Physical Modeling and CFD Simulation of Wave Slamming on Offshore Wind Turbine Structures

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Overview:

Potential & Problems

Test field Alpha ventus - RAVE
GIGAWIND av

Laboratory experiments

Numerical simulation

Summary & Perspectives

Quelle: REpower

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Fraunhofer IWES Institut Windenergie und Energiesystemtechnik

Leibniz Universität Hannover

RAVE RESEARCH AT ALPHA VENTUS

REpower Systems

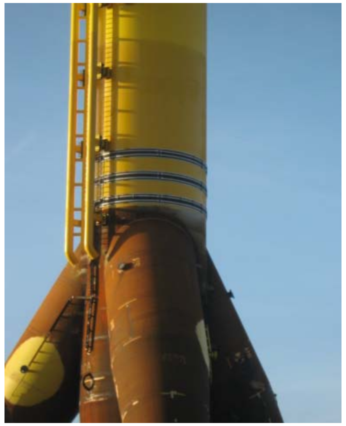
AREVA MULTIBRID

Approved projects in the German area of the North Sea

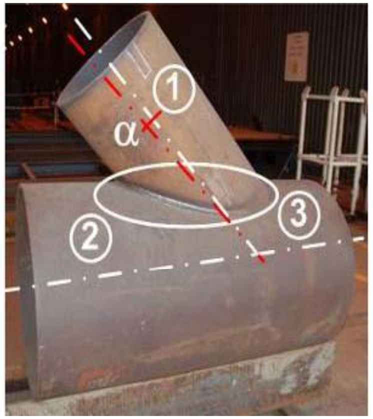
Project	Distance to shore [km]	Water depth [m]
Dollart Emden	0,01	3
Alpha Ventus (Borkum West I)	43	30
Sandbank 24	100	30-40
Bard Offshore 1	87	39-41
Dan Tysk	45	23-31
Borkum Riffgrund West	40	30-35
Borkum Riffgrund	34	23-29
Nordsee Ost	30	19-24
Butendiek	35	16-22
Enova Offshore North Sea	40	28-32
Amrumbank West	35	21-25
Nördlicher Grund	86	23-40
Global Tech I	75	39-41
Hochsee Windpark Nordsee	75	39
Gode Wind	45	26-35
Meerwind (Ost und Süd)	53	22-32
Hochsee Windpark, He Dreiht	75	39
Borkum West II	45	30
Nordergründe	15	8-15
Bard Offshore Hooksiel	0,4	2-8

Total: 4607

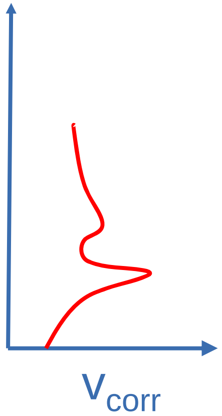
Research project „GIGAWIND alpha ventus“



Loads



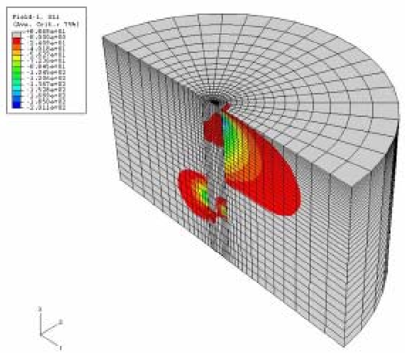
Mass production



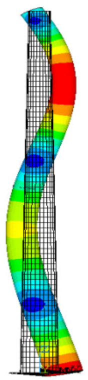
Corrosion

Structure health monitoring

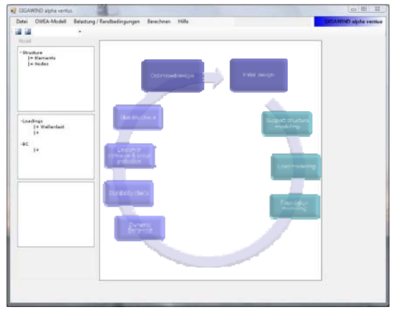
Scour



Structure soil interaction



Dynamic response



Holistic design

19 + 32 = 51 acceleration meters

67 + 46 = 113 strain gauges

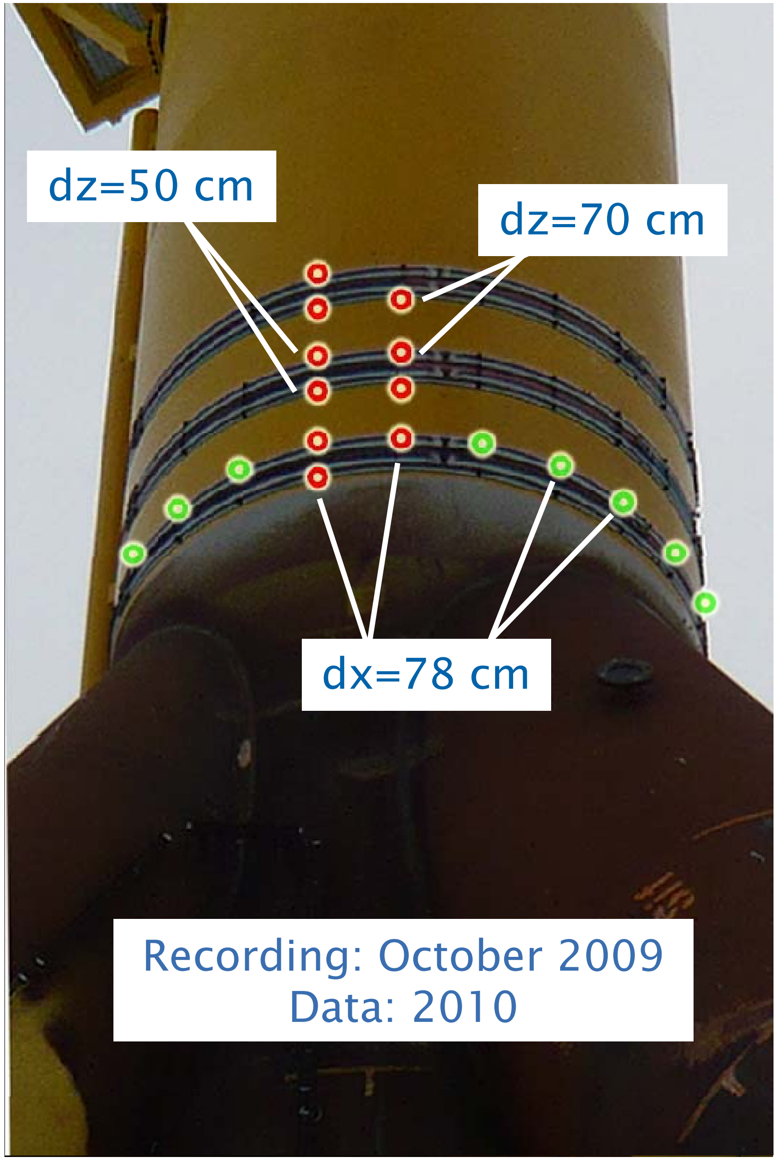
30 water pressure sensors (WPS)
=> 2 vertical profiles: 6 and 4 WPS
=> 1 horizontal profile: 22 WPS

