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Large scale experiments in coastal and ocean engineering

A short introduction to the Large Wave Flume (Großer Wellenkanal, GWK)

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Technische Universität Braunschweig

Why physical model tests?

Primary Objectives

1	Predict(*) and understand future behavior of a prototype system (Prospective analysis and design)
	Minimize penalties for errors in prototype
2	Hindcast and understand past behavior of a prototype system (Retrospective analysis forensic studies)
	Learning from the past to improve present/future behaviour in prototype

→ *In both cases*: Simulation of unknown physical prototype behaviour in the past, present or future

Why physical model tests?

Available tools

- **Field measurements**: Representing all physics in prototype scale, but boundary conditions are not (or very hardly) to control and effort is very high (e.g. installation or maintenance of equipment, ship times, …).
- **Analytical (theoretical) models**: Based on physical understanding, but only applicable to (very) simplified problems, usually focused on governing processes excluding interactions.
- **Numerical models**: Only as good as underlying equations (physical understanding), model assumptions needed (e.g. turbulence, sediment transport, …) and usually not covering all involved processes (and interactions).
- **Laboratory models**: Representing all physics, boundary conditions can be controlled, but focusing on governing processes and full scale hardly achievable, i.e. must be scaled.

Physical model tests in the laboratory have been and will be an invaluable tool

Limitations of physical models

Laboratory effects

Prototype conditions cannot be exactly reproduced in the laboratory due to

- Boundary conditions
  (e.g. side walls, wave paddle)
- Wave generation with a paddle
  (e.g. parasitic waves, re-reflections)
- Neglection of processes
  (e.g. 3D effects)

→ **ERRORS**

Irrespective of model scale

Scale effects

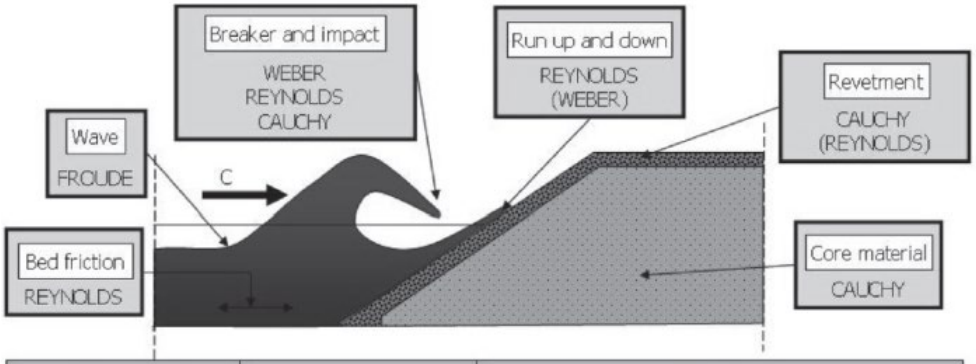
Scaling requires equality of forces, but only one similarity law can be fulfilled in the same model.

In a Froude model for example, surface tension, viscosity, elasticity and pressure forces are not properly scaled.

→ **ERRORS**

Errors decrease with larger scales

Why large scale models?



Type of Force	Scaling Law	Scale		
		1:1	1:10	1:100
Gravity	FROUDE	1	1	1
Friction	REYNOLDS	1	1:31,6	1:1000
Compressibility	CAUCHY	1	1:10	1:100
Surface Tension	WEBER	1	1:100	1:10000

Scale effects in FROUDE-model

"Users Guide to Physical Modelling and Experimentation: Experience of the HYDRALAB Network"
CRC Press/Balkema, Leiden, The Netherlands. ISBN: 978-0-415-60912-8 (Pbk)

A large scale is necessary for e.g.:

- Wave breaking
- Wave impact
- Sediment transport
- Soil dynamics
- Wave run-up
- Wave overtopping
- Wave transmission
- …

The Large Wave Flume (Großer Wellenkanal, GWK)

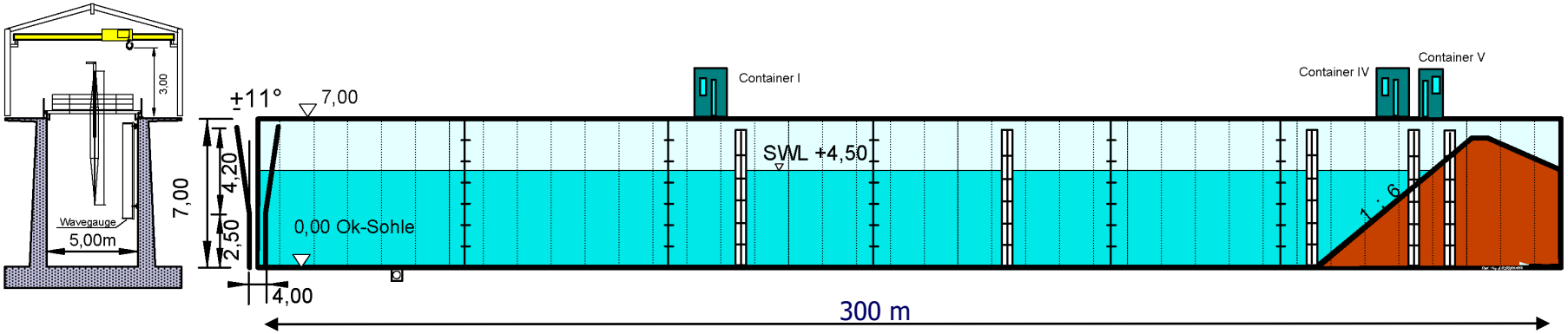
The Large Wave Flume
Großer Wellenkanal (GWK)

Historical background

- Planned and built within SFB 79 "Hydraulic research in coastal areas" (1969 – 1982)
- Construction: 1979 – 1983
- Costs: 20 Mio. DM
  (ca. 10 Mio. €)
- Inauguration: 16.09.1983
- Used within SFB 205 "Coastal Engineering – Sea states and transport processes in coastal protection, offshore and harbor engineering" (1.1.1983 – 31.12.1994)

Großer Wellenkanal (GWK)
• Dimensions

- 300 m length, 5 m width, 7 m height
- Regular waves of up to 2.0 m
- Irregular sea states up to H_s=1.3 m
- Piston type wave maker with active wave absorption
- Extensive instrumentation (e.g. wave gauges, velocity probes, pressure and force transducers, 2D & 3D laser scanners)



Selected projects in GWK

Selected projects in GWK

COASTAL STRUCTURES

SEDIMENT TRANSPORT

MARINE ENERGY

ECO HYDRAULICS

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Coastal structures - yesterday

Dikes and revetments (1980s)

Research questions:

- Behavior of different revetment types
- Run-up height
- Run-up velocities
- Impact pressures
- Pore water pressures / Soil mechanics
- Structural failure
- Scale effects

Selected projects in GWK
Coastal structures - today

Dikes and revetments (2010s)

Bonded revetment

Material properties

Grain size: 20/40 mm

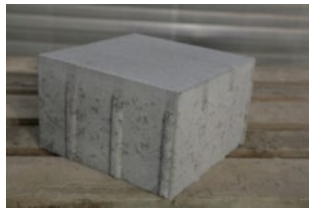
d_{50}: ≈ 30 mm

Porosity: ≈ 40 %

k_f: ≈ 1 m/s

Interlocked revetment

conventional

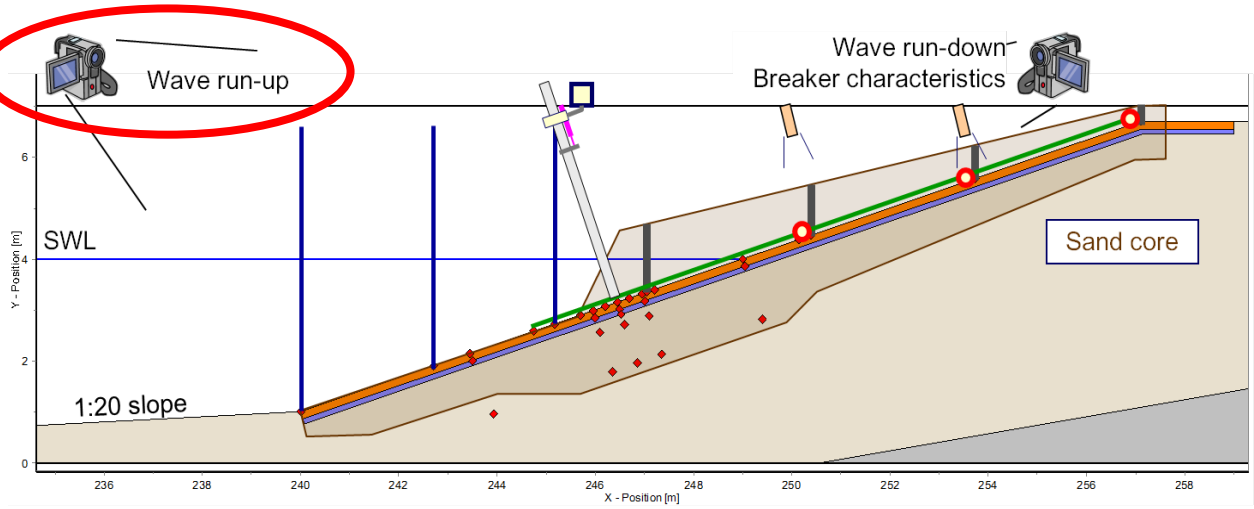


interlocked

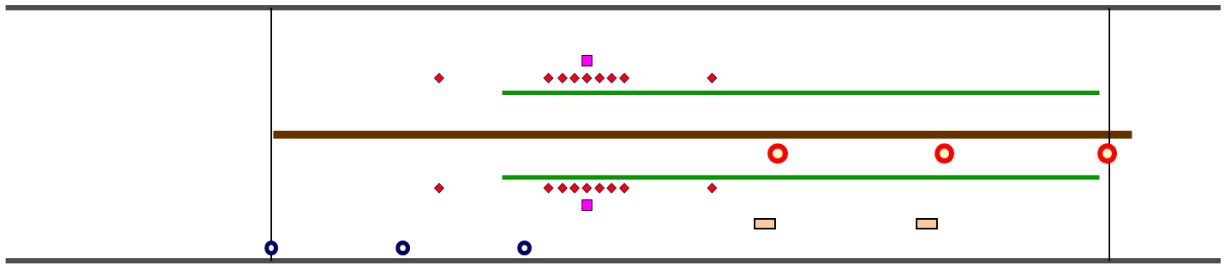
Bonded revetment – Model setup

Measurement techniques:

- Wave gauges
- Pressure sensors
- Run-up gauges
- Layer thickness gauges
- Ultrasonic gauges
- Velocity propellers
- Accelerometers
- Displacement meters
- Video cameras



