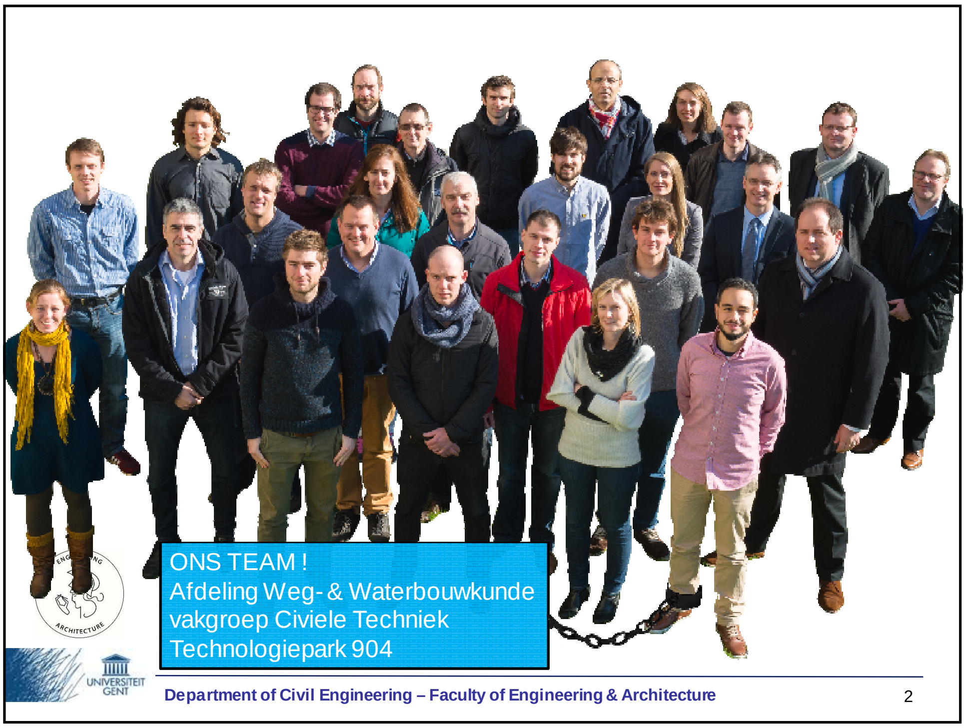

techBOOST voor ingenieurs
UNIVERSITEIT GENT
FACULTY OF ENGINEERING AND ARCHITECTURE
innovations
in the field of
coastal engineering
professor Peter TROCH
vakgroep EA15 CIVIELE TECHNIEK –
Faculteit Ingenieurswetenschappen & Architectuur


ONS TEAM !
Afdeling Weg- & Waterbouwkunde
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Department of Civil Engineering – Faculty of Engineering & Architecture
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relevance of the field of coastal engineering

INTRODUCTION

definition

coastal structures
in the field of
coastal engineering

… are structures …

… with the toe in the sea

… under wave loading

… effect on sand transport

Wave overtopping over vertical breakwater (UK).
Photo: Leichtweiss-Institute for Hydraulics

Wave overtopping over breakwater at Zeebrugge, 6 November 1999.
Photo: Peter Troch and Marc de Somer

Waves hit the dike at Porthleven, Cornwall (UK), 15 January 2015.
Photo: www.telegraph.co.uk

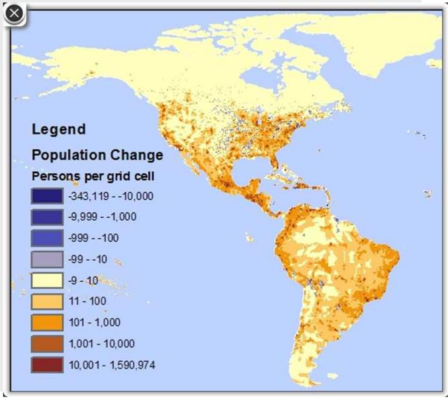
coastal areas … world wide?

- coastal areas are very important “hot spots”
  - ecological, economical, tourism, …
- 8 of the top 10 largest cities in the world located by the coast
- demographic evolution
  - 40% of the world’s population (2.8 billion people) lives within 100 km from the coastline

Flocking to the Coast:
World's Population Migrating into Danger

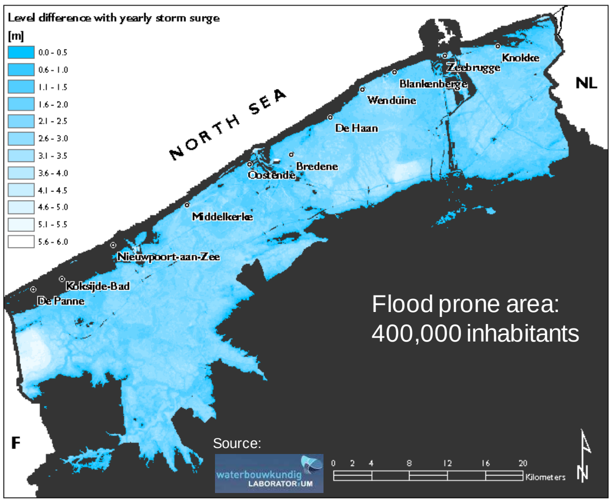
Map created by the Center for Climate Systems Research shows as an example increasing populations in coastal areas of North and South America, which will expose 2.8 billion people worldwide to the effects of sea level rise and other coastal threats posed by global warming.

Source: Sara Goudarzi, Stuart Gaffin, Lee Hachadoorian, and Robert Engelman

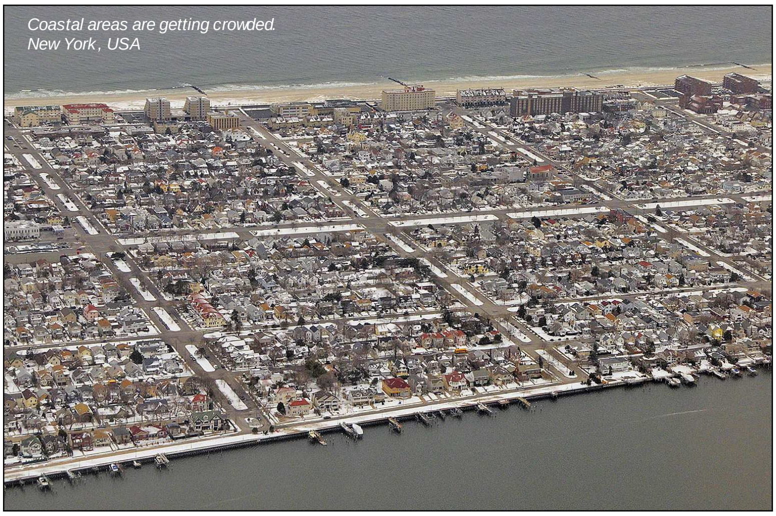


relevance of a coastal defence system in Belgium

relevance of a coastal defence system in Belgium



relevance of a coastal defence system in the world



two types of coastal defence systems

- a coastal defence system provides protection agains waves and water level
- **HARD** versus **SOFT**

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examples of a HARD coastal defence system

A typical example of a harbour protected by breakwaters (Hirtshals, DK).