Current velocity meter
=> ADCP + FINO 1

Wave recording
=> Wave buoy + FINO 1

Video camera
=> Wave run up

Wind data



30 Presssure Sensors (PS)
=> Vertical profile, 14+4 PS
=> Horizontal profile with 7 PS
=> Upper braces with 6 PS

2 Acceleration meters (xyz)

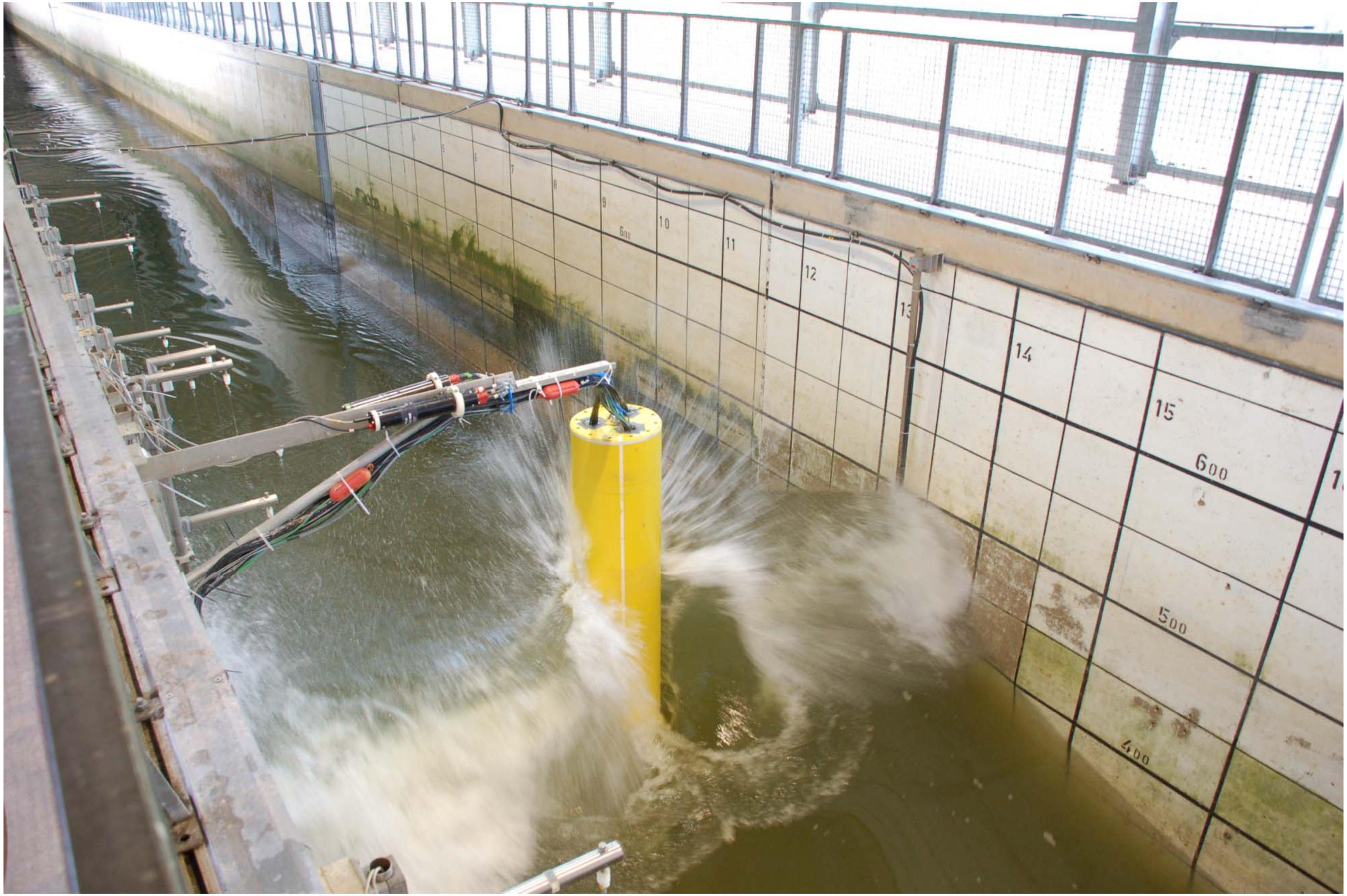
8 Strain gauges

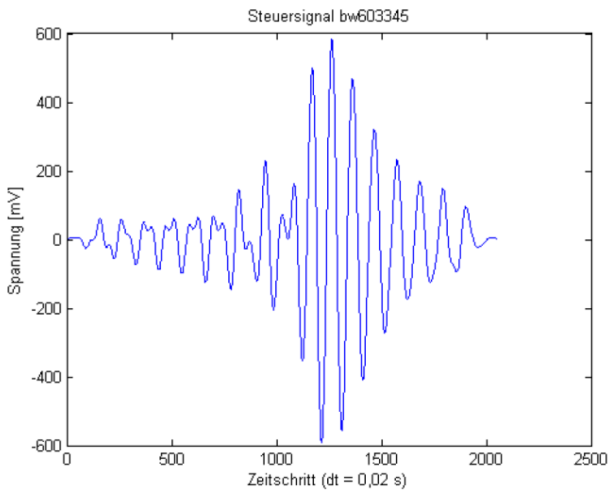
Current meters
=> 2 x 3 NSW probes (xz)

Water elevation
=> 24 Wave gauges

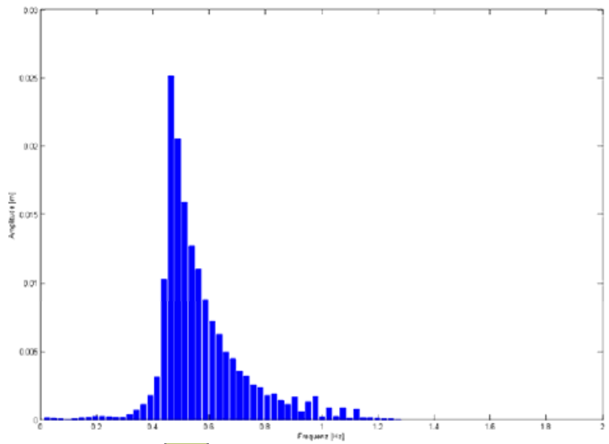
Cameras (front-, back view)
=> Wave runup, wave geometry


1:15:26





signal_2_fft

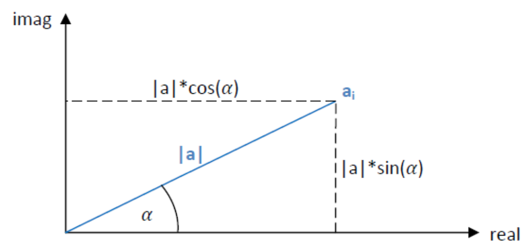


$$\eta(t_*) = \sum_{i=1}^{\frac{N}{2}-1} a_i \cdot \cos(2 \cdot \pi \cdot f_i \cdot t_* + \alpha_i)$$

fft_2_cfxPre

$\eta(t_*)$ = Free water surface in time domain
t_* = $t/\Delta t$ => $t_* = 1,2,\ldots N$
N = Number of timesteps Δt in time series
a = Amplitude
f = Frequency
α = Phaseshift

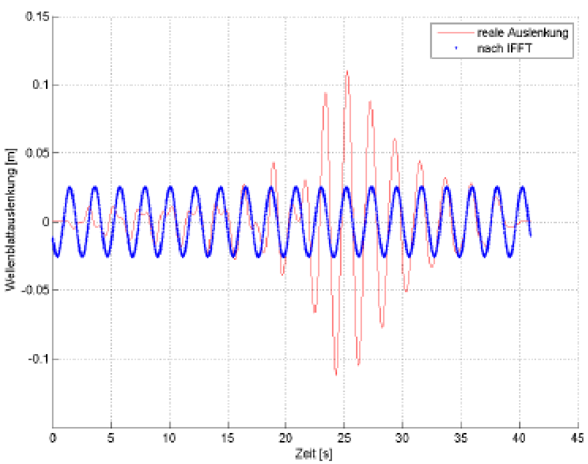
$$\alpha_i = \arctan\left(\frac{imag(|a_i|)}{real(|a_i|)}\right)$$

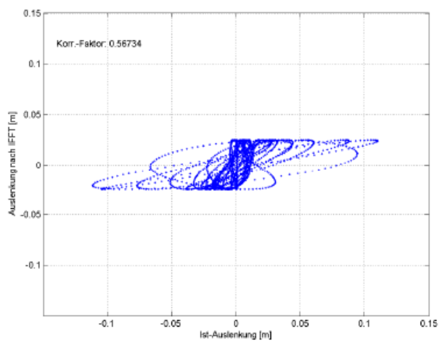


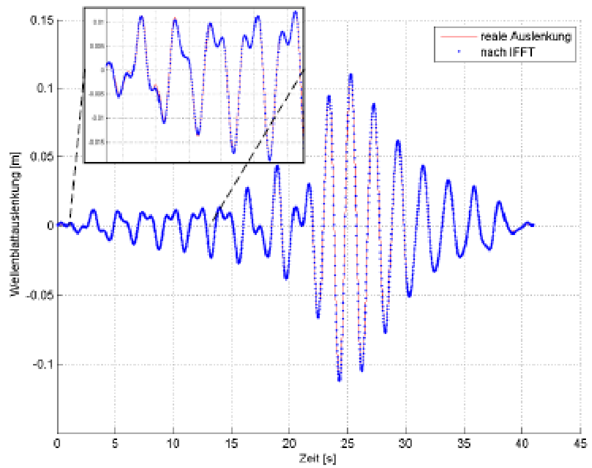
1 Frequency

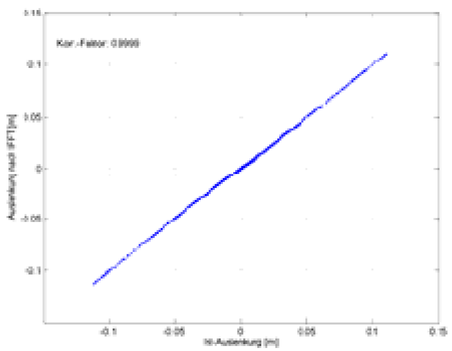
36 Frequencies

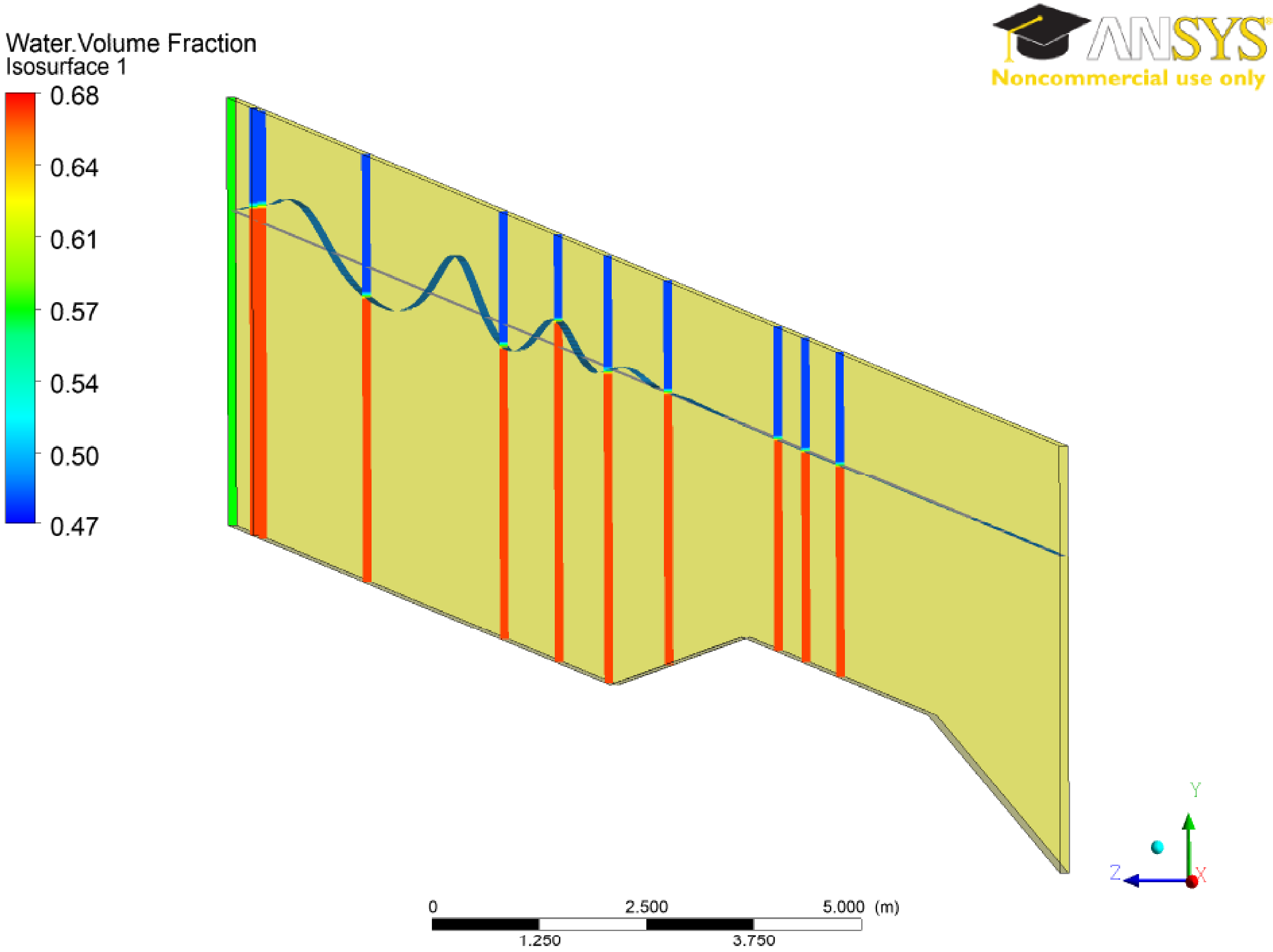
η(t) = 0.00029309*cos(2*pi*0.19531*t+2.7833)
+0.00030647*cos(2*pi*0.21973*t+2.9468)
+0.00028045*cos(2*pi*0.24414*t+-3.0928)
+0.00042436*cos(2*pi*0.31738*t+-1.1338)
+0.00073515*cos(2*pi*0.3418*t+-0.82781)
+0.0011736*cos(2*pi*0.36621*t+-0.65619)
+0.0018296*cos(2*pi*0.39063*t+-0.54339)
+0.0031425*cos(2*pi*0.41504*t+-0.47334)
+0.010265*cos(2*pi*0.43945*t+-0.48657)
+0.025146*cos(2*pi*0.46387*t+2.0443)
+0.020516*cos(2*pi*0.48828*t+-2.1838)
+0.015878*cos(2*pi*0.5127*t+0.034278)
+0.01269*cos(2*pi*0.53711*t+2.3999)
+0.010957*cos(2*pi*0.56152*t+-1.4619)
+0.0087465*cos(2*pi*0.58594*t+1.0126)
+0.0072024*cos(2*pi*0.61035*t+-2.5701)
+0.0062778*cos(2*pi*0.63477*t+0.14593)
+0.0049753*cos(2*pi*0.65918*t+3.026)
+0.0044647*cos(2*pi*0.68359*t+-0.20674)
+0.003576*cos(2*pi*0.70801*t+2.9292)
+0.0032275*cos(2*pi*0.73242*t+-0.0094087)
+0.0025998*cos(2*pi*0.75684*t+-2.7959)
+0.0024271*cos(2*pi*0.78125*t+0.87949)
+0.001837*cos(2*pi*0.80566*t+-1.5816)
+0.0019428*cos(2*pi*0.83008*t+2.3668)
+0.0014469*cos(2*pi*0.85449*t+0.57194)
+0.0011753*cos(2*pi*0.87891*t+-1.8296)
+0.0017064*cos(2*pi*0.90332*t+-3.1108)
+0.00064007*cos(2*pi*0.92773*t+2.3292)
+0.001356*cos(2*pi*0.95215*t+-0.31436)
+0.0017668*cos(2*pi*0.97656*t+-0.19722)
+0.00028315*cos(2*pi*1.001*t+1.0076)
+0.00093962*cos(2*pi*1.0254*t+-2.285)
+0.00029226*cos(2*pi*1.0498*t+0.45282)
+0.00094192*cos(2*pi*1.0742*t+2.9127)
+0.0008214*cos(2*pi*1.123*t+-2.7973)