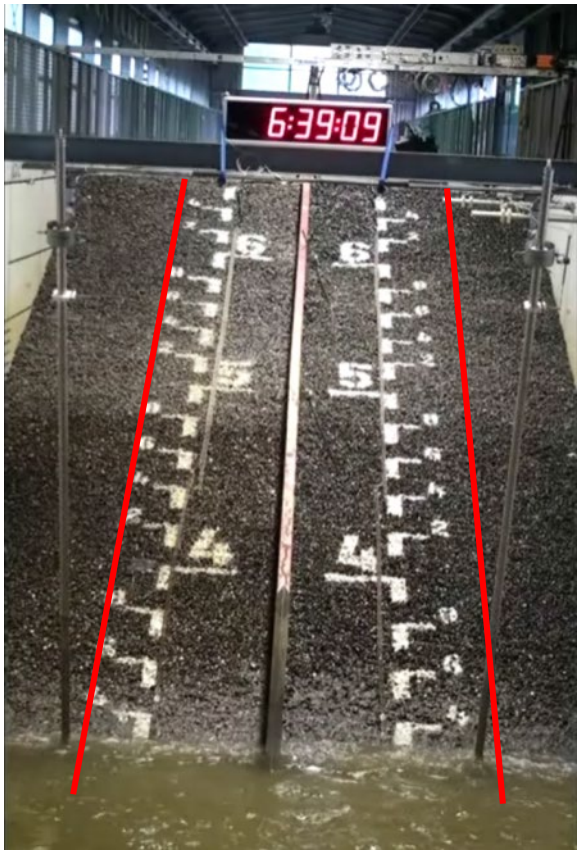
Cross section

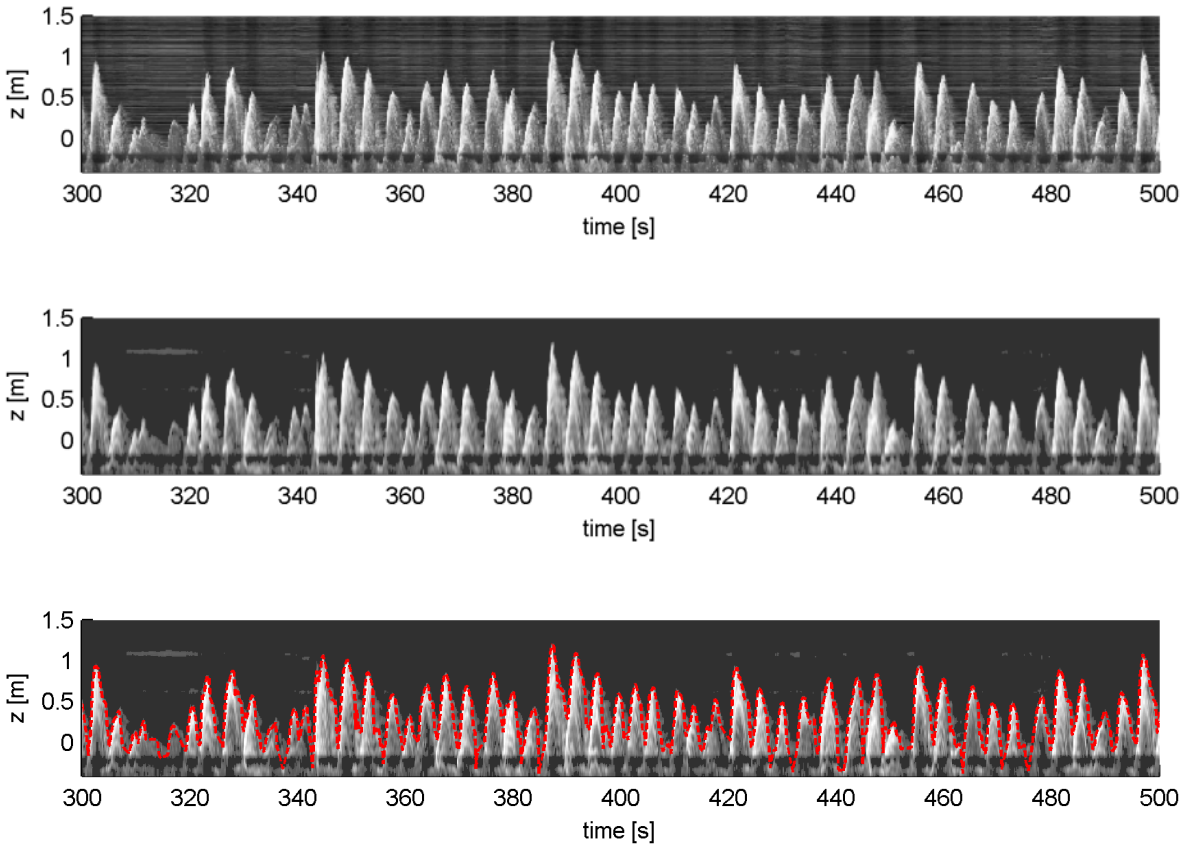


Plan view

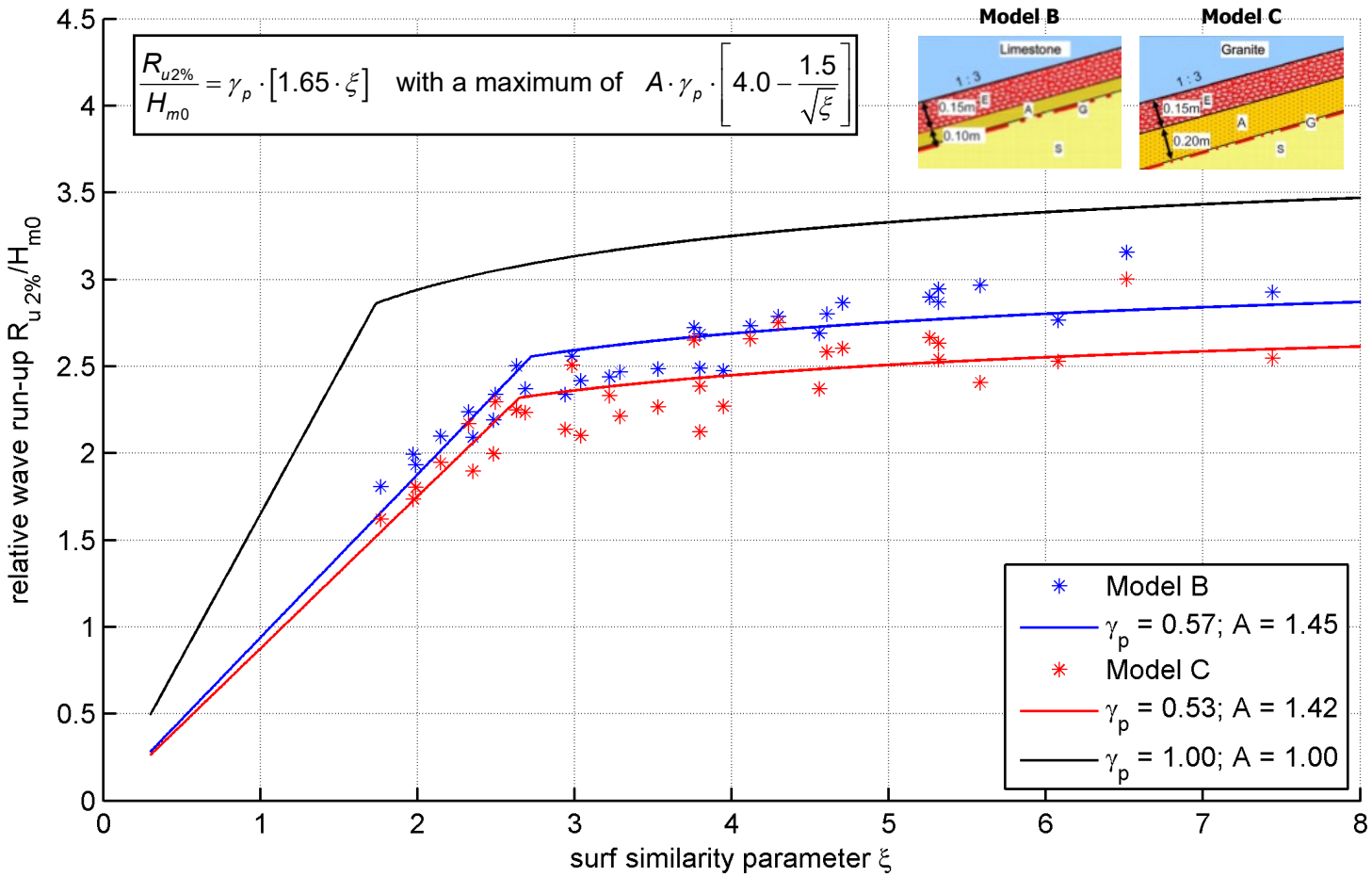
Selected projects in GWK
Coastal structures - today

Bonded revetment – Video data analysis





Bonded revetment – Video data analysis



Selected projects in GWK

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Selected projects in GWK
Sediment transport - yesterday

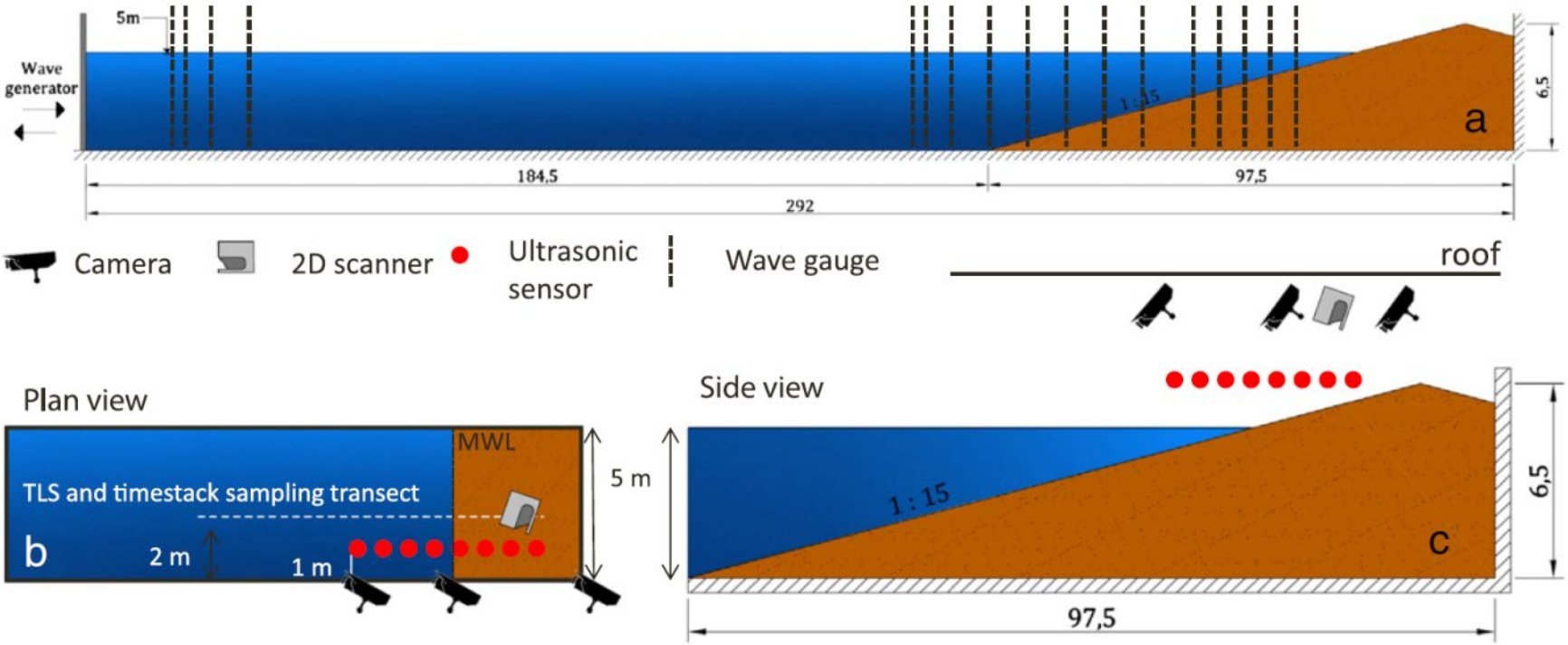
Sedimenttransport (1980s)

Research questions:

- Beach profile development
- Dune erosion processes
- Velocity profiles
- Sediment concentration profiles (averaged)
- Energy dissipation in the surf zone
- Scale effects

Selected projects in GWK
Sediment transport - today

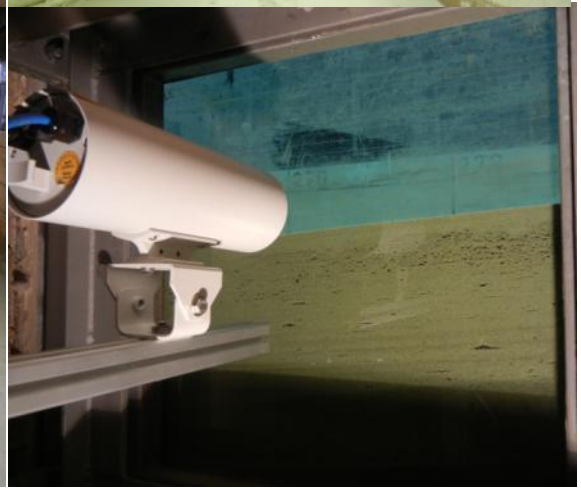
WISE Experiments (2013) – Experimental setup



Selected projects in GWK
Sediment transport - today

WISE Experiments (2013) – Measurement techniques

Instrument	Number
Wave gauges	17
Velocity (ADV)	4
Velocity (ECM)	3
Velocity profile (ADVP)	1
Sediment conc. profile (OBS)	4
Sediment conc. profile (ABS)	3
Pore water pressure	22
Layer thickness (echo sounder)	10
Video cameras	4
High-speed cameras	1
2D laser scanner	1
3D laser scanner	1



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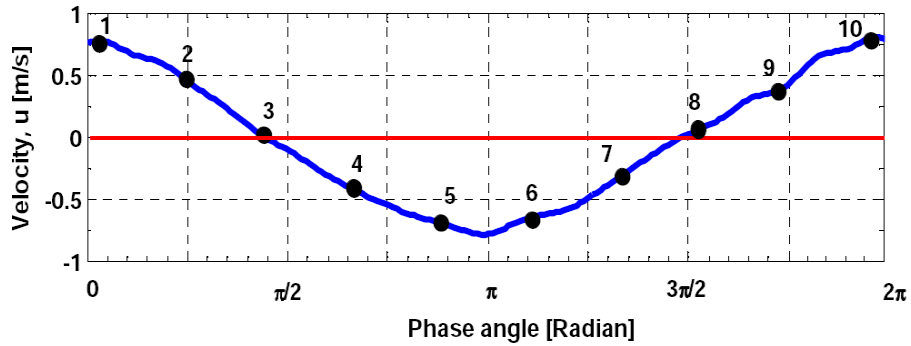
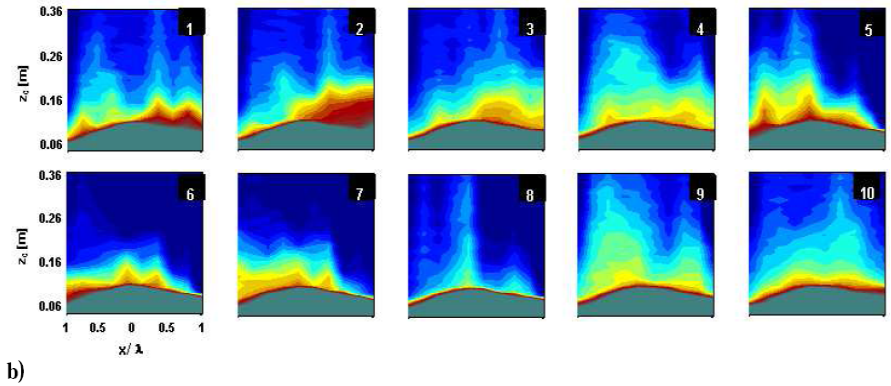
Sediment transport - today

