ICCE 2018
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Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

WAVE IMPACTS AT SMALL AND REAL SCALE FOR THE STEPPED SLOPED SEAWALL DESIGN AT DEN OEVER

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WAVE IMPACTS AT SMALL AND REAL SCALE FOR THE STEPPED SLOPED SEAWALL DESIGN AT DEN OEVER

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- ❑ Small scale model Tests
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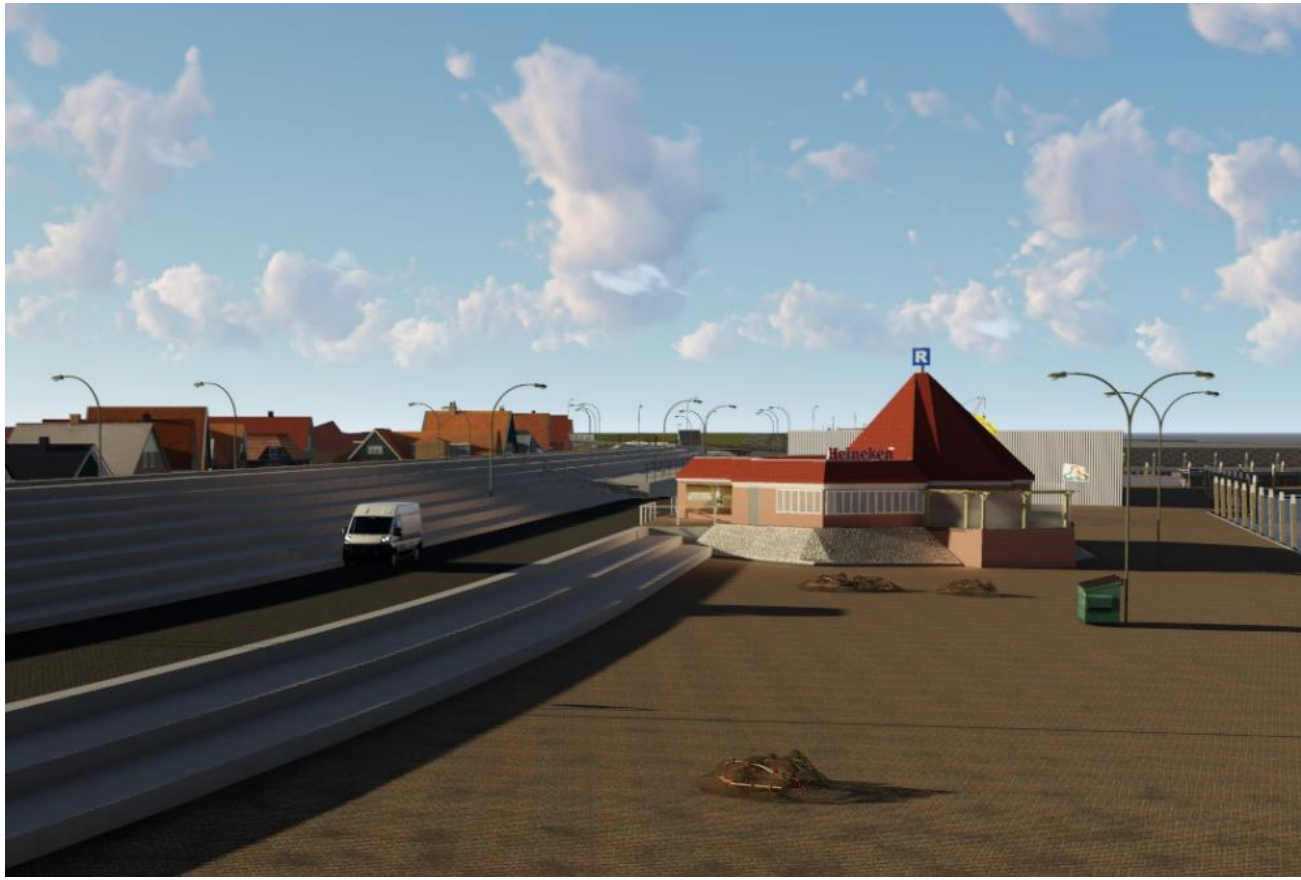
- ❑ Comparison
- ❑ Conclusions

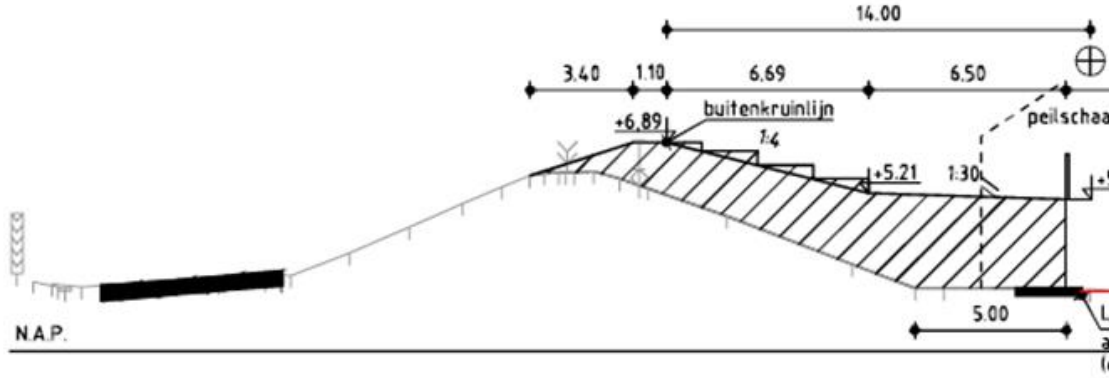
Introduction

- Den Oever: Dike reinforcement needed
- Limit height: stepped revetment
- Model tests
  - Roughness factor (overtopping)
  - Preliminary design crest height
  - Wave forces
- Full scale tests on wave forces



Small scale model tests

- Performed at Scheldt flume Deltares
- Scale 1:10
- Part of test preliminary design
- 2 pressure transducers lower step and 2 in second step
- Hydraulic conditions:
  - H_s = 1,41 m
  - $T_{m-1,0}$ = 5,2 s