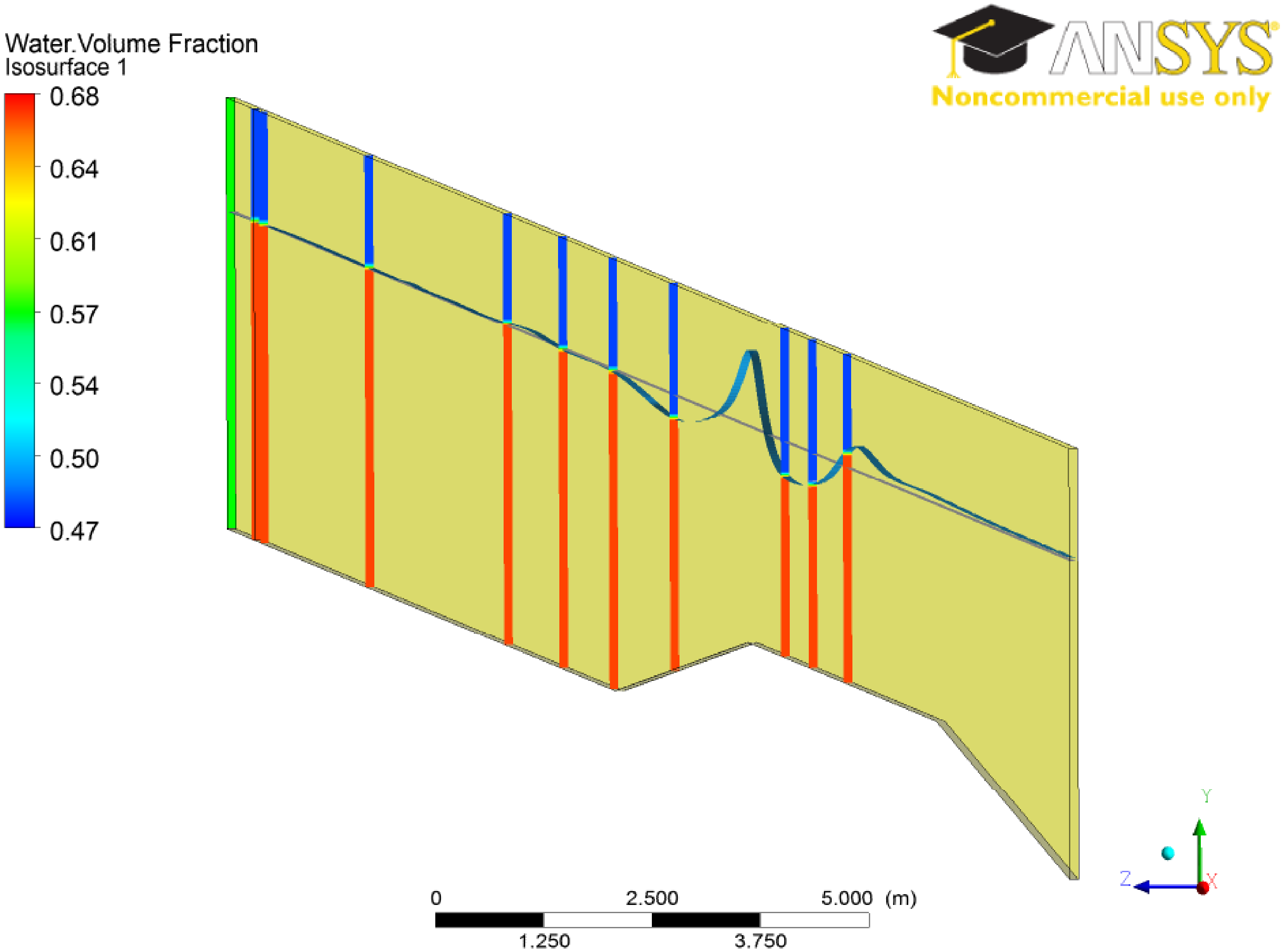









Water.Volume Fraction
Isosurface 1
0.68
0.64
0.61
0.57
0.54
0.50
0.47
ANSYS
Noncommercial use only
Y
Z
X
0
2.500
5.000 (m)
1.250
3.750