Example results from ABS measurements

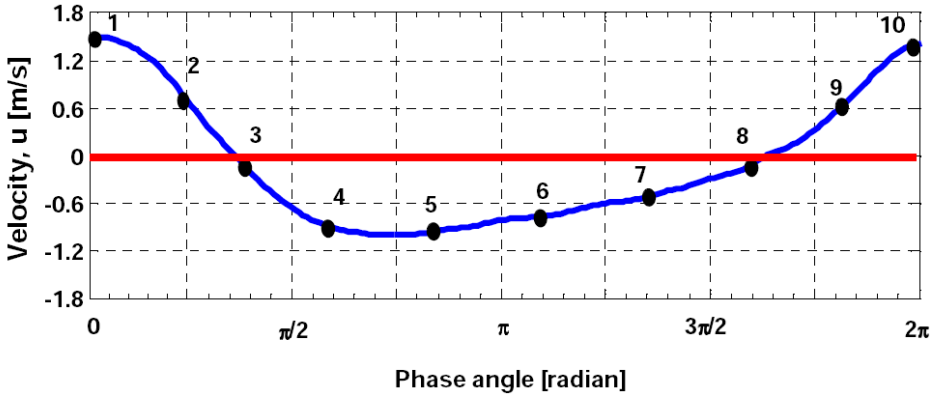
Phase-averaged sediment concentration profiles

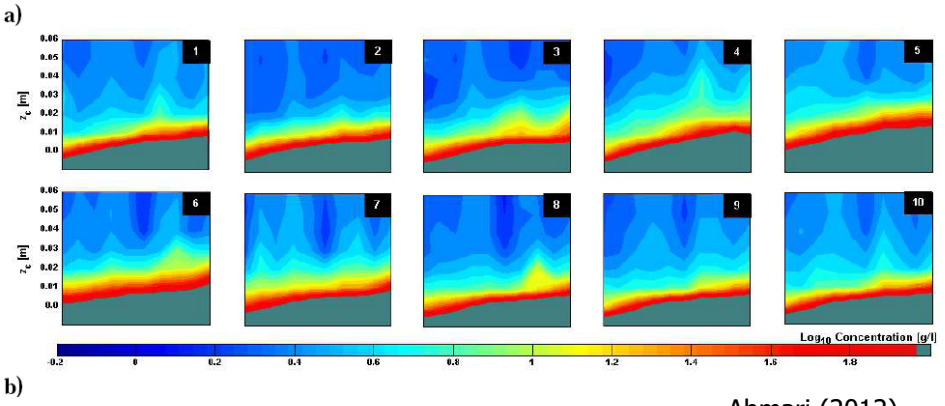
Rippel-Regime





Sheetflow-Regime





Ahmari (2012)

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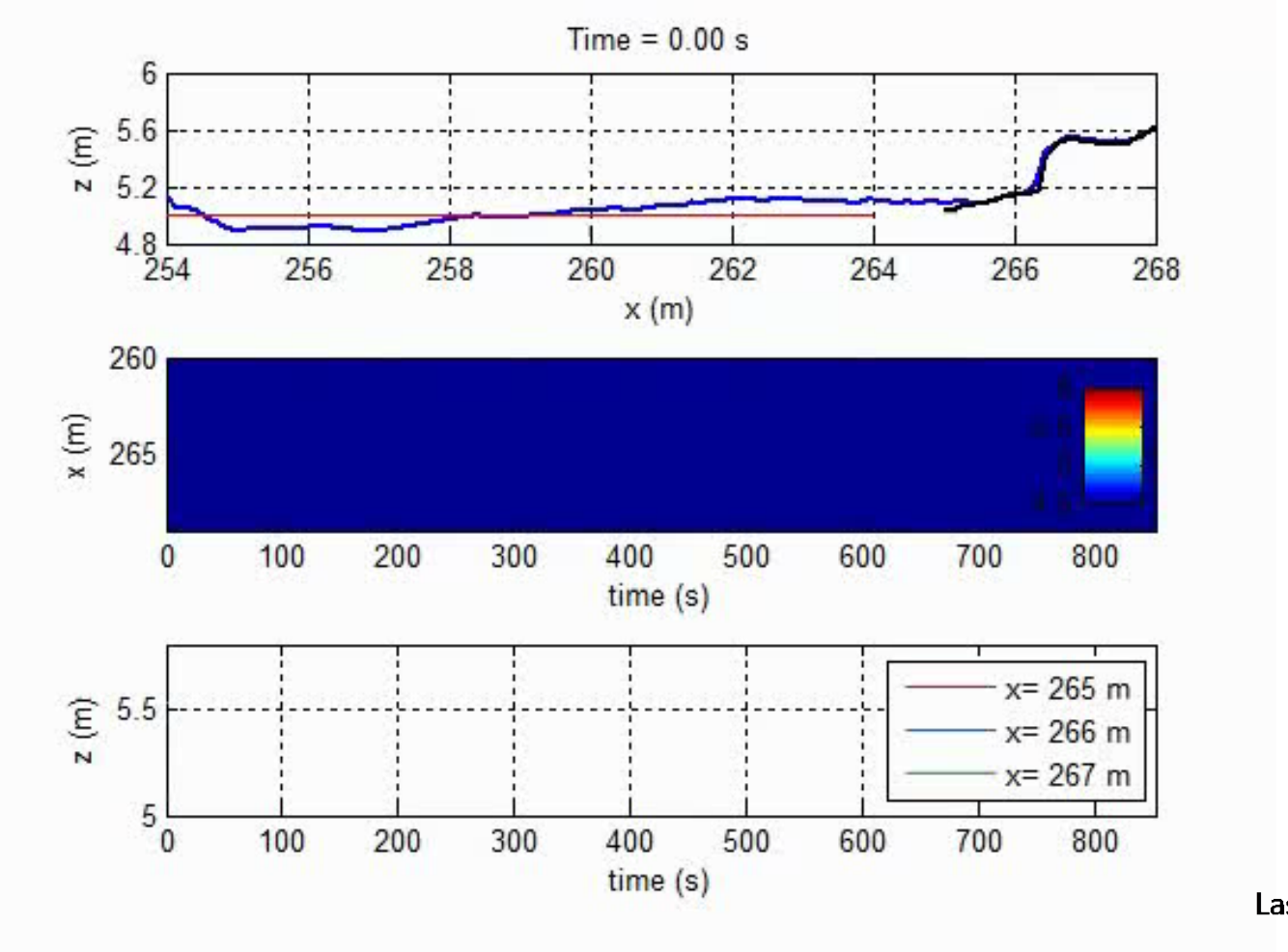
Sediment transport - today

Example results from 2D laser scanner



Laser_video4.wmv

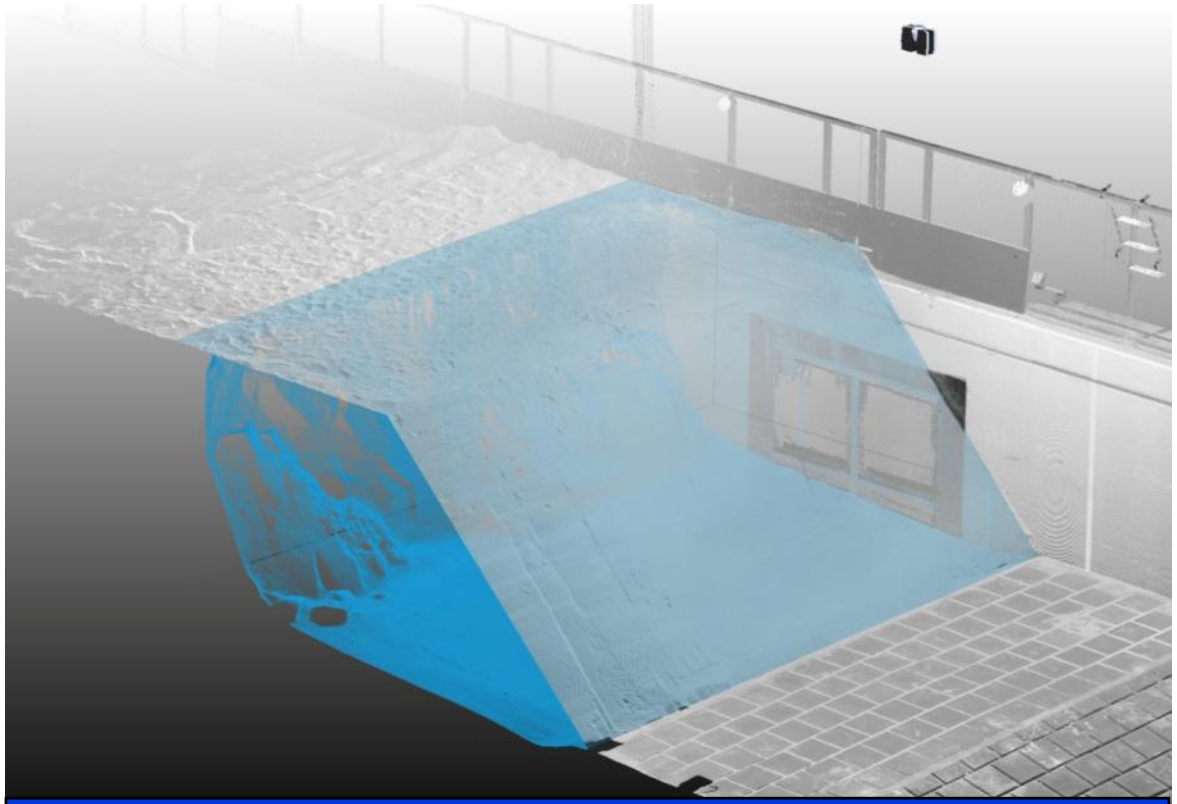
Selected projects in GWK
Sediment transport - today

1D profiler vs. 3D laser scanner

1988

1D profiler

2013



3D laser scanner

Selected projects in GWK

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Examples of foundation types investigated in GWK

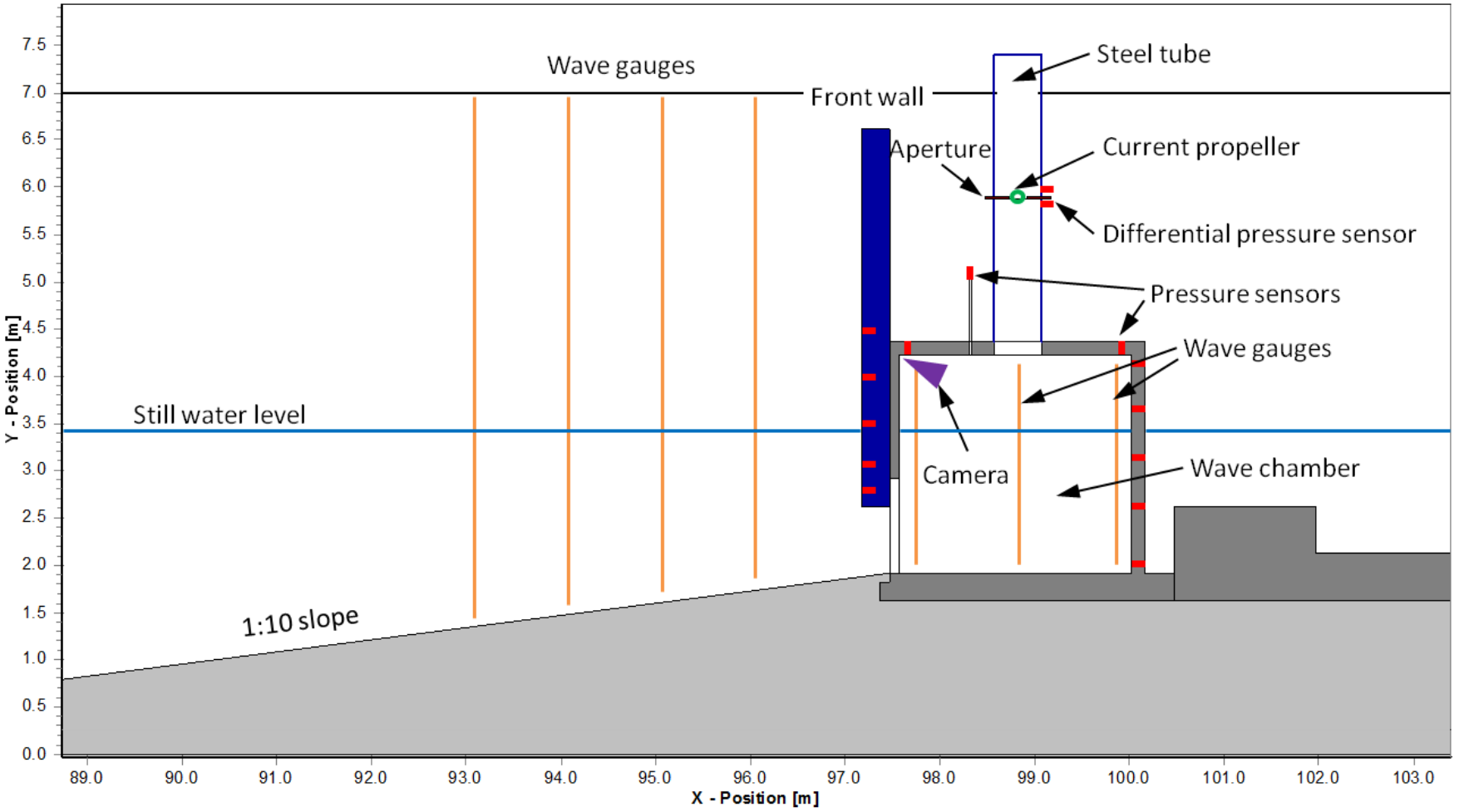
Research questions: (breaking) wave loads, scour, armour stability

