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Stability of Breakwaters Armored with Heavy Concrete Cubes

Project: Peute Breakwater Phase 1

WOWW2010, Berlin
30.09.2010

Dipl.-Ing. Mayumi Wilms
Dipl.-Ing. Nils Goseberg
Prof. Dr.-Ing. habil. Torsten Schlurmann

Franzius-Institute for Hydraulic, Waterways and Coastal Engineering
Leibniz University, Hannover, Germany
www.franzius-institut.de, wilms@fi.uni-hannover.de

Motivation

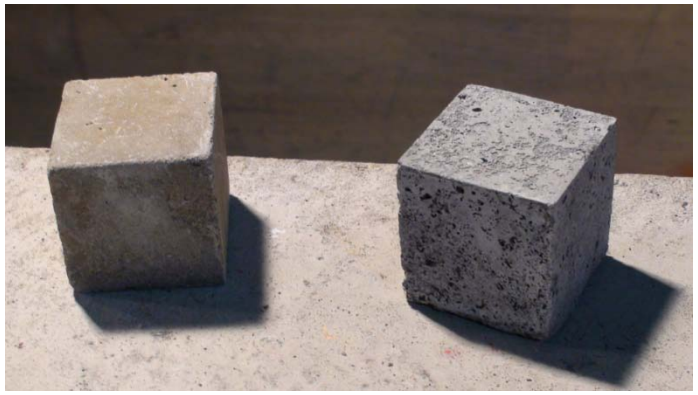
- *Peute Baustoff GmbH* produces and distributes iron-silicate products
- High specific density of iron-silicate (bulk density $\rho = 3{,}7\ t/m^3$)
  - → Reduction of structure dimensions
    - → Reduction of overall material usage
- Insufficient insights about the usage of iron-silicate as a concrete aggregate in coastal protection structures
  - → Hydraulic model tests to determine the position stability of an armor layer with iron-silicate as a concrete aggregate
  - → Influence of the density of armor stones on the hydraulic stability

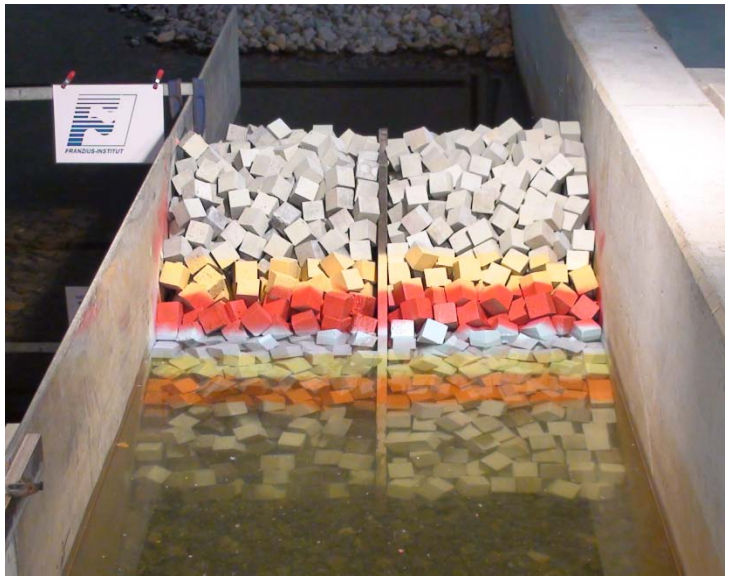
Source: Peute

Preliminary Design

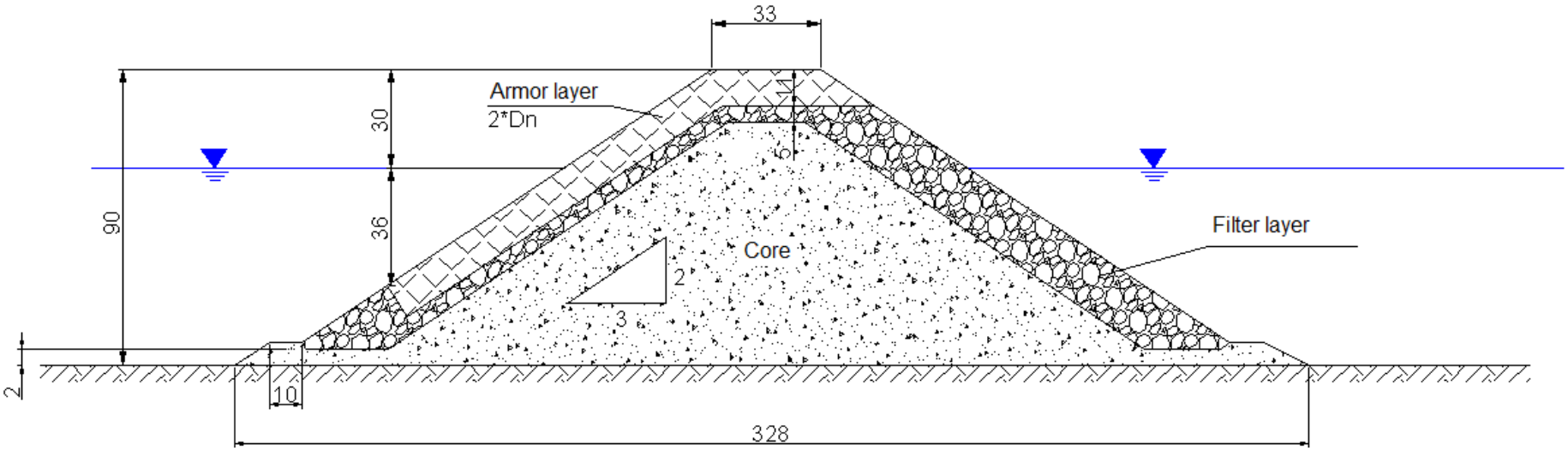
- Type of armor stones: cubes
  - Nominal diameter = length of edges = D_n = 5 cm
  - Design by formulae of Hudson (1959) and van der Meer (1993)
- Comparison between breakwaters armored with normal concrete cubes (NC) and with iron-silicate aggregated concrete cubes (heavy concrete, HC)
  - Bulk density HC cube: ρ = 3,2 t/m^3
  - Bulk density NC cube: ρ = 2,3 t/m^3

normal concrete heavy concrete





Test Setup

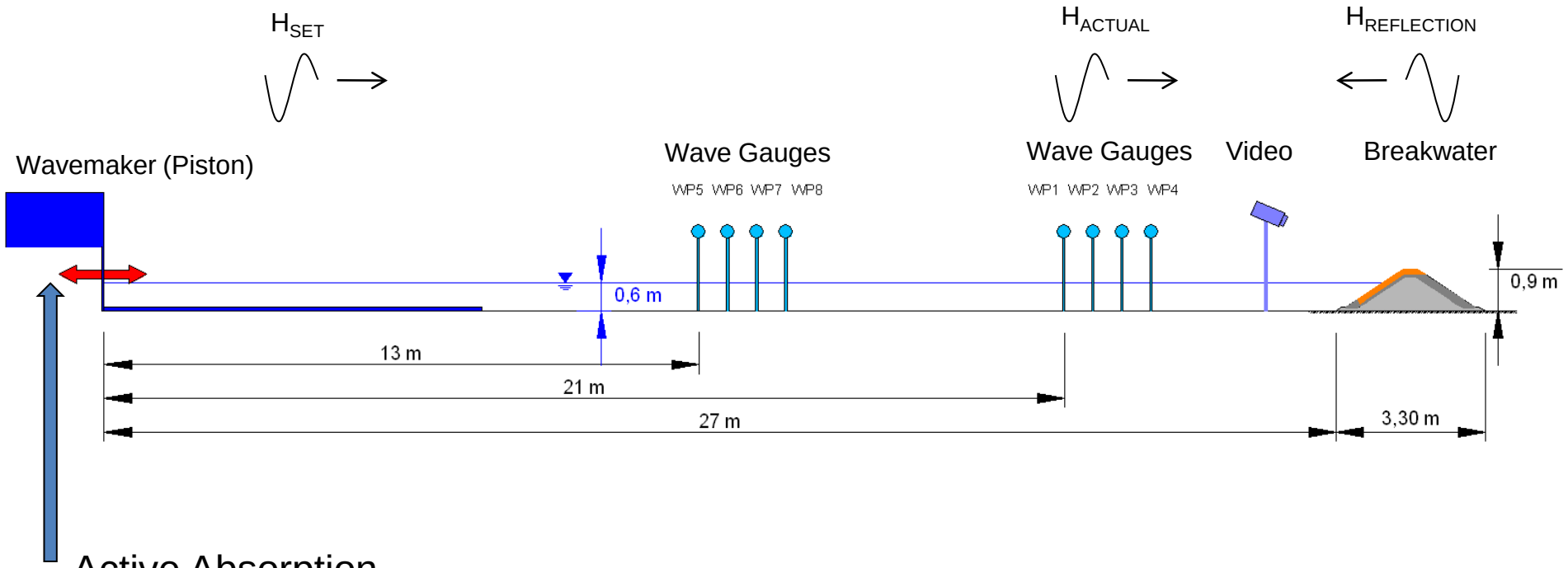


Parameters	Model	Nature
H_{design}	0,24 m	6 m
T_{design}	2,40 s	12 s
Water depth	0,60 m	15 m
Duration of design storm event	48 min	4 h

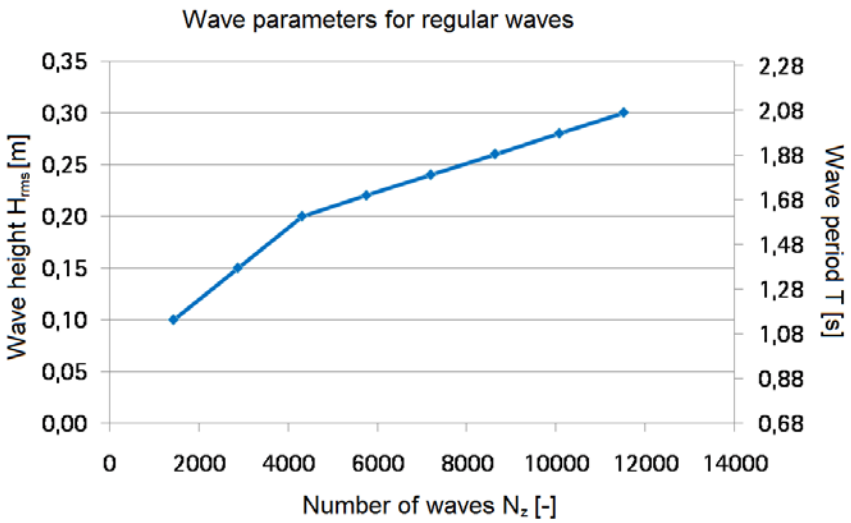
Scale 1:25
Froude scaling

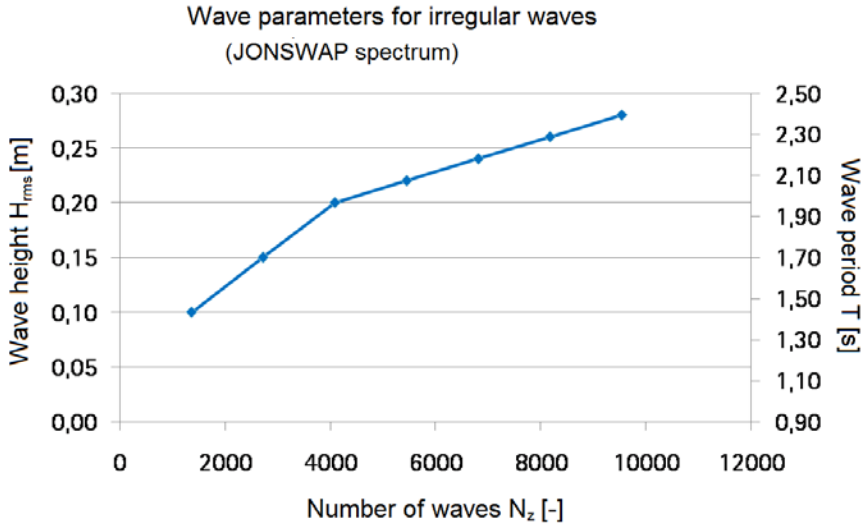
Random placement of cubes

Test Setup - Wave flume (longitudinal section)



Test Procedure

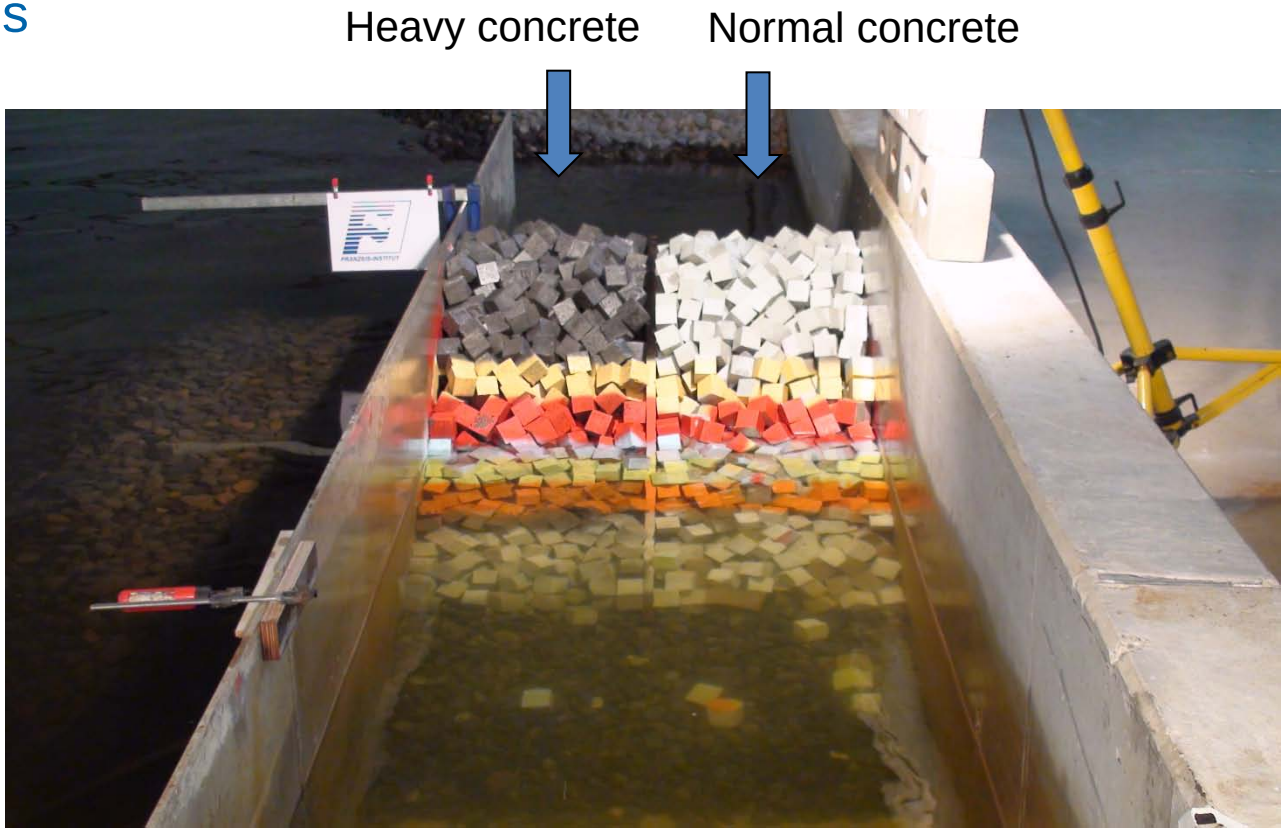




Test Procedure

Video

Analysis



In every test run, three pictures were taken and analyzed.

Two classes were defined for rearranged cubes:

1. Cubes moved more than 0,5*D_n („rocking“)
2. Cubes moved more than 1*D_n

Test Results

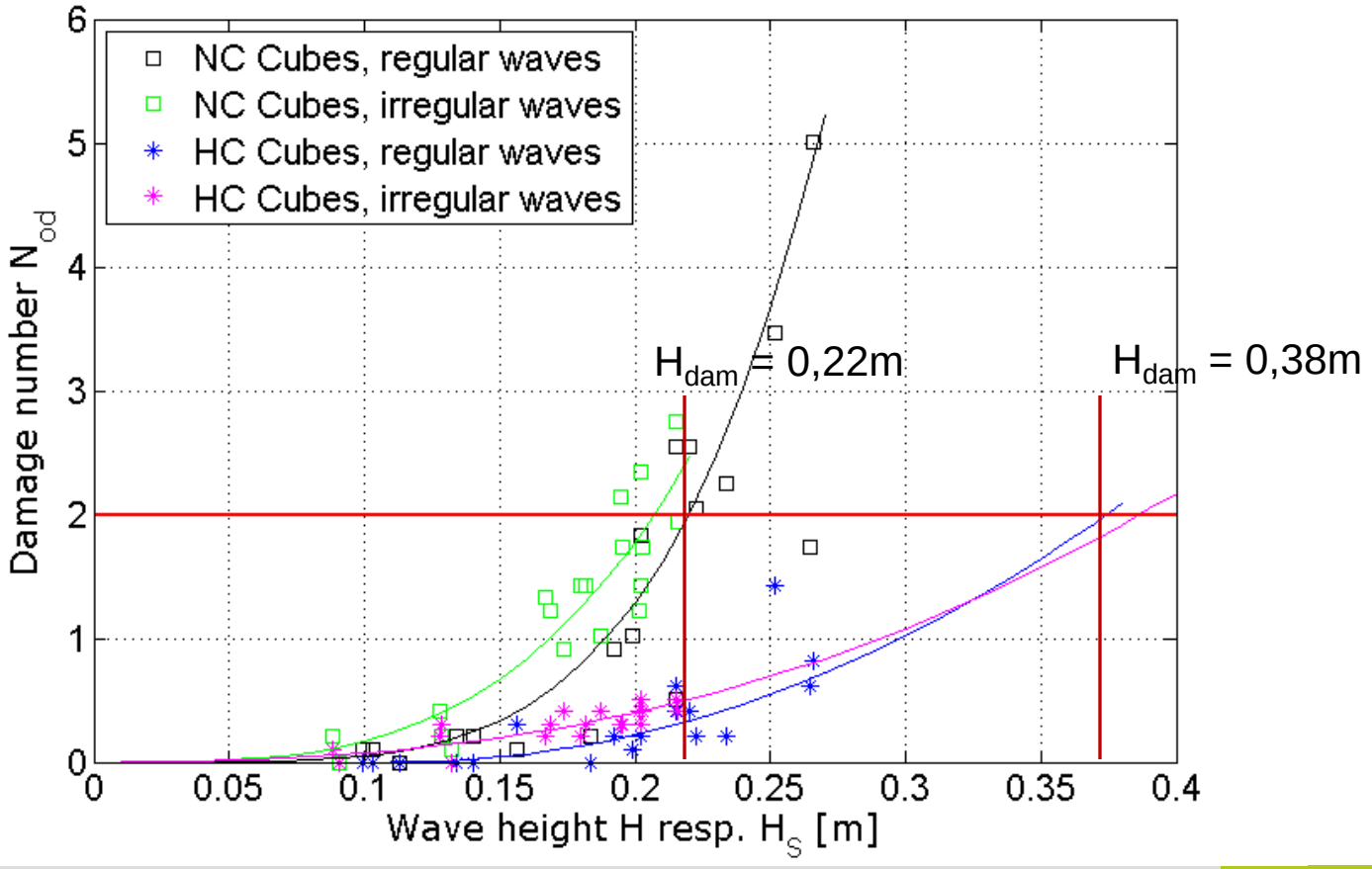
- Definition of damage (Van der Meer,1988)
  - Damage number N_{OD}, defined as

$$N_{OD} = \frac{\text{number of units displaced out of armor layer}}{\text{width of tested section} / D_n}$$

- According to van der Meer, an armor layer consisting of cubes finally fails at **N_{OD} = 2**

Test Results

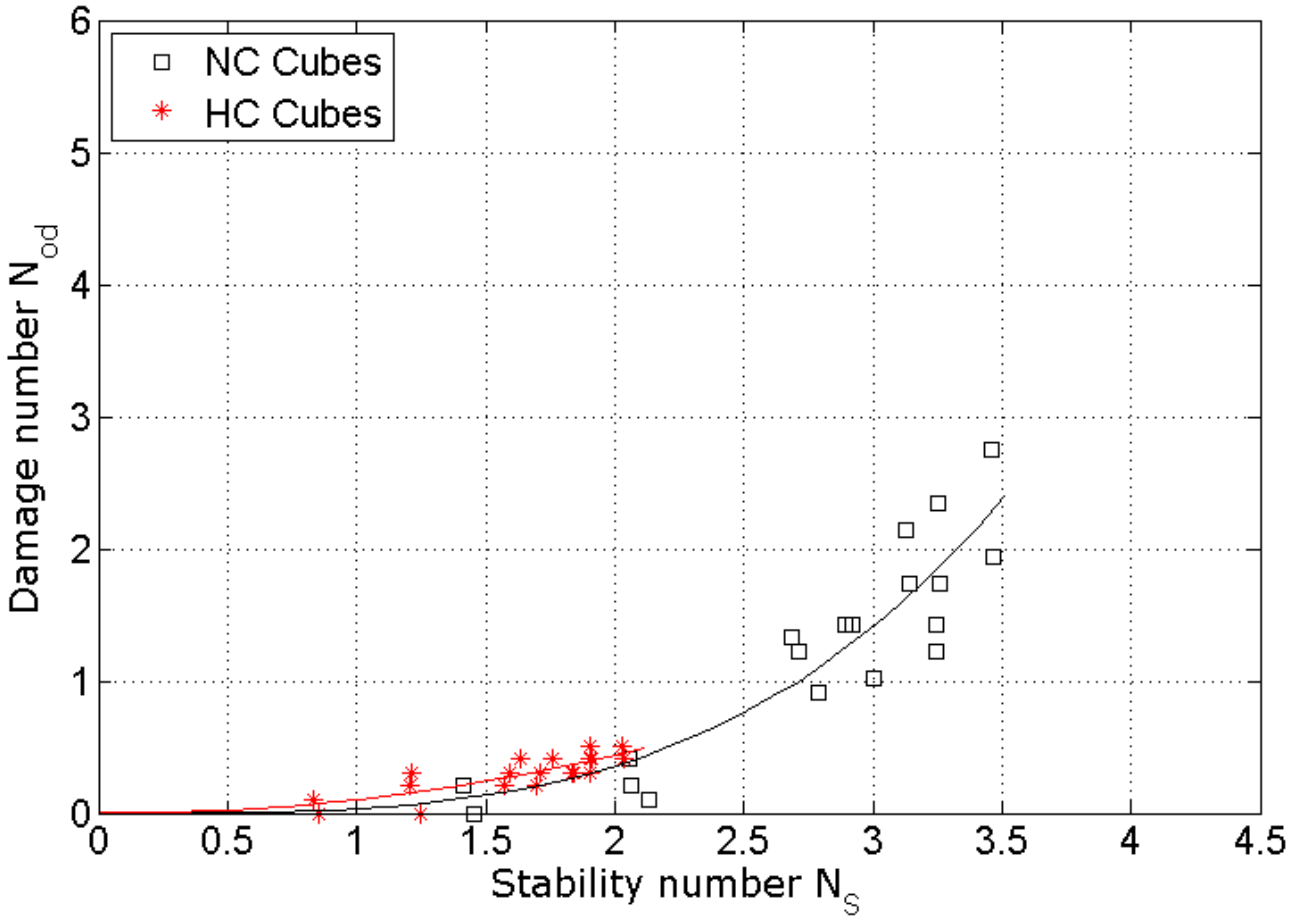
Damage number N_{OD} against incoming wave height



Results

Impact of the stone density on the position stability of the armourlayer

Damage number N_{OD} against the stability number exemplified for the test with irregular waves



Stability number N_S by Hudson (1959):

$$N_S = \frac{H}{\left(\frac{\rho_S}{\rho_W} - 1\right) \cdot D_n}$$

Results – Reduction of the structure geometry

	ρ_{NC} = 2.3 t/m³	ρ_{HC} = 3.2 t/m³	Reduction
Edge length D_n	100 %	59 %	41 %
Layer thickness (2 layer)	100 %	59 %	41 %
Volume V	100 %	20 %	80 %
Weight G	100 %	28 %	72 %

Conclusion

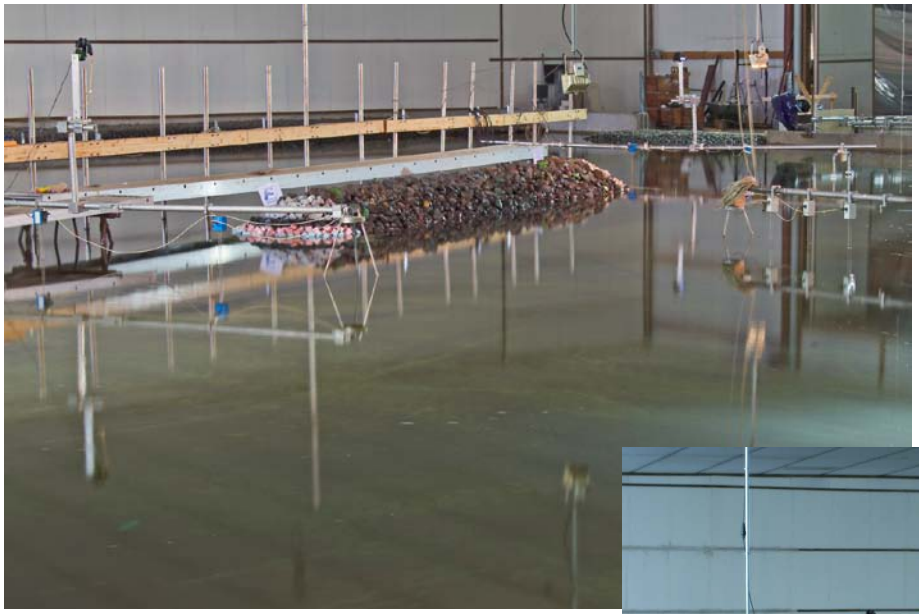
- An armor layer with heavy concrete cubes features a clearly higher position stability as one constructed with normal concrete cubes

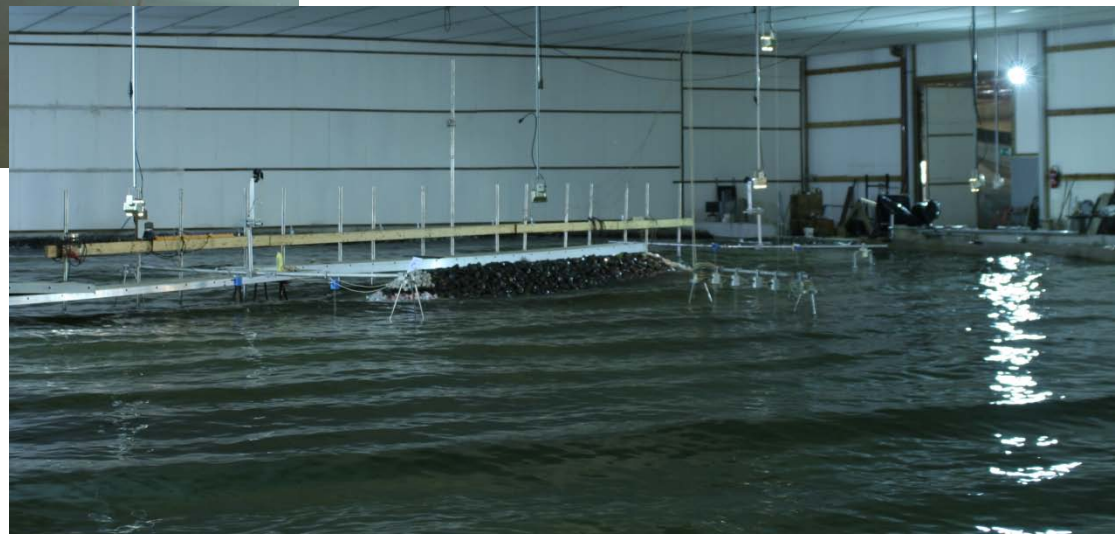
- For the armor layer contructed with heavy concrete cubes a 40% larger destroying wave height is required than for an armor layer contructed with normal concrete cubes

- The density of stones features a nearly linear influence on the position stability for cubes

Outlook

Phase 2: Analysis of a breakwater head with a sloping wave run-up





Thank you