Water.Volume Fraction
Isosurface 1
0.68
0.64
0.61
0.57
0.54
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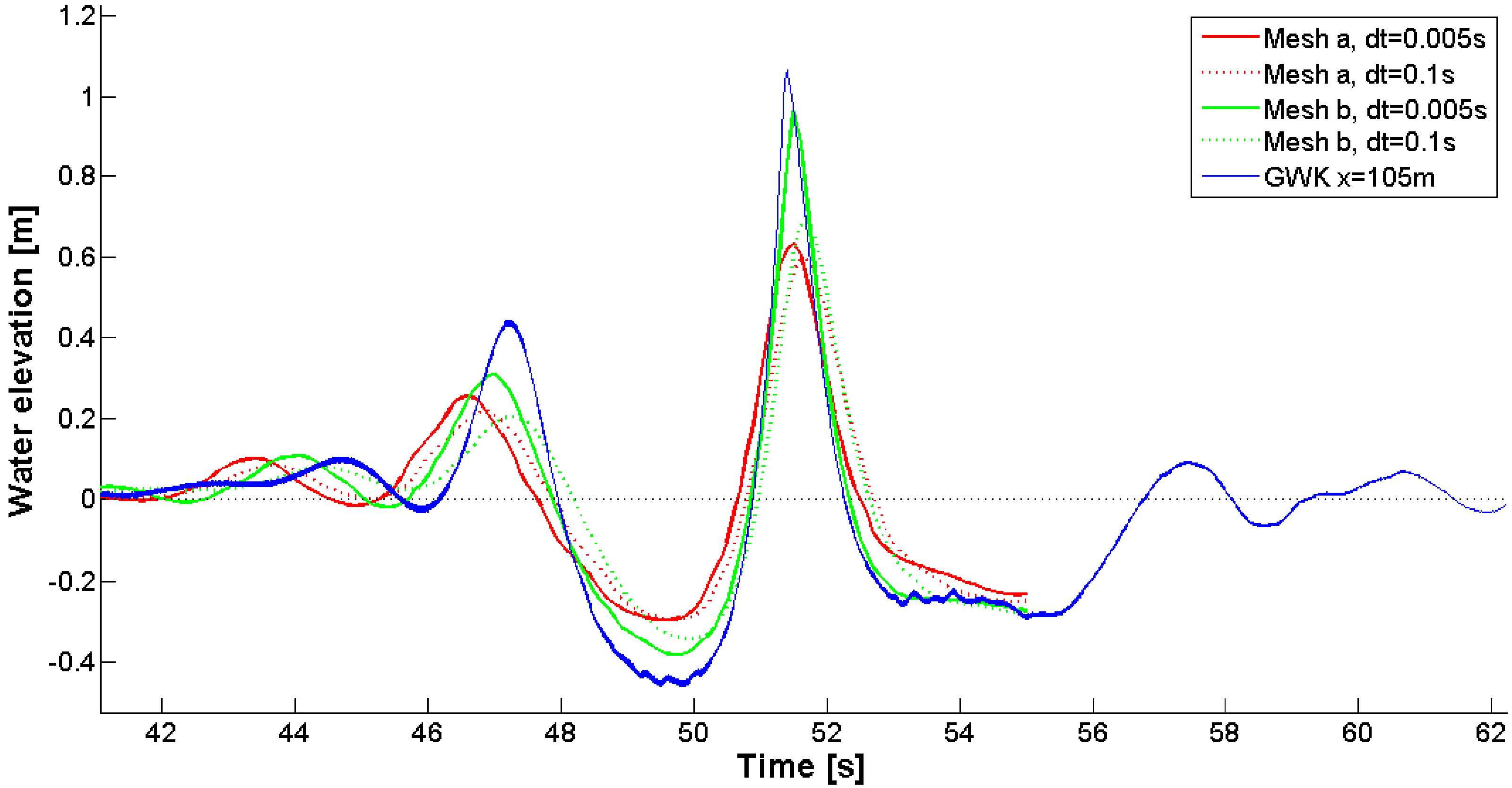
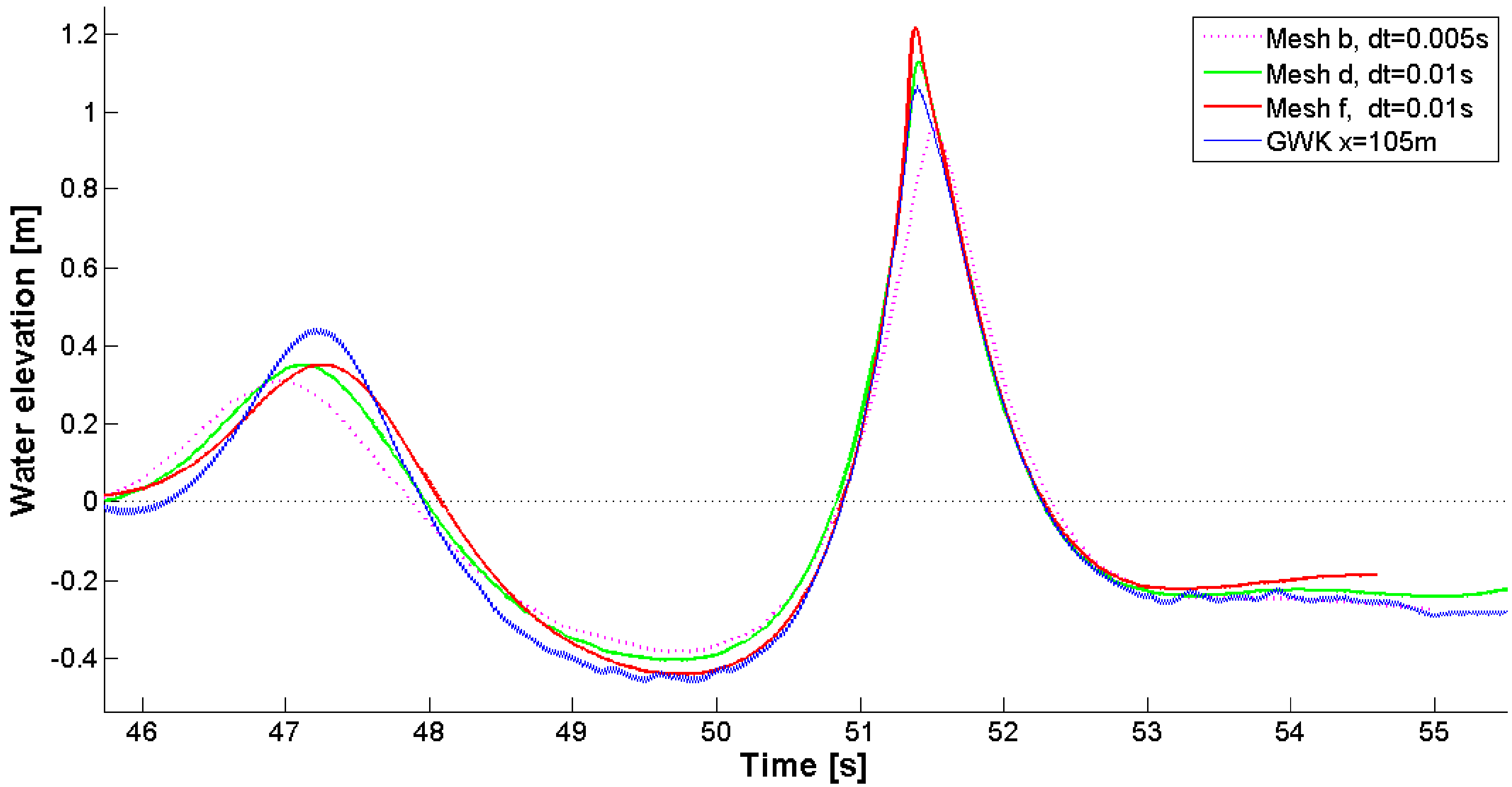
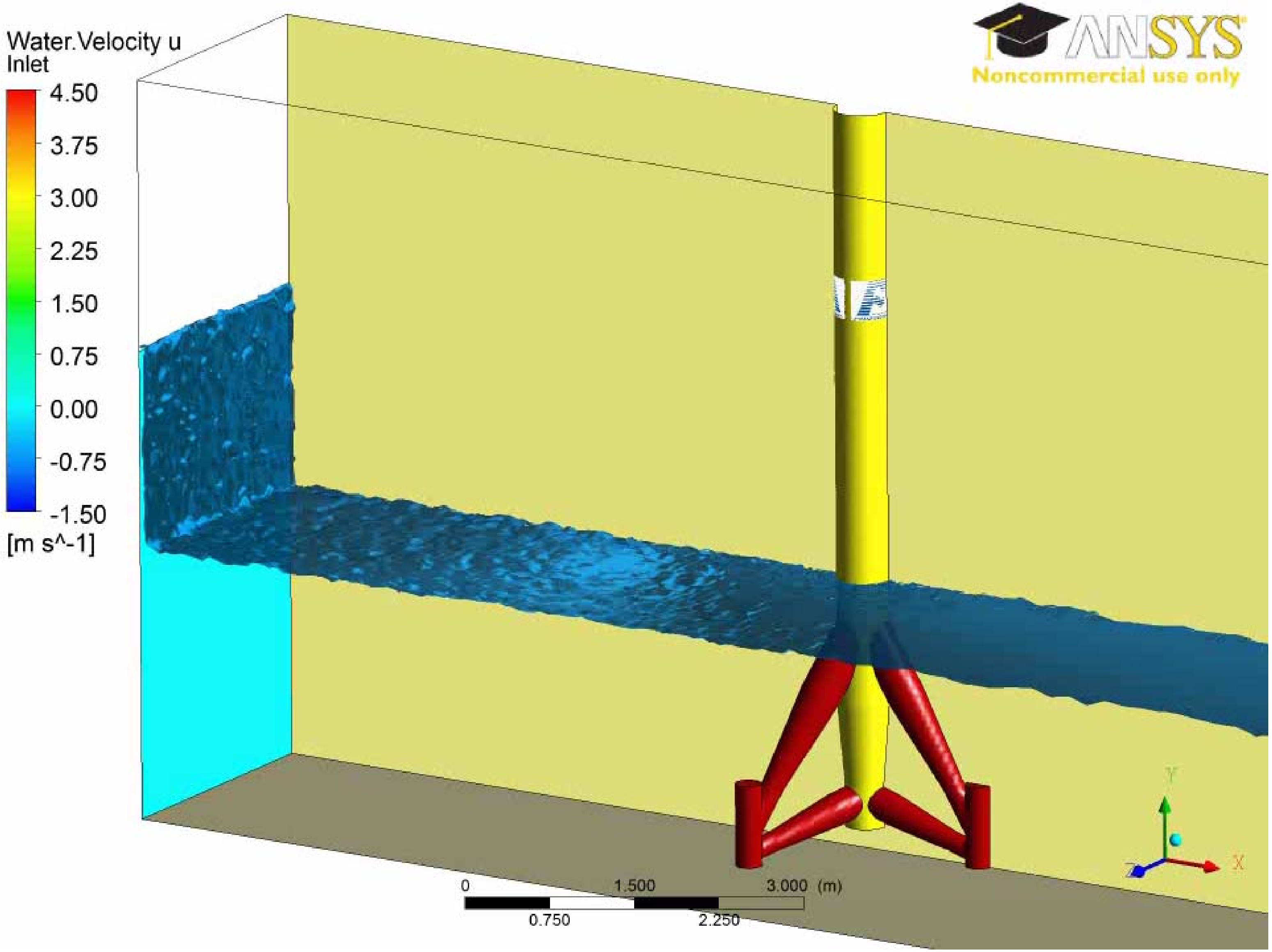
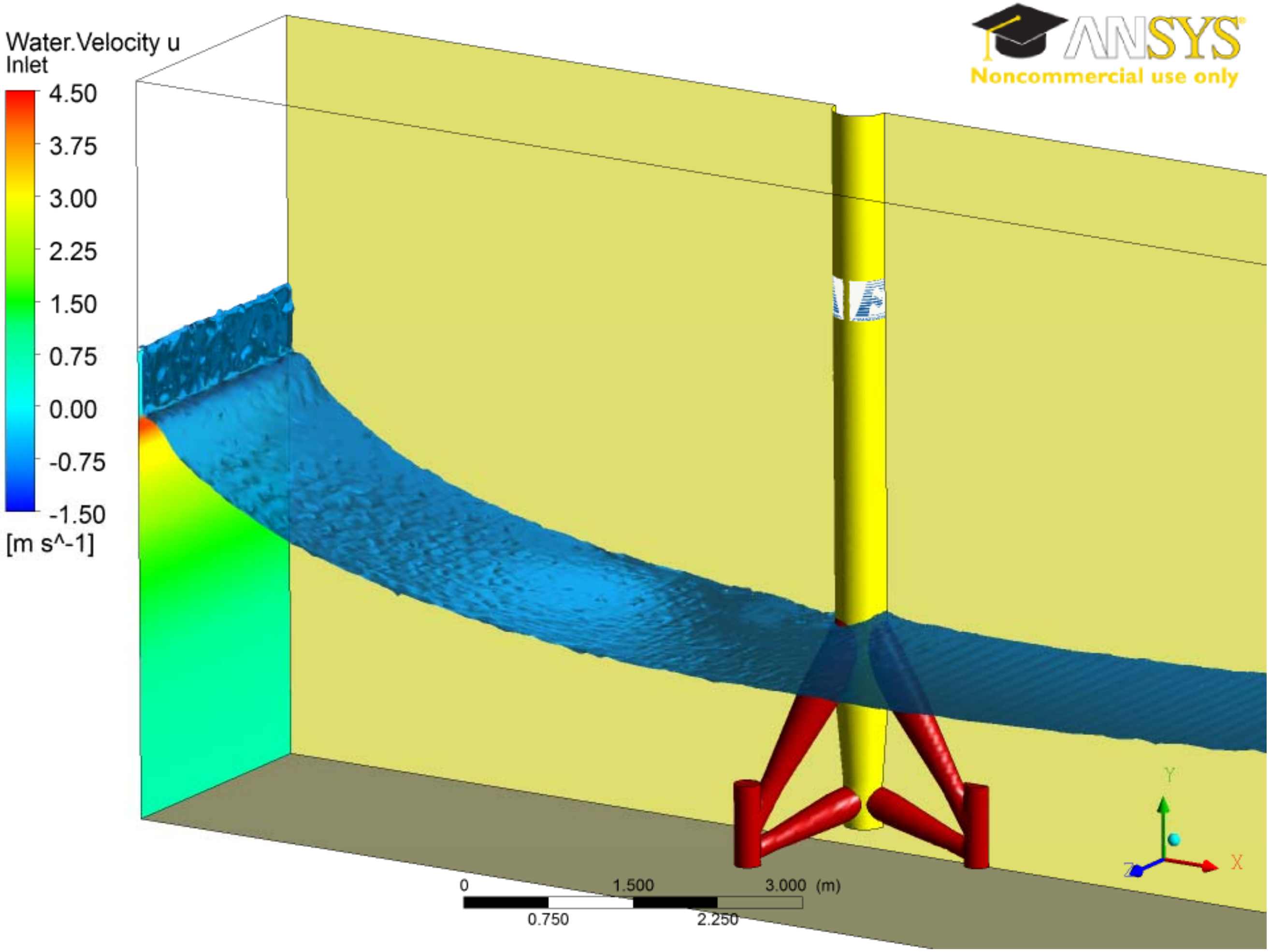
0.47
ANSYS
Noncommercial use only
0
2.500
5.000 (m)
1.250
3.750
Y
Z
X


