Wave Run-Up Offshore Windturbine Foundations

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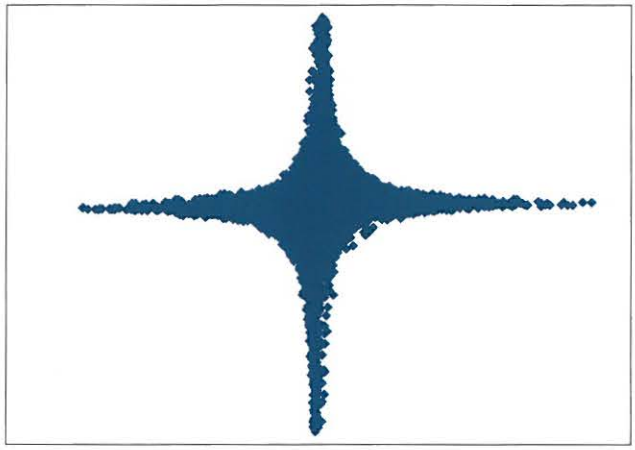

Wave Forces on Offshore Windturbine Foundations

on Borkum Riff

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Part C: Summary

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on Borkum Riff

Part C: Summary

By

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Contents

Introduction

The present report is a summary of the reports by Juul Larsen and Frigaard (2004) and Lykke Andersen and Frigaard (November 2004). It also contains some additional force measurements on a cone shaped structure and some new force measurements on the concrete tripod.

For further information on the conducted test programme contact Brian Juul Larsen (phone: +45 96 35 72 31, email: i5bjl@civil.aau.dk), Thomas Lykke Andesen (phone: +45 96 35 84 86, email: i5tla@civil.aau.dk) or Peter Frigaard (phone: 96 35 84 79, email: peter.frigaard@civil.aau.dk).

All measures given in this report is in prototype values unless otherwise is stated.

Tests

The overall test setup in the new tests are similar to the setup used in Juul Larsen and Frigaard (2004) and Lykke Andersen and Frigaard (November 2004). The water depth is 25 meters in all tests. At a water depth of 25 meters the models have the following eigenfrequencies:

Cone	0.53 Hz
Concrete tripod	0.39 Hz

Table 1. Eigenfrequencies with a water depth of 25 m.

The JONSWAP wave spectrum has been used with a peak enhancement factor of 3.3. The concrete tripod is placed with two legs in the direction facing the waves and one directly backward. A description of the models can be found on page 47 and 48 in the report by Juul Larsen, De Vos and Frigaard (November 2004). As in Lykke Andersen and Frigaard (November 2004) the data analysis has been performed by use of Wavelab using the same methods and techniques.

Results

The largest positive and negative forces and moments measured during the tests are listed in table 2.

Test	Structure	$H_{1/3}$ [m]	T_p [s]	F_{max} [kN]	F_{min} [kN]	M_{max} [kNm]	M_{min} [kNm]
1	Monopile	0.53	4.7	454	-393	9417	-6165
2	Monopile	1.65	6.6	1015	-871	25380	-11543
4	Monopile	3.70	8.0	2253	-2249	43860	-33447
5	Monopile	5.01	9.5	2432	-2451	46903	-29925
6	Monopile	5.74	10.3	2967	-2886	55926	-33607
7	Monopile	7.11	11.4	3056	-2914	69476	-31915
8	Monopile	7.84	12.9	3557	-3446	109122	-50266
9	Monopile	8.70	14.9	3843	-3760	96017	-48500
10	Monopile	1.51	5.7	1021	-893	17771	-11857
11	Monopile	3.73	8.2	2367	-1955	52246	-24892
12	Monopile	5.86	10.2	2782	-2636	58558	-32127
13	Monopile	7.84	11.8	3867	-3734	91038	-51478
14	Monopile	1.42	5.5	1155	-952	25882	-16324
15	Monopile	3.41	7.6	2131	-1932	50724	-27842
16	Monopile	5.63	9.8	2738	-2771	56548	-32524
17	Monopile	7.56	10.9	3359	-3277	90532	-41656
18	Monopile	1.79	6.4	1035	-980	20590	-20096
27	Monopile	2.99	9.8	1680	-1756	41196	-23324
28	Steel	1.62	6.6	1533	-1403	27149	-22197
29	Steel	3.70	9.5	2637	-2542	50299	-27717
30	Steel	5.69	12.1	3174	-3340	60807	-33837
31	Steel	7.62	13.5	3901	-4918	91466	-58595
32	Steel	1.49	6.1	1043	-1002	15922	-13016
33	Steel	3.51	8.5	2827	-2210	65896	-24248
34	Steel	5.71	10.3	3202	-3479	64040	-35499
35	Steel	7.84	12.1	3846	-4704	81824	-45403
TLA1	Monopile	7.93	12.9	3721	-2753	61960	-43720
TLA3	Concrete	7.80	12.5	6753	-5517	82780	-53060
TB01	Cone	3.56	9.5	4345	-4415	56810	-47610
TB02	Cone	4.23	9.5	5328	-4506	73090	-50610
TB03	Cone	6.86	12.1	8436	-6616	117000	-68820
TB04	Cone	7.51	13.9	8665	-6653	113100	-68280
TB05	Cone	8.71	13.9	8745	-6808	123400	-76210
TB06	Concrete	3.67	9.5	3413	-3241	47880	-37590
TB07	Concrete	4.06	9.3	3511	-3322	51090	-37050
TB08	Concrete	6.50	12.5	5044	-4901	67870	-48720
TB09	Concrete	7.27	12.9	6416	-4920	90370	-50120
TB10	Concrete	8.53	14.5	7196	-5084	90560	-52720

Table 2. Largest positive and negative forces and moments measured during the tests.

As a reasonable representative for the maximum and minimum forces of the tests the 1/250 values are compared in figure 1.

