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on Borkum Riff

De Vos, Leen; Larsen, Brian Juul; Frigaard, Peter

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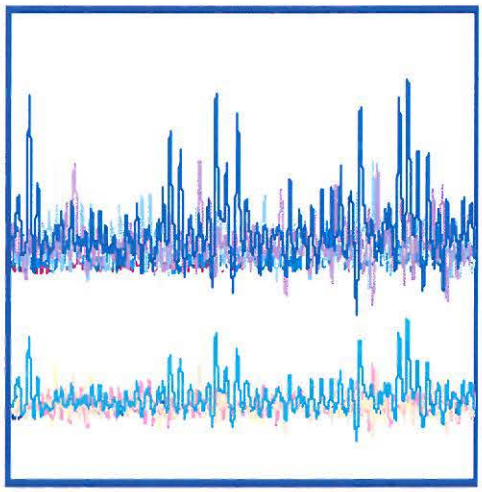

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DEPARTMENT OF CIVIL ENGINEERING
AALBORG UNIVERSITY
SOHNGAARDSHOLMSVEJ 57 DK-9000 AALBORG DENMARK
TELEPHONE +45 96 35 80 80 TELEFAX +45 98 14 25 55

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Run-up on Offshore Windturbine Foundations

on Borkum Riff

by

Leen De Vos, Brian Juul Larsen & Peter Frigaard, Aalborg University

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Introduction

By request from Energi E2 A/S (Søren Thorbjørn Larsen), Teglholmsgade 8, 2450 København SV (phone: 44 80 60 00) and in cooperation with Carl Bro A/S (Helge Gravesen), Granskoven 8, 2600 Glostrup (phone: 43 48 63 28) a testprogramme has been performed to determine the run-up on offshore windturbine foundations. The present report on the wave run-up is a complementary report made by Aalborg University on the Borkum Riff project. The next report will be on scour and scour protection.

For further information on the conducted testprogramme contact Brian Juul Larsen (phone: 96 35 72 31, email: i5bjl@civil.aau.dk) or Peter Frigaard (phone: 96 35 84 79, email: peter.frigaard@civil.aau.dk).

Tests

Scaling

The tests are performed with a length scale of 1:50. All values are scaled according to Froudes modellaw:

Length: $\lambda_L = 50$
Time: $\lambda_T = \lambda_L^{1/2} = 7.07$

All measures in the following report will be in prototype values.

Description of Models

The type of foundation that is being tested is a monopile with a diameter of 6 m. The model is made of plastic. 6 wave gauges were mounted on the model to measure the wave run-up and to determine the variation of run-up around the pile. Figure 1 shows the positions of the wave gauges.

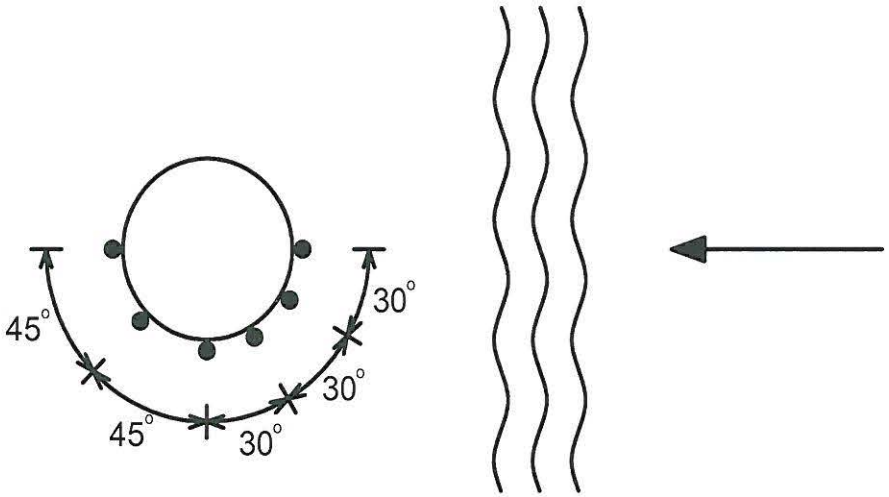

Figure 1. Position of wave gauges.

Figure 2 shows a picture of the mounted wave gauges.

Figure 2. Picture of the mounted wave gauges.

Description of Set-up

The tests are conducted in a wave flume that is 995 meters long and 75 meters wide, see figure 3.

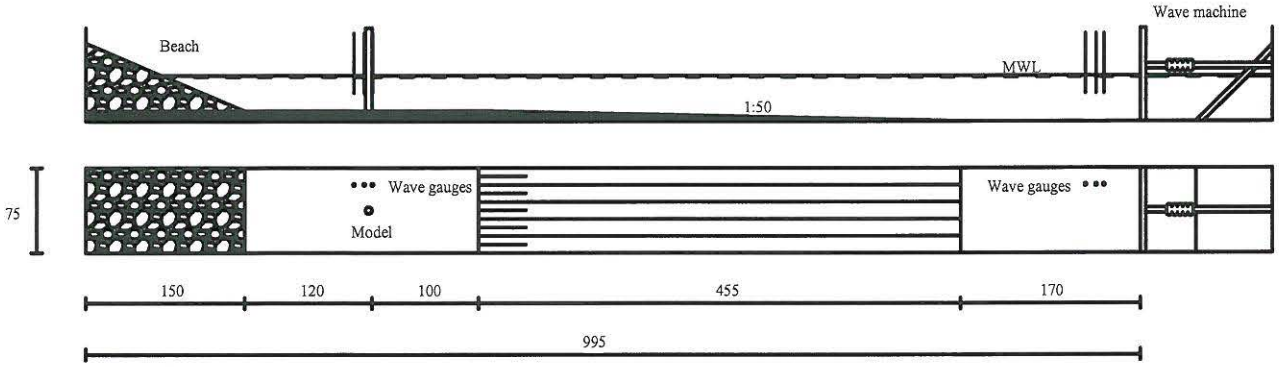

Figure 3. The wave flume. All measures in meters.

Waves

All tests weere made with a JONSWAP spectrum. The peak enhancement factor, γ, was at all times set at 3.3 and the test durations were set at 500 times T_p to insure at least 500 waves. The still water level at the model was 25 m at all times.

Measurements

The wave elevation signal was measured beside the model. Three gauges were mounted to separate the incoming and reflected waves by means of the method by Mansard and Funke (1980). As mentioned 6 wave gauges were mounted on the monopile to measure the run-up. Run-up is defined as the "green water" level on the surface of the pile. Splash is not taken into account. To create a visualization of the run-up a movie has been made. When watching the run-up movie DVD attached on the inside of the back page of this report, it can be seen that, when big waves occur, the splash height can easily be the double of the run-up height. For visualization purposes various colors of tape have been mounted on the pile. Every line has a width of 1 m.

Test programme

The aim of the test programme is to measure the run-up for regular and irregular waves, which have a varying steepness of approximately 0.03 and 0.044.

Test nr.	Hs [m]	Tp [s]	steepness [-]	h [m]	Measured angles [°]
1	0.56	4.81	0.03	25	0; 90
2	1.55	6.43	0.03	25	0; 90
3	2.60	8.27	0.03	25	0; 90
4	3.95	9.05	0.03	25	0; 90
5	4.70	9.81	0.03	25	0; 90
6	5.87	11.82	0.03	25	0; 90
7	6.80	12.32	0.03	25	0; 90
8	7.81	12.16	0.03	25	0; 90
9	8.13	14.48	0.03	25	0; 90
10	6.41	12.59	0.03	25	0; 30; 60; 90; 135; 180
11	7.225	13.79	0.03	25	0; 30; 60; 90; 135; 180
12	7.81	13.79	0.03	25	0; 30; 60; 90; 135; 180
13	6.44	9.98	0.044	25	0; 30; 60; 90; 135; 180
14	7.7	10.93	0.044	25	0; 30; 60; 90; 135; 180
15	8.13	11.36	0.044	25	0; 30; 60; 90; 135; 180

Table 1. Testprogramme.

Notice, that the tests shown on the movie DVD correspond to the tests given in the table above, but actually they represent their own testprogramme. Therefore wave heigths differ sligthly in some cases. On the DVD there is also a section with regular waves to enhance the visualization of run-up from some wave heights.

Results

Comparison with Mase, Kosho and Nagahashi

Mase, Kosho and Nagahashi (2001) have derived an equation that describes the 2% run-up on a vertical pile as a function of bottom slope, wave height, wave length and water depth.

$$\frac{R_{2\%}}{h} = \left(0.24 - \frac{0.004}{\tan\vartheta}\right) + \left(11.3 - \frac{0.20}{\tan\vartheta}\right) \cdot \exp\left[-\left(1.55 - 0.77\exp\left\{-69.46\left(\frac{H_0}{L_0}\right)\right\}\right) \cdot \left(1.02 - \frac{0.015}{\tan\vartheta}\right) \cdot \left(\frac{h}{H_0}\right)\right]$$

The applicable conditions are as follows:

$$\frac{1}{40} \le \tan\vartheta \le \frac{1}{10}$$

$$0.004 < \frac{H_0}{L_0} < 0.05$$

$$\frac{h}{H_0} < 6$$

with:

$R_{2\%}$	2 % highest run-up values
$\tan\vartheta$	Bottom slope
h	Water depth
H_0	Deep water wave height
L_0	Deep water wave length

In the test setup, the following condition are being used:

$$\tan\vartheta = \frac{1}{50}$$

$$0.03 < \frac{H_0}{L_0} < 0.044$$

$$2.8 < \frac{h}{H_0} < 25$$

Both bottom slope and h/H_0 can differ from the applicable conditions. The comparison of the calculated wave run-up and the measured wave run-up in the model setup is made in Figure 4.

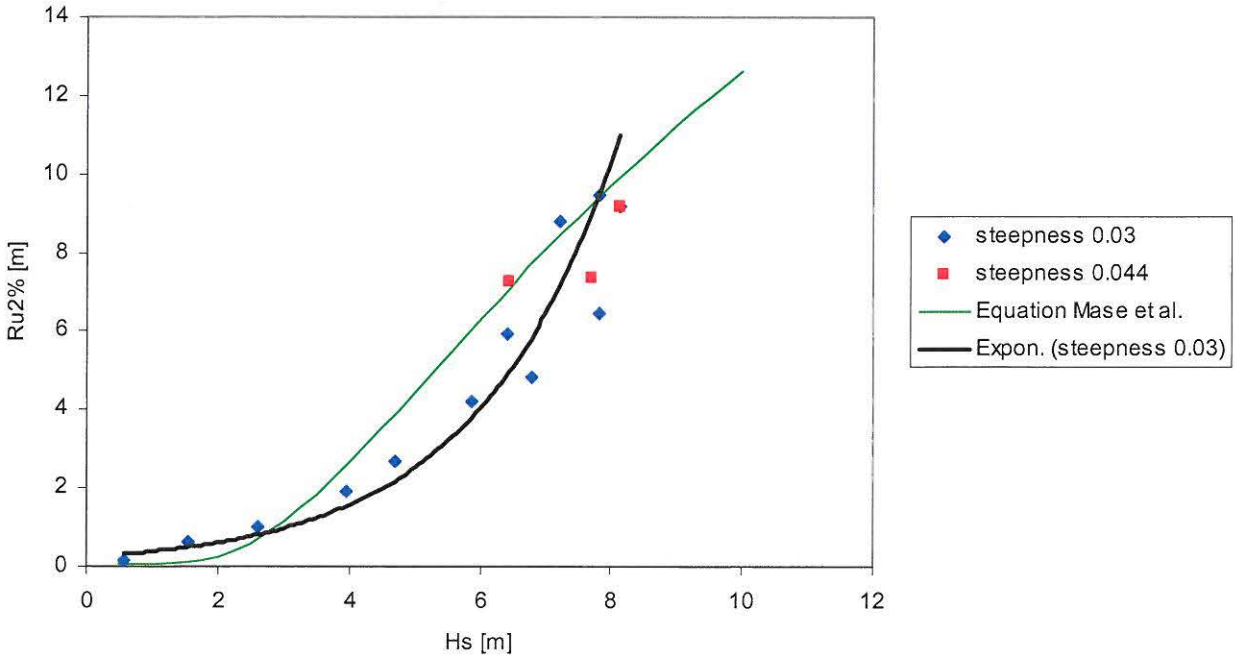

Figure 4. Comparison between calculated run-up with the formula of Mase, Kosho and Nagahashi and measured 2% run-up values.

Variation of run-up around the pile

The variation of the run-up around the pile was measured for three different wave heights (approximately H_s = 6.5, 7.5 and 8 m) and two different steepness (approximately 0.03 and 0.044). Figure 4 shows the measured $R_{2\%}$ value, relative to the $R_{2\%}$ value at the front side of the pile.

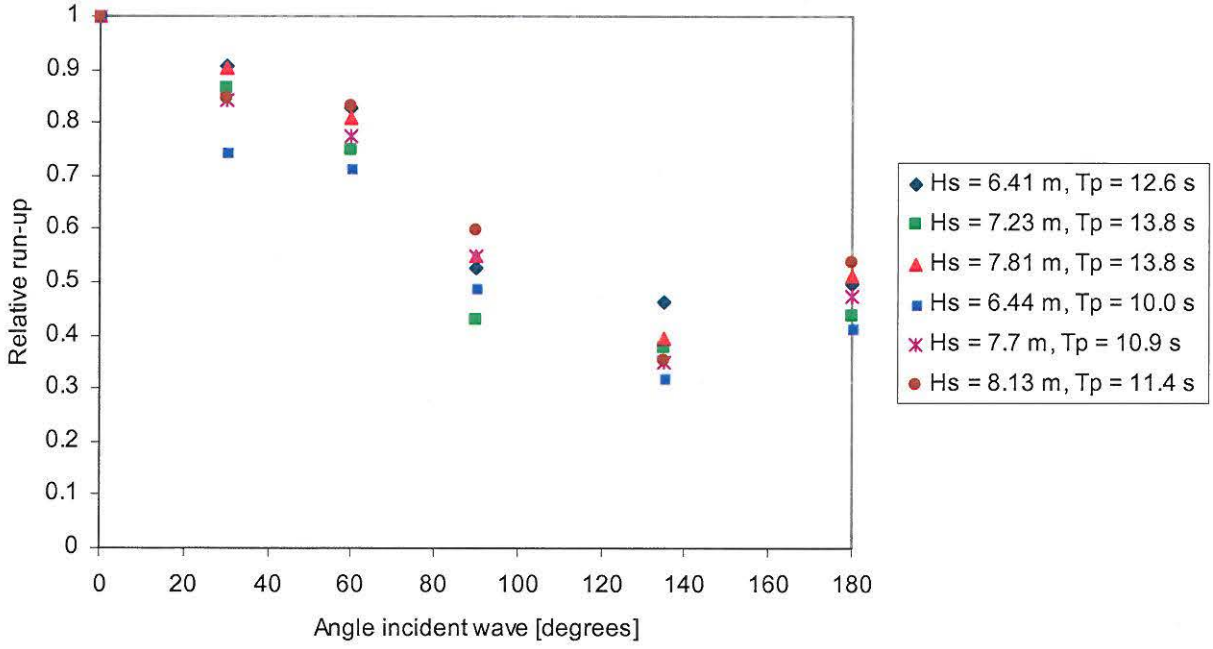

Figure 4. Relative $Ru_{2\%}$ along the pile.

As expected the maximum run-up is found on the front of the pile. The figure shows that the lowest run-up is not located on the leeside but at an angle of approximately 135°. The position with the lowest run-up gives approximately 40% of the maximum run-up.

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