Tripod

Gravity based

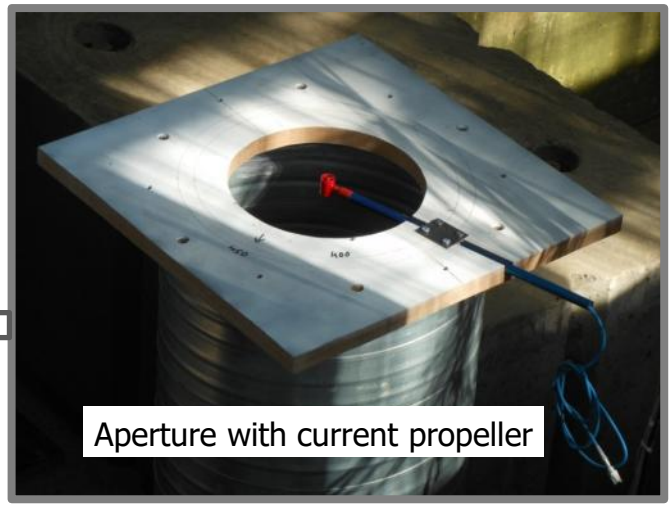
Jacket

OWC wave energy converter – Experimental setup

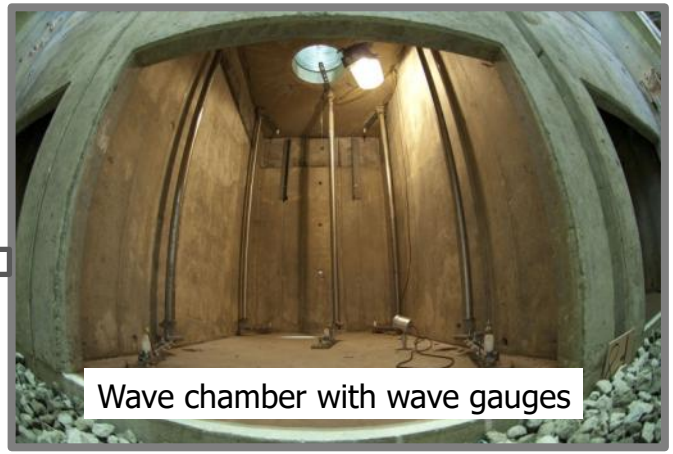


Selected projects in GWK
Marine Energy – Wave Energy

OWC wave energy converter – Experimental setup



Aperture with current propeller



Wave chamber with wave gauges

Selected projects in GWK
Marine Energy – Wave Energy

OWC wave energy converter – Video inside air chamber

Aperture
d = 0.05 m

Aperture
d = 0.30 m

Selected projects in GWK
Marine Energy – Wave Energy

OWC wave energy converter – Wave impact

Conclusions and Outlook

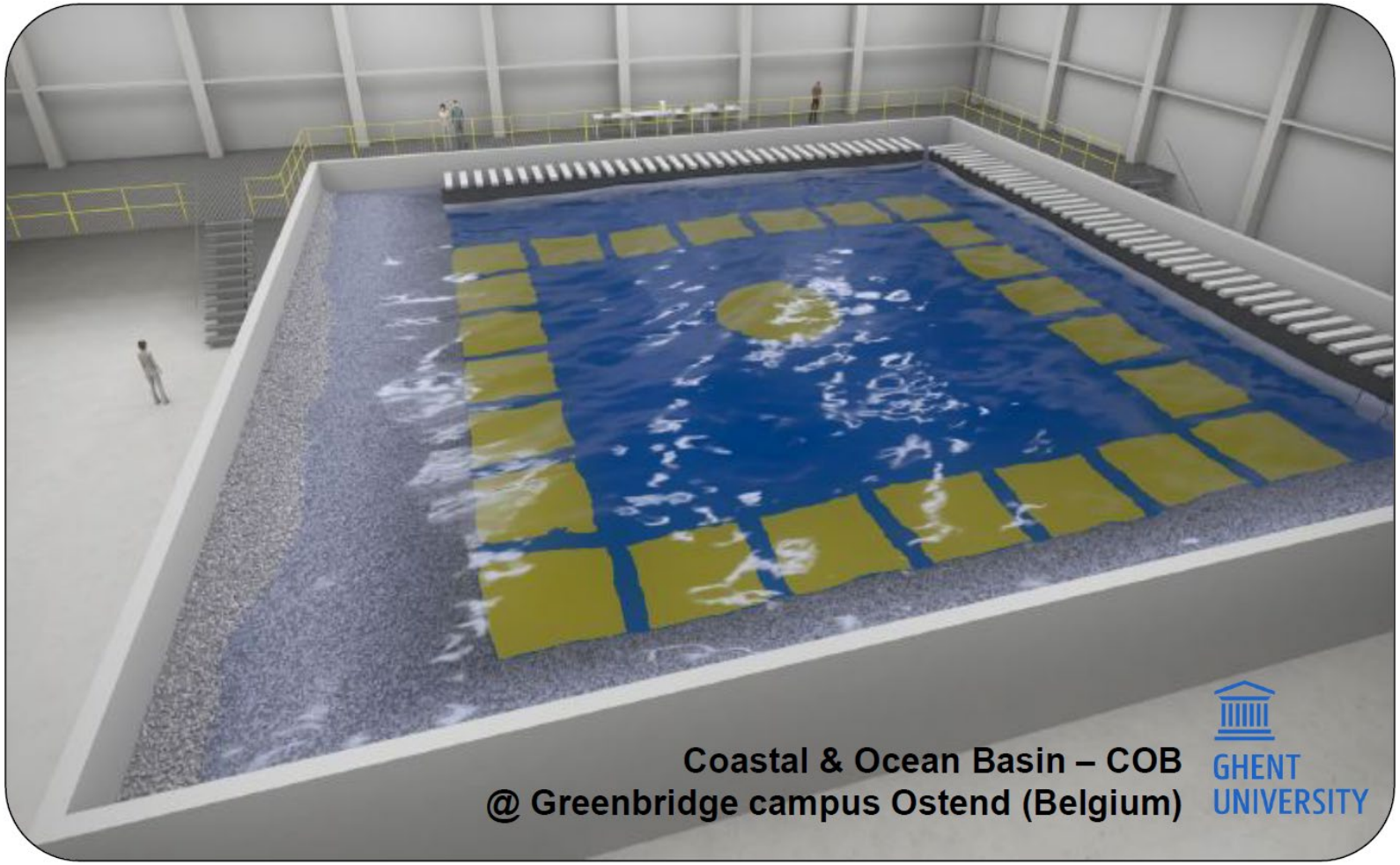
Conclusions and Outlook

- Physical model tests in the laboratory have been and will be an invaluable tool for coastal and offshore engineering
- **New materials and design concepts** for "traditional" coastal protection will always require new investigations and physical model tests.
- **Emerging technologies** (e.g. marine energy) and **ecological awareness** (Nature-based Solutions) require model tests as design basis.
- **New measurement techniques** (e.g. video analysis, laser scans, ABS) provide better results and insights for future basic and applied research.
- Further improvement and validation of **numerical models** rely on data from (large scale) laboratory experiments.

➔ **Strong need for new and improved laboratory facilities**

Conclusions and Outlook

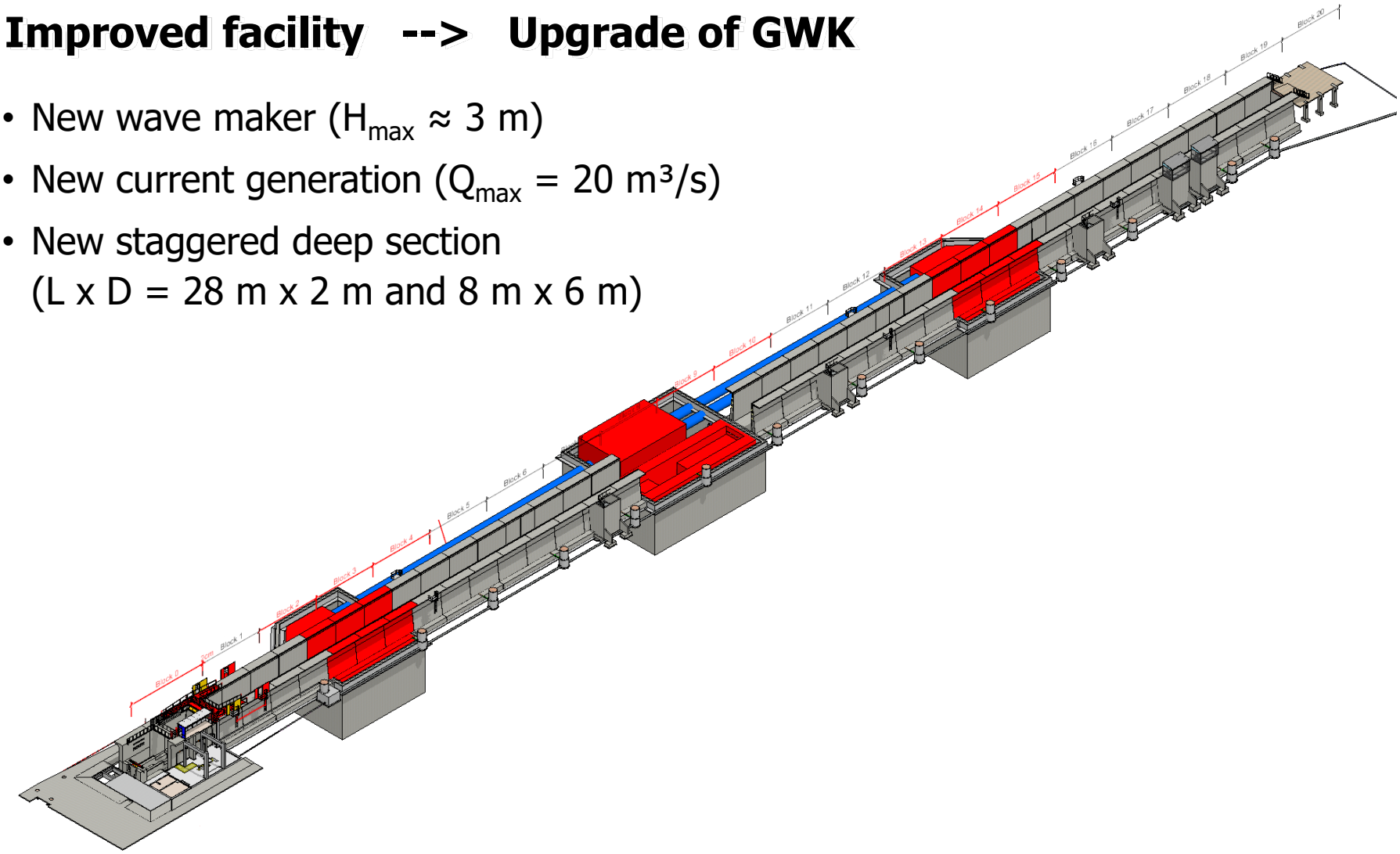
New facility



Conclusions and Outlook

Improved facility --> Upgrade of GWK

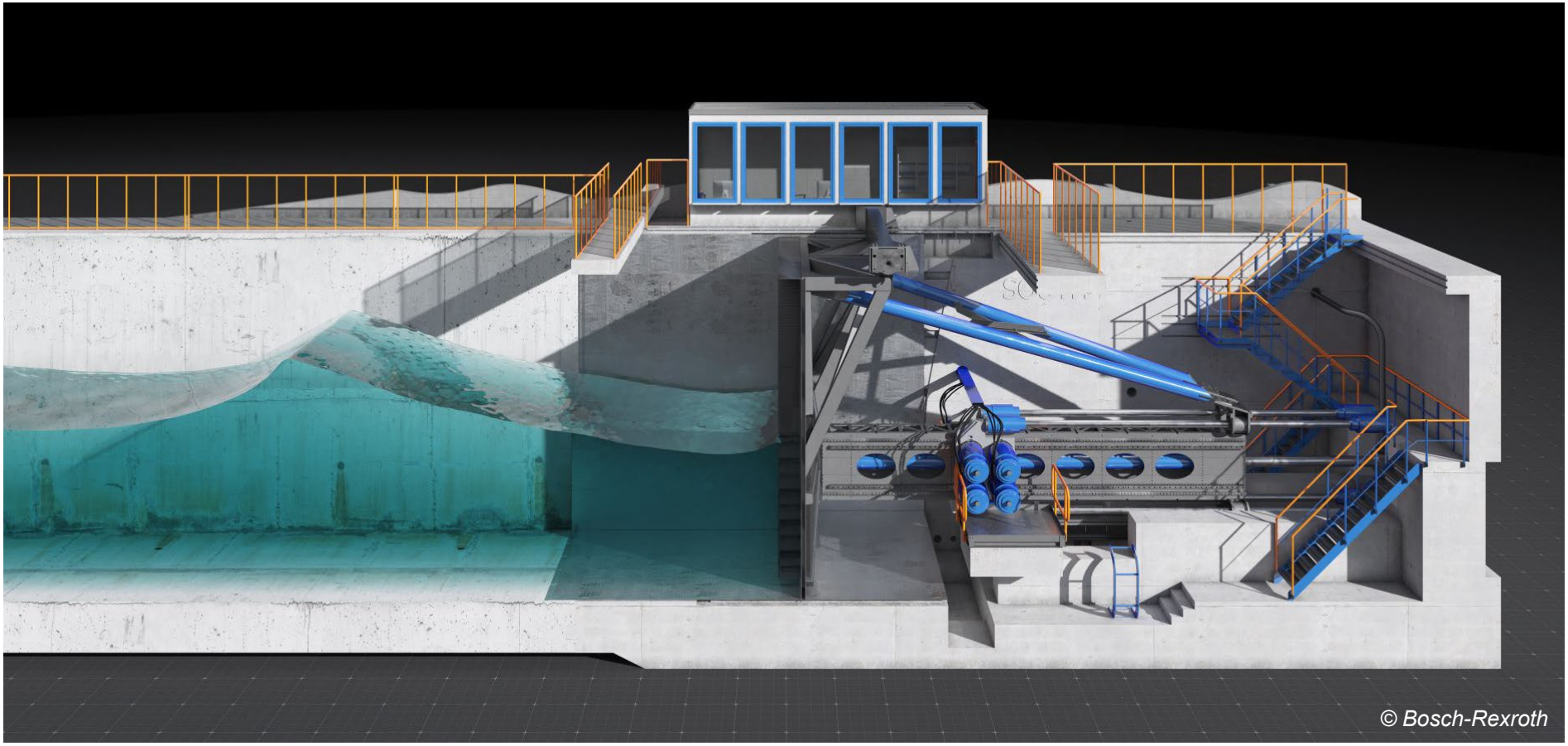
- New wave maker ($H_{max} \approx 3$ m)
- New current generation ($Q_{max} = 20$ m³/s)
- New staggered deep section
  (L x D = 28 m x 2 m and 8 m x 6 m)