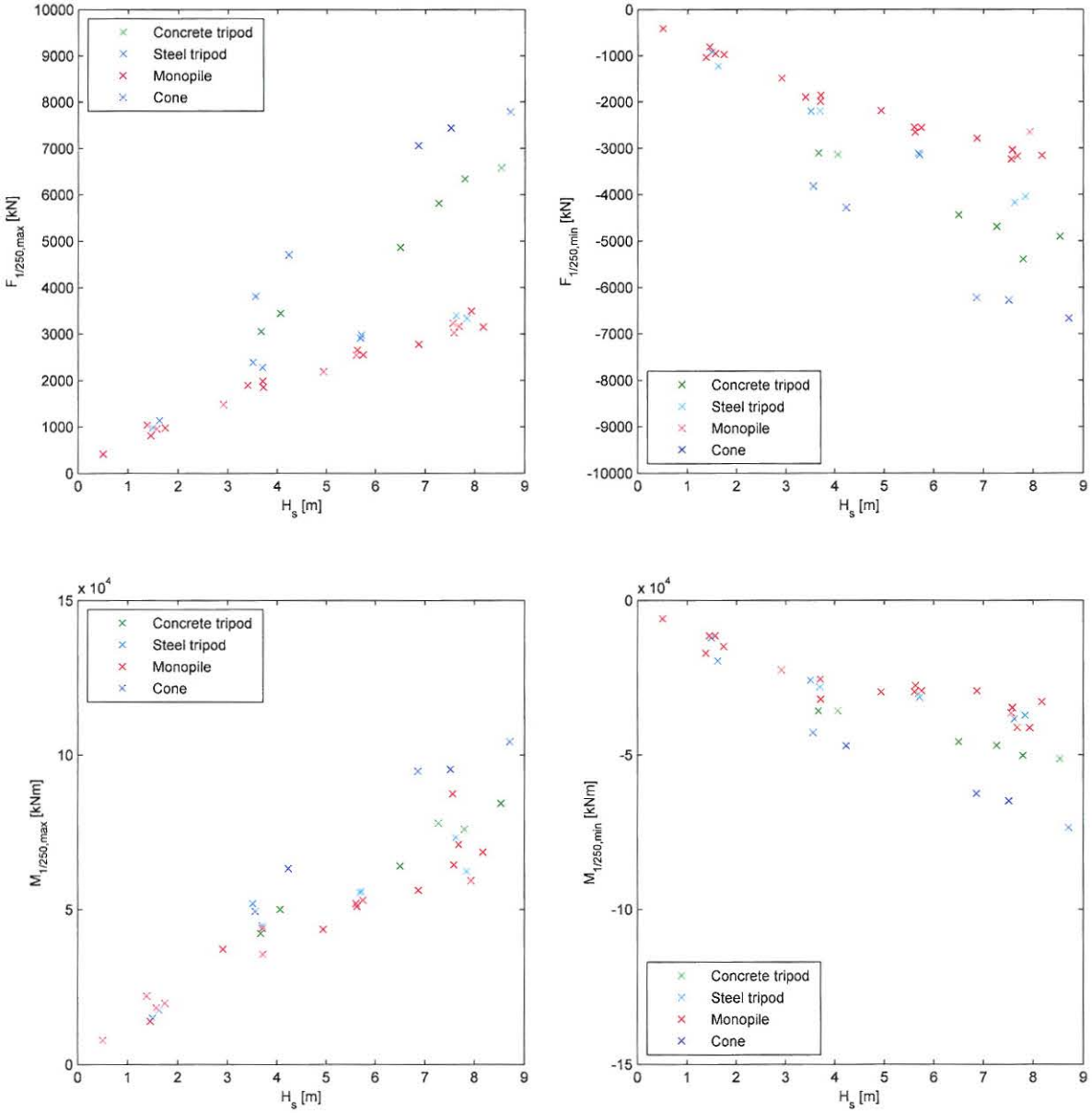


Figure 1. Comparison of measured 1/250 forces and moments.

A summary of the works by Aalborg University on the Borkum Riffgrund project gives the following result plots:

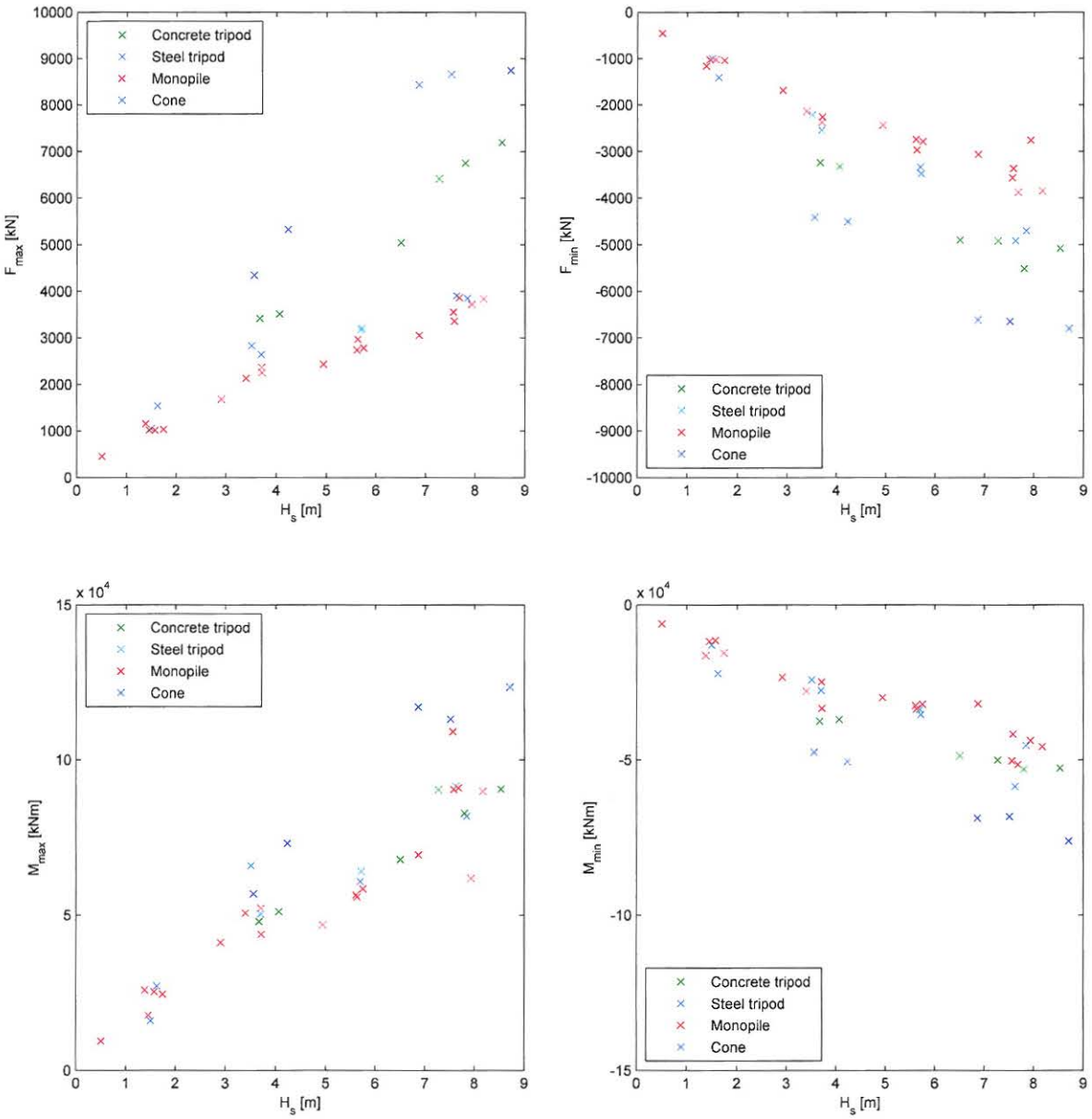


Figure 2. Comparison of largest measured forces and moments.

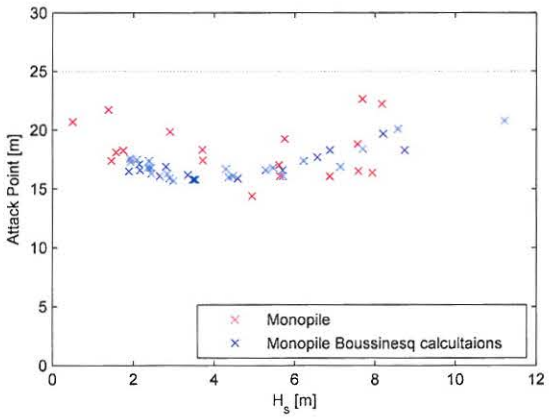


Figure 3. Comparison of measured attack point of largest forces with some Boussinesq calculations.