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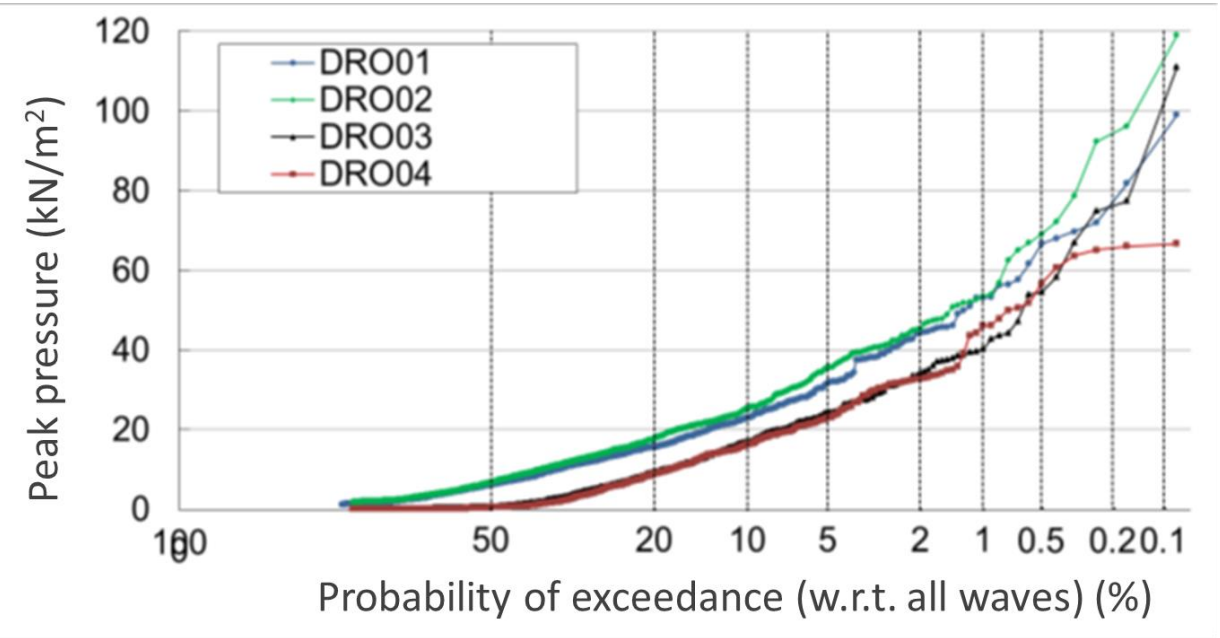
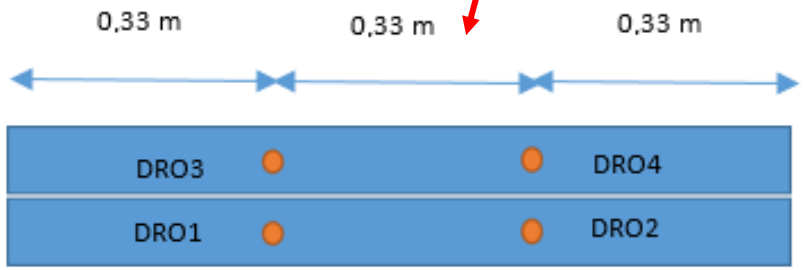
Small scale model tests – peak pressures



Presure sensor	Peak pressure (kN/m²)
DRO01	99
DRO02	119
DRO03	110
DRO04	66

Pl. Design: 120 kN/m²






Small scale model tests – wave forces

Presure sensor	Peak pressure (kN/m^2)
DRO01	99
DRO02	119
DRO03	110
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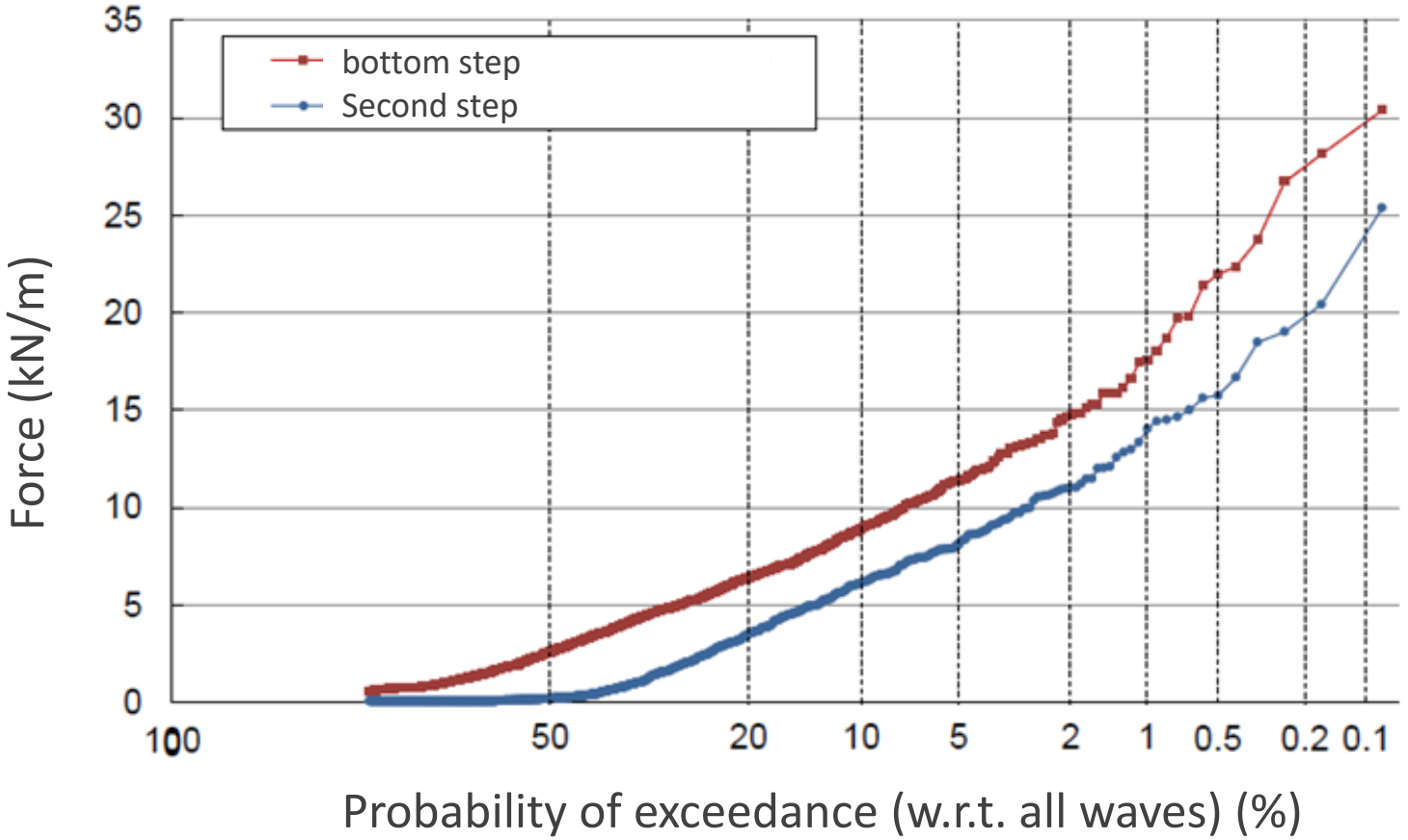

