



## **HYIII-DHI-10**

### **DHI Shallow Water Basin DHI-SWB\_UBUG\_Wave-Impact**

**EC contract no. 261520**

**Status: final  
Date: Sep 2009**

<b>Infrastructure</b>	DHI Shallow Water Basin		
<b>Project</b>	HYIII-DHI-10		
<b>Campaign</b>	Breaking wave impacts and non-breaking wave interactions with offshore wind turbine foundations		
<b>Title</b>	DHI-SWB_UBUG_Wave-Impact		
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<b>Date Campaign Start</b>	14/09/2009	<b>Date Campaign End</b>	14/09/2009
<b>Date Final Completion</b>	21/10/2009		

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## **1. Scientific aim and background:**

The primary aim of this research was to study steep wave and breaking wave impacts on offshore wind turbine foundations. Unique high quality data on wave impact pressures, free surface run-up, and total fluid loading on a vertical cylinder was obtained. Effects of caisson around the cylinder, sloping beach and directionality of spread wave on wave run-up and wave loading on the body have also been examined. These violent wave-structure interactions, triggered by localised wave groups, not only reveal physics, but also are ideal for numerical modellers to validate numerical simulations with a variety of numerical techniques.

In contrast to most previous experiments this campaign concentrated on hitting the column with localised wave groups not on regular or random waves. By repeating the tests with both focused wave groups and the same wave groups inverted, so each tall crest in one is replaced by a deep trough in the inverted form, one is able to identify unambiguously the complete Stokes expansion type representation of the applied force: linear, second order two-frequency sum and difference, 3<sup>rd</sup> order triple-frequency sum etc. The cumulative effect of this relatively small but significant high frequency excitation is to produce dynamic response or 'ringing' of the column if the lowest resonant frequency in the right range. Figure 1.1 shows two force time-histories for wave groups on constant depth hitting the cylinder.

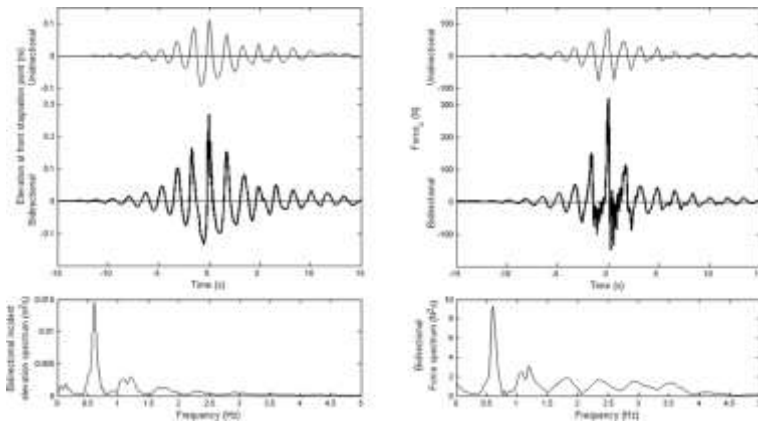


Figure 1.1. Wave impact with the vertical cylinder: incident wave time histories (left) and horizontal forces on the cylinder (right), for unidirectional focused wave group (top) and bi-directional pair  $\pm 20^\circ$  (middle). Bottom figures: incident wave spectrum (left), force spectrum (right), both for bi-directional pair only.

## 2. User-Project Achievements and difficulties encountered:

N/A

## 3. Highlights important research results:

A single vertical cylinder was exposed to a large series of carefully controlled incident wave groups. Manipulation of the phase of these groups allows extraction of the harmonic structure of the loading. Even for violently breaking waves, much of the harmonic structure of the resulting horizontal loading is still apparent and consistent with that measured for smaller non-breaking waves.