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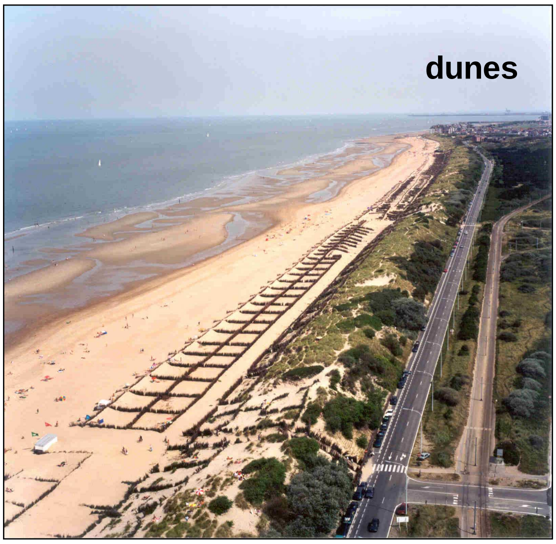
examples of a HARD coastal defence system

The **Costa Azul breakwater** (Mexico) is one of the largest offshore caisson breakwaters in the world.

examples of a HARD coastal defence system

examples of a SOFT coastal defence system



examples of a SOFT coastal defence system

combination of HARD & SOFT systems

Coastal defence strategy Flemisch Government (coastal safety plan):

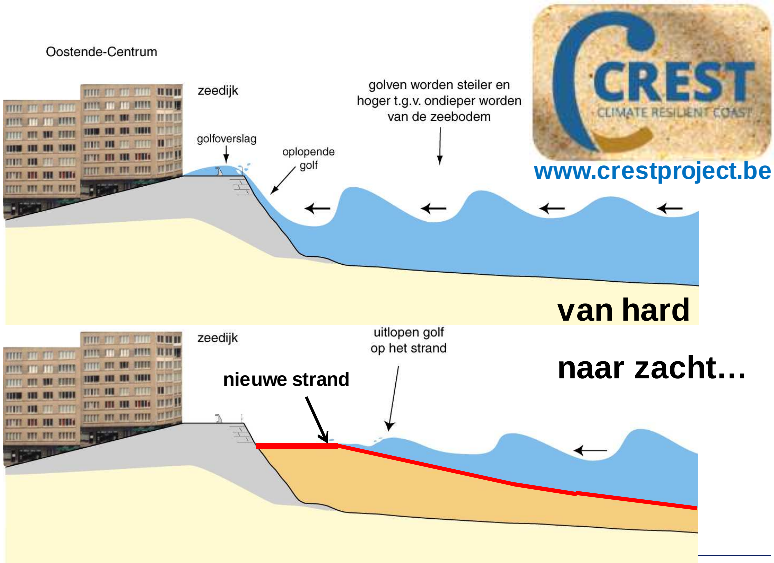
old measures

- protection of the coastal cities by using “hard” structures (dike)

recent measures (> 70ties)

- recovery of natural dynamics by combining
  - “hard” (*dike with storm wall*), and
  - “soft” (*sand nourishment*)
- adaptation to sea level rise

combination of HARD & SOFT systems



combination of HARD & SOFT systems

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recent measures (> 70ties)

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  - “hard” (*dike with sto*
  - “soft” (*sand no*
- adaptation to se

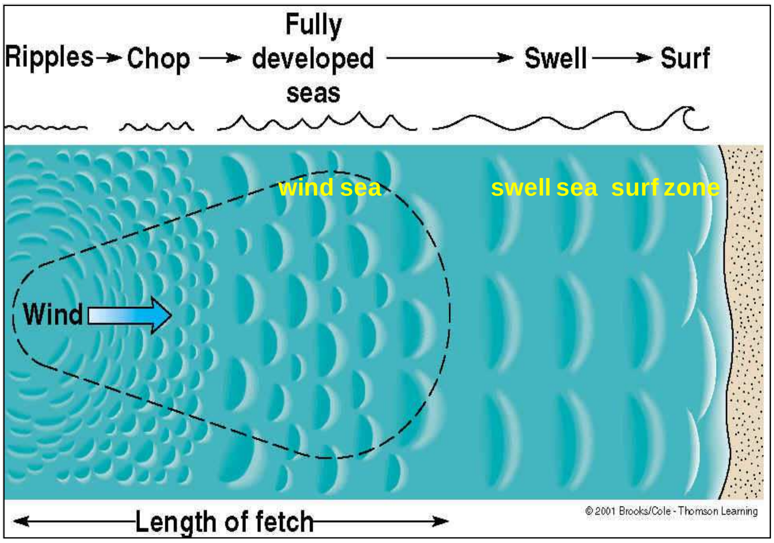
the future…?

✓ transdisciplinary design
✓ building with natural elements
✓ multi-functional use of a wider coastal defence system

generation and propagation of various wave types

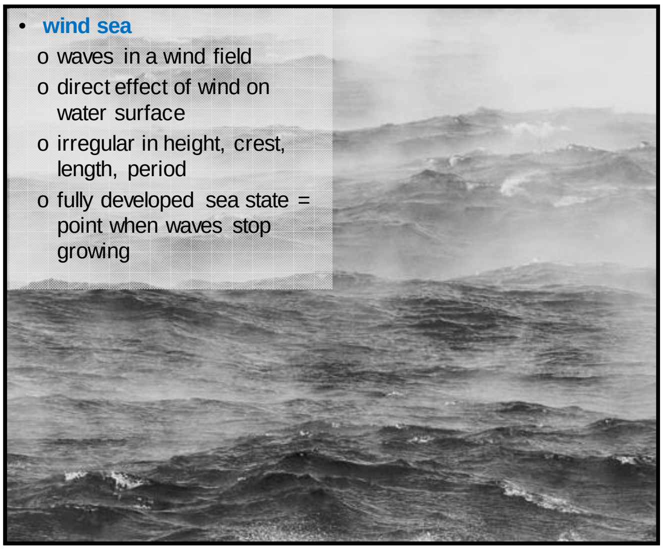
THE BASICS OF WAVES

the life cycle of a wind wave



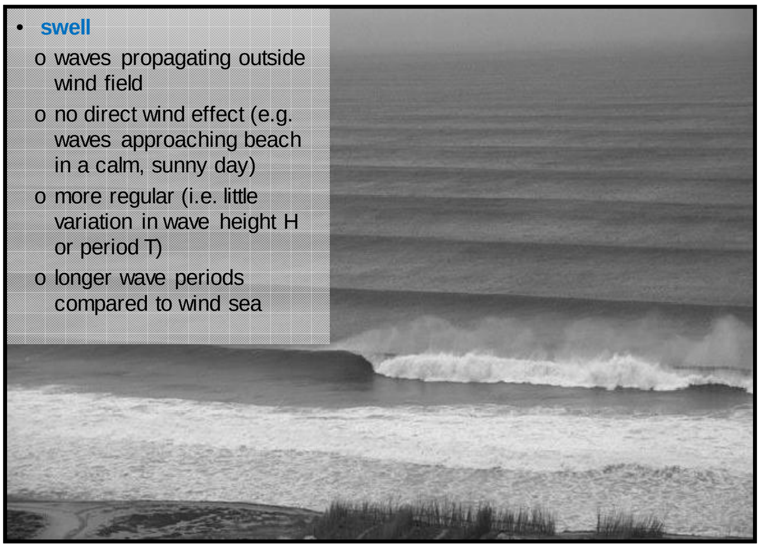
wind sea

- **wind sea**
  - o waves in a wind field
  - o direct effect of wind on water surface
  - o irregular in height, crest, length, period
  - o fully developed sea state = point when waves stop growing



swell sea

- swell
  - o waves propagating outside wind field
  - o no direct wind effect (e.g. waves approaching beach in a calm, sunny day)
  - o more regular (i.e. little variation in wave height H or period T)
  - o longer wave periods compared to wind sea

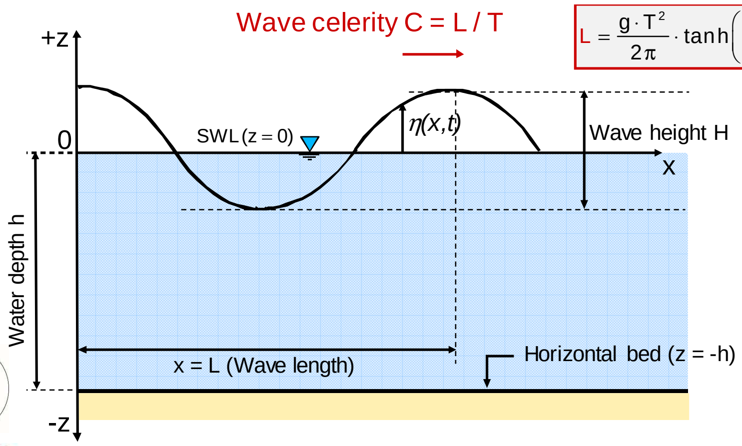


linear wave theory – Airy (1841)