- Peak values in the pressure sensors left and right do not appear at the exact same time
- Forces on bottom step higher than second step

Small scale model tests – wave forces

Preliminary design max. pressure 120 kN/m^2 * 0,46 m = max force		55 kN/m
Small scale tests exceedance probability averaged force at T_i	$F_{0,1\%}$ =	30 kN/m

Small scale model tests – wave forces

- Probably scale and model effects (e.g. fresh – salt water)
- Real pressures may differ factor 2 (smaller)

- Full scale test with the Wave Run up Simulator (WRS) was suggested
- First comparison of front velocities small scale test and previous tests with WRS showed good results
- Comparison layer thickness small scale tests and WRS tests showed clear differences (max. 1.2 m versus max. 0.7 m).

- As bottom step is normative → WRS tests performed

Full scale model tests

- Performed with Wave Run Up Simulator (7.3 m heigh, 2 m width)
- Scale 1:1, salt water
- 8 pressure transducers lower step
- 2000 Hz


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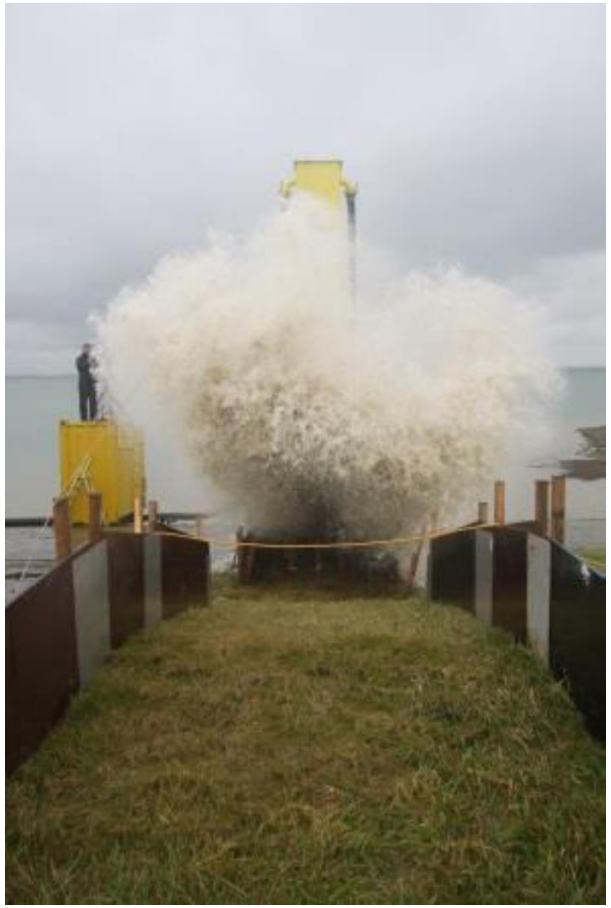
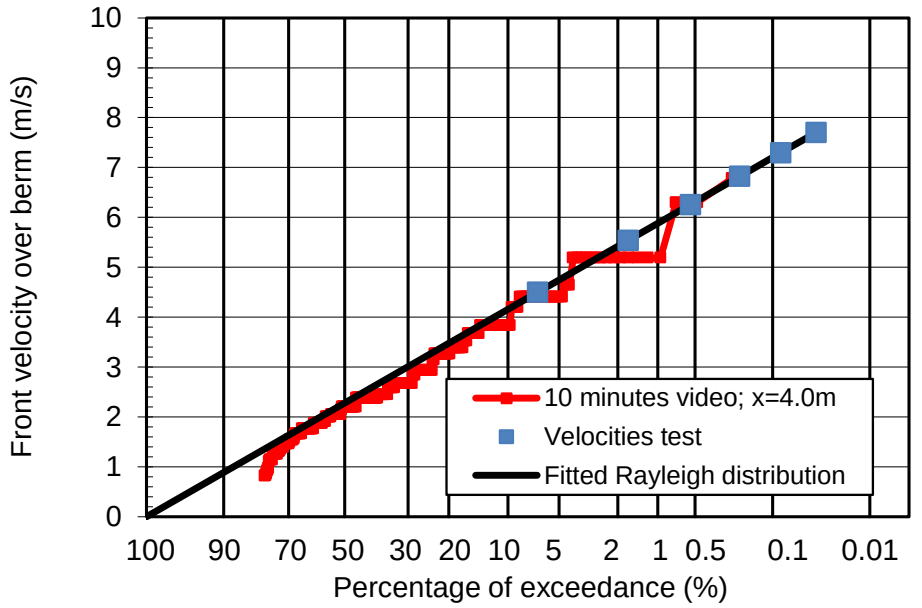
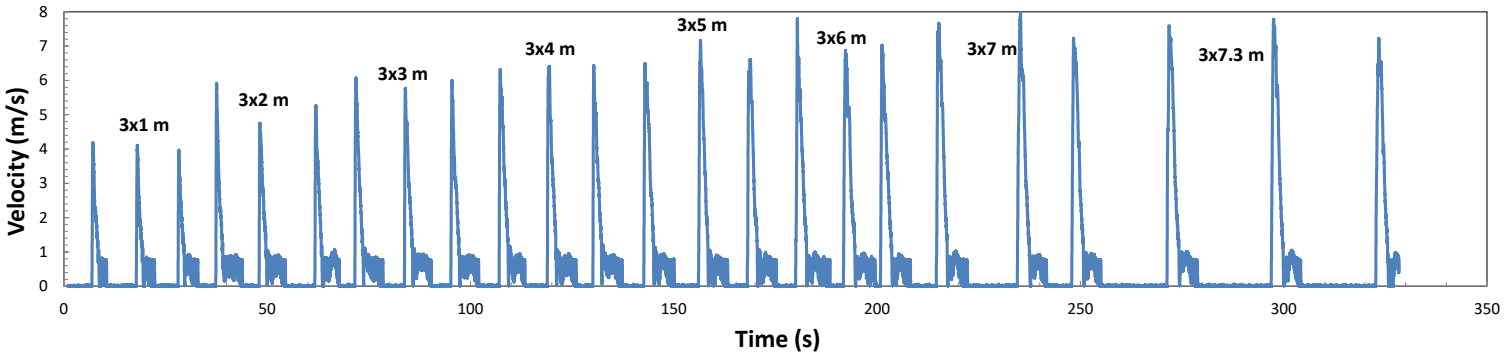
Full scale model tests



Full scale model tests – front velocity

impact	h_{vul} [m]	Impact	h_{vul} [m]	Impact	h_{vul} [m]
1	1	9	3	17	6
2	1	10	4	18	6
3	1	11	4	19	7
4	2	12	4	20	7
5	2	13	5	21	7
6	2	14	5	22	7,3
7	3	15	5	23	7,3
8	3	16	6	24	7,3
				25	4
				26	4
				27	5
				28	5

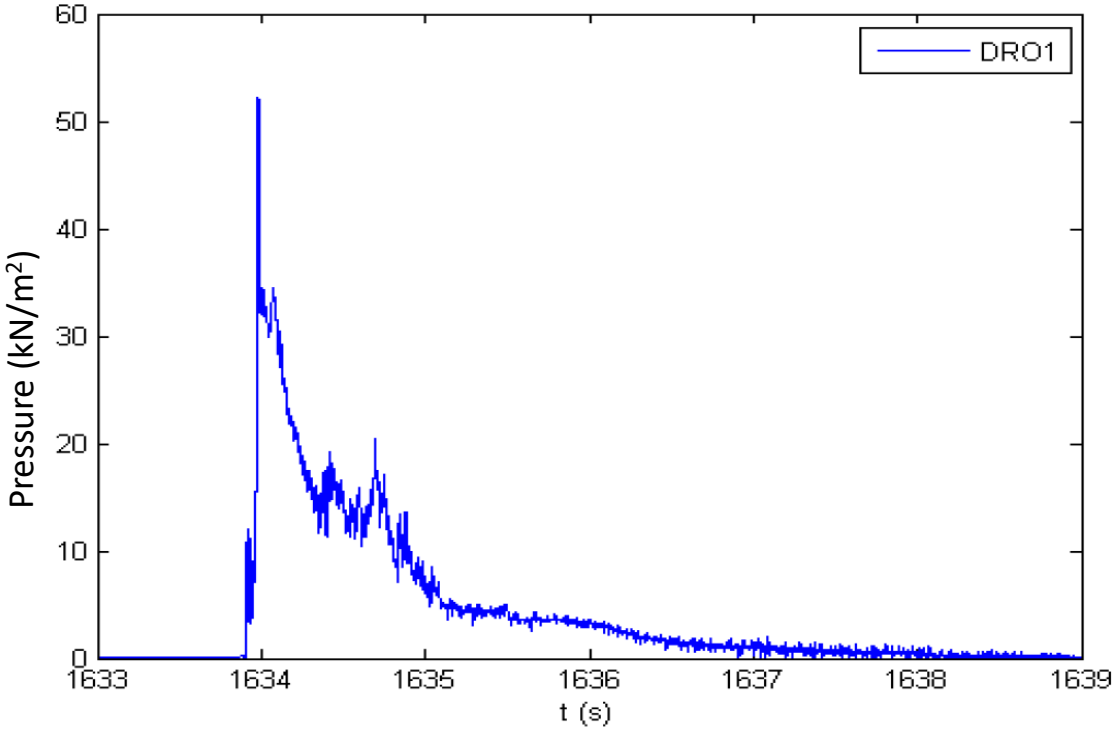




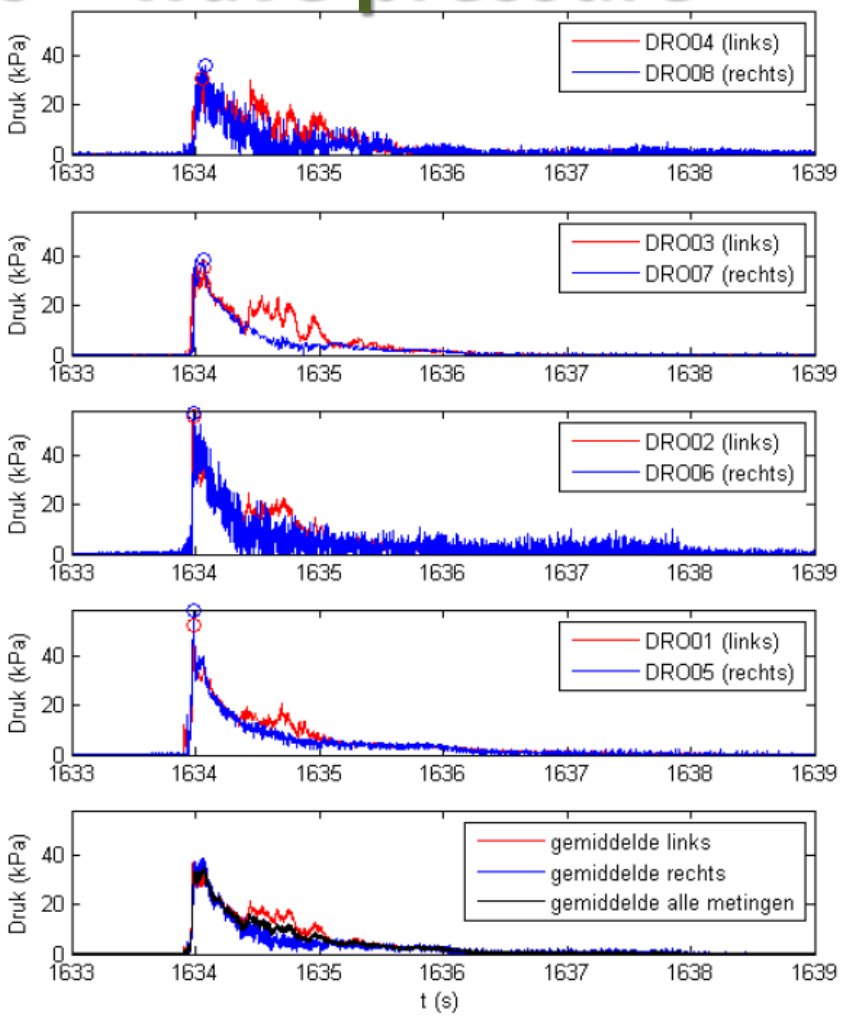
Relation fill height of simulator, front velocity and probability of exceedance.