Mesh a, dt=0.005s
Mesh a, dt=0.1s
Mesh b, dt=0.005s
Mesh b, dt=0.1s
GWK x=105m
Water elevation [m]
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
42
44
46
48
50
52
54
56
58
60
62
Time [s]


Mesh b, dt=0.005s
Mesh d, dt=0.01s
Mesh f, dt=0.01s
GWK x=105m
Water elevation [m]
Time [s]
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
46
47
48
49
50
51
52
53
54
55


Water.Velocity u
Inlet
4.50
3.75
3.00
2.25
1.50
0.75
0.00
-0.75
-1.50
[m s^-1]
ANSYS
Noncommercial use only
0
1.500
3.000 (m)
0.750
2.250
Y
X

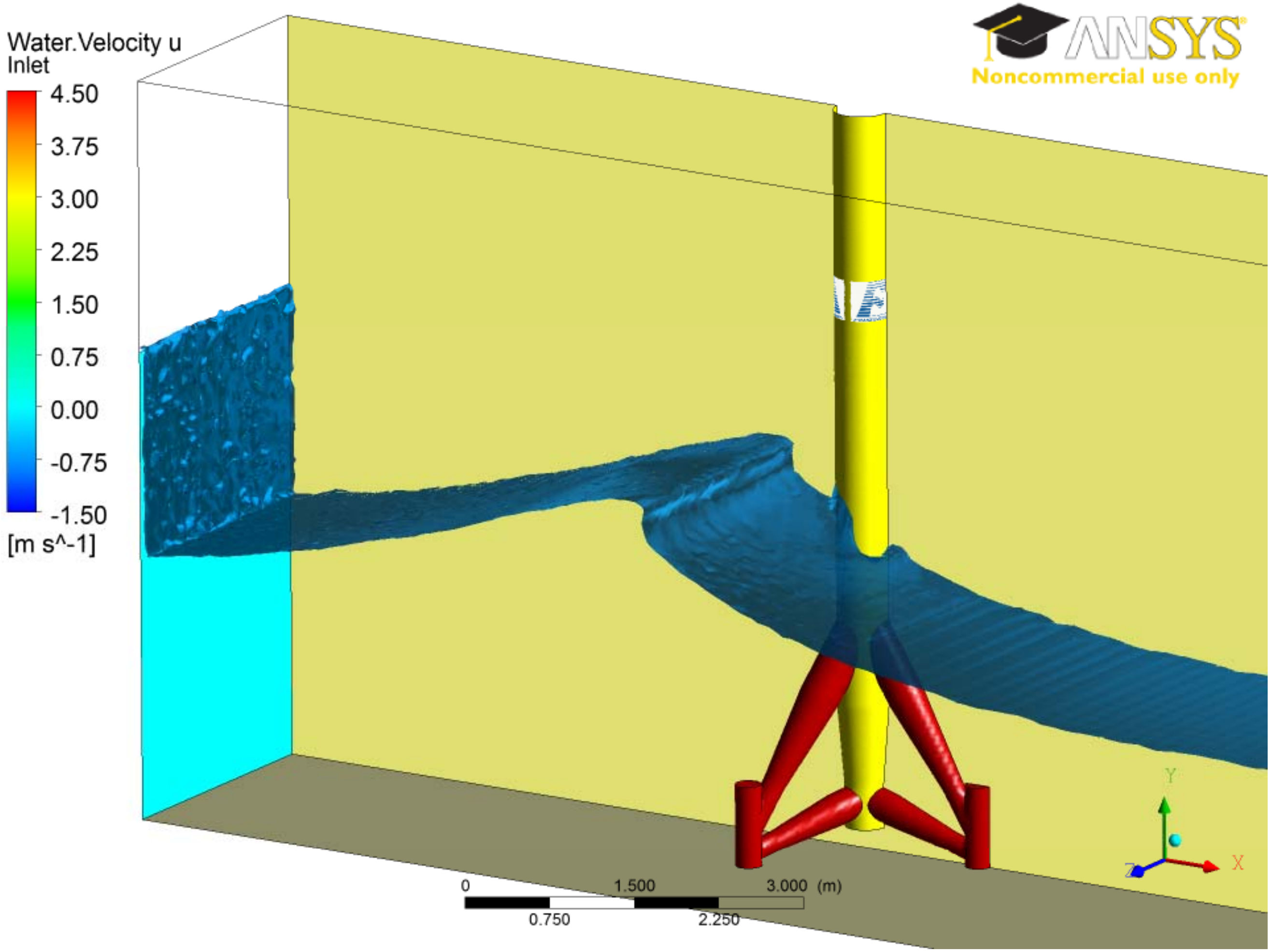


Snapshot (5.68 s / 8.00 s), $H_{B,\ x=105m}$ = 1.05+0.45 = 1.5 m

- Inlet:

  U_{max} = 4.0 m/s

- Small curling factor like deep water breaker
- Pile-up effect
- Water level gradient at pile during impact
- Diffusion in area of coarse mesh

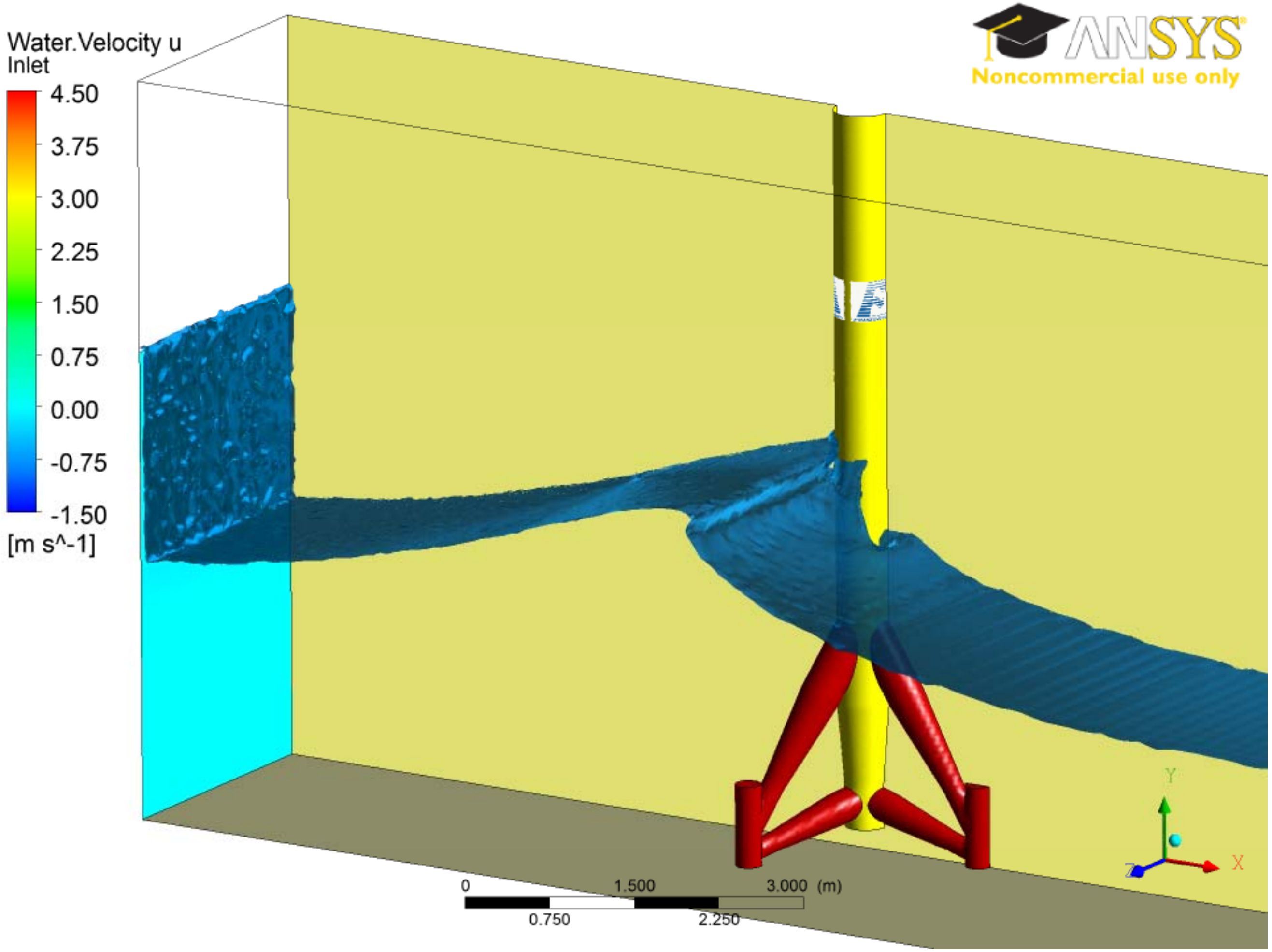


Snapshot (6.68 s / 8.00 s), $H_{B,\ x=105m}$ = 1.05+0.45 = 1.5 m

- Inlet:

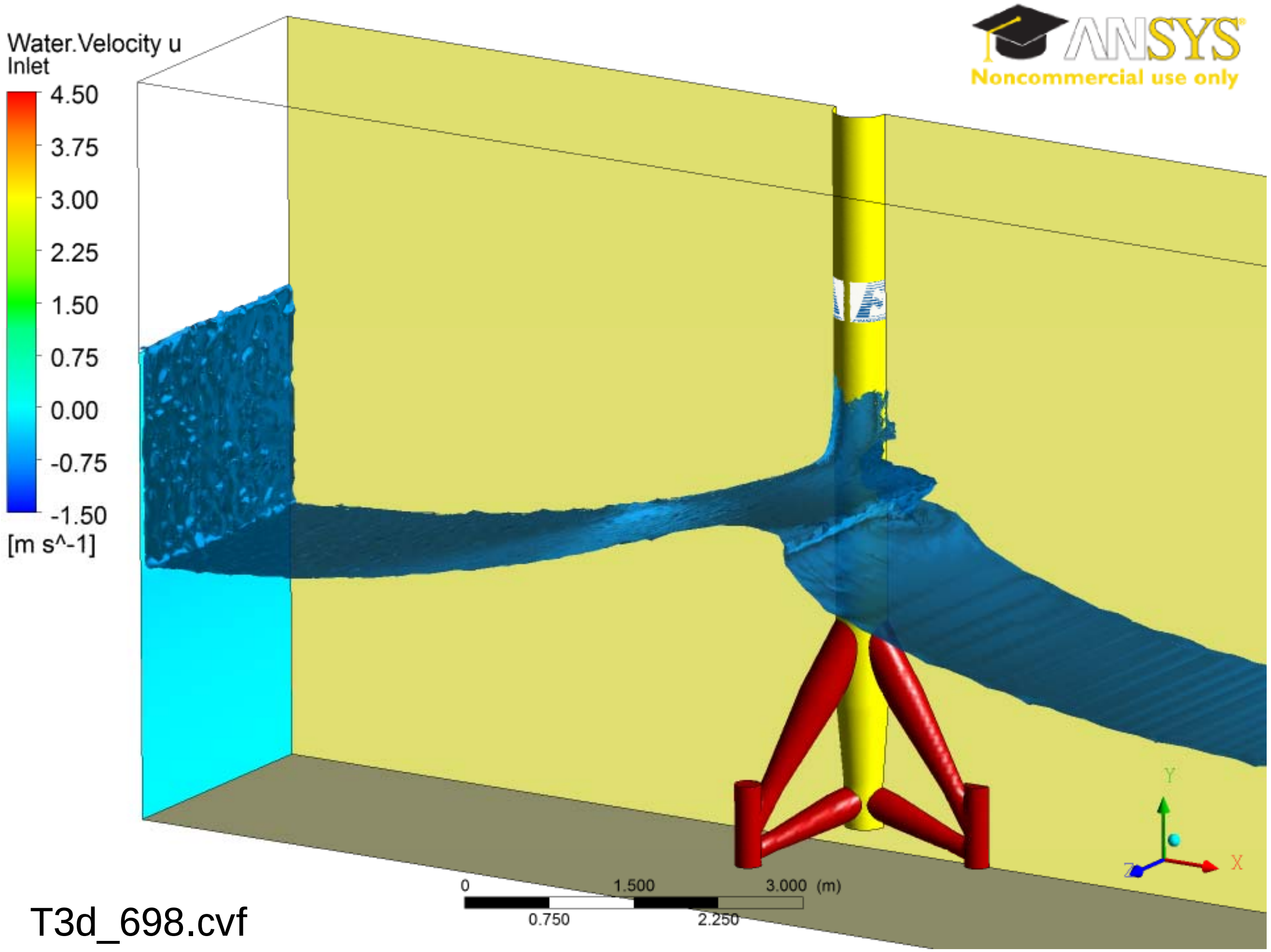
  U_{max} = 4.0 m/s

- Small curling factor like deep water breaker
- Pile-up effect
- Water level gradient at pile during impact
- Diffusion in area of coarse mesh



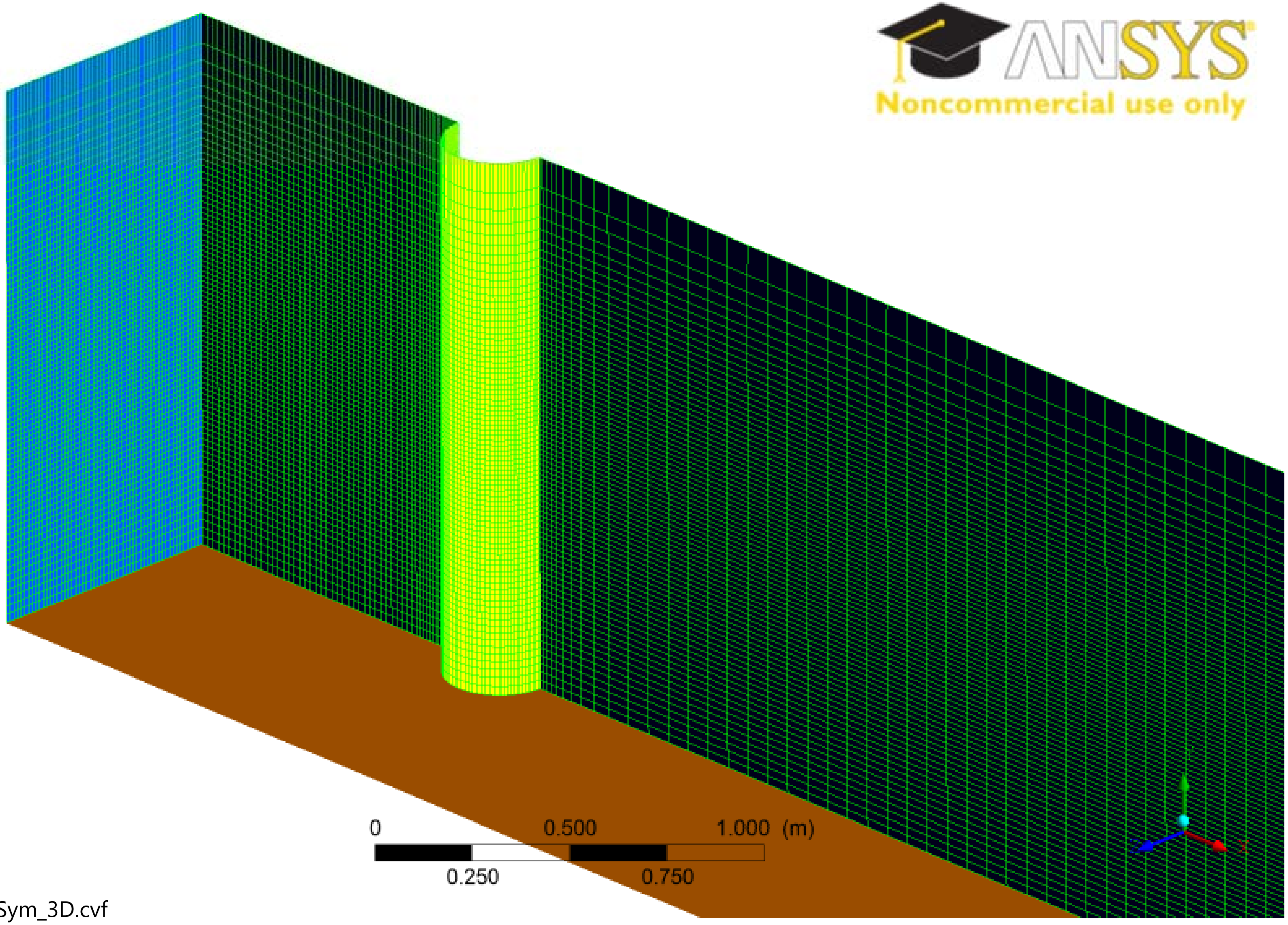
Snapshot (6.78 s / 8.00 s), $H_{B,\ x=105m}$ = 1.05+0.45 = 1.5 m

- Inlet:
  U_{max} = 4.0 m/s
- Small curling factor like deep water breaker
- Pile-up effect
- Water level gradient at pile during impact
- Diffusion in area of coarse mesh