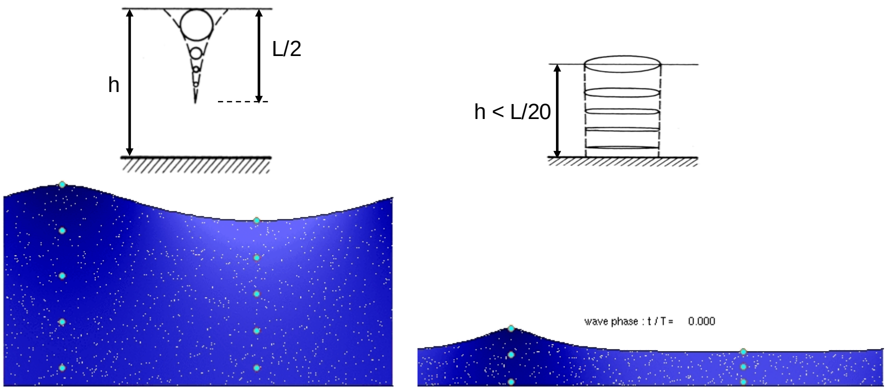
$$\eta(x,t) = \frac{H}{2} \cdot \cos(k \cdot x - \omega \cdot t)$$

$$L = \frac{g \cdot T^2}{2\pi} \cdot \tanh\left(\frac{2\pi}{L} \cdot h\right)$$

Wave celerity C = L / T



deep versus shallow water wave kinematics



deep water wave
"wave doesn't feel the bottom"

shallow water wave
"wave feels the bottom"

tidal waves

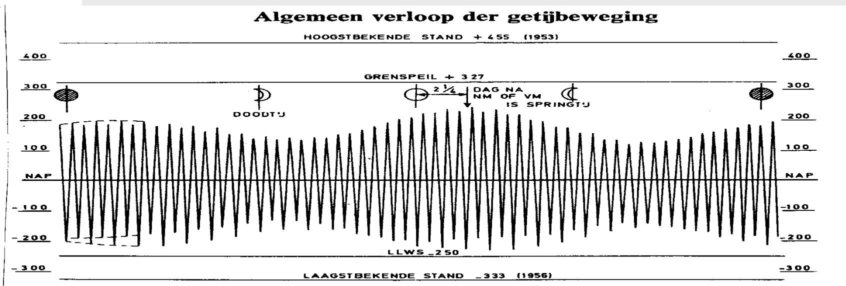
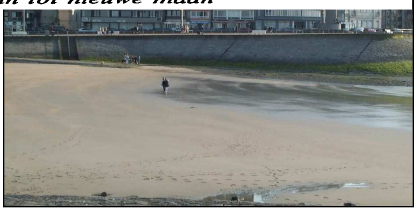


Fig. 9. *Voorbeeld van het verloop der getijbeweging te Vlissingen van nieuwe maan tot nieuwe maan*



tidal wave propagation

using shallow water celerity $C = \sqrt{gh}$

for $h = 50\ m$ (North Sea conditions)

$C = 80\ km/h$, and

$L = 900\ km$

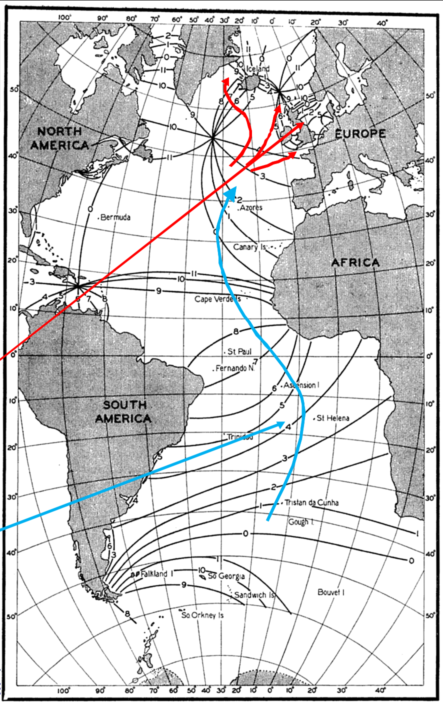
for $h = 4000\ m$ (Atlantic Ocean conditions)

$C = 720\ km/h$, and

$L = 8000\ km$

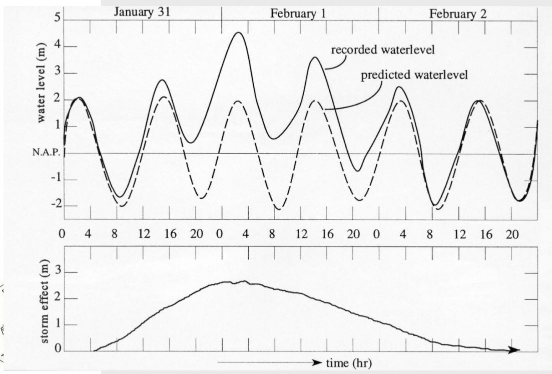
indirect or co-oscillating tide

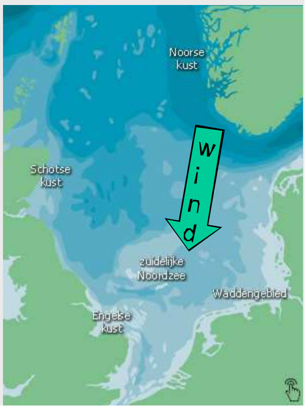
direct or astronomic tide



storm surge

- additional increase of the water level
  - caused by low pressure weather systems
  - long duration (days) and strong (8 à 12 Bft) wind fields from West to Nord West



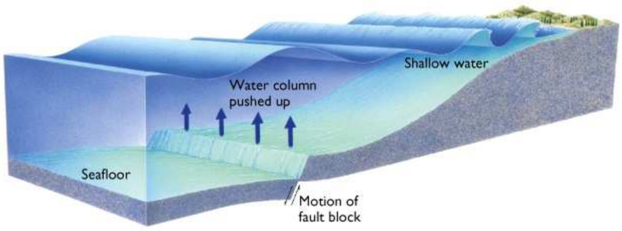


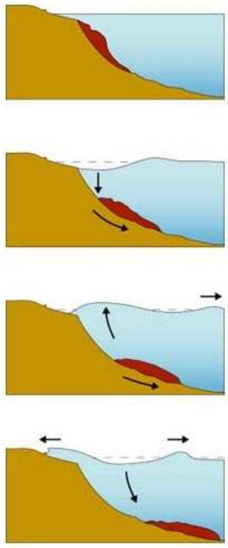
storm surge barrier

tsunami is “killer wave”

tsunami generation

earthquake with permanent
displacement of sea bottom





sliding of land mass
above / under water

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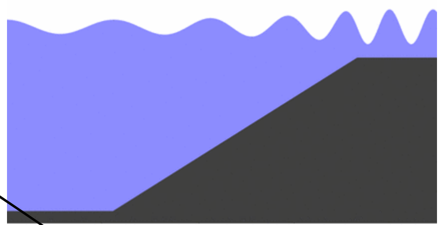
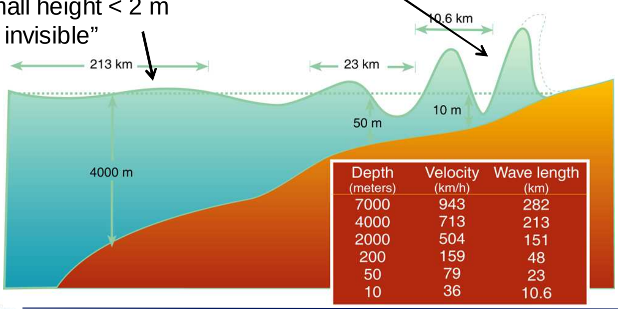
propagation of tsunami

SHALLOW WATER:
wave celerity decreases
and wave height increases strongly
“devastating wall of water”



DEEP WATER:
very long wave
with small height < 2 m
“nearly invisible”



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

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climate change seems to happen?!...