Conclusions and Outlook

Improved facility --> Upgrade of GWK

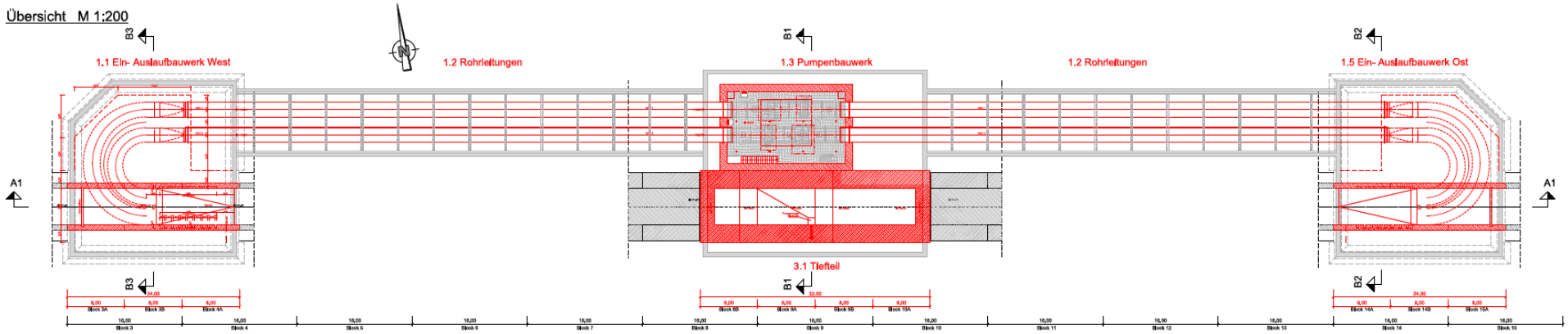
- New wave maker

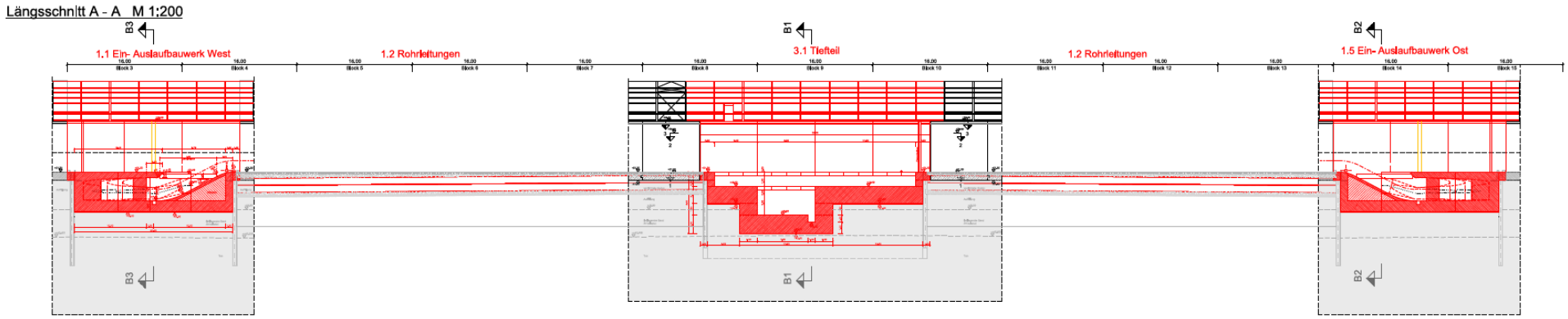


Conclusions and Outlook

Improved facility --> Upgrade of GWK

- New current generation and deep section

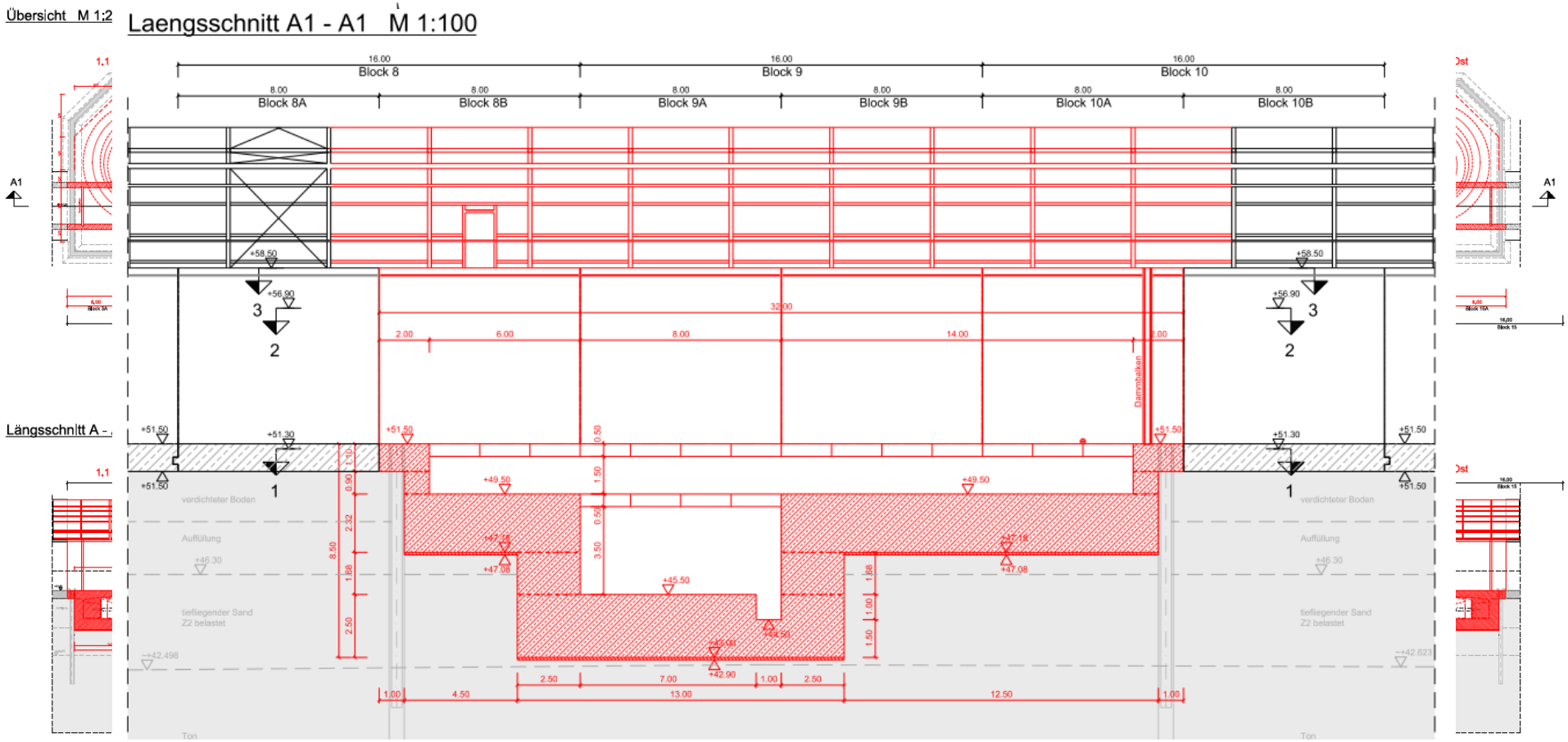




Conclusions and Outlook

Improved facility --> Upgrade of GWK

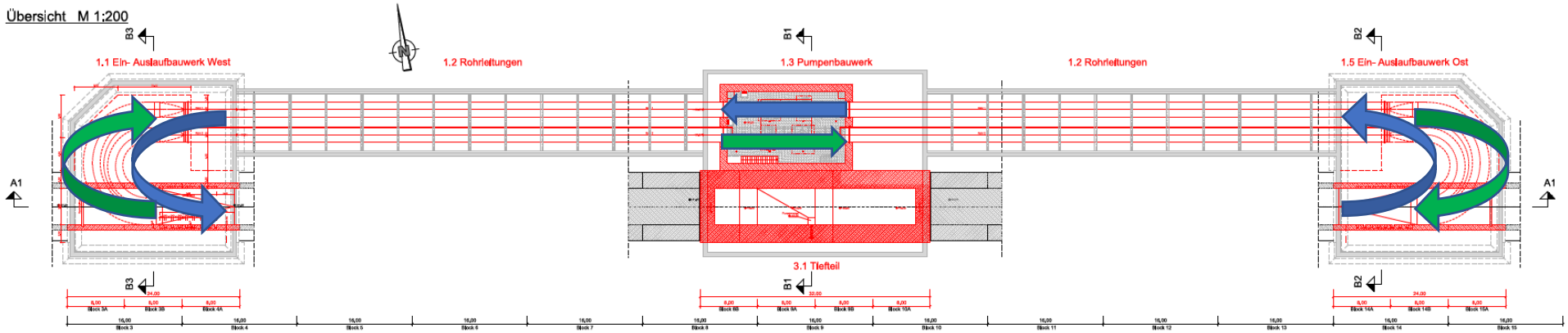
- New current generation and deep section