References

Juul Larsen, B. and Frigaard, P. (2004):
Wave Forces on Offshore Windturbine Foundations on Borkum Riff. Department of Civil Engineering, Aalborg University, Hydraulic and Coastal Engineering No. 5, ISSN 1603-9874

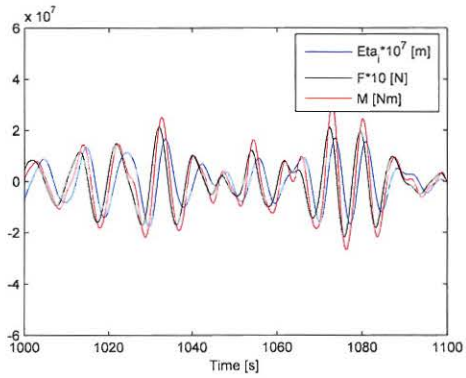
Lykke Andersen, T. and Frigaard, P. (November 2004):
Wave Forces on Offshore Windturbine Foundations on Borkum Riff – Part B: Verification Tests. Department of Civil Engineering, Aalborg University, Hydraulic and Coastal Engineering No. 5, ISSN 1603-9874

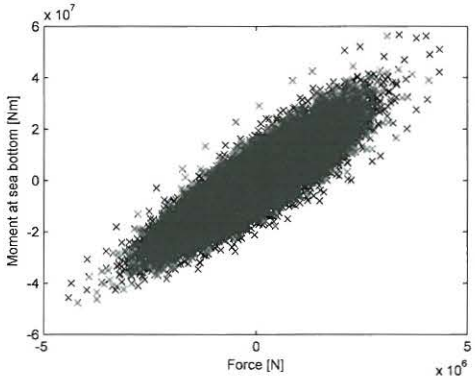
Juul Larsen, B., De Vos, L. and Frigaard, P. (November 2004):
Scour around Offshore Windturbine Foundations on Borkum Riffgrund. Department of Civil Engineering, Aalborg University, Hydraulic and Coastal Engineering No. 9, ISSN 1603-9874

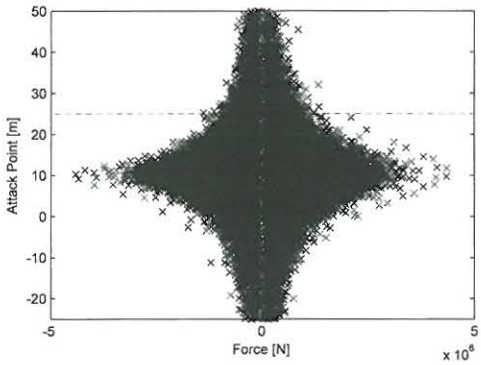
Appendix 1 – Result Plots

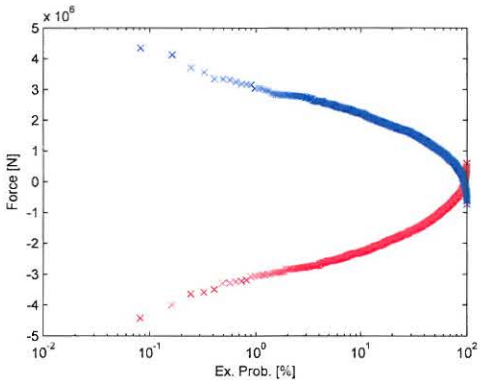
Test TB01

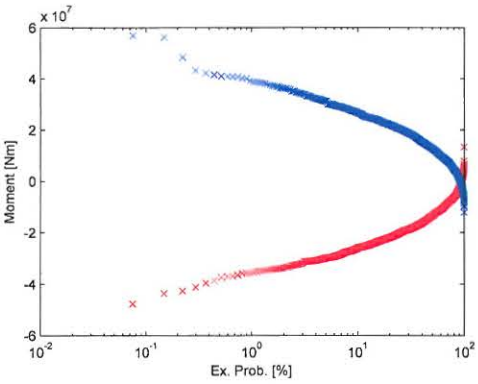
- With a cone structure
- $H_{1/3} = 3.56$ m, $T_p = 9.5$ s
- Maximum force: 4345 kN
- Minimum force: -4415 kN
- Maximum moment: 56810 kNm
- Minimum moment: -47610 kNm