- **cascade effect:**
  - increase of mean temperature, caused by greenhouse effect, results in:
    - mean sea level rise
    - frequency and/or intensity of storms increases
    - increase in rainfall intensity, with significant differences depending on season and region

- **sea level rise** (global effects) is caused by…
  - thermal expansion of water mass
    - water volume increases with increasing temperature
    - main cause "today" (i.e. till year 2100)
  - melting of ice and gletsjers in Greenland and Antarctica
    - water volume increases due to melting of ice
    - "later" (i.e. after year 2100)

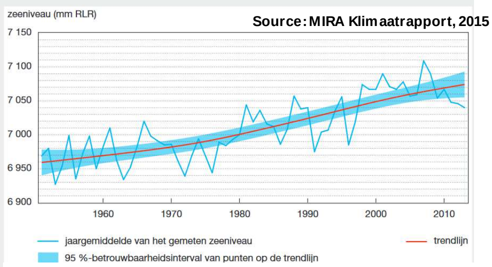
Sources:
- **worldwide:** "*5th Assessment Report (5AR)*" of the Intergovernmental Panel on Climate Change (IPCC), 2014
- **België:** "*Impact van de klimaatverandering in België*", J.-P. Van Ypersele en Ph. Marbaix (UCL) op vraag van Greenpeace, 2004
- **Nederland:** KNMI publicatie 221 "*Extreme klimaatverandering en waterveiligheid in Nederland*", *J. Bessembinder (Ed.), 2008*

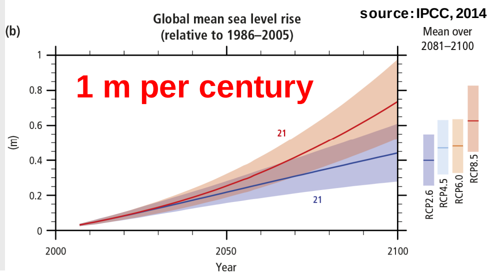
observation and prognosis for sea level rise

- **observation**
  - yearly average sea level increases, in Oostende in 2013 11.5 cm higher than in fifties
  - no increase for
    - storm surge
    - wave height statistics

- **estimates**
  - based on various scenarios of CO2 emissions:
  - 2000 – 2100: between 0.2 m and 1.0 m
  - 2000 – 3000: between 4.0 m and 8.0 m

Figuur 30: Evolutie zeeniveau aan de Belgische kust (Oostende, 1951-2013)





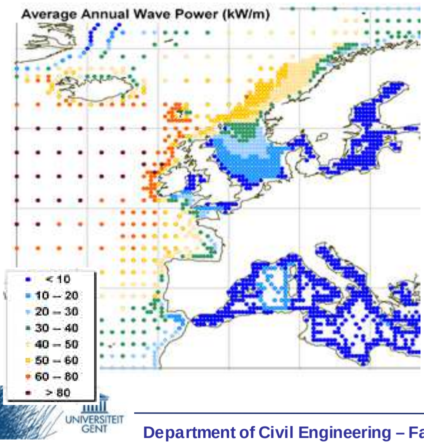
innovative experimental and numerical research

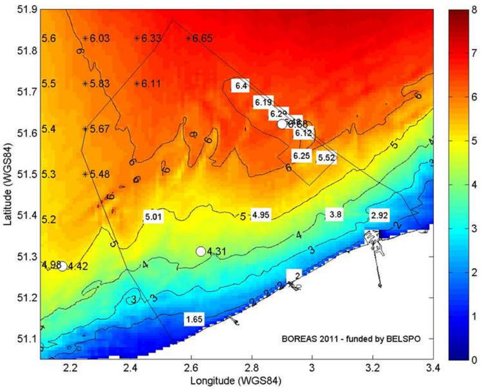
WAVE ENERGY RESEARCH

available wave power – Europe and Belgium

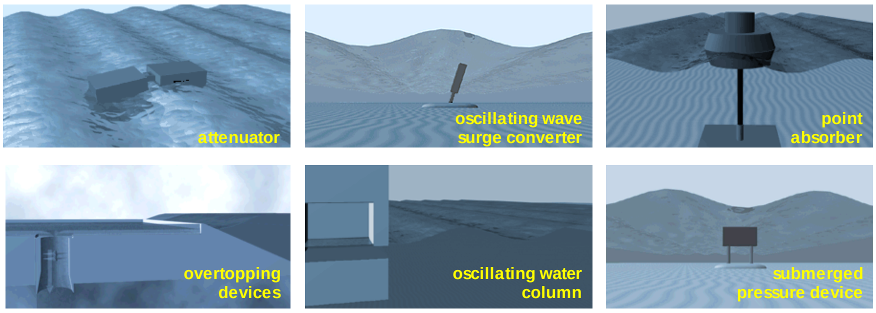
- wave energy mainly situated near the Atlantic: **Portugal, Spain, Ireland, Schotland, Iceland**
- **North Sea**: mild wave climate, sheltered by presence of UK

- **Belgium**:
  - mild wave climate, with mean power up to 6.7 kW/m (BOREAS project)
  - ideal for trials and testing: "testing ground" for WEC development





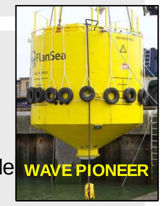
wave energy converter types - WECs

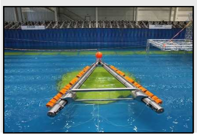


- classification into **6 main types** of WEC
- all **in full development**
- **no** clear **"winning" concept**

actual status of wave energy development

- Lots of **concepts** (inventory with about **150** concepts), **50%** are point absorbers
- No uniformisation, no choice for one type or standard solution
- Not a prototype (commercially) available, some large scale mode
- **Hybrid solution** with wind energy?
- **Survivability** remains a design issue
- Several notorious **failures**
- **Leading countries**: UK, Denmark, Norway
- **Belgium** very appealing for development stage tests in mild wave conditions





WEC farm and wake effects

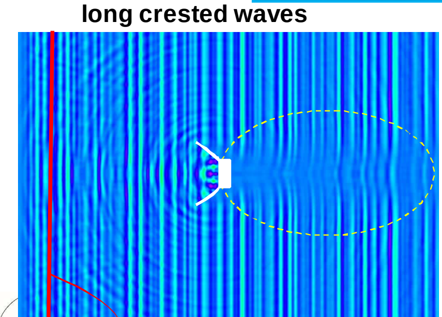
- **a farm of WECS**
  - power production of a single WEC is limited
  - arrangement of several WECs in a geometric configuration
  - power production of a farm of WECs depends on optimisation of farm lay-out

- **study of wake effects** behind
  - a single WEC
  - multiple WECs in a farm

wake effects behind a single WEC

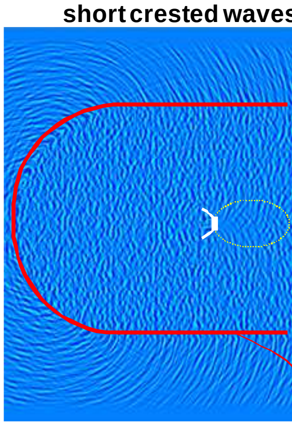
MILDwave® UGent

long crested waves



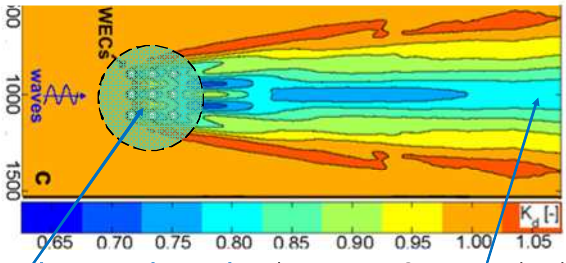
wave generation line

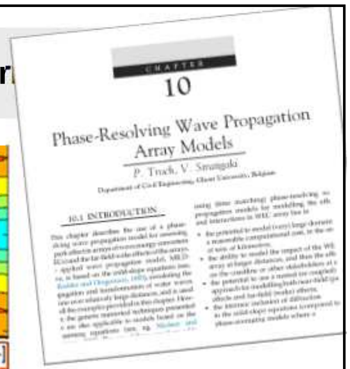
short crested waves



wave generation line

wake effects behind a WEC far





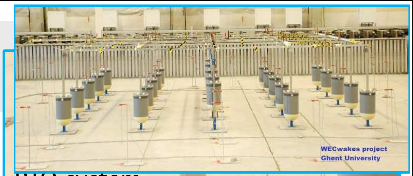
- **intra-array interactions** between WECs within the farm:
  - overall power production smaller (or larger) than expected
- wakes behind the WEC farm exhibit **extra-array effects** on:
  - neighboring farms
  - other activities or structures at sea
  - coastline morphology
  - coastal ecosystem
- **numerical coupling** between 2 solvers
  - book chapter
  - 5 PhDs
- **experimental validation?**