## 4. Publications, reports from the project:

Jun Zang, Paul H Taylor, Gerald CJ Morgan, Jana Orszaghova, James Grice, Manases Tello & Robert Stringer; *Violent wave interactions with a vertical cylinder - applications to offshore wind turbine foundations and "Ringing" re-visited*, Proceeding of the HYDRALAB III user meeting, 2-4 February 2010, Hanover, Germany

## 5. Description:

### 5.1. Description:

The [shallow water basin](#) at DHI was used for these tests. A vertical cylinder of diameter  $0.25m$  was suspended from a stiff triangular frame via a load-cell. For the tests reported here the water depth across the basin was constant at  $0.505m$  and the cylinder extended downwards to the basin floor, leaving a thin gap of  $1mm$  beneath. The cylinder was located at  $7.8m$  from the paddles in the centre of the tank. An array of wave gauges was used to monitor the wave-field around the cylinder, pressure gauges were installed at 4 vertical locations on the front stagnation line of the cylinder and the wave kinematics were measured with an ADV. A range of wave conditions was tested, from small close to linear waves up to spilling and plunging breakers. In each case a compact wave group focussed at the front stagnation point of the cylinder was used to avoid reflections from the basin walls.

In other experiments, the cylinder was embedded in a caisson on the bed of the basin, and also located midway up a 1:20 plane beach on a small horizontal ledge at a depth of  $0.5m$ .

Because only linear transfer functions were used to drive the paddles an error wave train, a second pulse of waves in the second harmonic component, was generated by the paddle. The waves which were created were inherently nonlinear so instantaneous cancellation occurs between the correct 2<sup>nd</sup> order bound waves for the main group and these error components which then propagate down the tank as free components. The error wave train takes longer to reach the model than the main group and these error waves were observed at the location of the cylinder at this time even when the cylinder was removed.



Figure 5.1.2: Schematic description of vertical cylinder

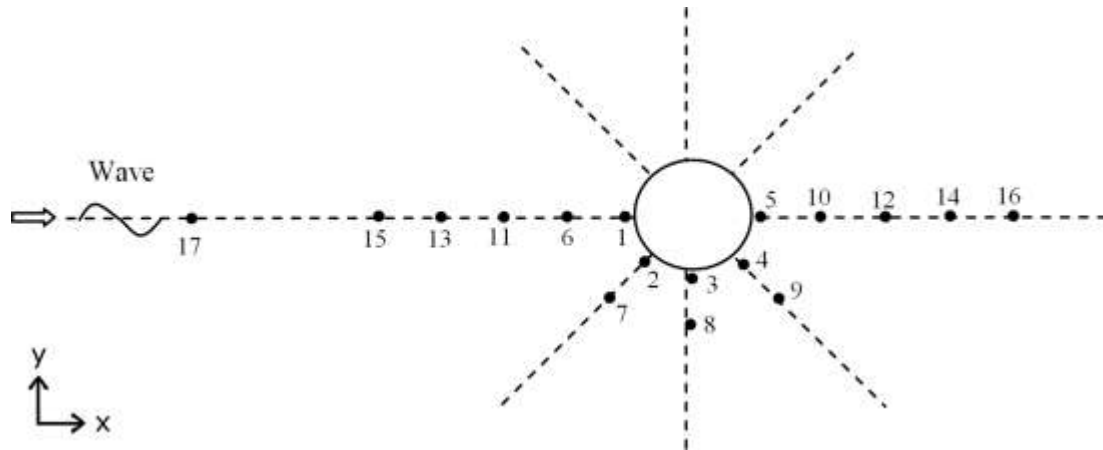


Figure 5.1.3: Location of wave gauges and definition of right-hand coordinate system

## 5.2. Definition of the coordinate systems used:

see figure 5.1.3 above and the layout of [DHI's Shallow Water Basin](#) (figure 1).

## 5.3. Instruments used:

Instrument(s)	ID	Amplifier	#	DAQ	Parameter
Wave gauges	DHI-202	DHI-102E	19	Computer w/DHI-WS	$\eta$
Acoustic Doppler Velocimeters (ADV)	Nortek		1	- do -	$u, v, w$
Accelerometer	Setra 141A		1	- do -	$a_x, a_y, a_z$
Force gauge	DHI-205/3C	DHI-106E	1	- do -	$F_x, F_y, F_z$
Pressure gauges			4	- do -	$p$

Table 5.3.1 List of instruments

## 5.4. Definition of time origin and instrument synchronisation:

All acquired instruments were synchronized and data were stored in a single data file using DHI's data acquisition system DHI-WS (see [9. Organisation of data files](#))

## 6. Definition and notation of the experimental parameters:

### 6.1. Fixed parameters:

Notation	Name	Unit	Definition	Remarks
x, y, z	longitudinal, transverse and vertical direction	m		longitudinal direction perpendicular to wavemaker
g	gravity	$\text{m s}^{-2}$	$= 9.815 \text{ m s}^{-2}$	

Table 6.1.1 Fixed parameters

### 6.2. Variable independent parameters:

Notation	Name	Unit	Definition	Remarks
H	wave height	m		
T	wave period	m		
$\theta$	wave direction	degrees		

Table 6.2.1 Variable independent parameters

### 6.3. Derived parameters and relevant non-dimensional numbers:

Notation	Name	Unit	Definition	Remarks
$a_x, a_y, a_z$	acceleration	g		see table 6.1.1
$F_x, F_y, F_z$	force	N		
p	pressure	$\text{m}_{\text{H}_2\text{O}}$		height of equivalent water column
x, y, z	longitudinal, transverse and vertical direction	m		
u, v, w	velocity	cm/s		
$\eta$	surface elevation	m		

Table 6.3.1 Other relevant parameters

## 7. Description of the experimental campaign, list of experiments:

ID	Wave height	Wave period	Wave direction	Remarks
New Cell	H (m)	T (s)	$\theta$ (degree)	
F1				Focussed wave group
F2				

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.				
.				
F18				
BF1				Bi-directional Focussed Wave Group
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BB1				Bi-directional Bichromatic Regular Wave
BB2				
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.				
.				

*Table 7.1 Waves*

A total of 851 experiments, see [List of Experiments](#), were performed with regular waves, solitary waves, focussed wave groups, bi-directional regular waves, bi-directional focussed wave groups, bi-directional bichromatic waves. The experiment identification describes the applied wave conditions:

Focussed Wave Group Identification String<sup>\*)</sup>: [Wave ID (Table 7.1)]-[C/T]-[Breaker Point in meters from wavemaker]

Bi-Directional Focussed Wave Group Identification String<sup>\*)</sup>: [Wave ID (Table 7.1)]-[C/T]-[Breaker Point in meters from wavemaker]\_[ $\Delta\theta$ ]

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<sup>\*)</sup> For the focussed wave groups the character C stands for "crest", and indicate a 180 degree phase shift, as opposed to T, which stands for "trough".

## 8. Data processing:

Acoustic Doppler Velocimeters (ADV), Channel 20, 21 and 22 should be applied an offset of +100 and subsequent divided by a factor of 2.

## 9. Organisation of data files:

Each experiment was given a unique sequential four digit number and data from each experiment was stored synchronised in one binary data file ([.dfs0](#)) with the filename "[4-DIGIT NUMBER]log1.dfs0".

A text based metadata file ([4-DIGIT NUMBER]log1.log) accompanying each data file holds the following information

creation date and time

identification string

number of channels and channel description

sample frequency

minimum, maximum, mean and standard deviation for each channel

If automatic offset adjustment was applied to any channel (e.g. wave gauges) before each experiment, then the duration of the offset scan and standard deviation for each channel was stored in the text file: [4-DIGIT NUMBER]oscn.log.

The data was stored in the folder "[PROJECT FOLDER]\data\".

## **10. Remarks about the experimental campaign, problems and things to improve:**

N/A

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