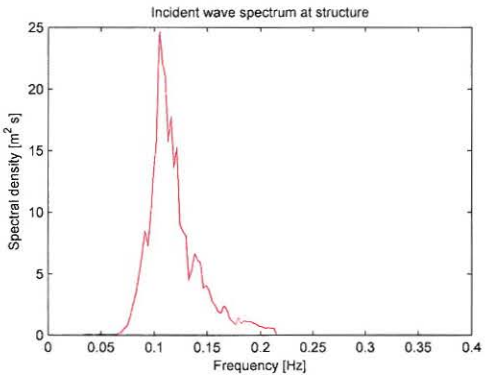


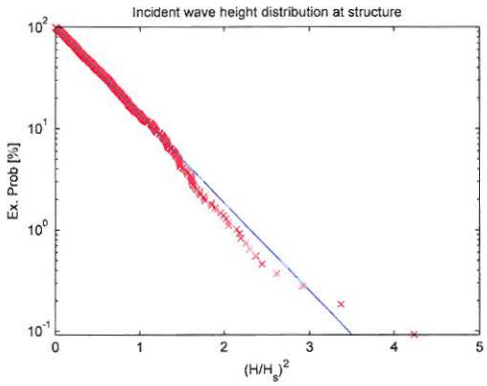






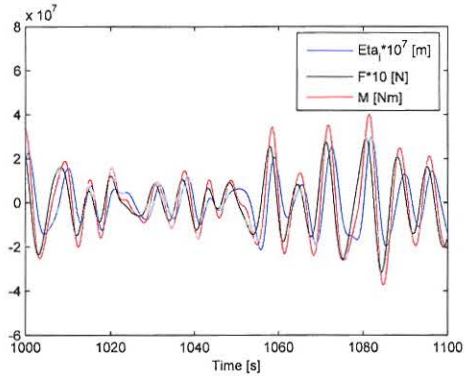


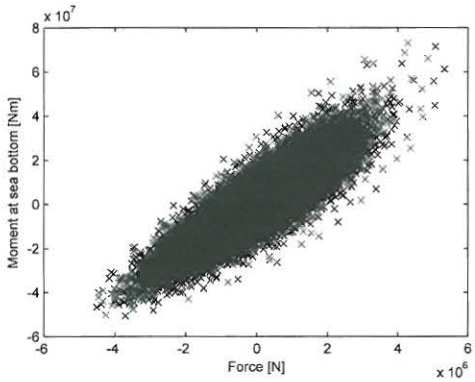


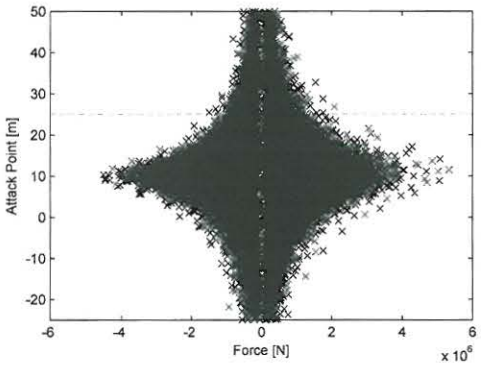


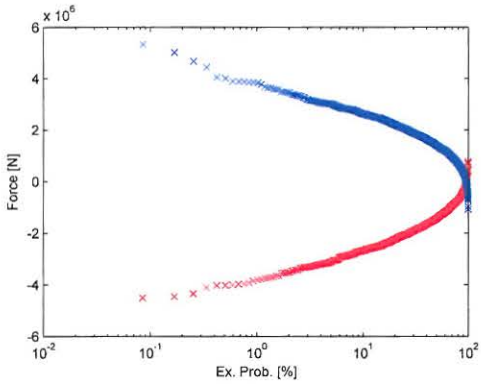
Test TB02

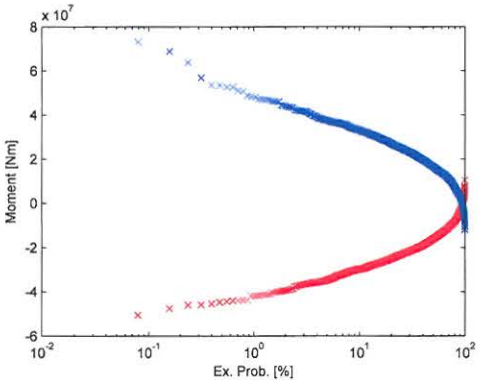
- With a cone structure
- $H_{1/3} = 4.23$ m, $T_p = 9.5$ s
- Maximum force: 5328 kN
- Minimum force: -4506 kN
- Maximum moment: 73090 kNm
- Minimum moment: -50610 kNm

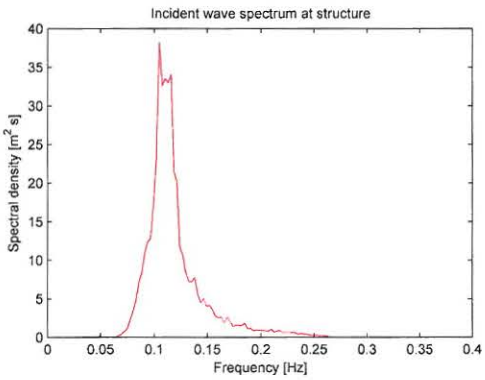


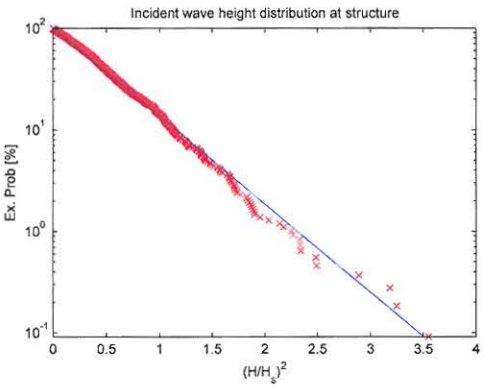






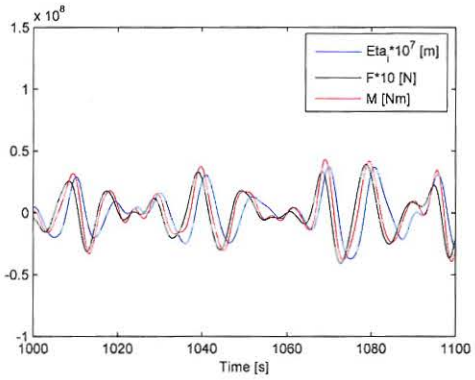


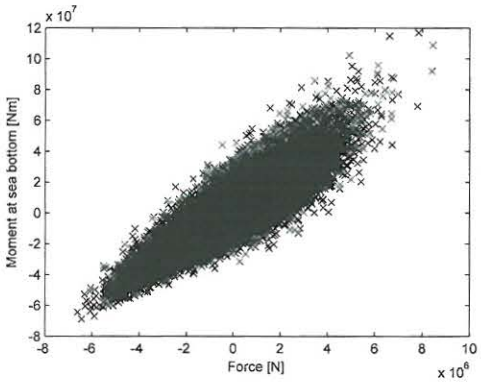


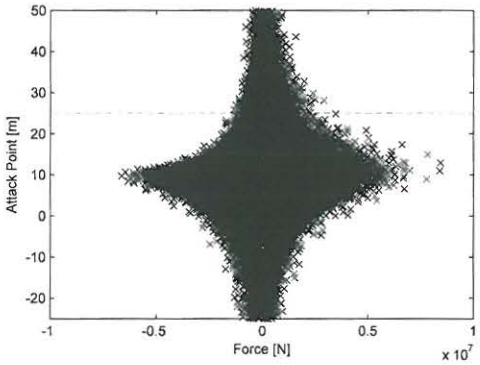


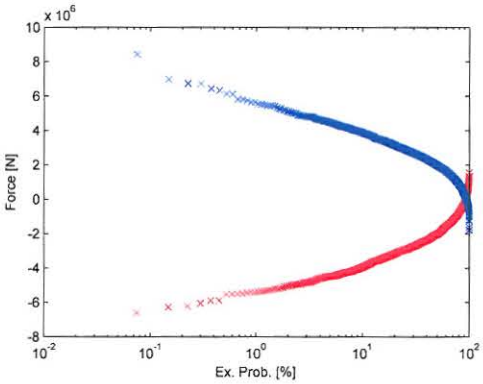
Test TB03

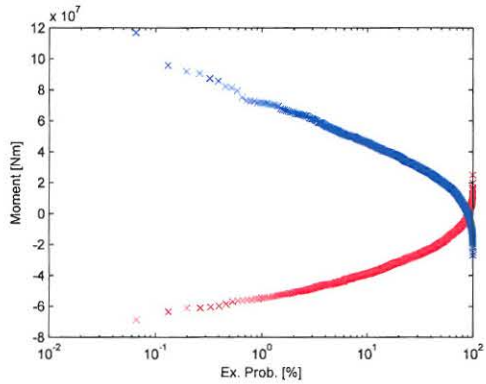
- With a cone structure
- $H_{1/3}$ = 6.86 m, T_p = 12.1 s
- Maximum force: 8436 kN
- Minimum force: -6616 kN
- Maximum moment: 117000 kNm
- Minimum moment: -68820 kNm