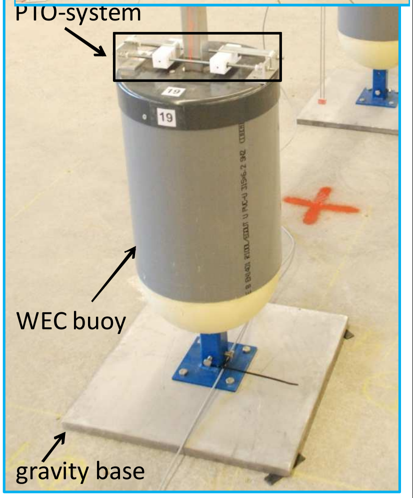
WECwakes – EU HYDRALAB IV project

a set of 25 WEC units

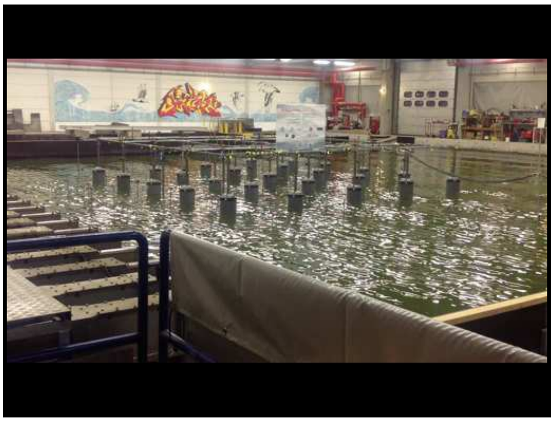
REQUIREMENTS:
- no new WEC concept
- appropriate for numerical treatment
- robust and simple to use in basin

- point absorber with a **simple** generic **geometry** and 1 DOF motion (**heave only**)
- **low cost** for construction and reproduction in large numbers
- easy **repositioning** within an array and easy to **operate**
- **measurable** buoy response and energy extraction





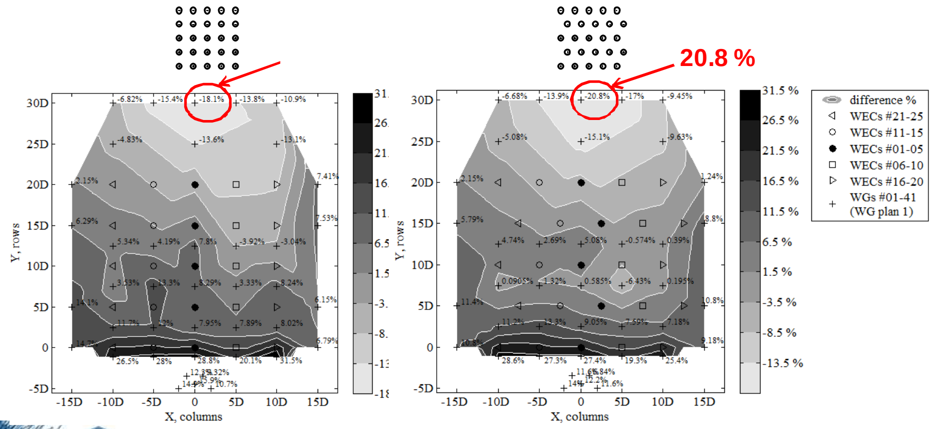
WECwakes – an array of 25 WEC units



WECwakes – unique database

extra-array effects

impact on the wave field behind the WEC farm: wave height attenuation



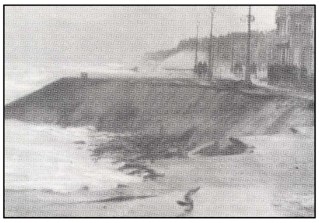
how to design a rubble mound breakwater?

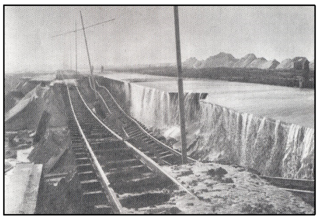
WAVE OVERTOPPING AS DESIGN CRITERION !

wave overtopping over structures

wave overtopping over a dike

Storm surge **1 February 1953** in Flanders





wave overtopping over a dike

Storm surge **1 February 1953** in Zeeland: 1835 victims

140 dike breaches
due to erosion of landward slope
caused by **wave overtopping**

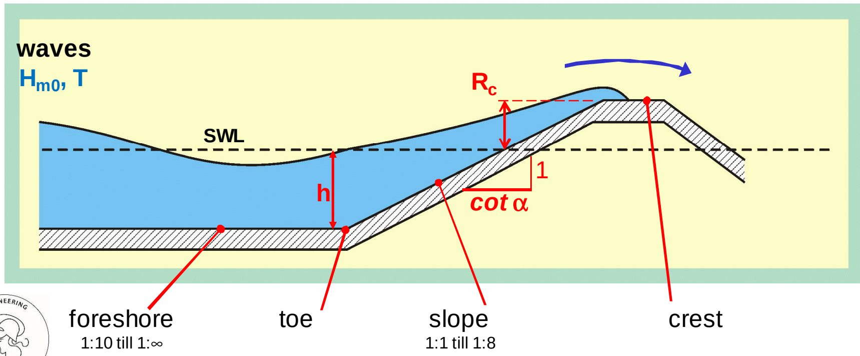
accurate wave overtopping
prediction formulae
are **crucial**

definition sketch: geometrical and wave characteristics

- structural elements
- geometrical characteristics
- wave characteristics
- overtopping parameters

overtopping volume per wave: V_i (m^3/m)

average overtopping discharge: q ($m^3/s/m$)



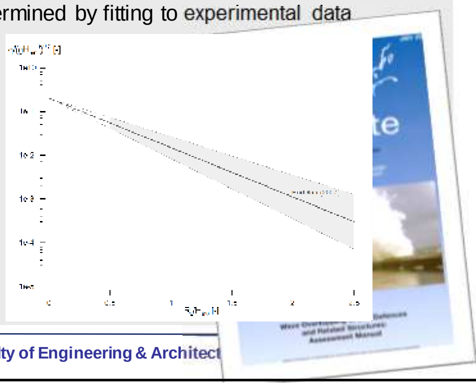
overtopping prediction formulae in literature

- **Wave overtopping**
  - determines the design crest level of the structure, as a function of the allowable overtopping discharge

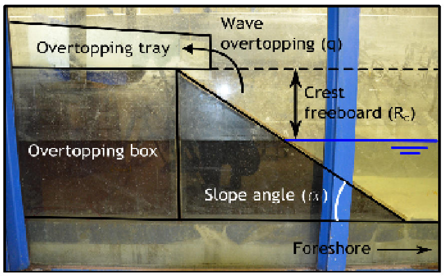
- wave overtopping is described by a semi-empirical formula
  - form based on physical consideration and insight: exponential decay of q for increasing relative crest freeboard R_c / H_{m0}
  - empirical constants a, b determined by fitting to experimental data

