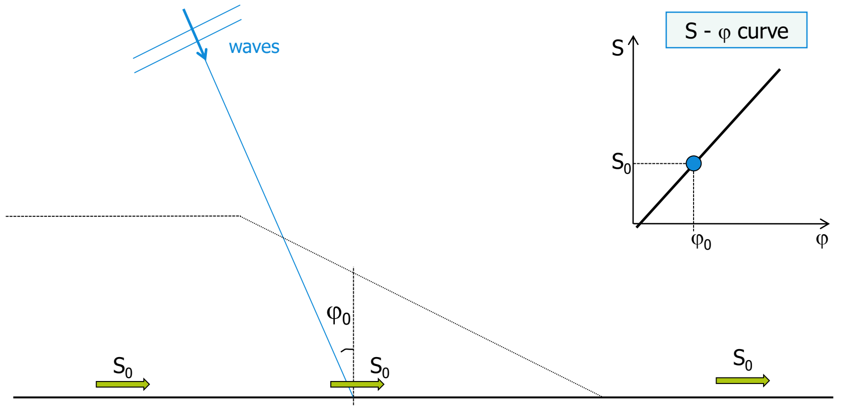
Groynes to protect transition of reclamation



How to stabilize the transition A-B of land reclamation? If not => deformation!

10-E 'Hard' measures influencing littoral drift

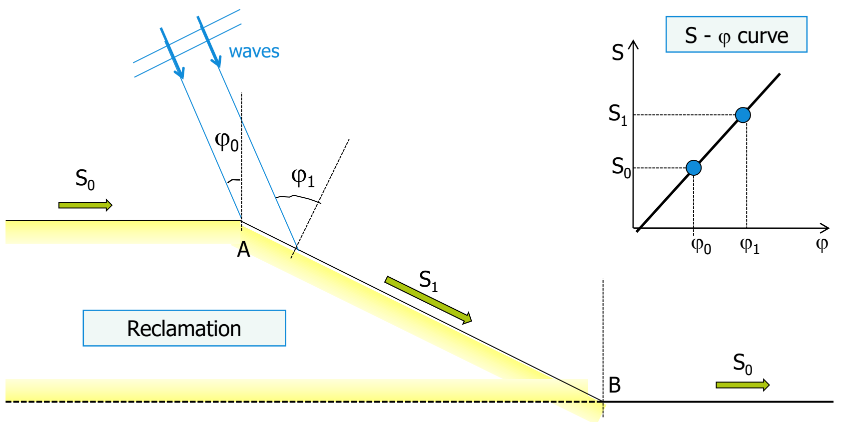
Groynes to protect transition of reclamation



Original situation of area to be reclaimed

10-E 'Hard' measures influencing littoral drift

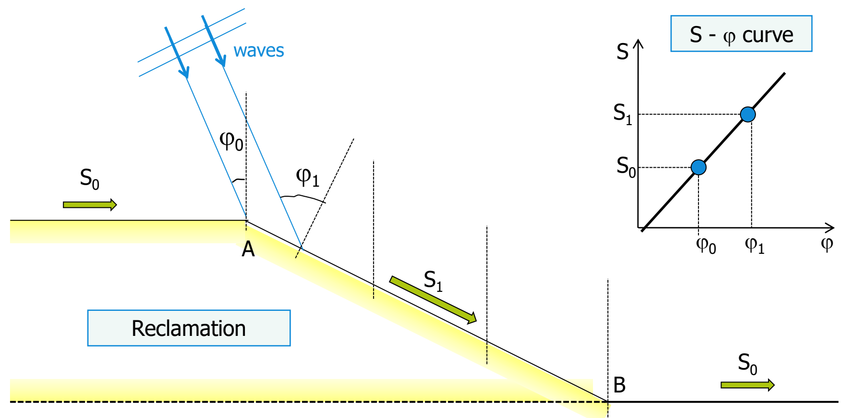
Groynes to protect transition of reclamation



Define scheme with 3 groynes for a stable transition A-B of reclamation.

10-E ‘Hard’ measures influencing littoral drift

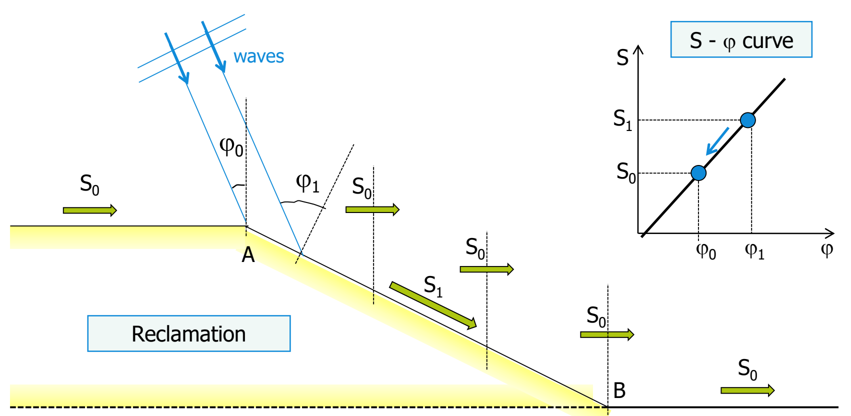
Groynes to protect transition of reclamation



Define scheme with 3 groynes for a stable transition A-B of reclamation.

10-E ‘Hard’ measures influencing littoral drift

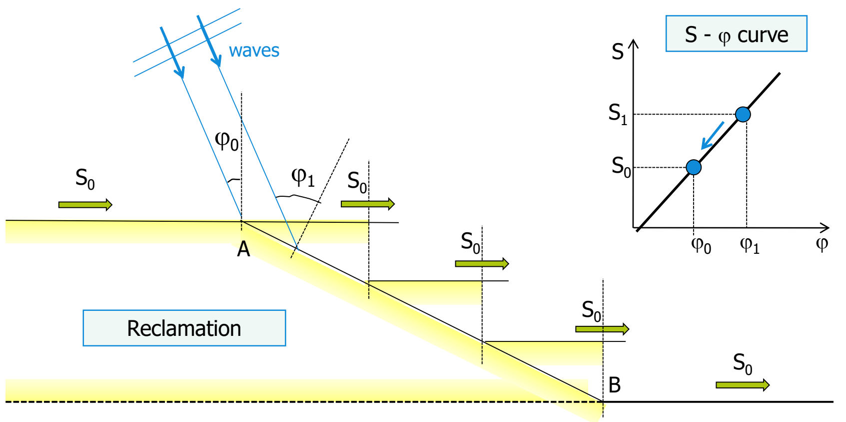
Groynes to protect transition of reclamation



Stable transition means no gradient in longshore transport: S_1 must reduce to S_0

10-E 'Hard' measures influencing littoral drift

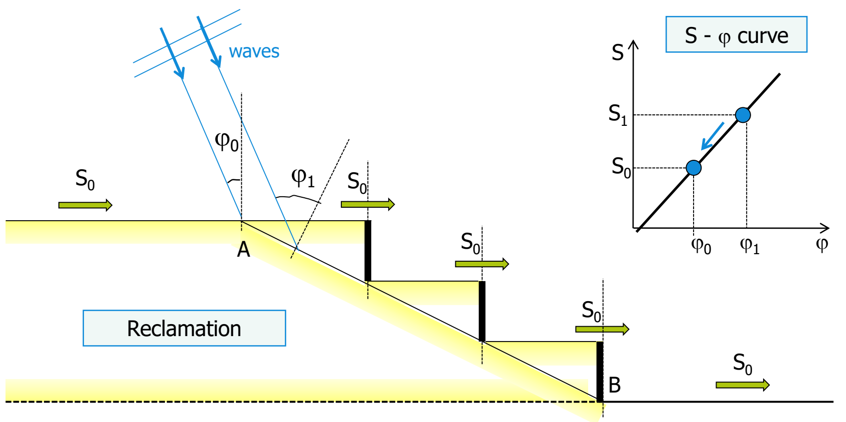
Groynes to protect transition of reclamation



Corresponding orientation of beach in groyne bay is defined by S - φ curve.

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.

10-E 'Hard' measures influencing littoral drift

Some practical remark about groynes

- Trapping efficiency of groynes can be improved by using for instance, L-head, T-head or Fish-tail groynes.
- Crest levels of groynes are usually relatively low (just above MSL) .
- Spacing is usually in range of 1.5 to 3 times their length.
- Ensure that sufficient sediment is by-passing such that lee-side erosion is prevented as much as possible.
- Down-drift erosion could be reduced by gradually reducing lengths at the down-drift end of the groyne field (increasing S).
- Start construction of groynes at down-drift boundary and move toward up-drift boundary to avoid initial erosion of area to be protected.
- Groynes are generally combined with initial beach nourishment (in groyne bays to avoid down-drift erosion).

10-E 'Hard' measures influencing littoral drift

Detached breakwaters (offshore breakwaters)

Detached breakwaters at Happisburgh, Norfolk, UK

- **Tombolo formation:** spit touching breakwater, causing blockage of sediment transport
- **Salient formation:** allows sediment to be transported via shadow zone behind breakwater to down-drift beaches.

10-E 'Hard' measures influencing littoral drift

Detached breakwaters at Happisburgh, Norfolk, UK

1. Variable sedimentation pattern (tombolo/salient)
2. Down-drift erosion due to tombolo formation

10-E 'Hard' measures influencing littoral drift

Detached breakwaters (offshore breakwaters)

- Parallel to shore at certain distance from the waterline ('detached'):
  - Emerged (crest above MSL); or
  - Submerged (crest below MSL).
- They interfere with sediment transport, causing accretion in their lee.
- Relative high construction cost and maintenance costs
- May be dangerous for swimmers and small boats.
- From an aesthetic point of view sometimes submerged breakwaters are preferred.

10-E 'Hard' measures influencing littoral drift

Detached breakwaters (offshore breakwaters)

- Fine-tuning design of detached breakwaters is difficult task, especially for submerged breakwaters.
- Successful project must be based on good mathematical and possibly physical modeling.
  Always perform monitoring after construction.
- If not designed properly, negative morphological effects such as local scour and shoreline erosion may occur.
- Attention should be paid to mitigation of down-drift erosion. (f.i. by creating a transitional zone with gradually increasing gap lengths and/or decreasing crest levels).

10-E 'Hard' measures influencing littoral drift

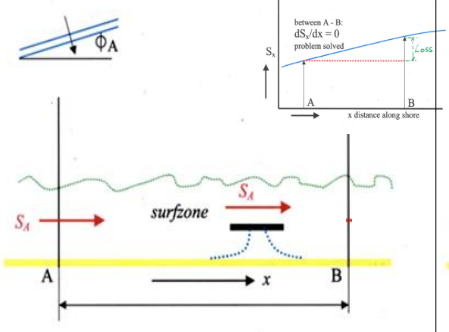
Emerged detached breakwaters


High breakwater may result in low visual quality beach

10-E 'Hard' measures influencing littoral drift

Detached breakwaters with tombolo or salient: $S_B = S_A$

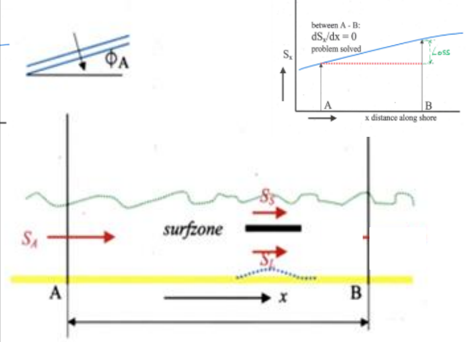
Tombolo formation



Tombolo formation

Seaward from breakwater: $S = S_A$

Salient formation



Salient formation

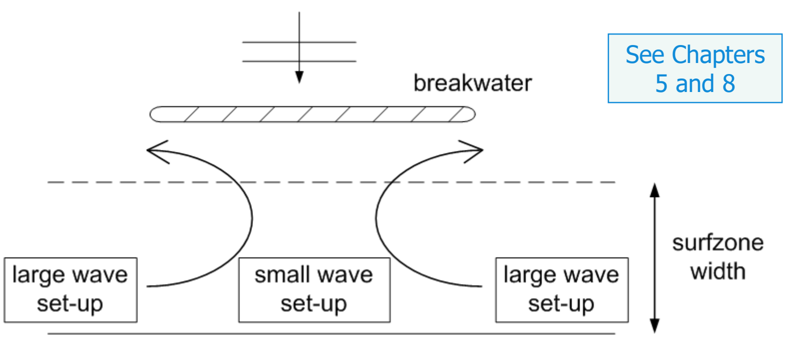
Seaward from breakwater: $S = S_S$

Landward from breakwater: $S = S_L$

$S_S + S_L$ must be equal to S_A

10-E 'Hard' measures influencing littoral drift

Current patterns behind emerged detached breakwater

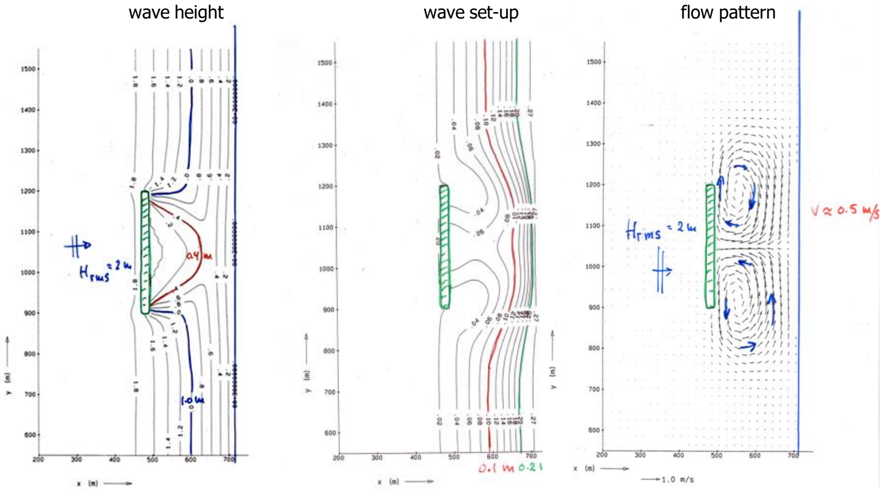


See Chapters 5 and 8

Variations in wave height along a coastline create alongshore set-up differences and hence 3D current patterns

10-E 'Hard' measures influencing littoral drift

Current patterns behind **e**merged detached breakwater (DELFT3D)

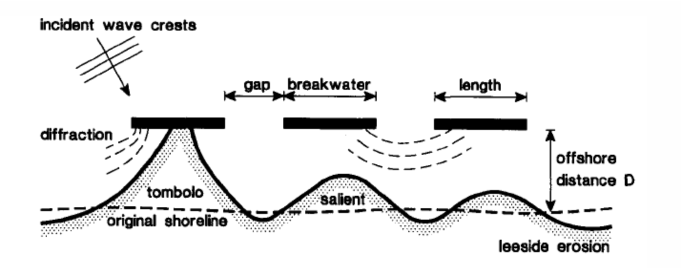


10-E 'Hard' measures influencing littoral drift

Circulation due to wave set-up differences

10-E ‘Hard’ measures influencing littoral drift

Emerged detached breakwaters (some rules of thumb)

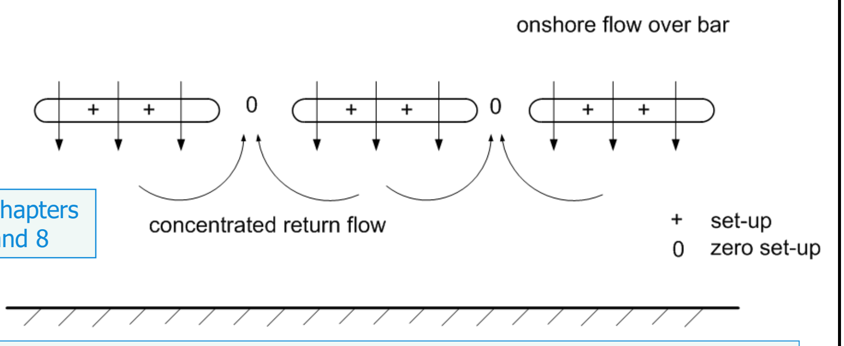


Analysis of 27 emerged breakwater projects along NE coast Catalunya with offshore distances (D) 80 - 230 m and breakwater lengths (L) 60 - 240 m.

- Tombolo formation: $D < 0.8\,L$
- Salient formation: $0.8\,L < D < 2\,L$
- Erosion coastline opposite gap: $L_{gap} > L$ to $1.5\,L$

10-E ‘Hard’ measures influencing littoral drift

Possible erosional effect in case of **sub**merged breakwater



See Chapters 5 and 8

- Wave breaking on breakwater drives a current pattern with diverging currents in shadow of breakwater.
- Along the end sections, currents flow in seaward direction, transporting sediment outside the area.
- This may cause coastal erosion especially if breakwater is too close to shore.

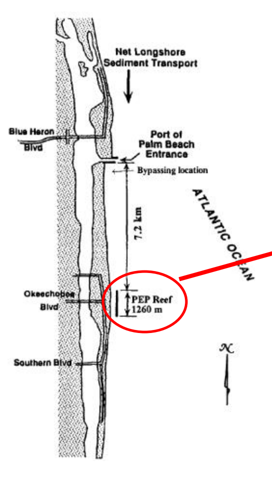
E ‘Hard’ measures influencing littoral drift

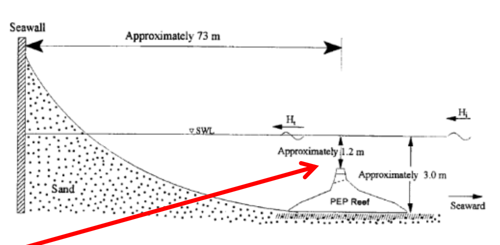
Submerged detached breakwaters

- Submerged breakwaters reduce wave height in their shadow which may result in accretion behind the breakwater.
- However, examples are known of severe erosion landward of submerged breakwaters (see east coast of Florida at Palm Beach).
- Successful application of submerged breakwaters must be based on good understanding of shoreline response (morphodynamic models).

E ‘Hard’ measures influencing littoral drift

Palm Beach Miami, USA (Prof. Bob Dean, 1997)

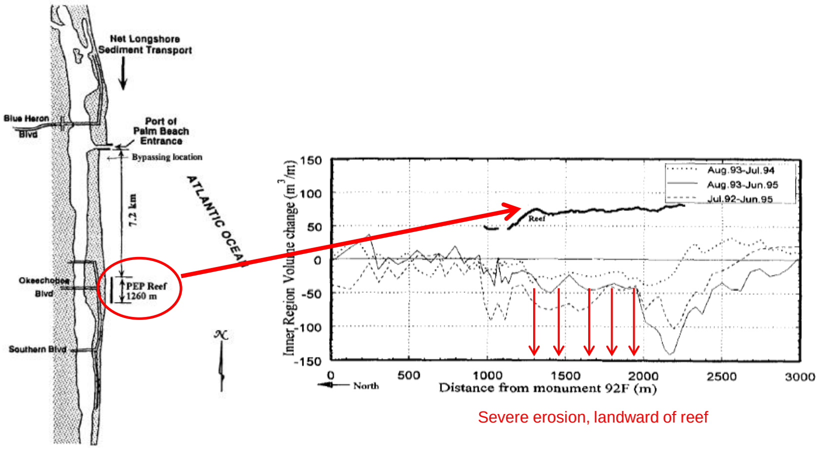




- In 1993 submerged breakwater (MSL -1.2 m) was built for coastal protection.
  Length 1,260 m at distance of 70 m from shoreline in 3 m water depth.
- Resulted in beach erosion until breakwater was removed in August 1995.
- Subsequent nourishment of 600,000 m^3 to compensate for erosion.

E ‘Hard’ measures influencing littoral drift

Palm Beach Miami, USA (Prof. Bob Dean, 1997)

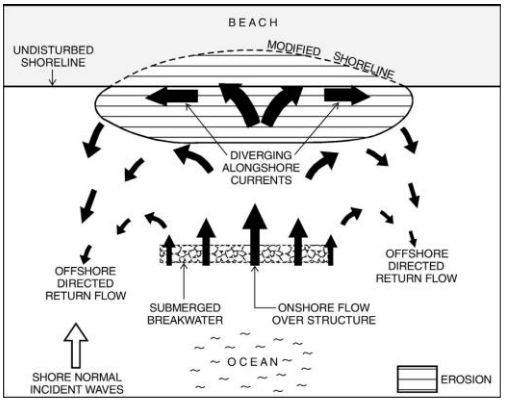


E ‘Hard’ measures influencing littoral drift

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



E 'Hard' measures influencing littoral drift

Submerged offshore breakwaters (Rasaninghe, 2010)

Erosion or accretion based on:

- Distance of submerged breakwater from shore
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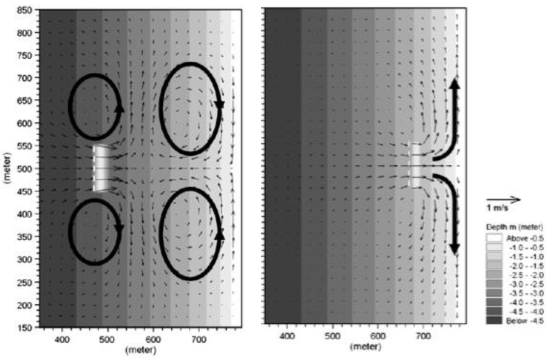
- Incident significant wave height



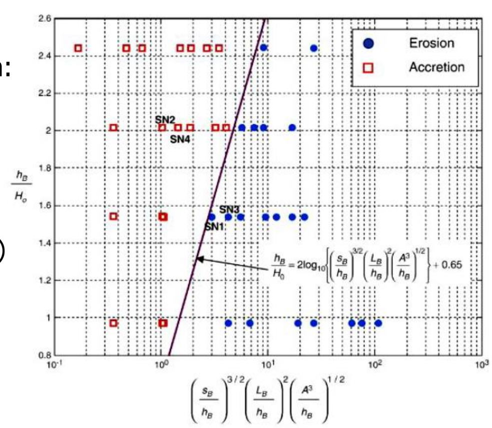
- far from shore: 4 cell patron => accretion
- close to shore: 2 cell patron => erosion
- Use DELFT3D type of model!

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 rules based on DELFT3D runs

10-E 'Hard' measures influencing littoral drift

Final remarks about detached (offshore) breakwaters

- Fine-tuning design of detached breakwaters is not easy.
- Use guidelines as a first approach.
- Successful project must be based on good mathematical and possibly physical modeling
- Always perform monitoring after construction.
- If not designed properly, negative effects such as local shoreline erosion may occur.
- Attention should be paid to mitigation of down-drift erosion.

10. Coastal protection

10.

Coastal protection

Jan van Overeem

29 March 2017