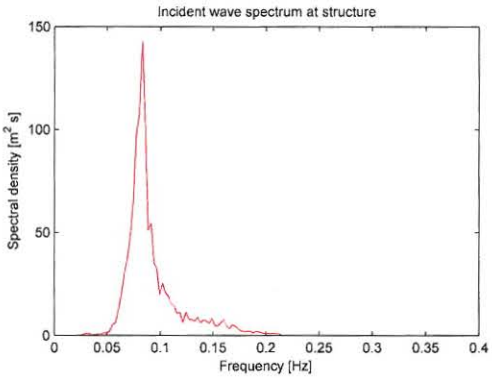


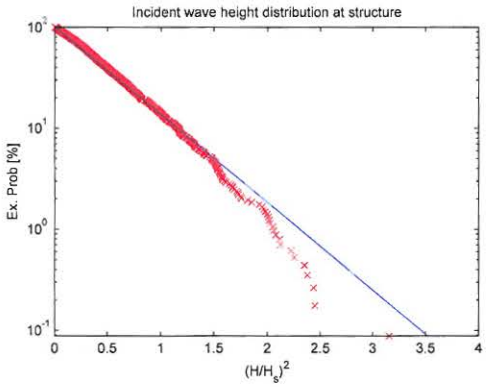






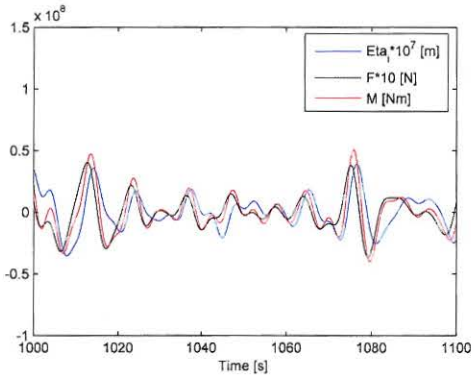


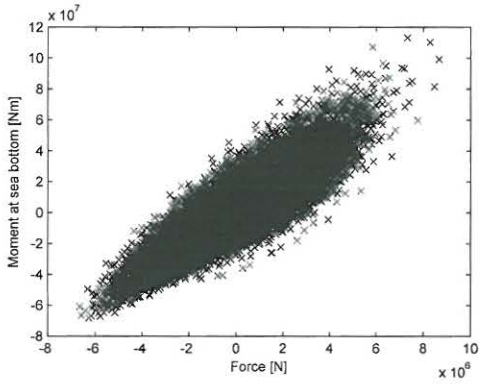


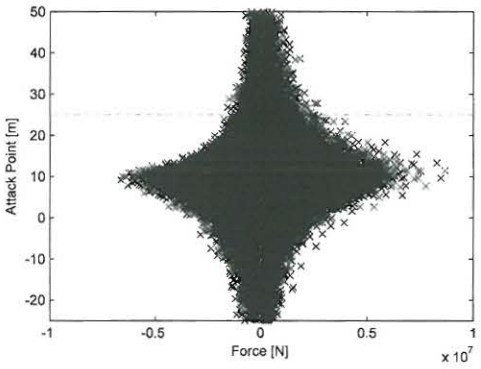


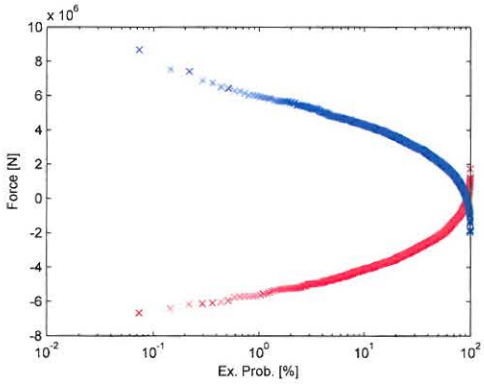
Test TB04

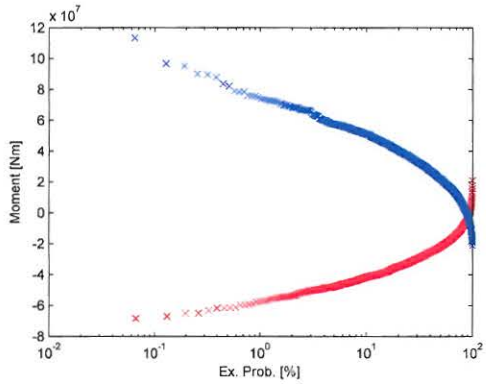
- With a cone structure
- $H_{1/3}$ = 7.51 m, T_p = 13.9 s
- Maximum force: 8665 kN
- Minimum force: -6653 kN
- Maximum moment: 113100 kNm
- Minimum moment: -68280 kNm