- EurOtop (2007) formula

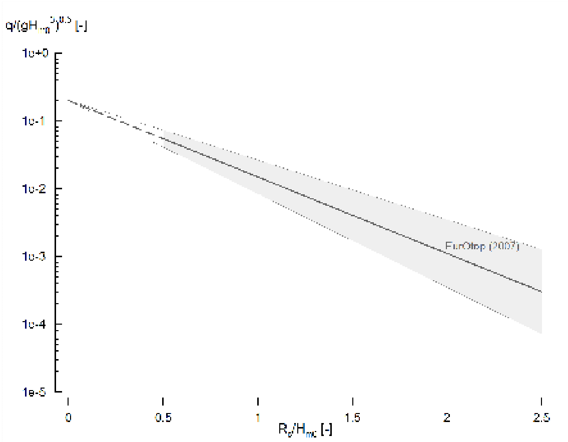
$$\frac{q}{\sqrt{gH_{m0}^3}} = a\ exp\left(-b\,\frac{R_c}{H_{m0}}\right)$$



experimental overtopping tests in the wave flume



development of new overtopping formula



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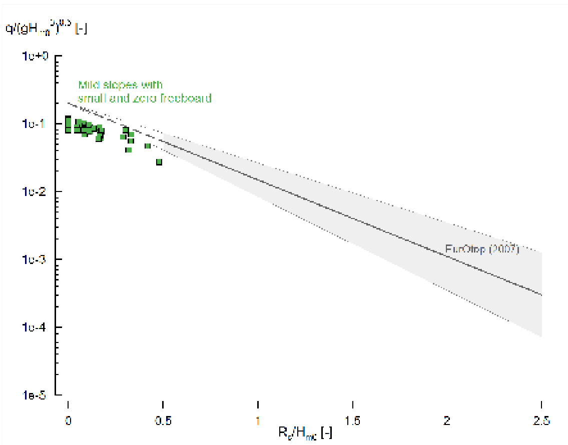
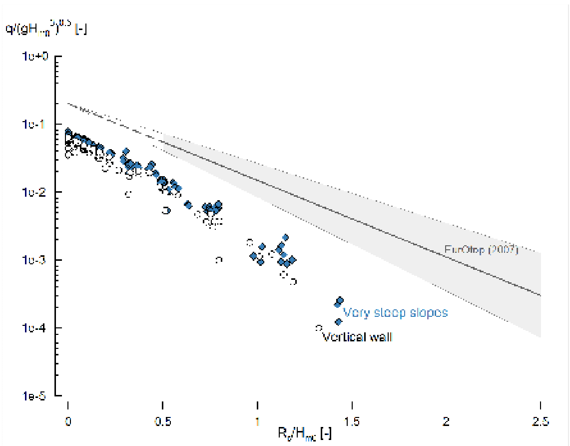


development of new overtopping formula



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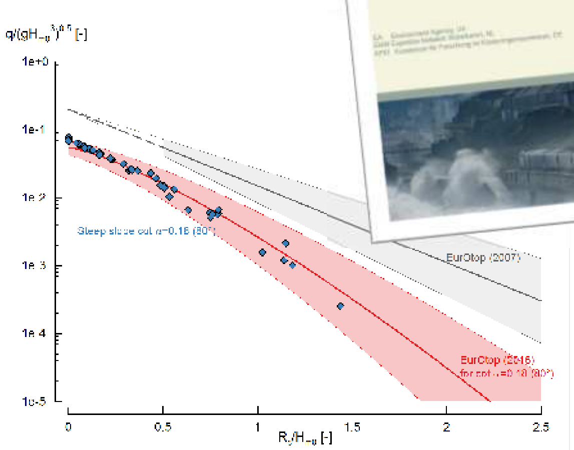
development of new overtop



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ADVANCES IN NUMERICAL MODEL TOOLS

development of numerical modelling tools for wave-structure interaction

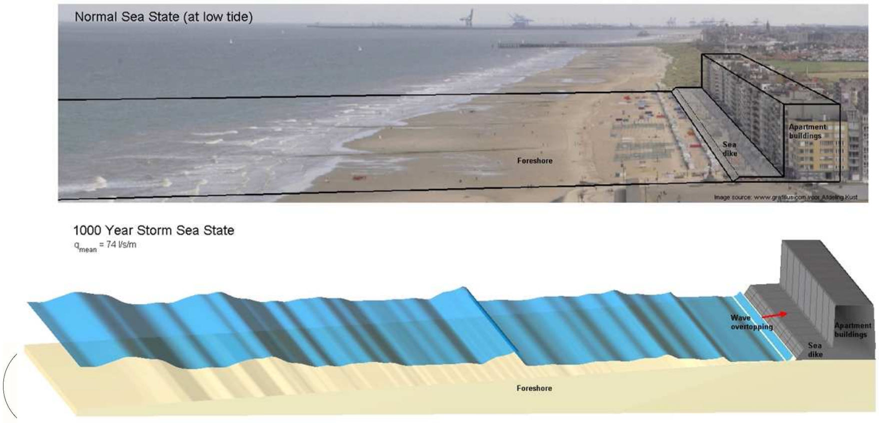
models	NLSW models	NS models	SPH models
equations	**N**on-**L**inear **S**hallow **W**ater equations	**N**avier-**S**tokes equations	**S**moothed **P**article **H**ydrodynamics
description of physical processes	extremely simplified version of the NS equations	most complete flow description	same flow description as NS equations but Langrangian formulation of particle kinematics
flow	1D, depth integrated, horizontal flow	3D turbulent flow (VARANS formulation)	3D turbulent flow
free surface treatment	depth function	VOF method to track free surface	intrinsically
computational cost	cheap – already +20yr used	expensive – gradually used in design practice	very expensive – only research practice
range of application	(very) shallow water and simple structures	applicable to wide range of (im)permeable structures with complex geometries	also applicable to wide range of structures, however not yet mature technique
example codes	**SWASH**: dispersive NLSW equations, vertical resolution of the flow, 2D version for short crested waves	**VOFbreak²**, **FLOW-3D**, **OPENFOAM**	**DualSPHysics**

example of NLSW model: SWASH 2D

wave overtopping estimation for a dike on a shallow foreshore

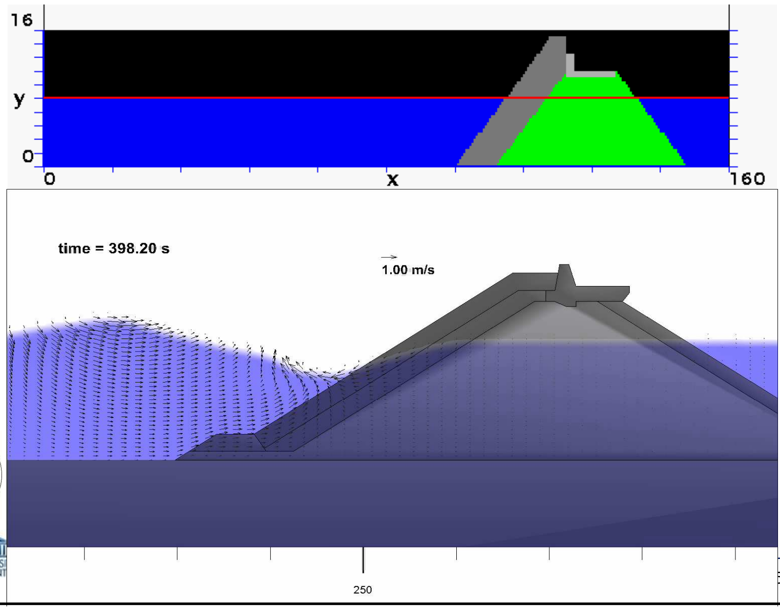
WENDUINE, BELGIUM
EXISTING COASTAL DEFENCE

courtesy of
dr. T. SUZUKI

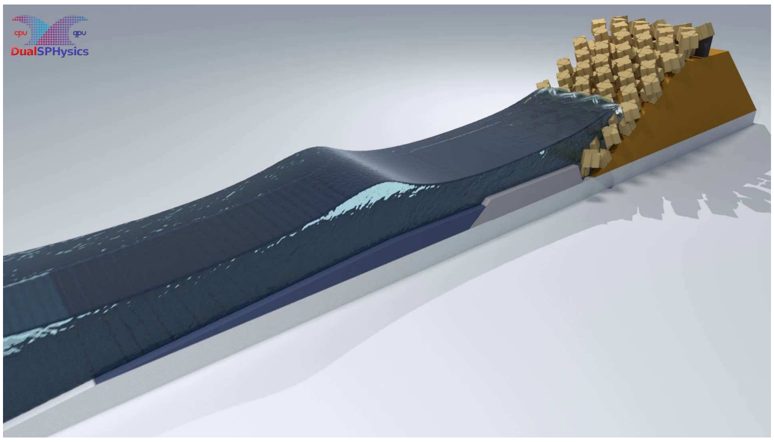


example of NS model:

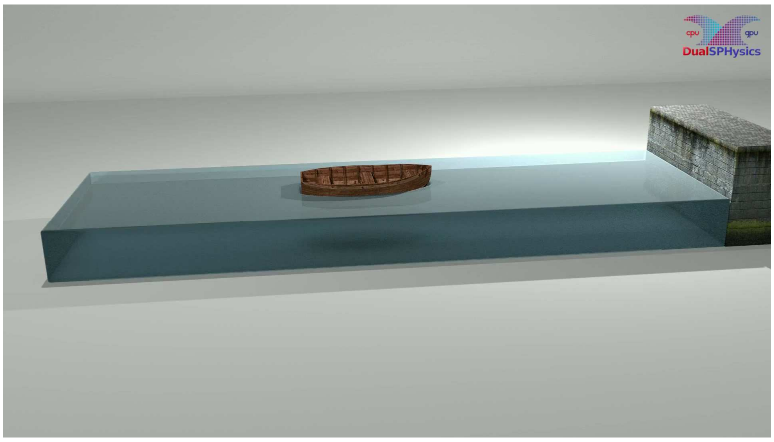
modelling of porous flow inside permeable breakwater



example of SPH model:
modelling of porous flow inside permeable breakwater

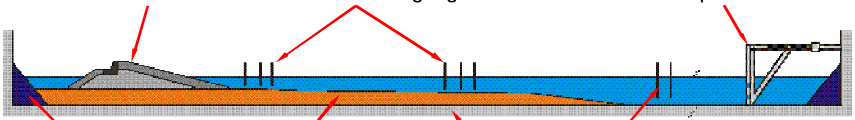


example of SPH model:
modelling coupling between flow and floating obstacle

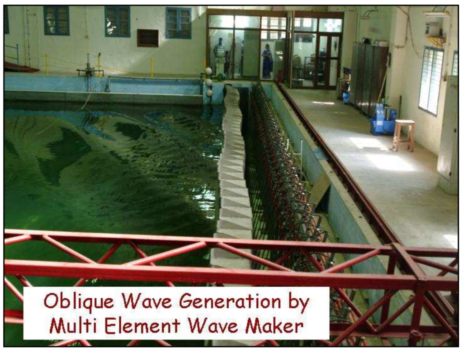


ADVANCES IN PHYSICAL MODEL TOOLS

features of a wave flume



wavemakers in 2D wave flumes and 3D tanks



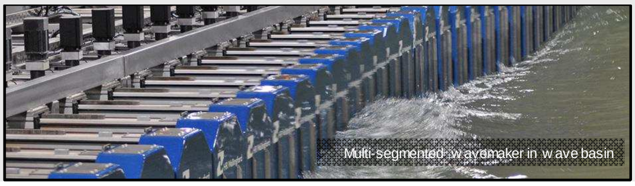
3D wave basin with multi-segmented wavemaker for wave generation

2D wave flume with piston-type wave paddle for wave generation

development of wavemakers ?

- Development of technology (hydraulic servo-systems, computer, …) provided more control over the wave paddle motion resulting in “better” waves
  - irregular waves and non-linear waves in the flume
  - directional waves in the wave basin using multi-segmented wavemaker
  - 2D and 3D active wave absorption

Circular wave and current basin FLOWAVE, University of Edinburgh (UK)



Multi-segmented wavemaker in wave basin

recent international developments

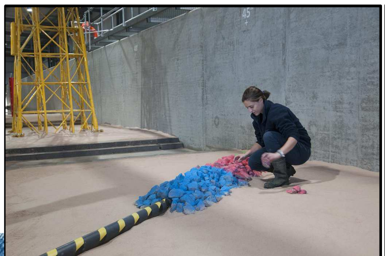
Delta flume, Deltares (NL)

large scale modelling 1:5 to 1:1
9.5 x 5 x 300 m (deep x wide x long)
H_{max} = 4.5 m

recent international developments

Fast Flow Facility, HR Wallingford (UK)

waves and current combined
water depth 0.8 m to 2 m
H_{max} = 1.0 m – currents 2 m/s



The Coastal & Ocean Basin @ Greenbridge campus Oostende

NEW RESEARCH INFRASTRUCTURE

background

- **Gen4Wave project**
  - initiated by **UGent** + **AGORIA**
  - organised by **UGent** + **KU Leuven** + **WL**
  - 3 core activities:
    - wave basin **COB**
    - **R&D** (innovation) **projects** (e.g. FLANSEA)
    - **discussion platform** academia <> industry <> government
- **Hercules foundation project**
  - large research infrastructure only
  - academia only: **UGent** + **KU Leuven** (**WL** in LOI and in background)
  - Wave and Current Generator
- **Ministry of Public Works and Mobility**
  - housing
  - concrete structures for COB

the Hercules consortium

ACRONYMS	UGent - AWW	UGent - MMS	UGent - AMT	KU Leuven- HYD
RESEARCH GROUPS	Coastal Engineering	Mechanics of Materials & Structures	Maritime Technology	Hydraulics Laboratory
PROMOTERS	Peter TROCH	Joris DEGRIECK	Marc VANTORRE	Jaak MONBALIU
	Tomas VAN OYEN	Wim VAN PAEPEGEM		Erik TOORMAN
	Andreas KORTENHAUS			Pieter RAUWOENS

RESEARCH FIELDS

specific expertise

coastal and offshore structures engineering	composite materials	wave energy	coastal engineering
wave and tide energy	renewable offshore energy	maritime technology	ocean waves
flow-vegetation interaction	slamming and deformation	floating bodies	sediment mechanics

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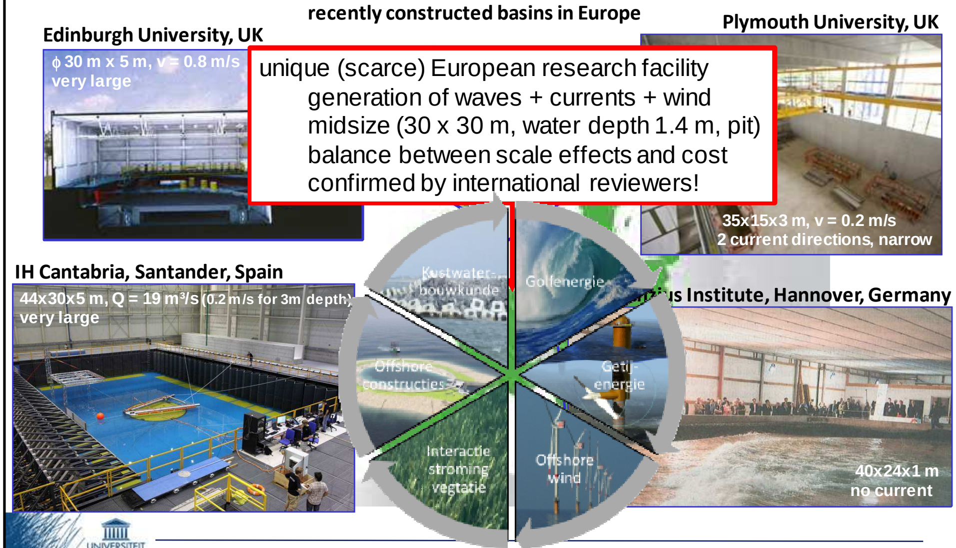
unique positioning in Europe

recently constructed basins in Europe

unique (scarce) European research facility
- generation of waves + currents + wind
- midsize (30 x 30 m, water depth 1.4 m, pit)
- balance between scale effects and cost
- confirmed by international reviewers!



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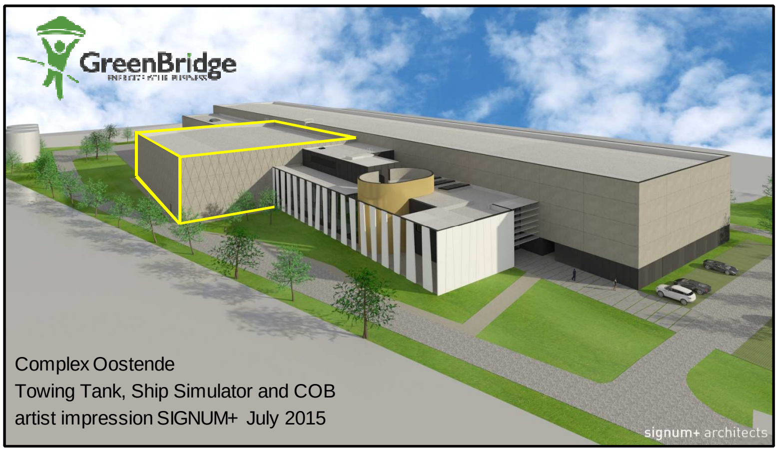
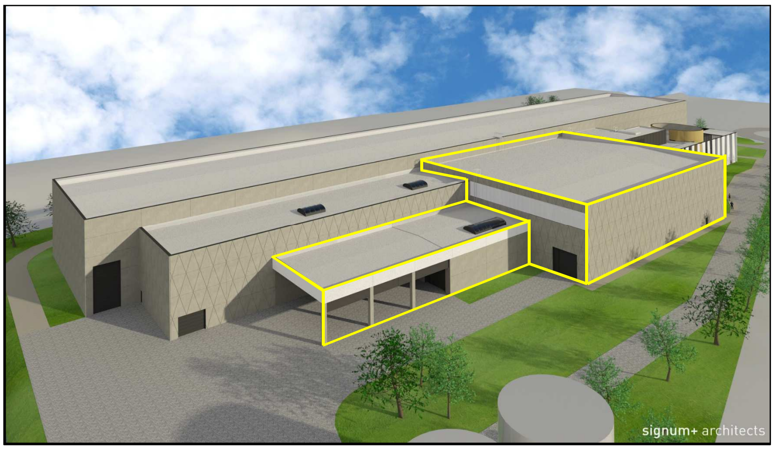
Coastal and Ocean Basin – COB, Oostende



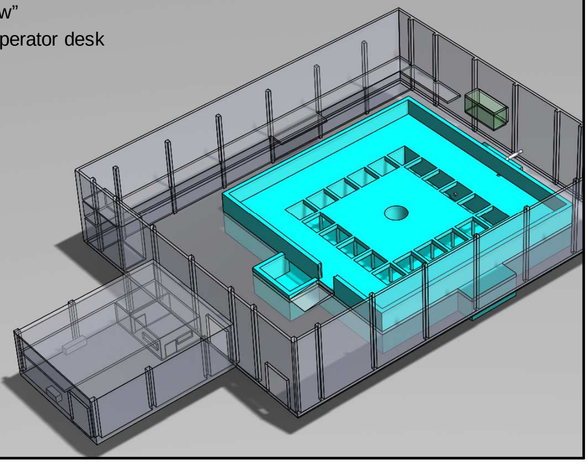
UNIVERSITEIT GENT
KU LEUVEN & campus Oostende
waterbouwkundig LABORATORIUM

Coastal and Ocean Basin – COB, Oostende

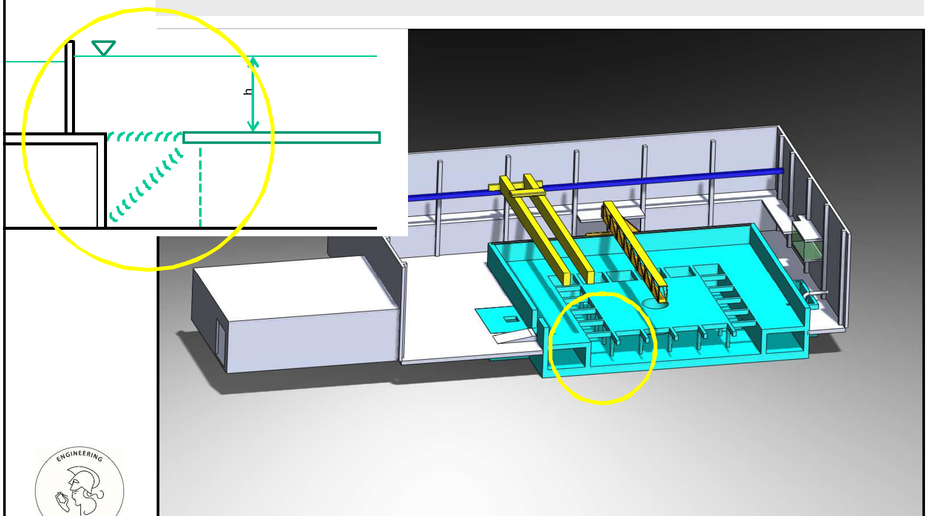


Coastal and Ocean Basin – COB, Oostende

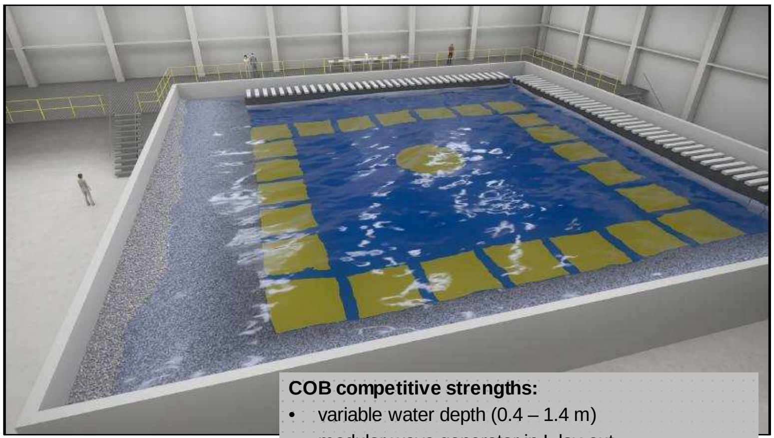
- COB main hall
- “room with a view”
- Gangway with operator desk
- Wave tank
- Current tank
- Central pit
- Working area
- Workshop
- Wave generator
- Wind generator
- Current pumps
- Bridge crane
- Passerelle
- Pumping station
- Wheelloader
- Forklift
- DAQ



Coastal and Ocean Basin – COB, Oostende



Coastal and Ocean Basin – COB, Oostende



COB competitive strengths:
- variable water depth (0.4 – 1.4 m)
- modular wave generator in L lay-out
- wave-current interaction in any direction
- exceptional quality velocity profile
  based on numerically design of inlet grid vanes

Blue Growth

- **Europe**:
  - long term strategy to create growth and jobs in the marine and maritime sectors, supporting the Europe 2020 strategy
- **Flanders**: proposal for "*speerpuntcluster*" with consortium of:
  - industry,
  - universities and knowledge centres,
  - government,
- **UGent** clusters in Greenbridge, Oostende
- **UGent** Blue Growth summerschool (12 - 23 September 2016)

CONCLUSIONS

conclusions

- **coastal defence systems** protect coastal areas as multi-functional hot spots
- **waves**, their generation and propagation characteristics
- **wave energy conversion** is still in the research phase
- **wave overtopping** is a crucial structural response in the design of a coastal structure
- recently huge developments in both **numerical and physical (with revival) modelling tools**
- the **new COB wave basin** on the Greenbridge campus (Oostende) is ready to start the construction phase!