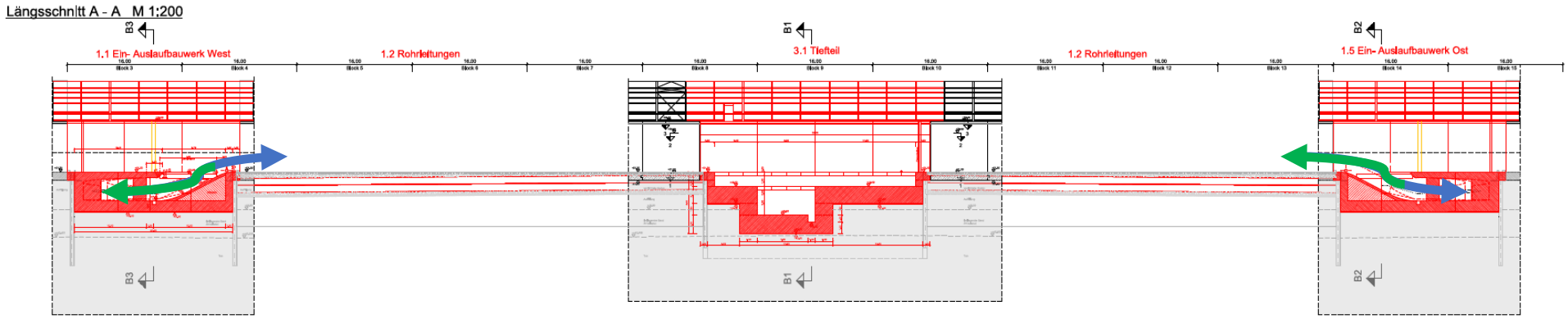


Conclusions and Outlook

Improved facility --> Upgrade of GWK

- New current generation and deep section

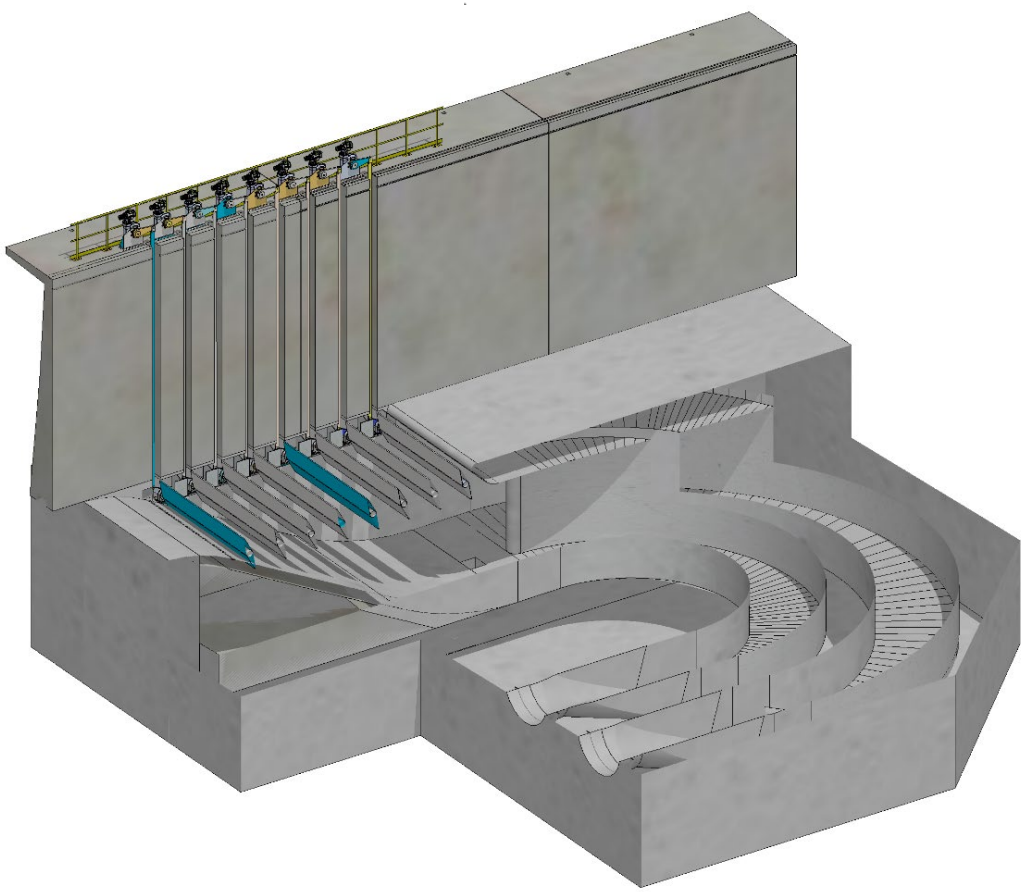


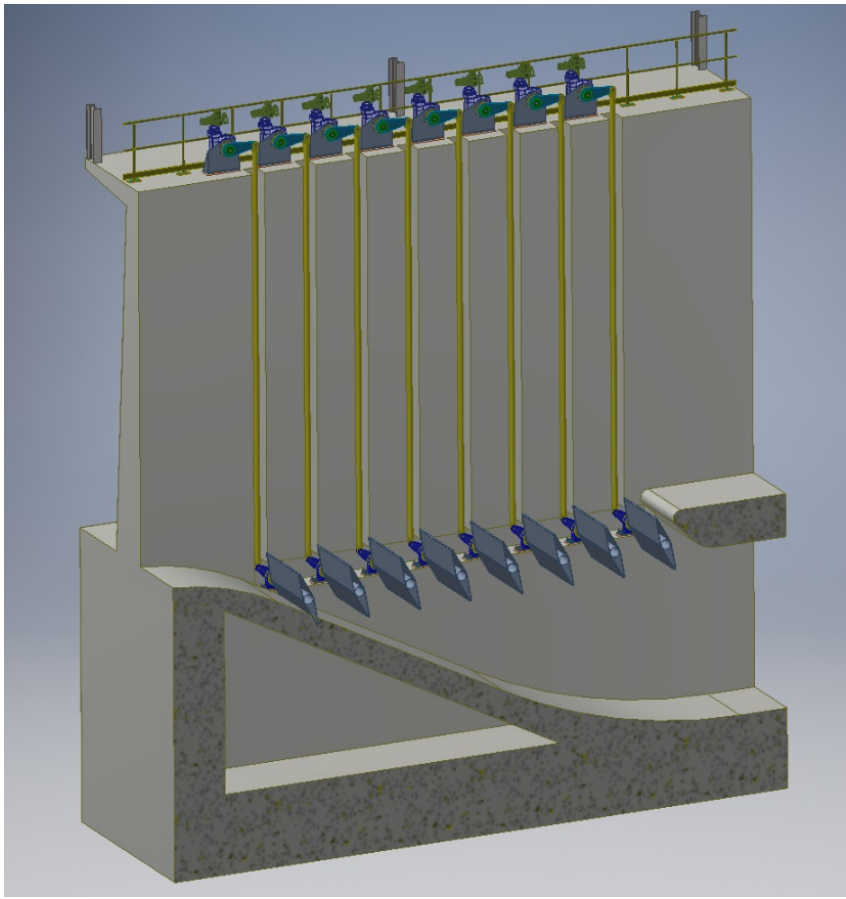


Conclusions and Outlook

Improved facility --> Upgrade of GWK

- New current generation and deep section

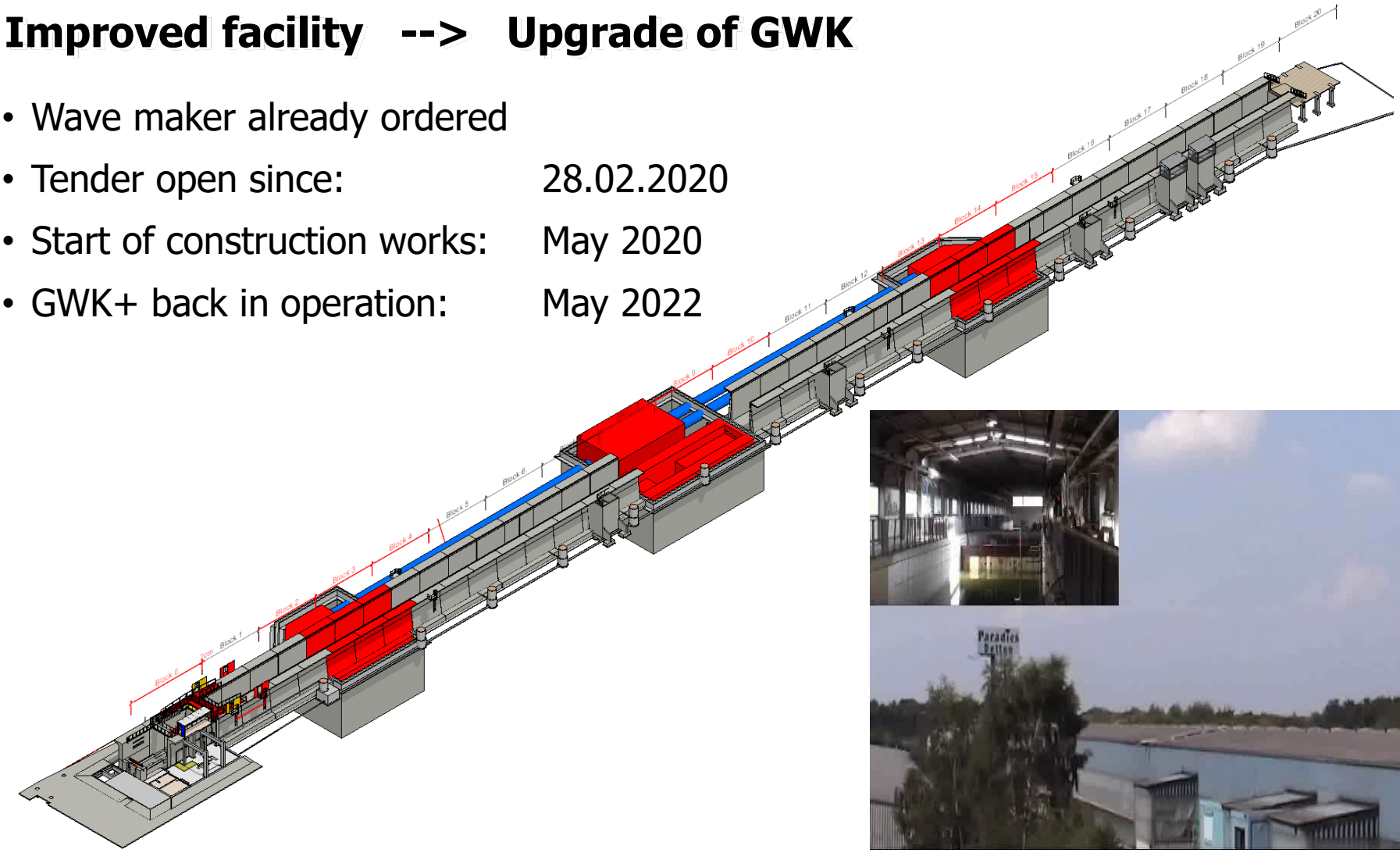




Conclusions and Outlook

Improved facility --> Upgrade of GWK

- Wave maker already ordered
- Tender open since: 28.02.2020
- Start of construction works: May 2020
- GWK+ back in operation: May 2022



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Stefan Schimmels, Forschungszentrum Küste (FZK)

Leibniz Universität Hannover

Technische Universität Braunschweig


Paradies

APPENDIX

Selected projects in GWK

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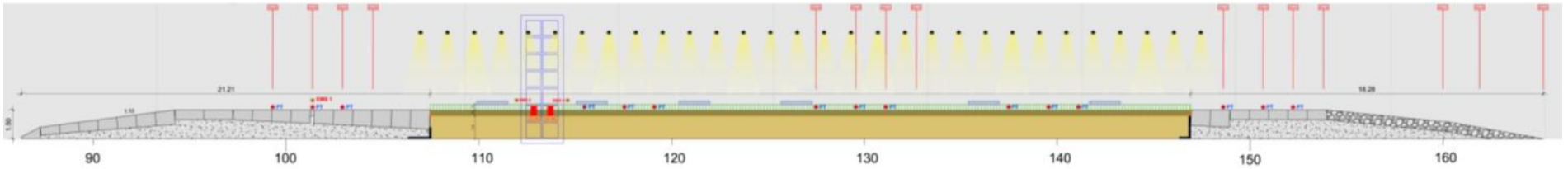
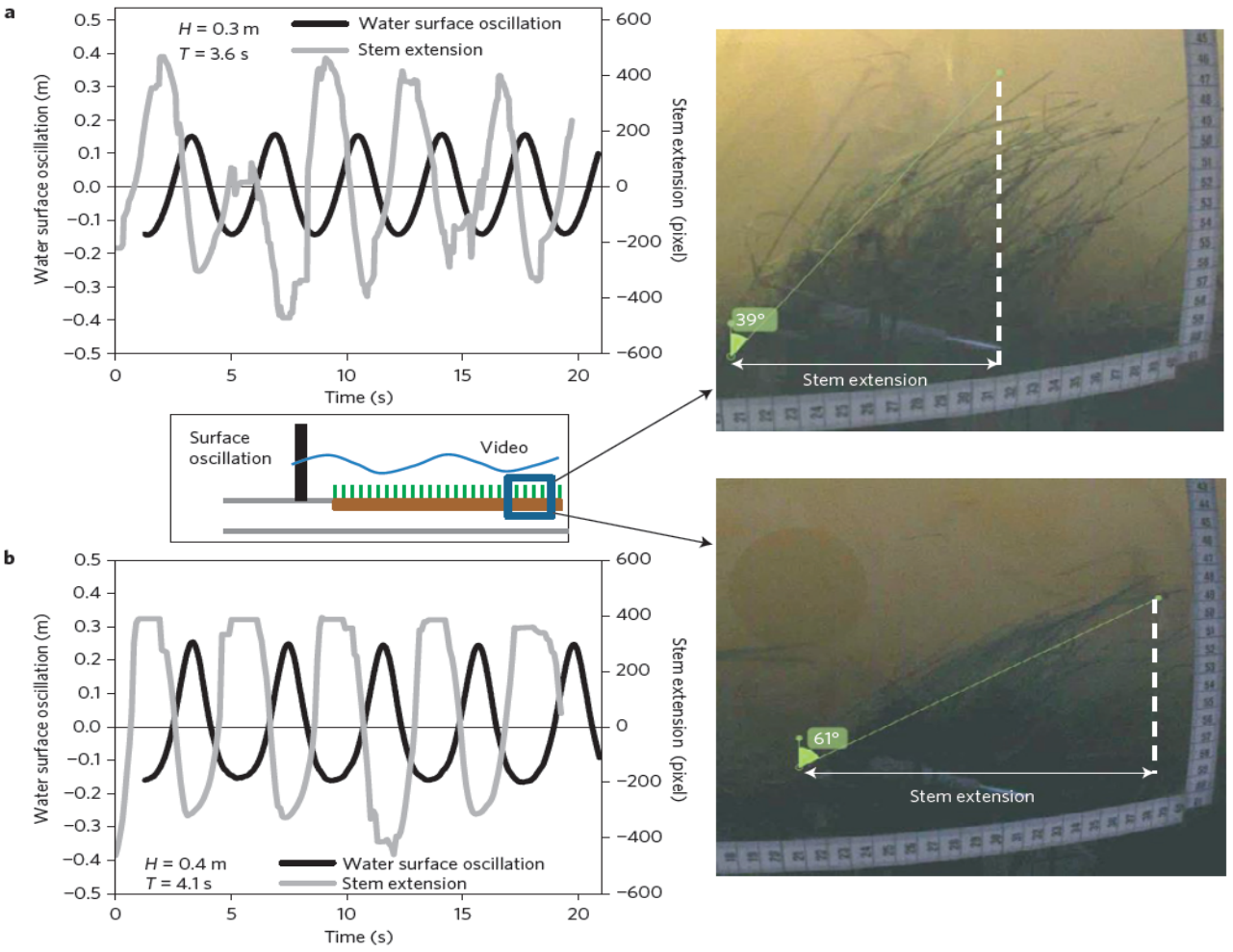
Natural salt marsh – Experimental setup



Natural salt marsh – Experimental setup

Natural salt marsh – Measurements

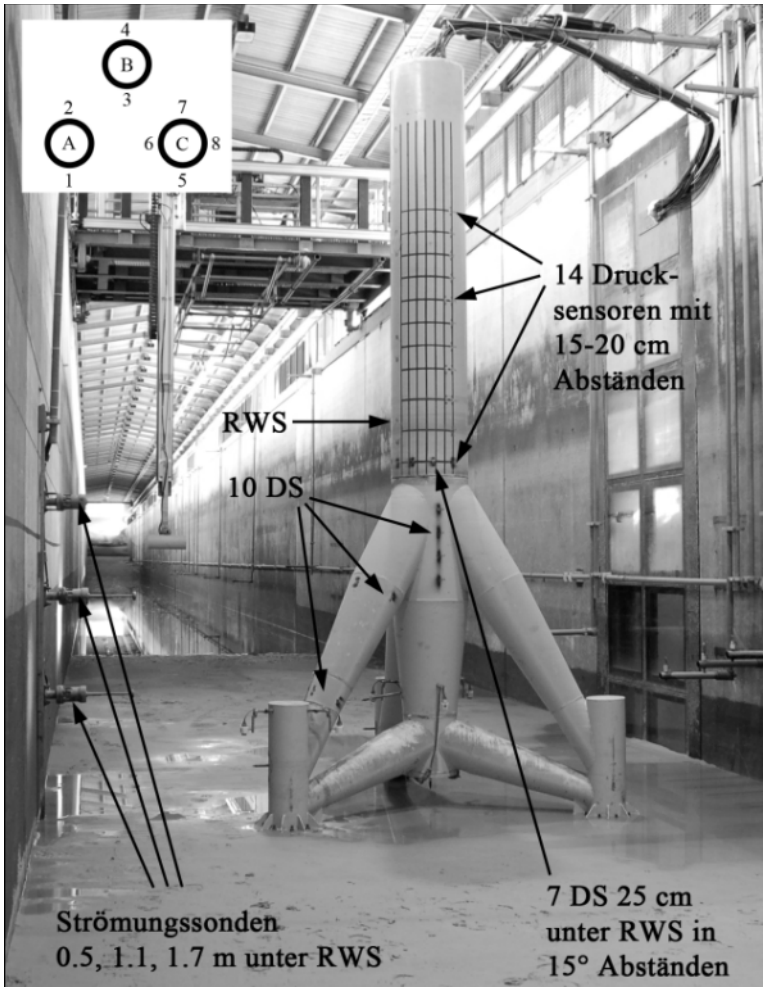
Natural salt marsh – plant wave interaction

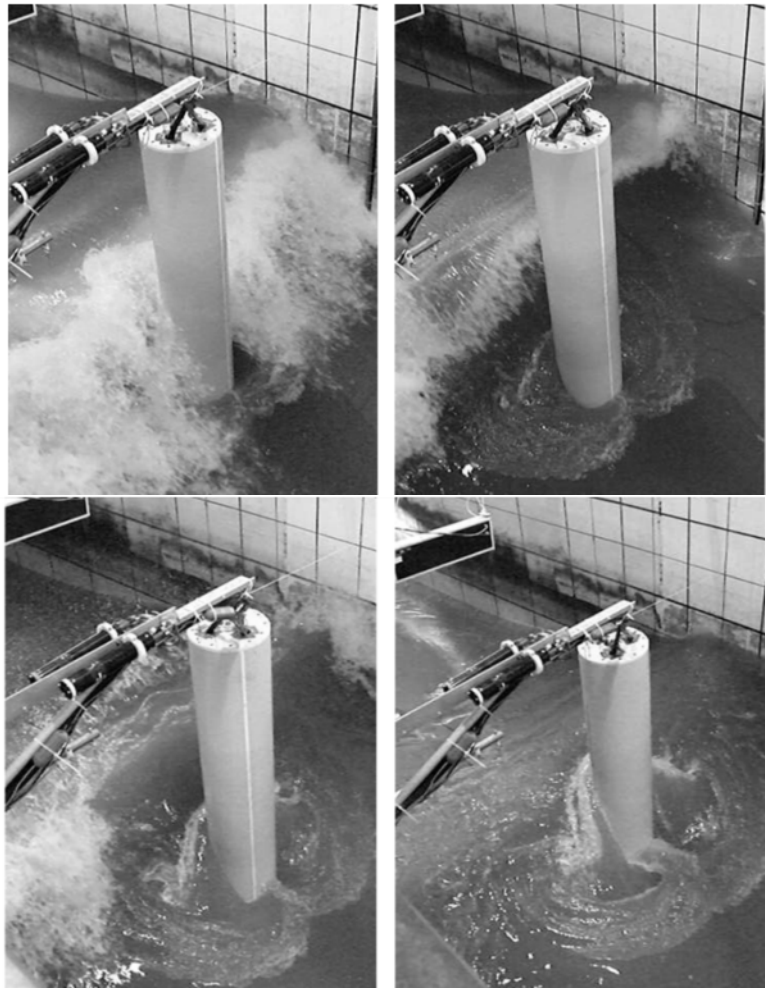


Wave impact on a monopile and pile groups

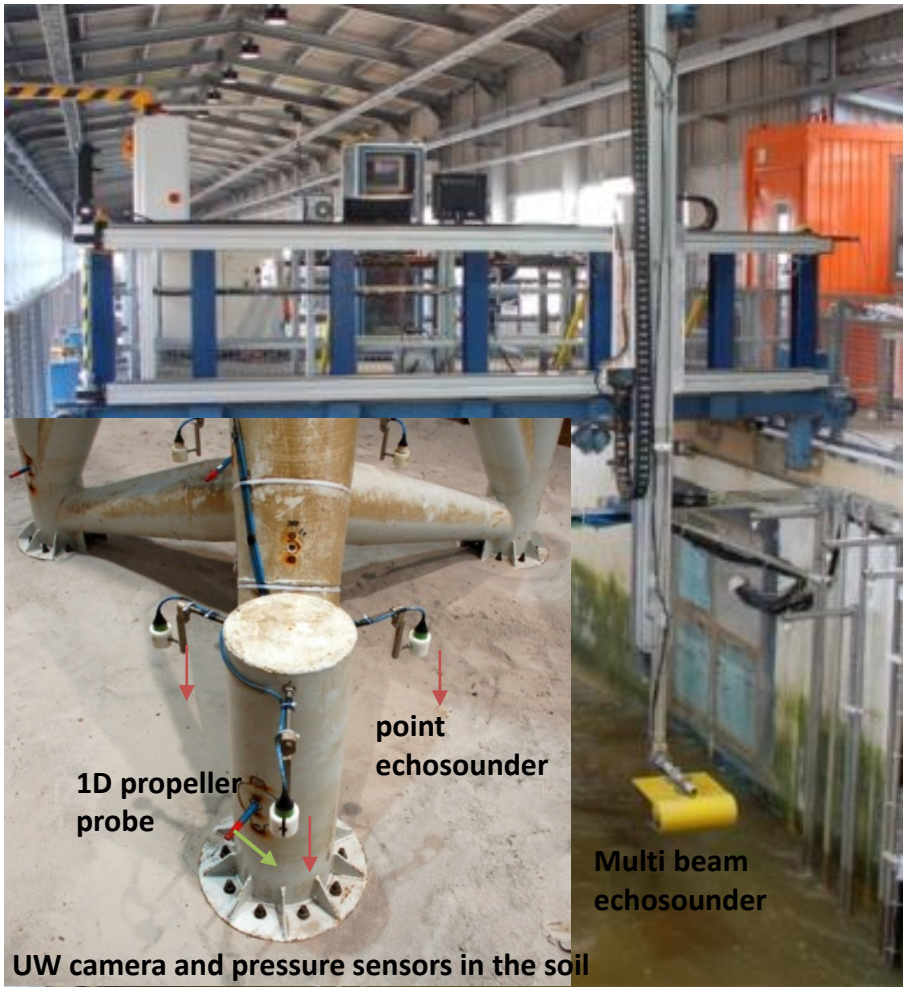
Selected projects in GWK
Marine Energy – Wind Energy

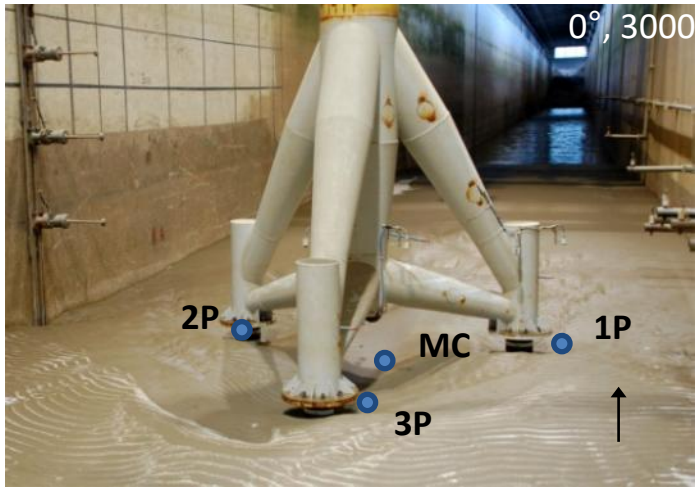
Wave impact on a tripod foundation

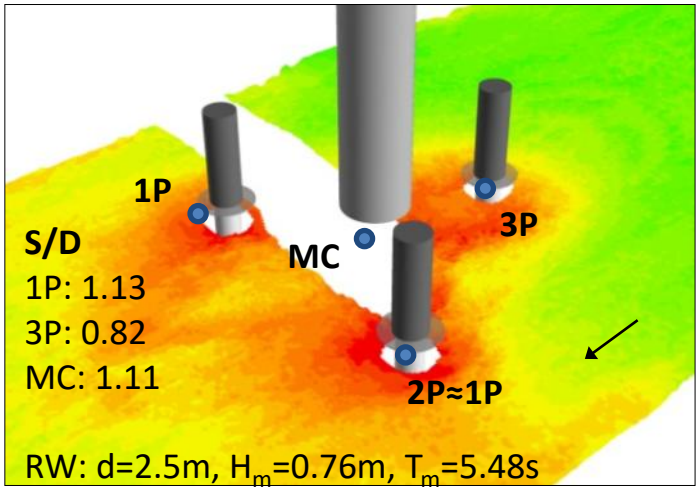




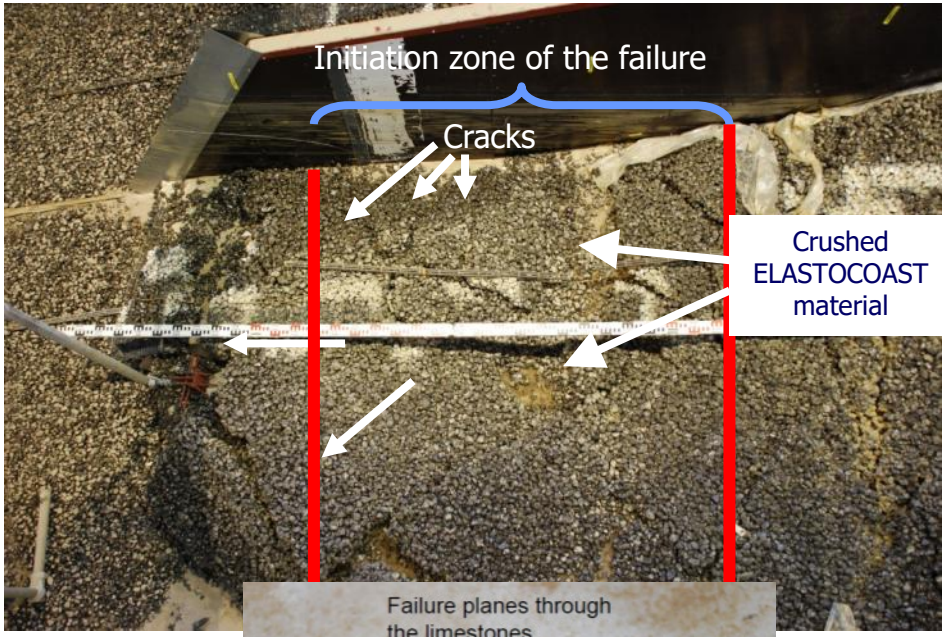
Scour around a tripod foundation



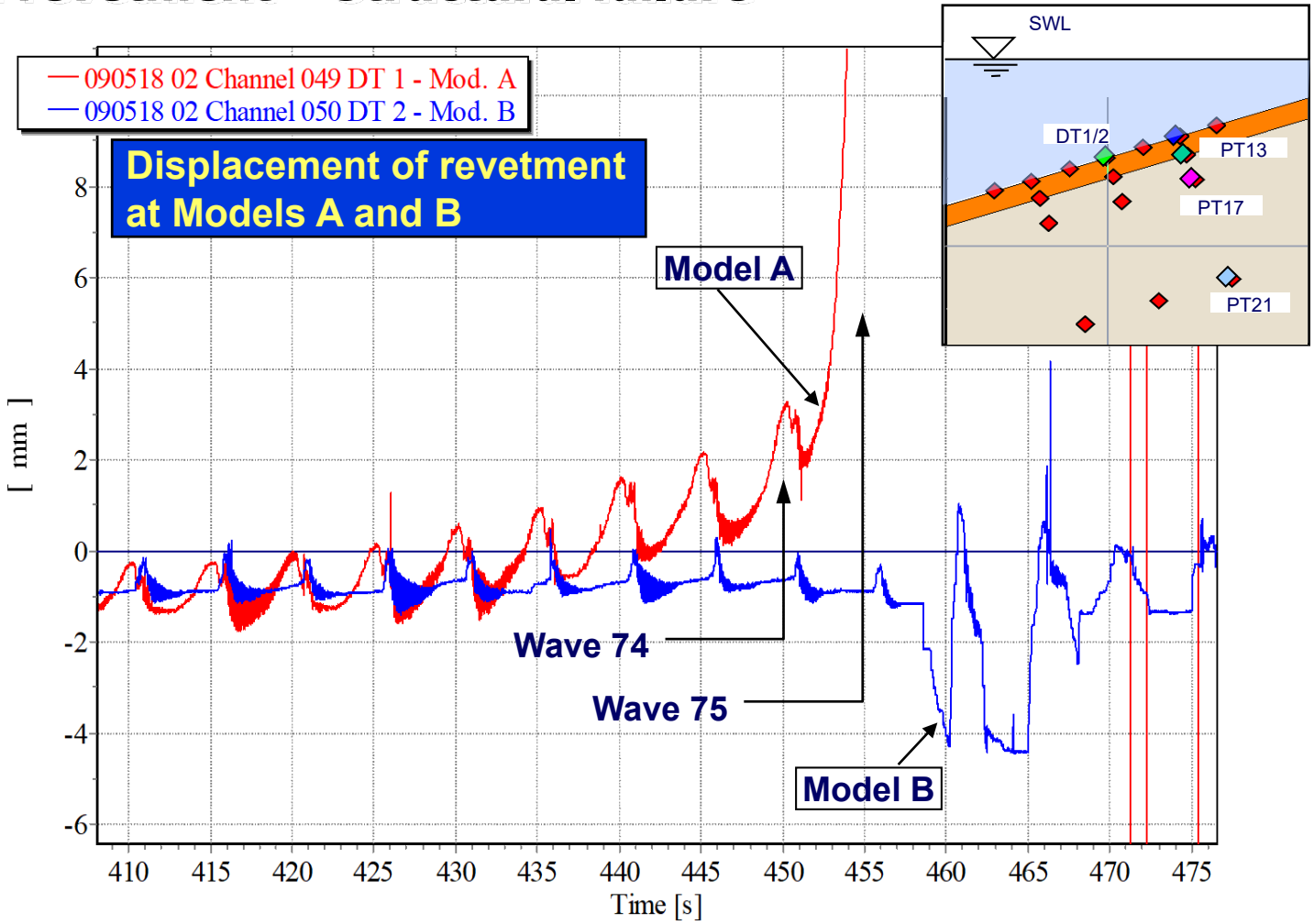




Bonded revetment – Structural failure

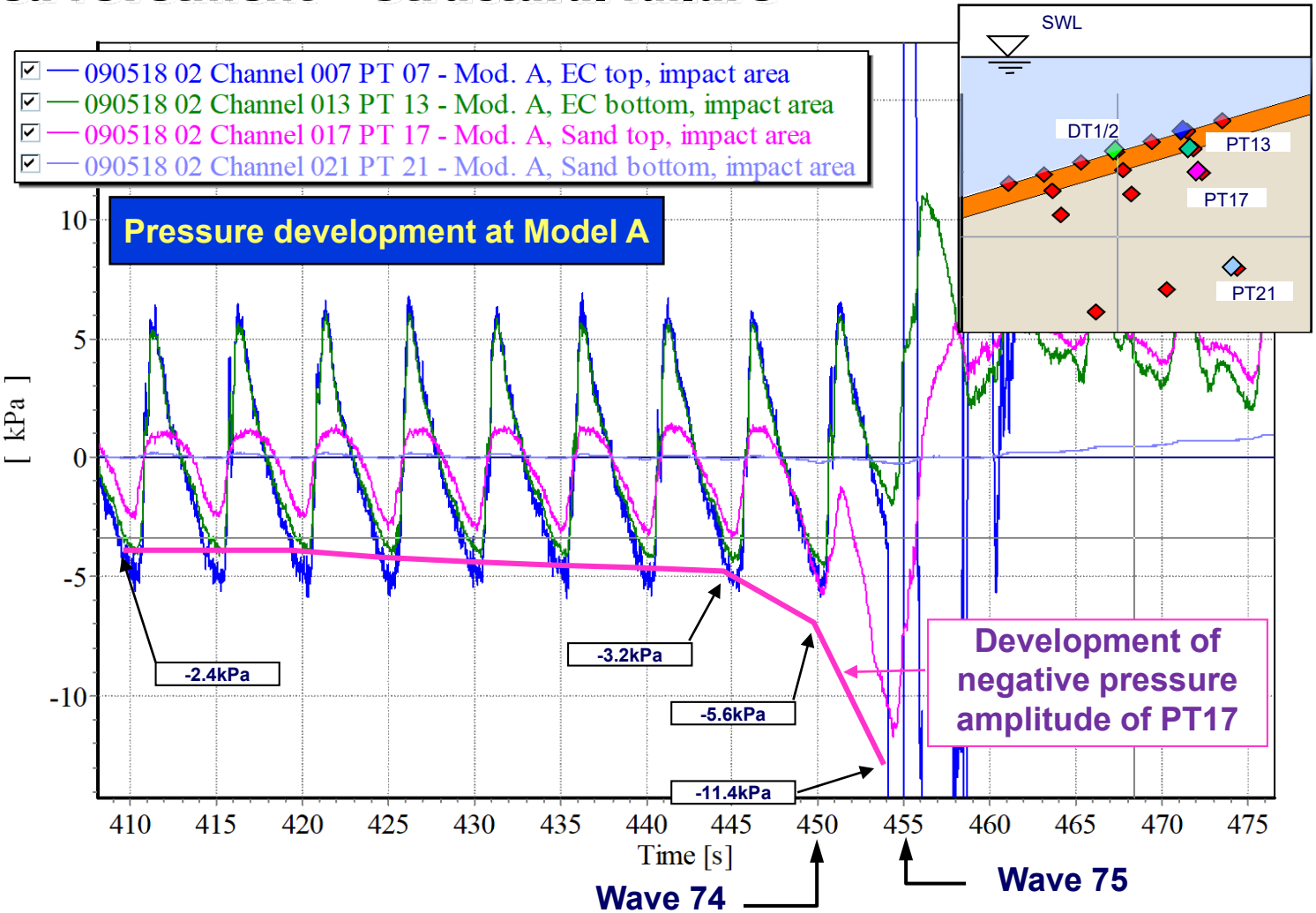


Bonded revetment – Structural failure



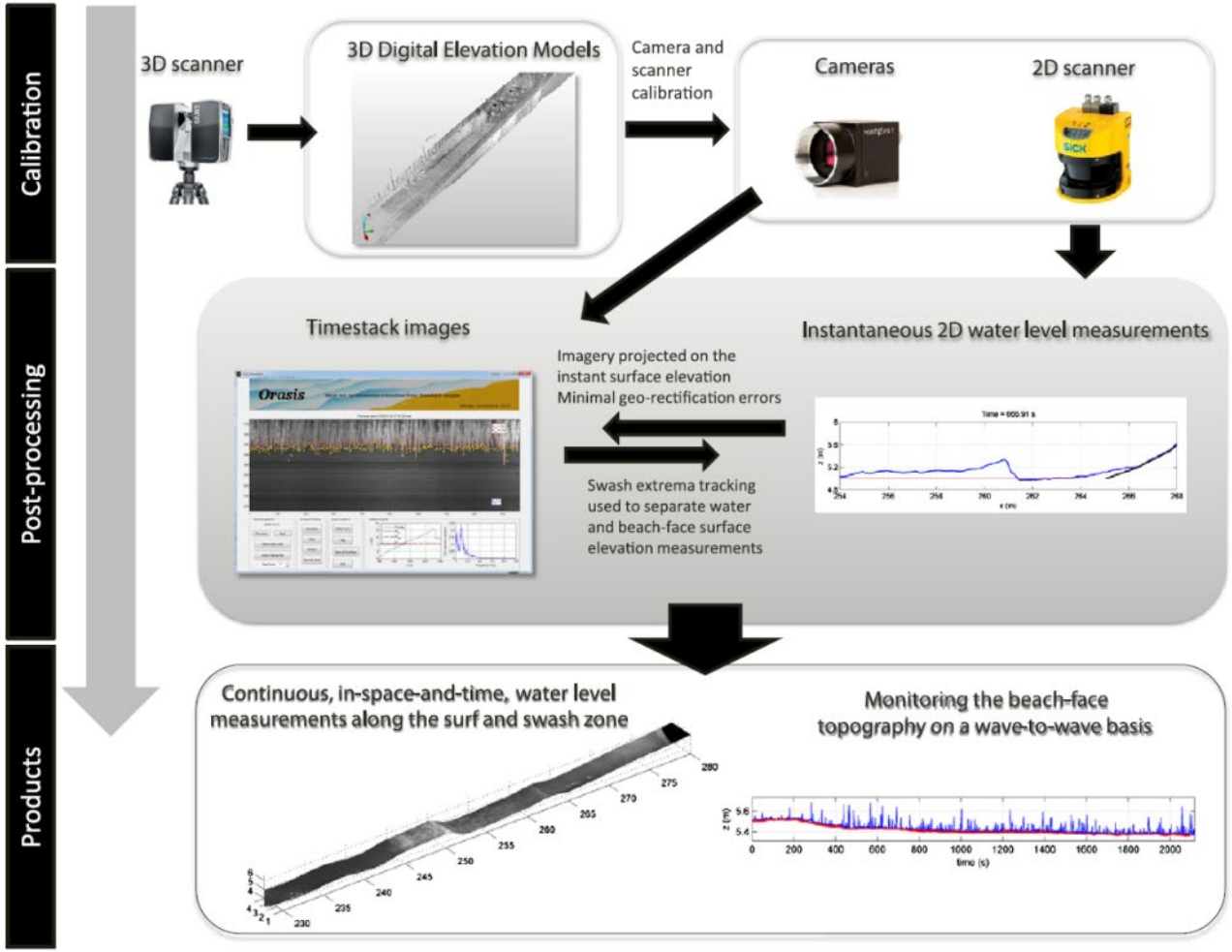
Selected projects in GWK
Coastal structures - today

Bonded revetment – Structural failure



Selected projects in GWK
Sediment transport - today

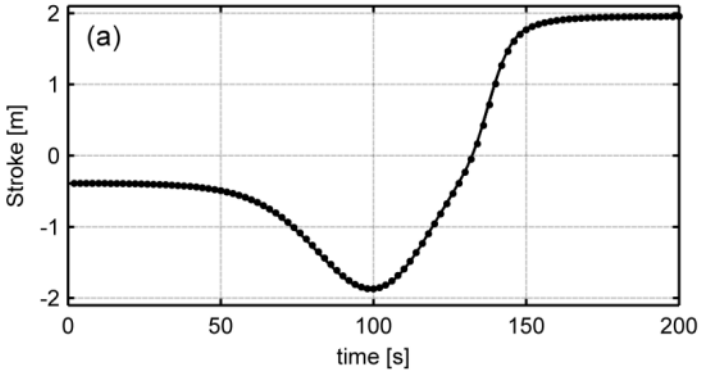
WISE Experiments (2013) – Video laser scan combination

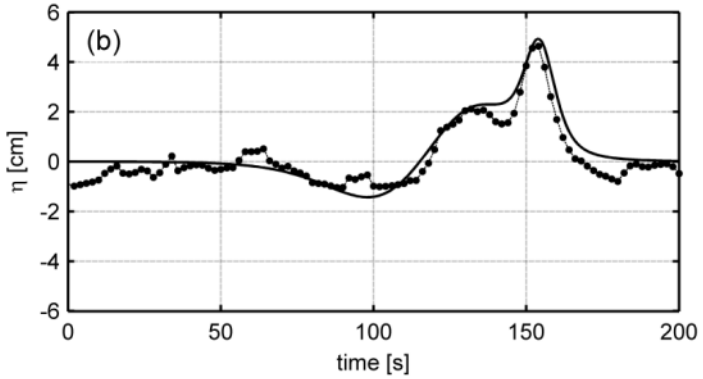


Conclusions and Outlook

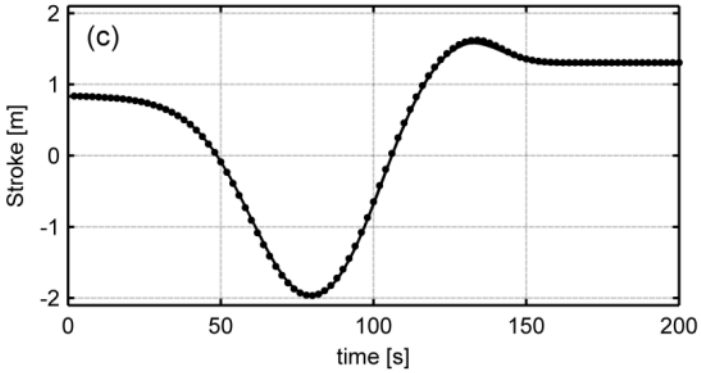
Generation of „real“ tsunamis

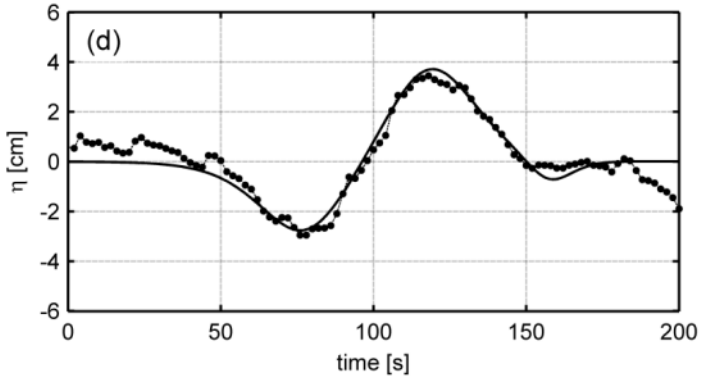
"Iwate South" (2011)





"Mercator" (2004)





<u>lines:</u>

target profile

<u>dots:</u>

measurements