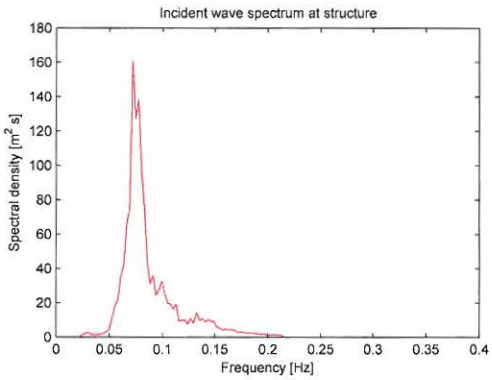


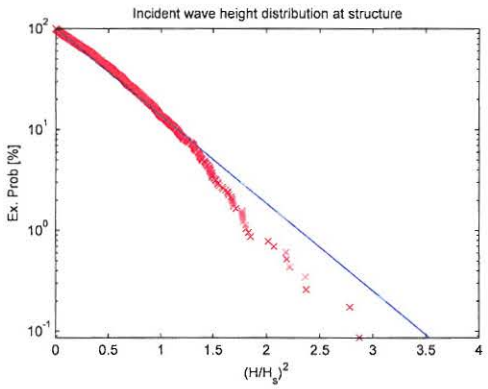






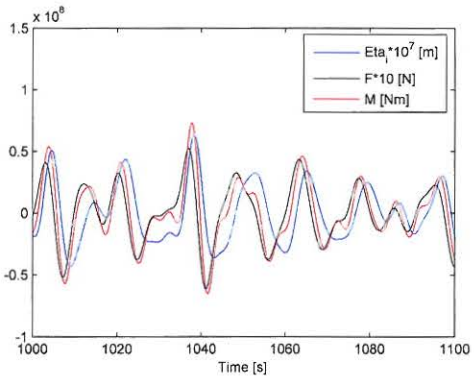


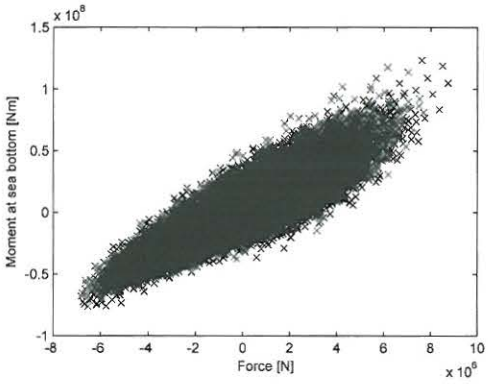


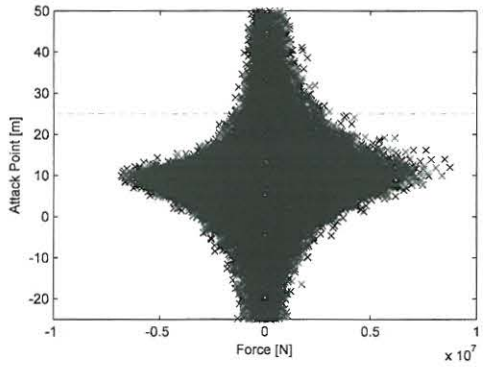


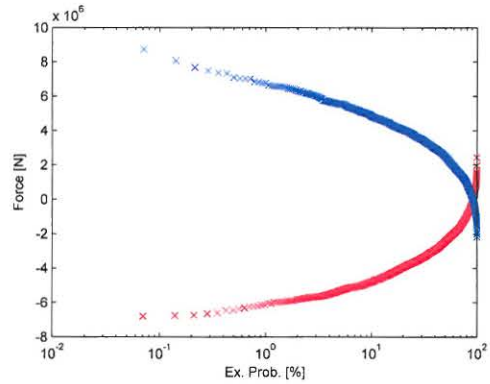
Test TB05

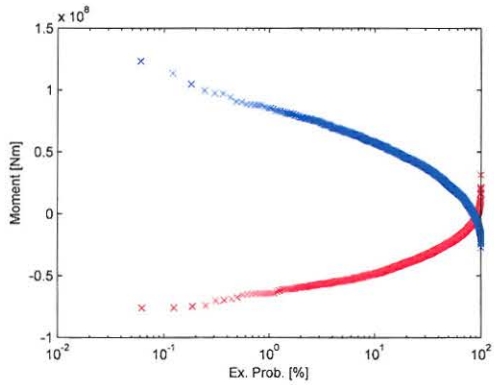
- With a cone structure
- $H_{1/3}$ = 8.71 m, T_p = 13.9 s
- Maximum force: 8745 kN
- Minimum force: -6808 kN
- Maximum moment: 123400 kNm
- Minimum moment: -76210 kNm

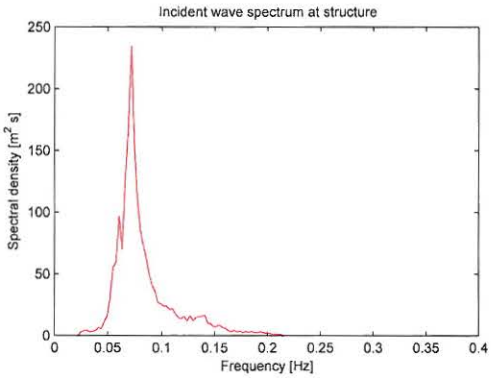


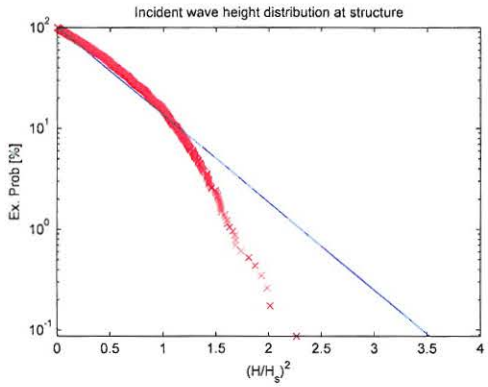






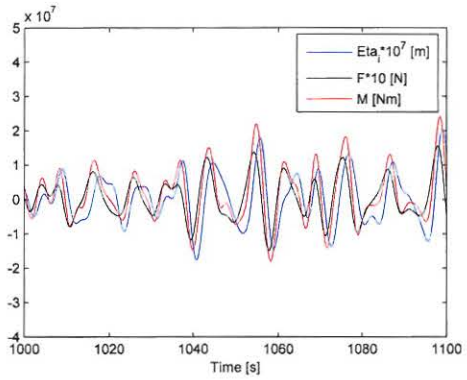


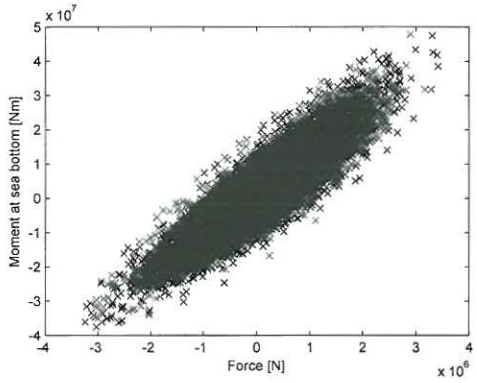


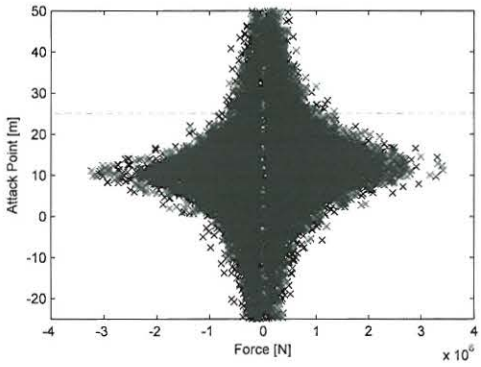


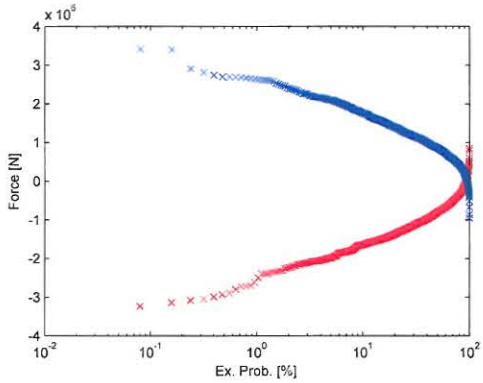
Test TB06

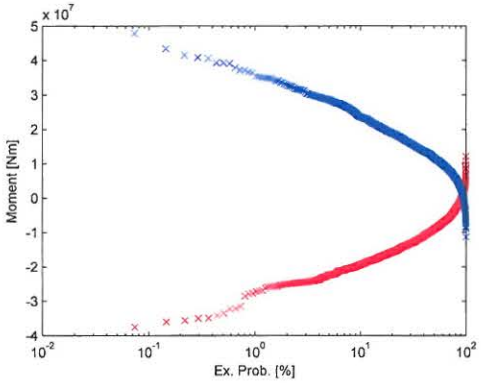
- With a concrete tripod structure
- $H_{1/3} = 3.67$ m, $T_p = 9.5$ s
- Maximum force: 3413 kN
- Minimum force: -3241 kN
- Maximum moment: 47880 kNm
- Minimum moment: -37590 kNm

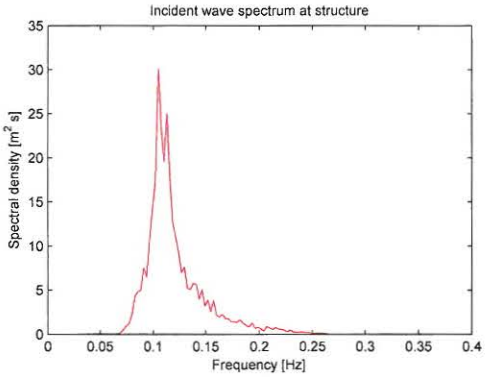


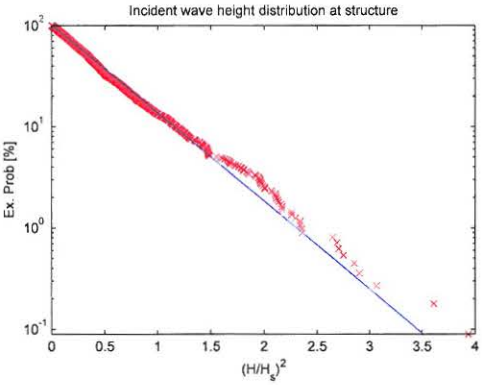






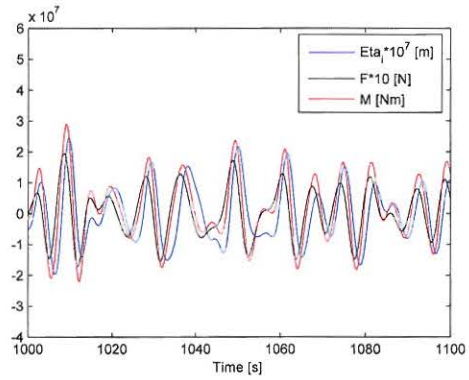


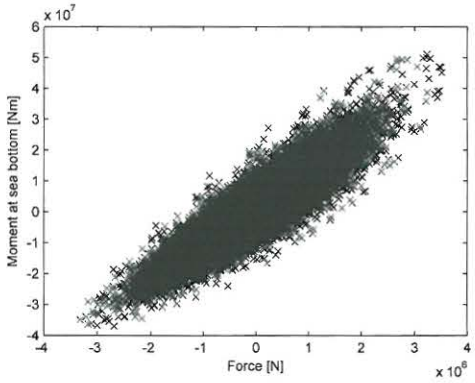


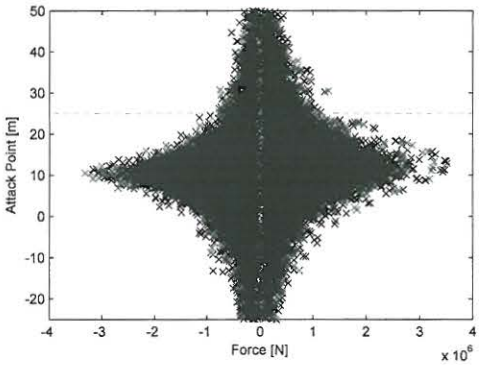


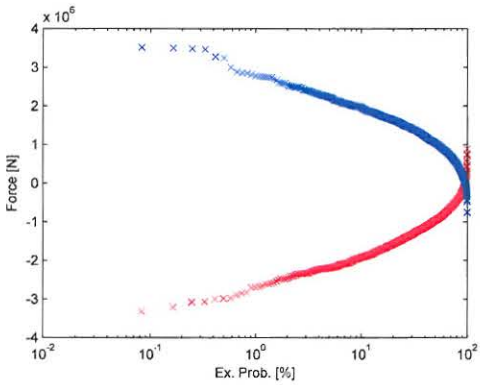
Test TB07

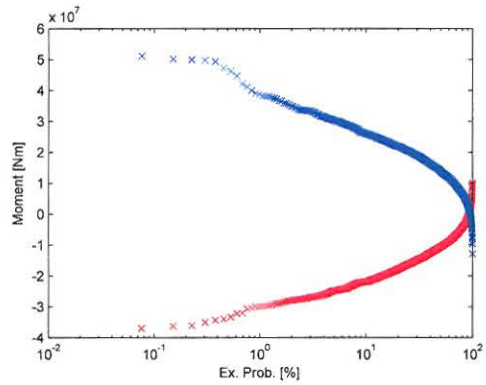
- With a concrete tripod structure
- $H_{1/3}$ = 4.06 m, T_p = 9.3 s
- Maximum force: 3511 kN
- Minimum force: -3322 kN
- Maximum moment: 51090 kNm
- Minimum moment: -37050 kNm

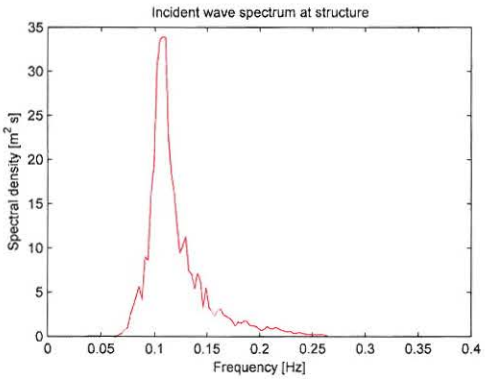


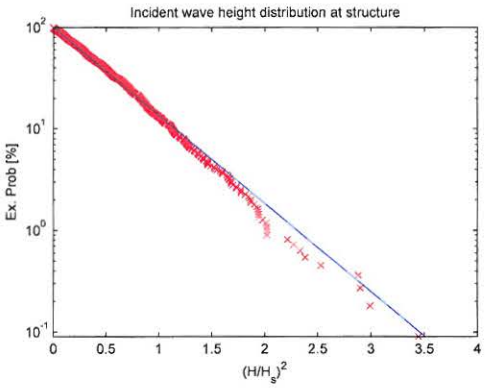






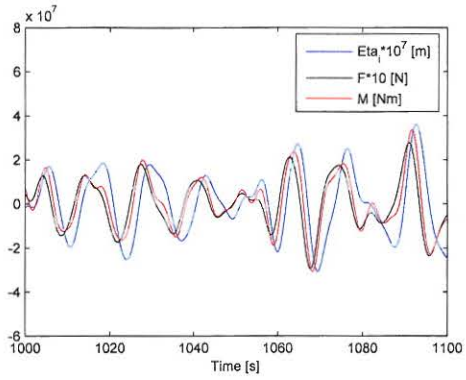


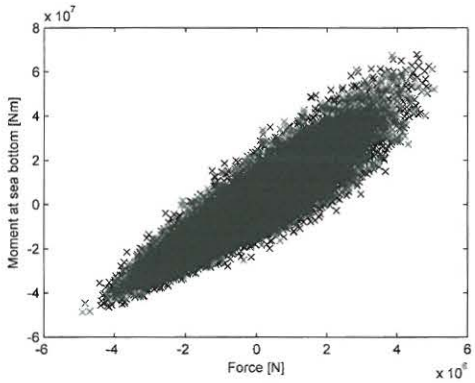


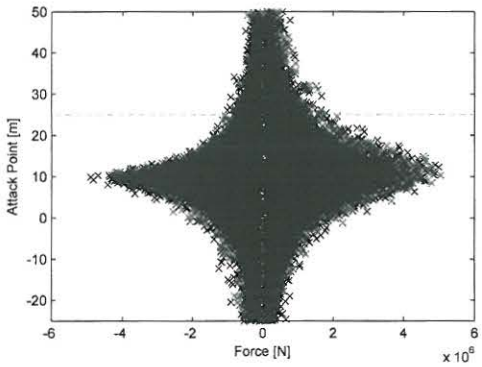


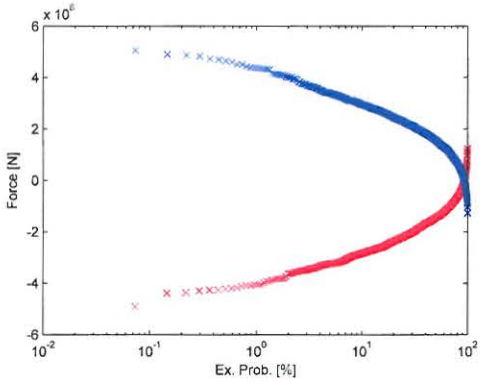
Test TB08

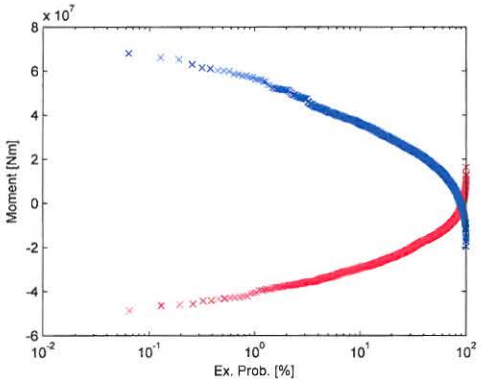
- With a concrete tripod structure
- $H_{1/3}$ = 6.50 m, T_p = 12.5 s
- Maximum force: 5044 kN
- Minimum force: -4901 kN
- Maximum moment: 67870 kNm
- Minimum moment: -48720 kNm

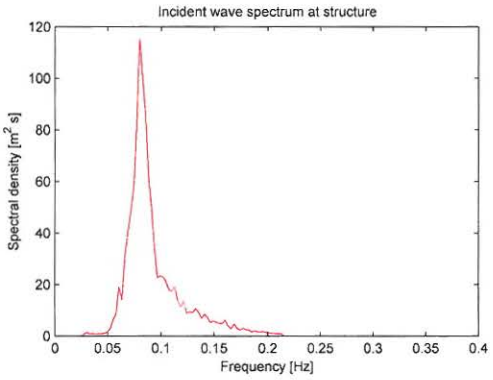


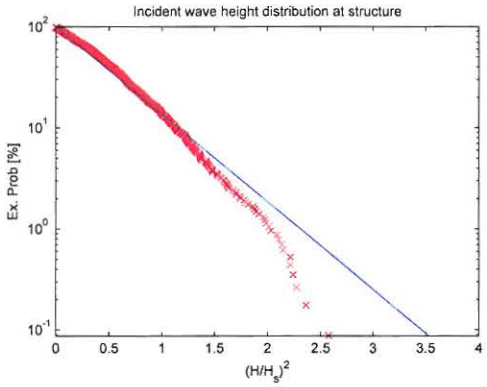






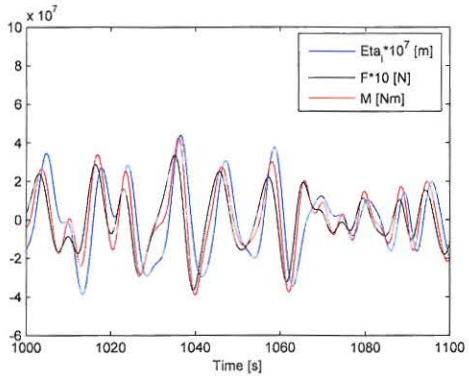


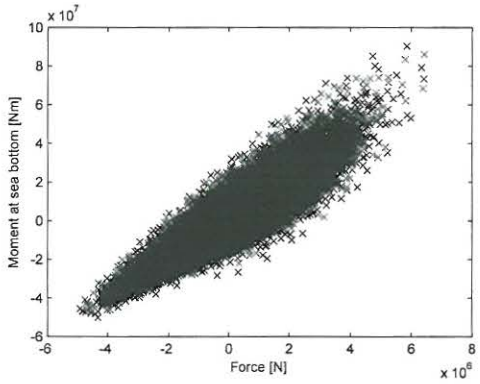


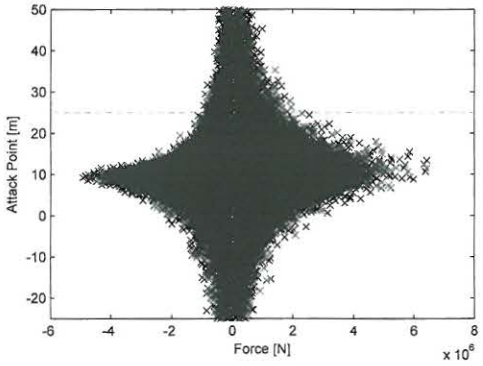


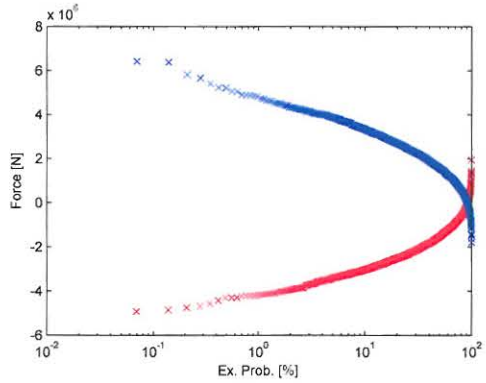
Test TB09

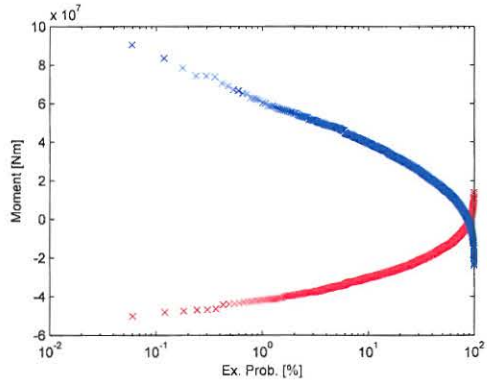
- With a concrete tripod structure
- $H_{1/3}$ = 7.27 m, T_p = 12.9 s
- Maximum force: 6416 kN
- Minimum force: -4920 kN
- Maximum moment: 90370 kNm
- Minimum moment: -50120 kNm

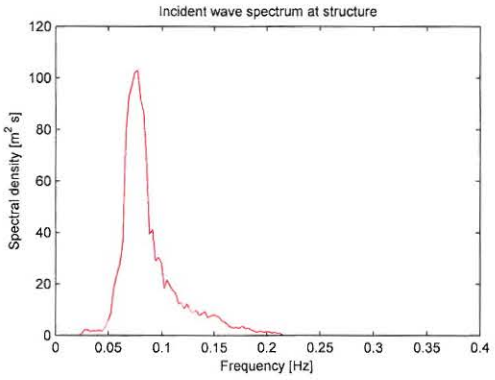


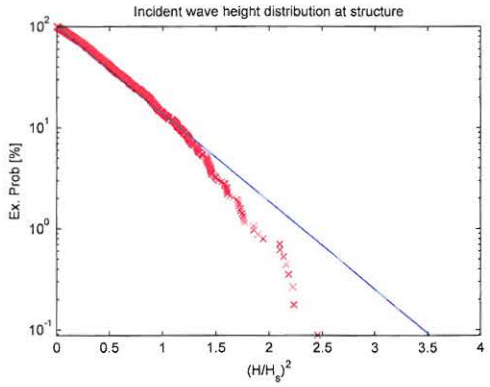












Test TB10

- With a concrete tripod structure
- $H_{1/3}$ = 8.53 m, T_p = 14.5 s
- Maximum force: 7196 kN
- Minimum force: -5084 kN
- Maximum moment: 90560 kNm
- Minimum moment: -52720 kNm