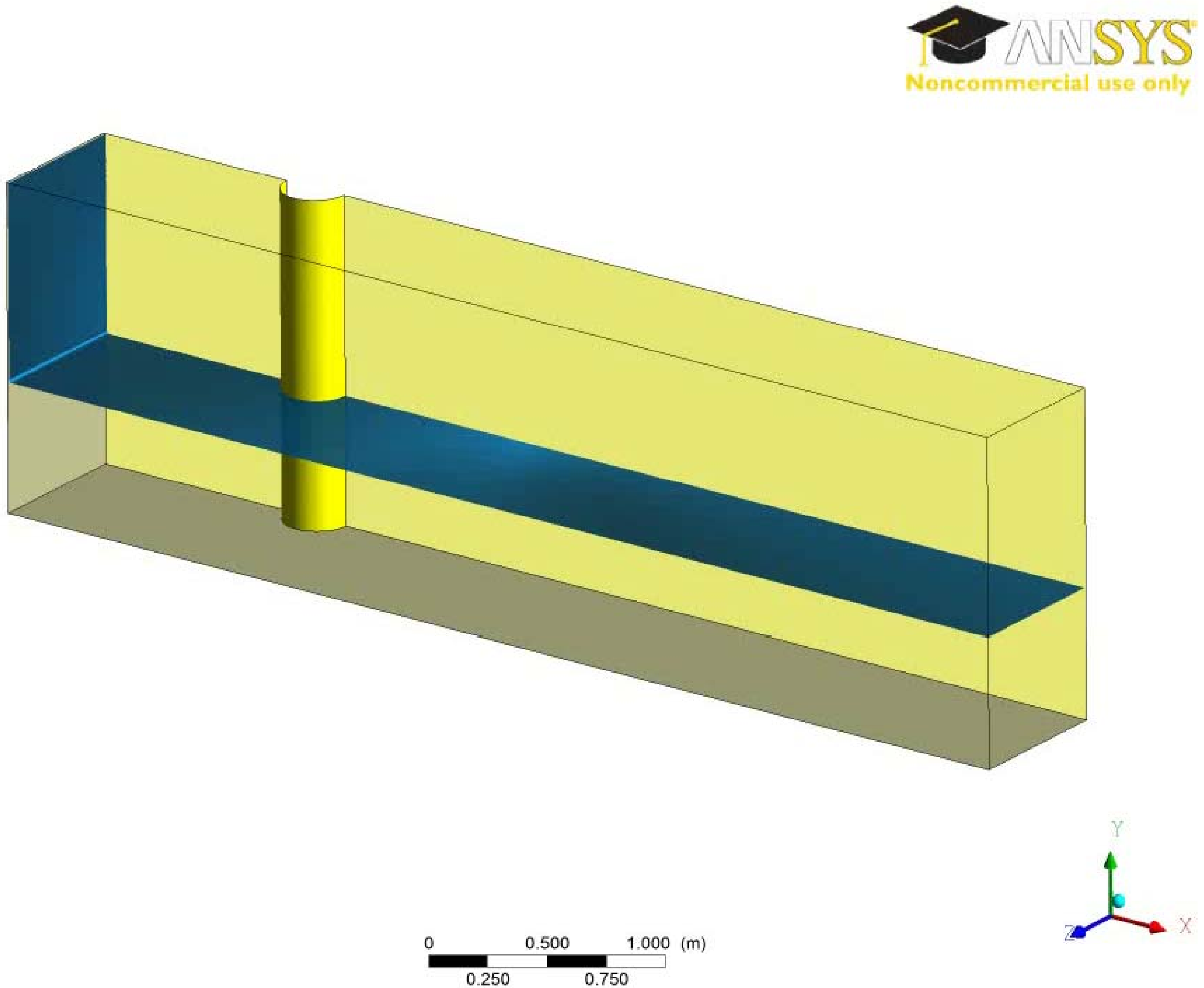


Snapshot (6.98 s / 8.00 s), $H_{B,\ x=105m}$ = 1.05+0.45 = 1.5 m

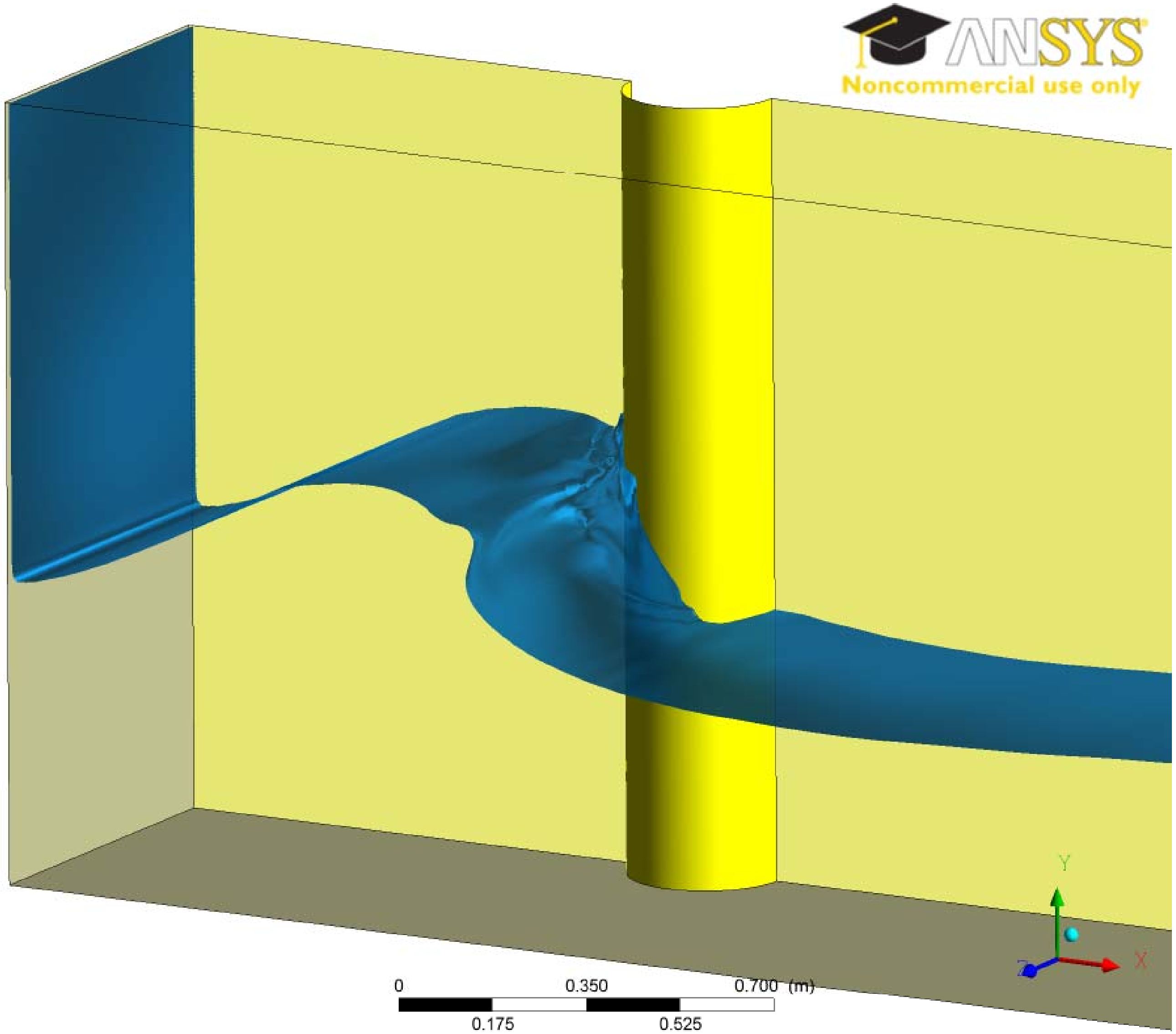
- Inlet:
  U_{max} = 4.0 m/s
- Small curling factor like deep water breaker
- Pile-up effect
- Water level gradient at pile during impact
- Diffusion in area of coarse mesh



WKS_Monopile_Sym_3D.cvf

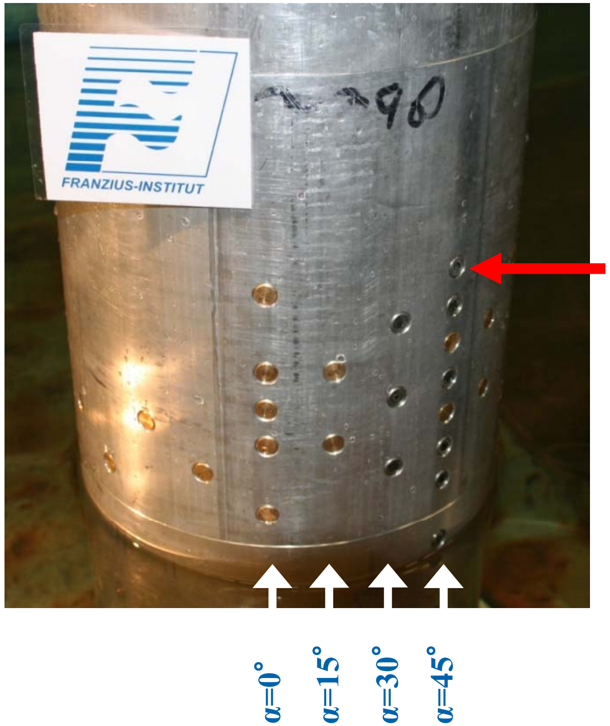

ANSYS
Noncommercial use only
0
0.500
1.000 (m)
0.250
0.750
Y
X
Z

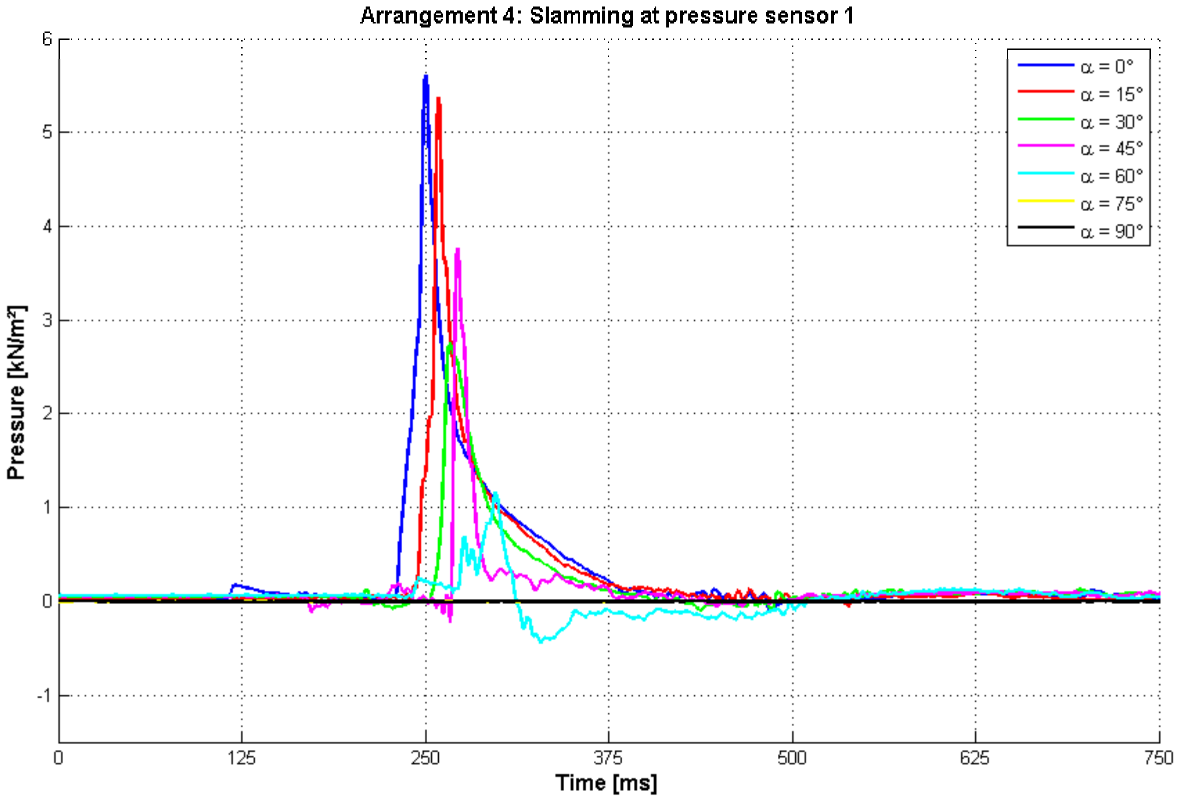
Snapshot of the wave profile during wave impact. Partly vertical water front.