Fill level (m)	Front velocity (m/s)	Exceedance prob. (%)
1	4.50	6.739
2	5.54	1.677
3	6.26	0.544
4	6.82	0.204
5	7.29	0.084
6	7.70	0.037
7	-	-
7.3	-	-

Full scale model tests – wave pressure

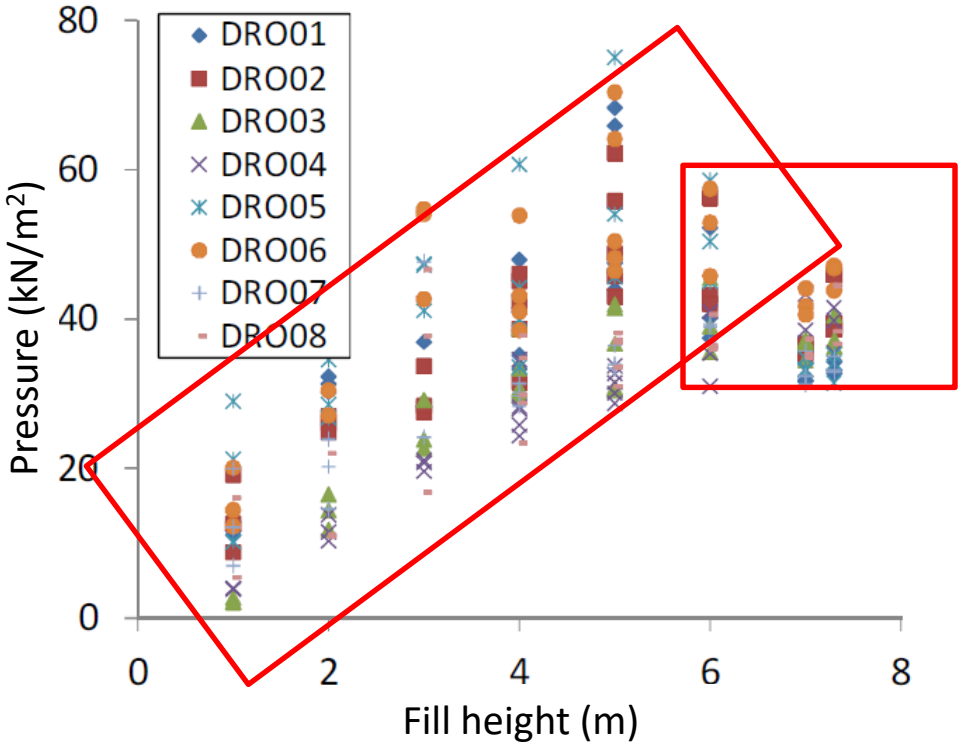


Pressure measured at impact 6 at pressure sensor DRO01 (peak 50 kN/m²)



Pressure at impact 6 of all sensors. Peak values range between 31 kN/m² and 59 kN/m²

Full scale model tests – wave pressure

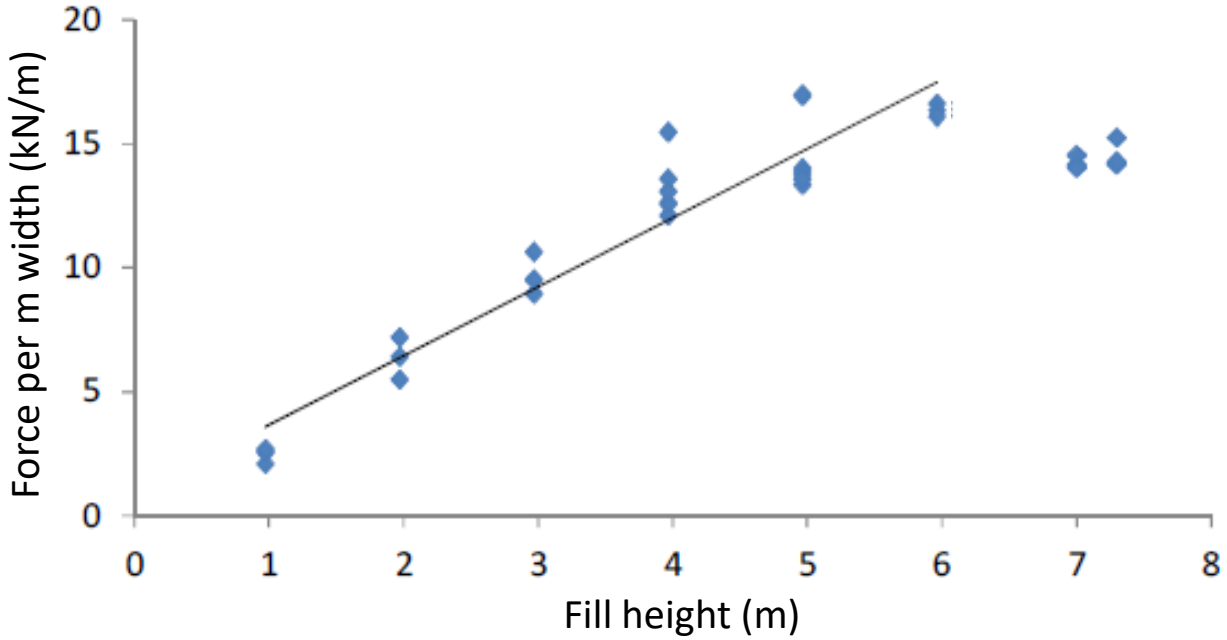


Peak pressures of all sensors related to fill height of simulator (filtered for outlayers)

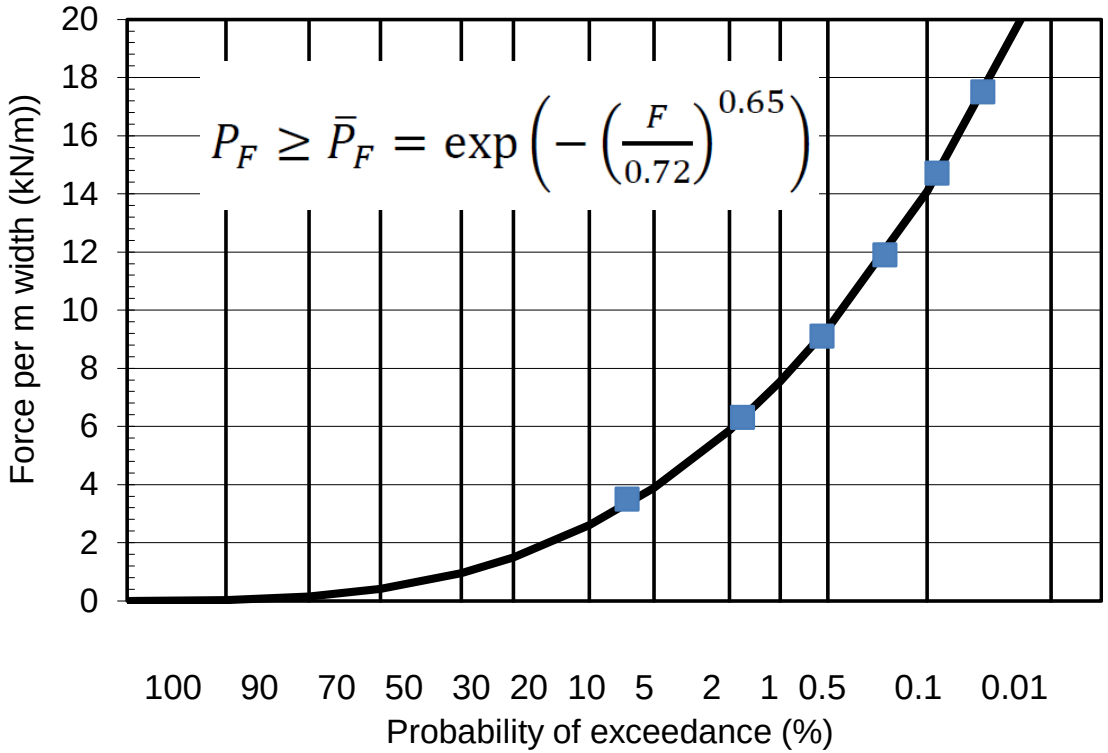
- No increase above 6 m fill height probably related to design of simulator

Full scale model tests – wave forces

$F = 2{,}8\ h_{fill} + 0{,}7$ for $1m \leq h_{fill} \leq 6\ m$

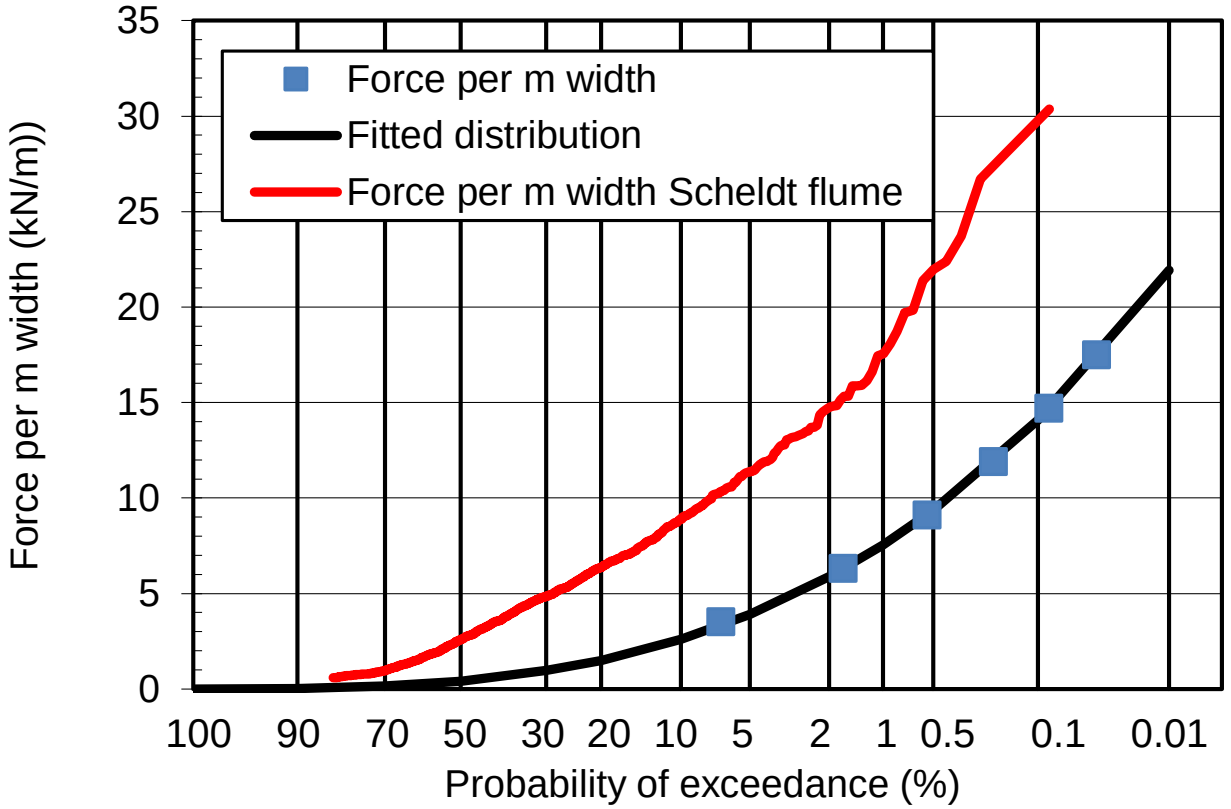


Forces related to fill height of simulator



$F = 0.72 \cdot [-\ln(1/N)]^{1/0.65}$

Comparison small and full scale model tests



Forces found in full scale tests are much lower than in small scale tests – factor 2

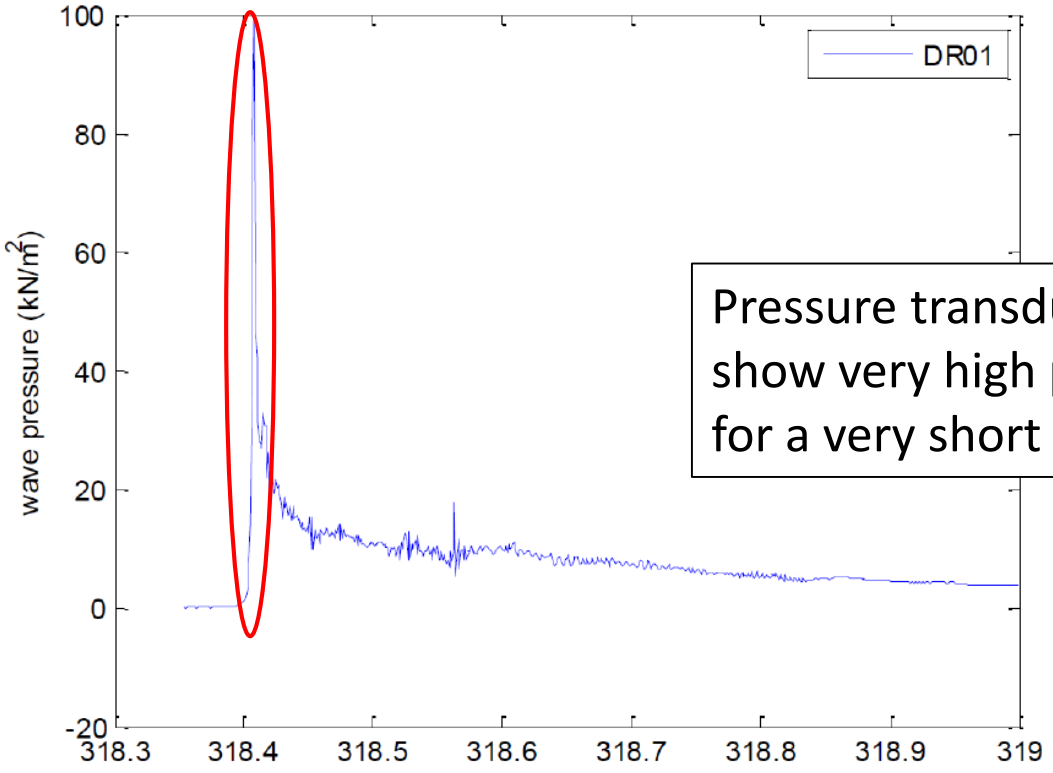
$F_{0,1\%,\ small}$ = 30 kN/m versus $F_{0,1\%,\ full}$ = 15 kN/m

Comparison small and full scale model tests

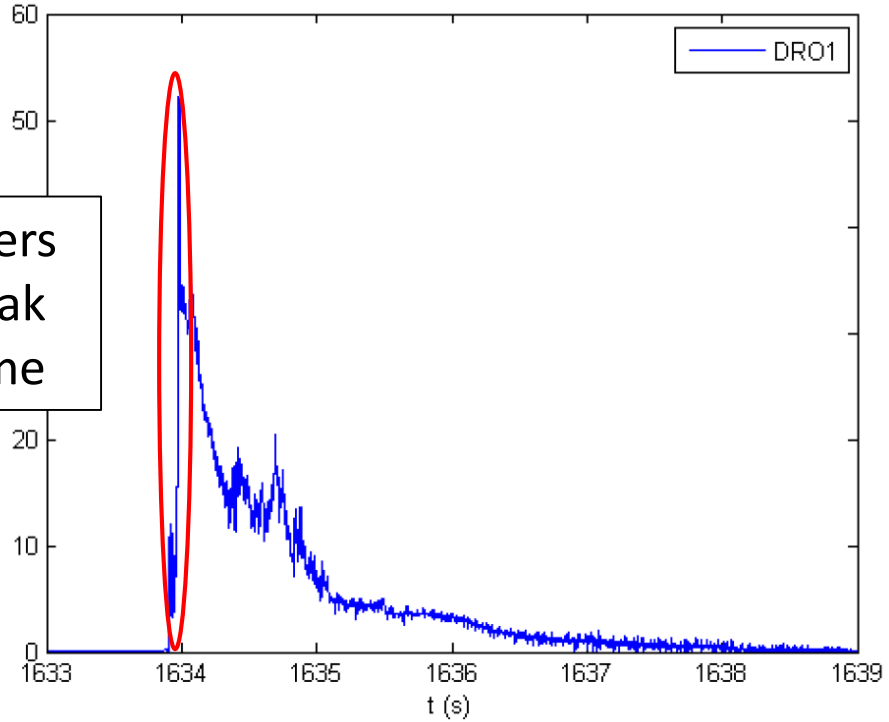
Preliminary design max. pressure: 120 kN/m^2 * 0,46 m =	55 kN/m
Small scale tests exceedance probability averaged forces at T_i	
$F_{0,1\%}$ =	30 kN/m
Full scale tests exceedance probability averaged forces at T_i	
$F_{0,1\%}$ =	15 kN/m

h = 0,46 m

Impulse $\mathbf{I} = \int P_{avg}(t) \,.\, h \;\; dt$



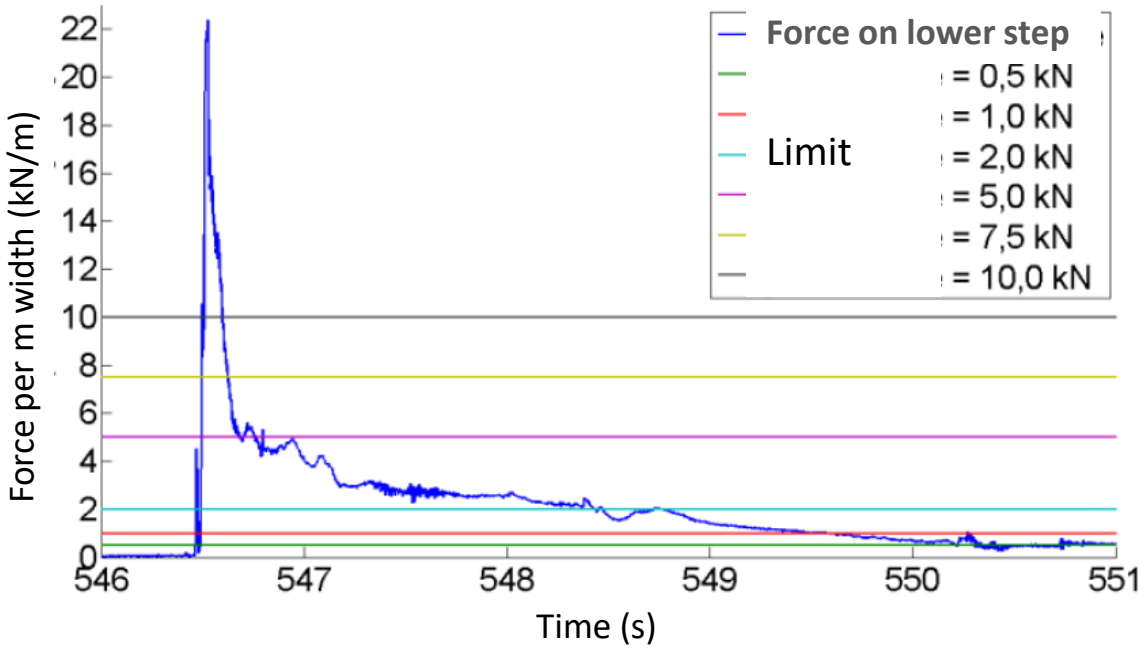
Pressure transducers show very high peak for a very short time



Example Pressure small scale test

Example Pressure full scale test

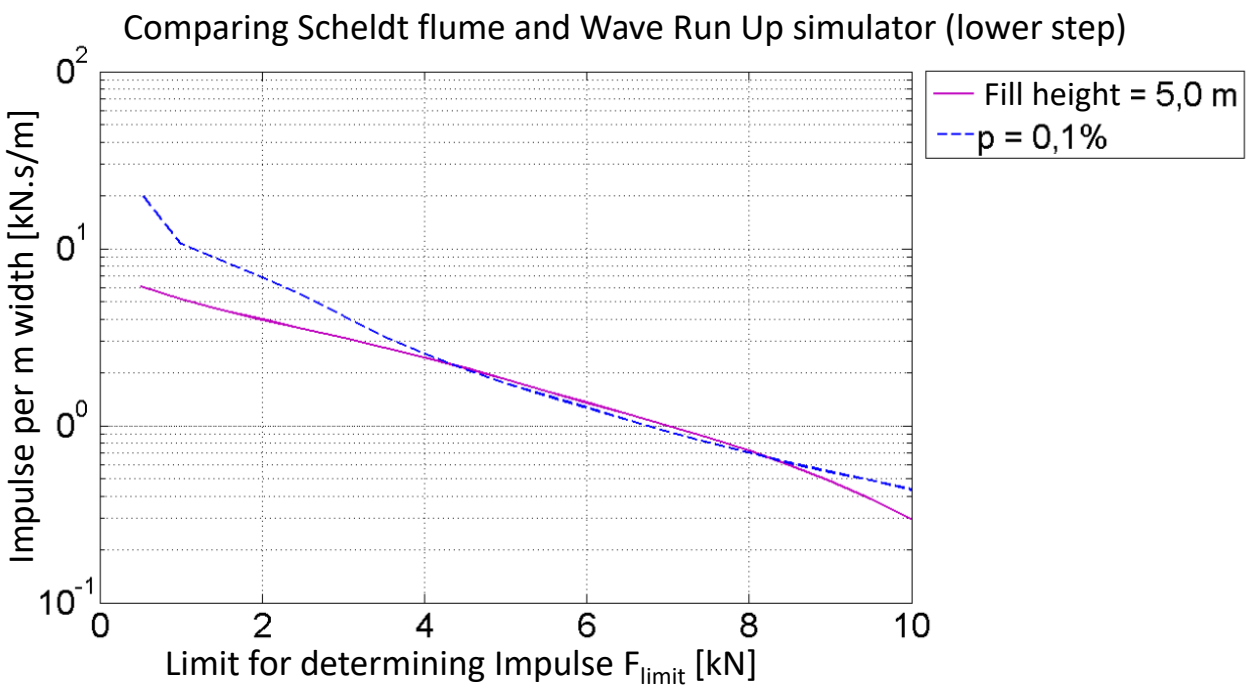
Impulse $\mathbf{I} = \int \boldsymbol{F(t)}\ \boldsymbol{dt}$



Impulse is assumed to be less susceptible to scale effects as peak pressures

Treshold to overcome counterforces preventing the block to move; height counterforces → only peaks cause movements

Impulse



Fill height 5 m corresponds with $P_{0,084\%}$ based on front velocities.

Analysis of the impulse of the fast peak of the impacts showed that they were quite similar in small and real scale. The lower maximum peak for real scale had to be combined with a longer duration of the peak, compared to small scale modelling.

Above threshold 4 kN very good fit between impulses determined for small and full scale tests
➔ corresponds with expectation

Conclusions

- Both analysis of front velocities and impulses showed **good match** between **small and full scale** tests

- At small scale tests scale and **model effects** are present in measured **maximum forces** (probably due to difference in air inclusion, but also due to scale)

- Based on this it is assumed that maximum forces determined with the **Wave Overtopping Simulator may be used**

- Design forces (without safety factor) are found to be a **factor 4 smaller** than determined with maximum measured pressures in small scale tests
  - A **factor 2** was found in **averaging** between **pressure transducers** at same time
  - A **factor 2** was found in **small scale versus full scale** (scale and model effects)

Questions?

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