Case_06a_x_167.cvf

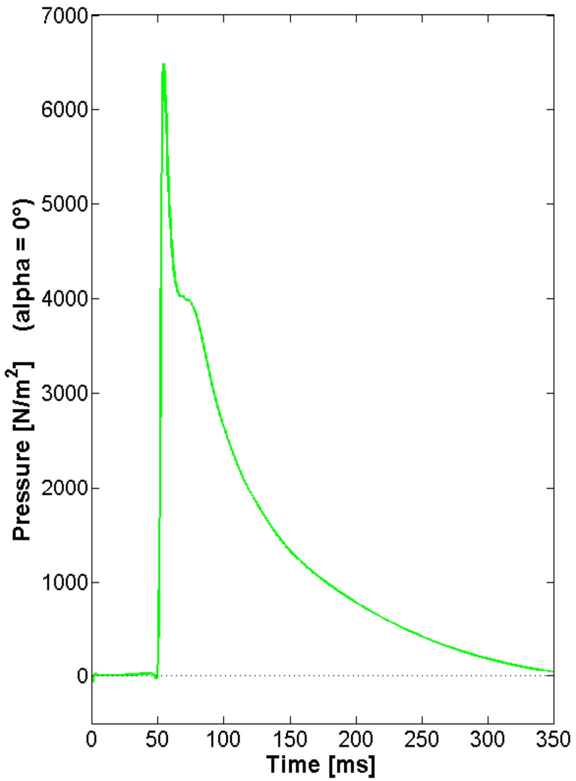
Pressure at various heights

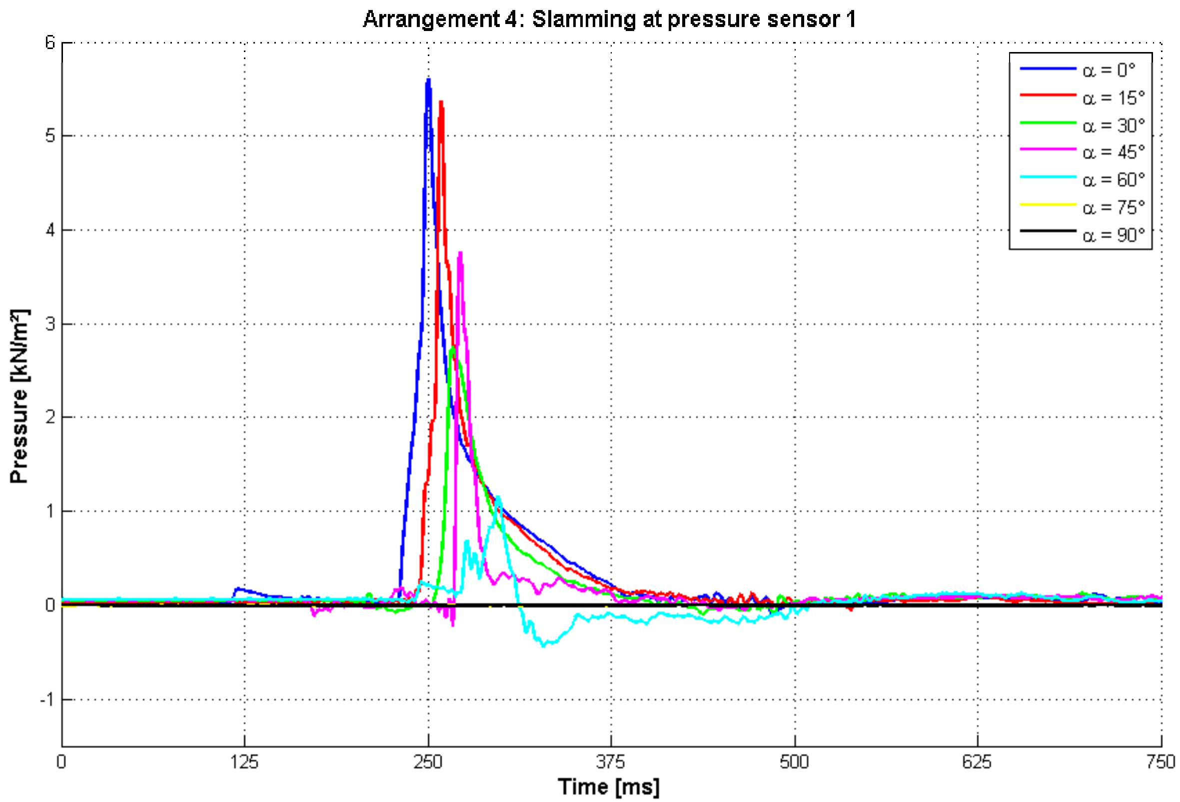




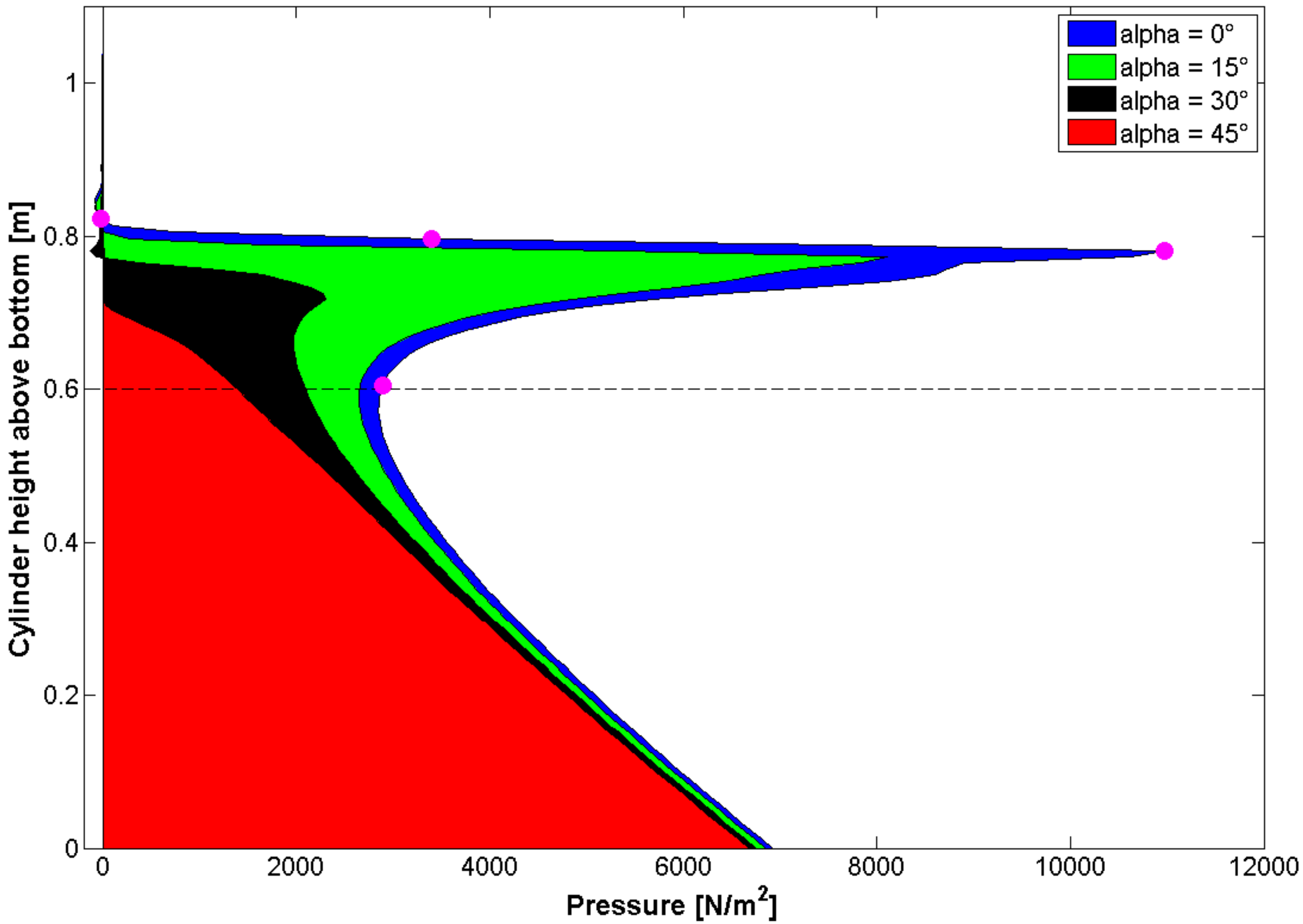
- Symmetric pressure distribution
- 30% reduced pressure over 7% of H_b in upper zone => curling factor
- Increasing rise time at lower pressure sensors

Pressure sensor 22 cm above SWL





- Symmetric pressure distribution
- Roughly 250 ms pressure „crest“
- Peak value shows 1 kN/m² difference (wave front, heighest sensor position)



- Pressure peak at cylinder front
- Small area with rapid decrease at the upper limit (small dy)
- Peak characteristic >30° & < 45° for this point of time (dt < 0.01s)

Summary & perspective

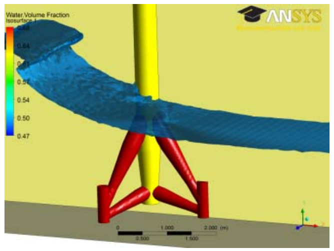
GIGAWIND alpha ventus

Wind, shallow waters, renewable
Prototype installed
Data 2010

Development

Physical and numerical modeling, field data
Ongoing tests
Large Wave Flume (GWK) tests 2010

Efficient design



Calibration of numerical models for breaking waves
Peak pressure distribution, curling factor, rise time

Source: Offshore-Stiftung/Multibrid/Jan Oelker, 2009

Thank you for your kind attention!

Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety