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Characterization of Wave Climate at Hanstholm Location with Focus on the Ratio between Average and Extreme Waves Heights

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The wave energy sector is in need of showing positive experience from the real sea trial in order to prove its feasibility. For this purpose, an accurate knowledge of wave conditions at the selected location of installation is fundamental. A design challenge for wave energy devices is the large differences between the extreme wave conditions in which the device is designed to survive and the average wave conditions for which the device is to be optimised. Indeed, the ratio between extreme loads and operational loads has been identified to be a fundamental factor for the design and the cost analysis of the wave energy units. The present paper provides an estimate of everyday wave conditions at Hanstholm location, by mean of scatter diagrams for different locations within the harbour vicinity. Results on wave heights transformation from offshore to shore realized with numerical model for operational and extreme waves are then presented and compared in different strategic points for WECs installation in the proximity of Hanstholm harbour within the Danish Wave Energy Centre (DanWEC).

Deployment of WECs, Design Waves, Operational Conditions.

I. INTRODUCTION

The Danish Wave Energy Centre (DanWEC) has been realized because of participated desire to market the trial wave energy projects which are already on the way to Hanstholm, namely WaveStar, Waveplane and Dexa [1]. Additionally, the center will contribute at creating a local base for knowledge, education and possibly a workplace which will be leased out to trial projects. It is therefore likely that different developers will deploy their wave energy devices during the next years in this location. The DanWEC is a part of Hanstholm harbour in the North-West of Denmark (Fig. 1). The location is particularly challenging for the construction of a harbour and very interesting for the establishment of a wave energy centre due to its wave conditions. It is indeed because of the proximity of the Harbour, inaugurated in the 1967, that long time wave measurements are available. The areas South of Hanstholm is characterized by the beaches and sand dunes on the West coast. East of Hanstholm the landscape consists of reefs and cliffs. The main part of the harbour is characterized by the fishing industry. Today Hanstholm harbour began a process of expansion and modernization that includes the creation of the DanWEC.

Successful demonstration of full scale wave energy converters is one of the primary challenges of the sector, especially when discussing floating devices. The loads that devices have to survive during storm conditions are much greater than the loads during operation conditions to such an extent that some WECs have been developed to include one "storm mode" by either removing the most delicate parts out of the water [2], or by submerging entirely for protection and accepting a reduced or nil power production when the significant wave height exceeds specific threshold [3]. Both wave loads and wave power are proportional to the wave height. It is also important to consider wave transformation going from offshore conditions to close to shore that can result in decreased wave power and loads.

The objectives of the present paper are to describe the wave conditions in the proximity of Hanstholm harbour where the DanWEC is located and to highlight the ration between operation and extreme wave heights in three representative points for potential WECs installations. Indication on the wave resource will also be provided.

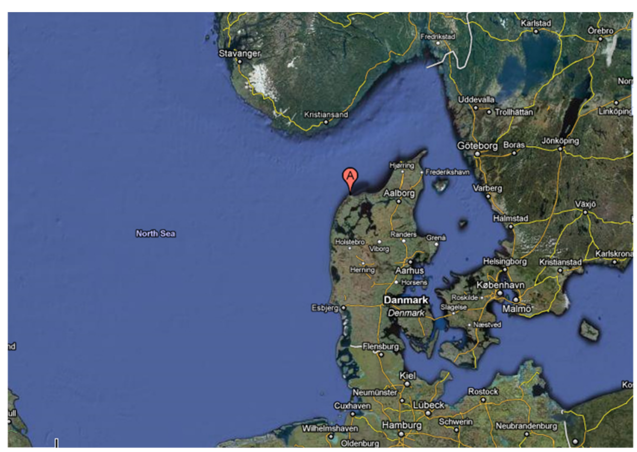

Fig. 1 Hanstholm harbour location.

II. WAVE DATA AND OFFSHORE WAVE CLIMATE

Wave data used in the present study come from different buoys and time records [4][5]:

1) Operational conditions. Hanstholm (buoy 3110; 474 700 E, 6 332 100 N, 20 m. water depth. Duration: 01/11/05-25/02/09). Fjaltring (buoy 2031; 441976 E, 6 259 466 N, 17.5 m. water depth. Duration: 11/08/99-25/02/09). Hirtshals (buoy 1041; 524 559 E, 6 381 744 N, 17 m. water depth. Duration: 11/12/91-25/02/09).
2) Extreme conditions. Hanstholm (buoy 3110; 474 700 E, 6 332 100 N, 20 m. water depth. Duration: from 19/5/1998 to 25/2/2009).

The buoy outputs are H_{m0} and T_{m01} calculated over 30 minutes:

$$H_{m0} = 4 \cdot \sqrt{m_0} \quad (1)$$

$$T_{m01} = \frac{m_0}{m_1} \quad (2)$$

$$m_0 = \int_0^{+\infty} f^n \cdot E(f)df \quad (3)$$

Where f is the frequency [s^{-1}] and $E(f)$ is the spectrum energy density depending on the frequency [m2s].

A. *Operational wave conditions*

Hanstholm buoy is not directional and therefore the data from the other buoys provided the information on directionality. The angle of the incoming waves in Hanstholm has been interpolated by a vectorial addition of the wave directions in Hirtshals and Fjaltring. In occasions, the vectorial addition could not be executed because the times of the extracted data in the different buoys were not equal. In those cases, a weighed mean has been calculated between the next and the previous recordings from the specific buoy (Fjaltring or Hirtshals buoy) as:

$$DirX_i = Dir\_timeX\_next_i \cdot \left(\frac{timeHa_i - timeX\_prev_i}{timeX\_next_i - timeX\_prev_i} \right) + \\ + Dir\_timeX\_prev_i \cdot \left(1 - \frac{timeHa_i - timeX\_prev_i}{timeX\_next_i - timeX\_prev_i} \right) \quad (3)$$

Where:

$DirX_i$ is the direction of the waves in the location (Hirtshals or Fjaltring) in the time *i* (time from Hanstholm).

$Dir\_timeX\_next_i$ is the direction of the waves in the location (Hirtshals or Fjaltring) in the successive time to time *i* from Hanstholm.

$timeX\_next_i$ is the time of the location successive to the time *i* from Hanstholm.

$timeHa_i$ is the time *i* from Hanstholm.

$timeX\_prev_i$ is the time of the location previous to the time *i* from Hanstholm.

$Dir\_timeX\_prev_i$ is the direction of the waves in the location (Hirtshals or Fjaltring) in the previous time to time *i* from Hanstholm [7].

Wave directions in Hanstholm have been distributed in directions of 45°. The main wave direction results to be West direction with 52.0% probability of occurrence, followed by North-West and North directions with 27.10% and 10.28% (Fig. 2).

Wave power has been calculated in deep water assumption as:

$$P_{wave} = 0.49 \cdot H_S^2 \cdot (T_P / 1.15) \quad (4)$$

		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5	
	Hs [m]		0.92		1.50	2.00	2.50	3.00	3.69	
	Tp [s]		5.23		5.94	6.67	7.09	7.83	8.55	sum
N	Prob.	0	0.07	0.00	0.02	0.01	0.00	0.00	0.00	**0.10**
	Pwave [kW/m]	0	1.87	0.00	5.70	11.38	18.87	30.02	49.61	
	P*prob	0	0.13	0.00	0.10	0.10	0.04	0.04	0.01	**0.43**
		<0.5	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**2.0-2.5**	**2.5-3.0**	**3.0-3.5**	**>3.5**	
	Hs [m]		0.90		1.50	2.00	2.50	3.00	4.03	
	Tp [s]		5.72		6.21	6.59	7.05	7.59	8.85	sum
NW	Prob.	0	0.16	0.00	0.05	0.03	0.02	0.01	0.01	**0.27**
	Pwave [kW/m]	0	1.97	0.00	5.95	11.23	18.78	29.10	61.30	
	P*prob	0	0.32	0.00	0.28	0.33	0.32	0.26	0.39	**1.91**
		<0.5	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**2.0-2.5**	**2.5-3.0**	**3.0-3.5**	**>3.5**	
	Hs [m]		0.92		1.50	2.00	2.50	3.00	4.05	
	Tp [s]		6.25		6.34	6.64	7.09	7.63	8.72	sum
W	Prob.	0	0.28	0.00	0.11	0.07	0.03	0.02	0.01	**0.52**
	Pwave [kW/m]	0	2.26	0.00	6.08	11.31	18.88	29.27	60.92	
	P*prob	0	0.62	0.00	0.66	0.77	0.64	0.52	0.81	**4.01**
		<0.5	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**2.0-2.5**	**2.5-3.0**	**3.0-3.5**	**>3.5**	
	Hs [m]		0.86		1.50	2.00	2.50			
	Tp [s]		5.73		5.56	6.13	6.86			sum
SW	Prob.	0	0.06	0.00	0.01	0.00	0.00	0.00	0.00	**0.07**
	Pwave [kW/m]	0	1.82	0.00	5.33	10.45	18.28	0.00	0.00	
	P*prob	0	0.11	0.00	0.03	0.02	0.00	0.00	0.00	**0.16**
		<0.5	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**2.0-2.5**	**2.5-3.0**	**3.0-3.5**	**>3.5**	
	Hs [m]		0.88		1.50					
	Tp [s]		5.32		5.44					sum
S	Prob.	0	0.02	0.00	0.00	0.00	0.00	0.00	0.00	**0.02**
	Pwave [kW/m]	0	1.75	0.00	5.22	0.00	0.00	0.00	0.00	
	P*prob	0	0.04	0.00	0.00	0.00	0.00	0.00	0.00	**0.04**
SUM-Prob		0.000	0.591	0.000	0.180	0.108	0.053	0.028	0.020	**0.98**
SUM-P*prob		0.000	1.224	0.000	1.075	1.220	0.999	0.823	1.209	**6.55**

Fig. 2 Directional offshore wave climate at Hanstholm buoy.

B. *Design wave conditions*

To determine the design wave height for specific return period, the general procedure is from Liu and Frigaard [5] is adopted. This makes use of "Peak Over Threshold method" to select the storm events over the record and the choice of Gambel or Weibull theoretical distributions for the extreme wave height distribution by mean of Maximum Likelihood Method or Least Square Method. A 90% fractal of the confidence interval provides a design wave height = 8.0 m for 50 years return period.

In accordance to the standard the range of the wave peak period T_P is given by:

$$\sqrt{\frac{130 H_S}{g}} < T_P < \sqrt{\frac{280 H_S}{g}} \quad (5)$$

Corresponding to 10.3 s. < T_P < 15.1 s.

III. NUMERICAL SIMULATIONS

The bathymetry at location comprehends an area going from the Hanstholm buoy to shore, therefore including water depth from 20 m. to 0 m. Transformation of waves from offshore to three different locations (Fig.3) has been done using the computer model MILDwave [8] for specific combinations of Hm_0 and T_p representative of offshore operational and extreme conditions. The three close to shore locations have coordinates:

- 1: 475400E, 6331700N; 9.26 m water depth.
- 2: 475900E, 6332100N; 11 m water depth.
- 3: 476500E, 6332500N; 14 m water depth.

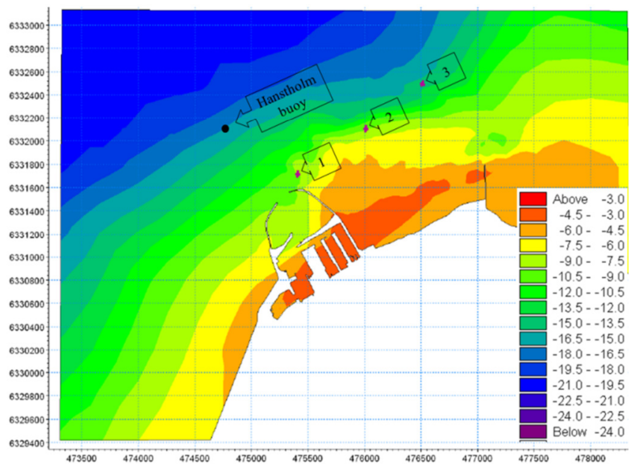

Fig. 3 Bathymetry and reference points 1, 2 and 3.

The waves are modelled as long crested irregular waves, characterized by a JONSWAP spectrum (γ = 3.3) defined by significant wave height Hm_o and T_p. The wave directions West (270°), North-West (315°) and North (0°) have been simulated. The operational conditions were calculated for water level at +0.00 m, while the extreme wave conditions for a water level at +1.20 m.

In each simulation, a uniform rectangular grid is created with cell spacing dx = 1.5 m and dy = 1.5 m. For the applications of the "long" grid for West direction a cell spacing of dx = 3.0 m is used. Several grids have been constructed, according to each wave direction. Grid areas situated above water level (dry land) are simulated as fully transmitting, considering 'land grid cells' as 'water grid cells'.

C. *Numerical settings*

No lateral sponge layers were used. At the top and bottom boundaries, sponge layers have been added for absorption of the generated waves. The width of each of the sponge layers is equal or larger than: 3x "Wave Length".

For each of the wave directions runs have been performed, for operational and extreme conditions. In all simulations the possibility that wave breaking occurs is taken into account.

The land area at the coastline is simulated as not reflecting, in order to achieve a negligible amount of reflection from the land. The waves that are propagating towards the coast are being absorbed by the downwave sponge layer.

D. *Contour plots*

Results are here graphically presented by mean of contour plots generated by the MILDwave program for few representative cases (Fig.4-8). The model generation line is to be considered parallel to the top edge the figures, several meters away out from them. The waves have been generated in order to obtain the required wave height at the buoy location (considered here to be the offshore incoming wave).

For incoming waves of 3 m and higher, points 1, 2 and 3 are bottom limited.

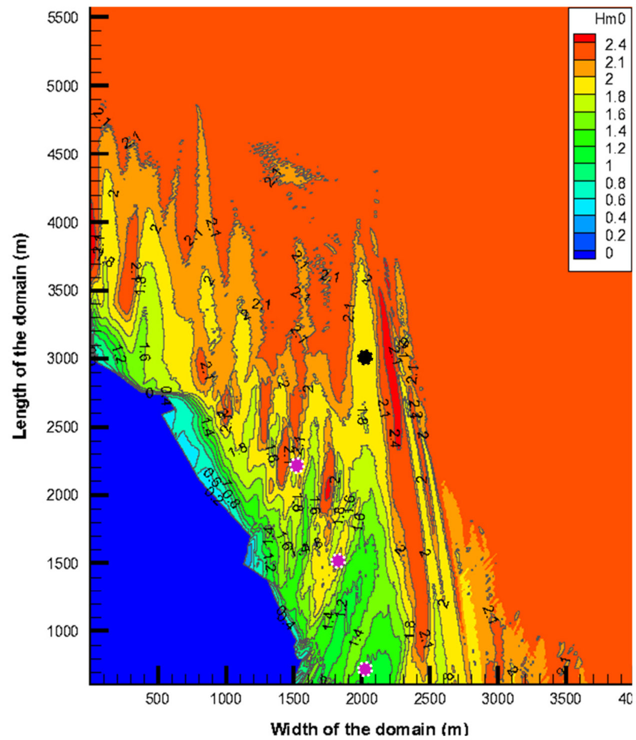

Fig. 4. Contour plot of the calculated Hm_0 (W, Hm0 = 2.0 m, Tp = 5.9 s).

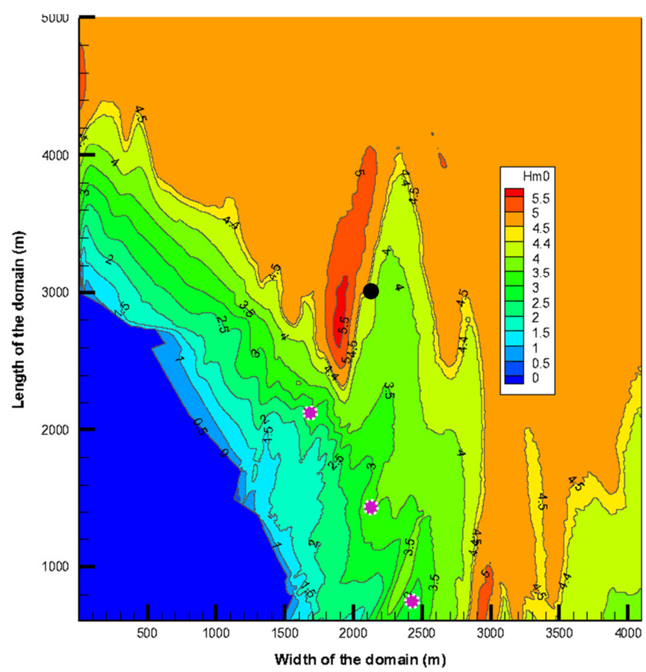

Fig. 5 Contour plot of the calculated Hm_0 (W, Hm0 = 4.4 m, Tp = 9.1 s)

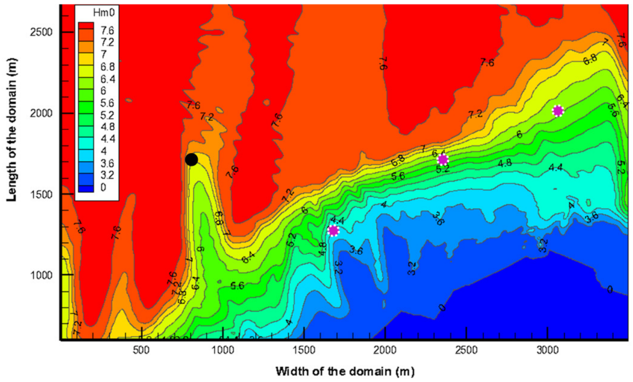

Fig. 6 Contour plot of the calculated Hm0 (N, Hm_0 = 7.0 m, Tp=11.9 s)

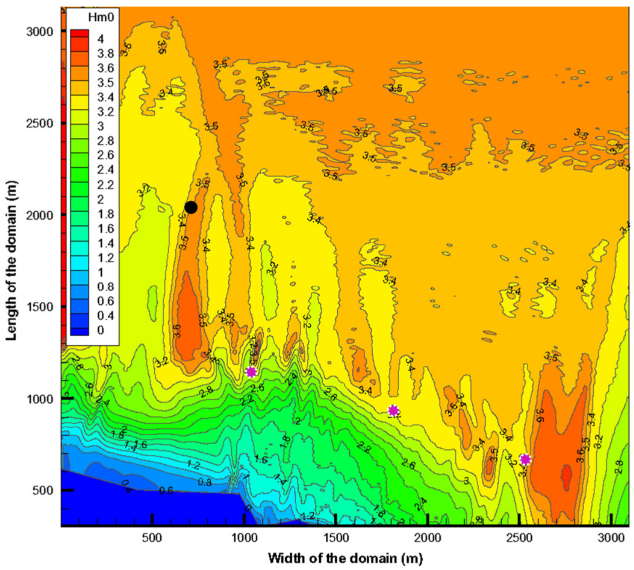

Fig. 7 Contour plot of the calculated Hm_0 (NW, Hm_0 = 3.5 m, Tp = 8.2 s).

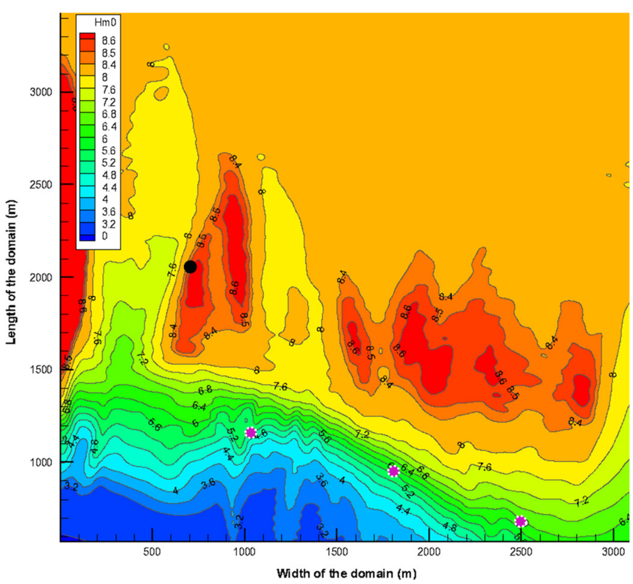

Fig. 8 Contour plot of the calculated Hm0 (NW, Hm_0 = 8.5 m, Tp=13.1 s).

E. *Transformation matrices*

For each direction, results are presented for various "7–gauges" arrays, placed at distances according to the limits suggested by the Coastal Engineering Manual (CEM) [9]. In the matrices (Tables 1 and 2) only the results of significant heights and peak periods for the third gauge of each array (i.e. the central location) are given, after an analysis using WaveLab.

There is a weak tendency for longer waves to lose less in height than waves of the same height and shorter periods. The point with the highest reduction in wave height when waves are coming from West direction is point 2, located at 11.0 m water depth. This is not straightforward considering that point 1, despite being at a shallower location, has the least wave heights reduction for waves coming from the same direction. Indeed point 1 is approximately 0.5 Km further West from point 2 and 1 Km from point 3 and that could partially justify the results. What is probably explaining the results better is the shoaling, appreciable regularly in the studied wave conditions only for point 1, for waves coming from West direction. It is anyways difficult to explain local phenomena dominated by bottom interactions of different incoming waves and wave periods, such as the one under discussion now but there is a noticeable difference between the three locations under exam despite the relative small distance among them.

With regard to changes on the directionality, this has been studied only for point 2. It appears that there is not a big change in directionality when waves approach the shore from Hantholm buoy to point 2: only in few cases the difference from the incoming wave direction is above 15° and anyways never more than 18°.

TABLE 1. TRANSFORMATION MATRIX OF SELECTED OPERATIONAL CONDITIONS FROM THE HANTHOLM BUOY TO POINTS 1, 2 AND 3 IN FIG.3, WEST, NORTH-WEST AND NORTH DIRECTIONS. WATER LEVEL +0.0M

Buoy			Point 1		Point 2			Point 3	
H_{mo} [m]	**T_p [s]**	**θ [°]**	**H_{mo} [m]**	**T_p [s]**	**H_{mo} [m]**	**T_p [s]**	**θ [°]**	**H_{mo} [m]**	**T_p [s]**
0.9	5.4	271	0.9	5.4	0.6	5.4	279	0.7	5.4
0.9	7.8	278	1.1	7.8	0.5	7.8	289	0.7	7.8
1.5	5.7	271	1.0	5.7	1.0	5.7	285	1.0	5.7
1.5	7.3	283	1.9	7.3	1.0	7.3	298	1.1	7.3
2.0	5.9	273	1.9	5.9	1.4	5.9	288	2.0	5.9
2.0	7.0	282	2.2	7.0	1.5	7.0	290	1.5	7.0
2.5	7.1	280	2.8	7.1	2.0	7.1	291	2.0	7.1
3.0	7.6	283	3.3	7.6	2.0	7.6	300	2.5	7.6
3.5	8.2	286	3.3	8.2	2.5	8.2	300	3.0	8.2
4.4	9.1	280	2.9	9.1	3.3	9.1	302	3.5	9.1
0.9	5.2	316	0.7	5.2	0.8	5.2	318	0.8	5.2
1.5	5.7	316	1.2	5.7	1.4	5.7	319	1.4	5.7
2.0	5.9	315	1.7	5.9	1.9	5.9	319	1.9	5.9
2.5	7.1	316	2.5	7.1	2.5	7.1	322	2.4	7.1
3.5	8.1	317	3.0	8.1	3.4	8.1	327	3.4	8.1
0.9	5.1	1	0.6	5.1	0.8	5.1	359	0.9	5.1
1.5	5.6	1	1.0	5.6	1.4	5.6	357	1.4	5.6

All the extreme waves tested are bottom limited for point 1. The highest wave reaching point 1 is 5.0 m in extreme conditions corresponding to an incoming wave of 8.6 m from North-West, Tp=13.1s with a water set-up of +1.2 m in a total water depth of 10.26 m. In general, for the same offshore conditions, the highest extreme waves arrive in point 3 where under these circumstances some shoaling may occur. For the mentioned offshore wave condition, the wave reaching point 3 is 8.1 m in a total water depth of 15.2 m.

TABLE 2. TRANSFORMATION MATRIX OF SELECTED EXTREME CONDITIONS FROM THE HANTHOLM BUOY TO POINTS 1, 2 AND 3 IN FIG.3, NORTH-WEST AND NORTH DIRECTIONS. WATER LEVEL +1.2M.

Buoy			Point 1	Point 2		Point 3	
H_{mo} [m]	T_p [s]	θ [˚]	H_{mo} [m]	H_{mo} [m]	θ [˚]	H_{mo} [m]	θ [˚]
7.0	11.9	321	4.9	6.7	329	7.0	316
8.6	13.1	322	5.0	7.4	329	8.1	328
7.0	11.9	3	4.3	7.0	349	7.2	348
8.5	13.1	2	4.4	7.0	348	7.7	348

IV. CLOSE TO SHORE WAVE CLIMATE

It was then possible to extrapolate the scatter diagrams for points 1, 2 and 3; in particular, directional scatter diagram of point 2 is presented (Fig. 9), while for point 1 and 3 non-directional results are reported (Tables 3, 4). The average wave power associated to the different points is 5.86 kW/m for pint 1, 4.20 kW/m for point 2 and 4.56 kW/m for point 3. Again, the highest wave climate in point 1 may surprise as this point is featuring the shallower water depth. Nevertheless point 1 is the one further West among the three (and the west direction is the main wave direction covering 52% of all offshore incoming waves), but most of all because of the occurrence of shoaling effects for operational conditions, resulting in an increased wave height compared to offshore conditions. If this is indeed the main reason, wave length should be decreased as consequence of shoaling. This has not been deeply investigated in the present report.

		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5	
	Hs [m]		0.8	1.4	1.8	2.3	2.8	3.2	3.7	
	Tp [s]		5.2	5.6	6.7	7.1	7.8	8.4	3.7	
N	Dir.		361.0	361.0	361.0	361.0	361.0	361.0	361.0	SUM
	Prob.	0.000	0.072	0.013	0.009	0.002	0.001	0.000	0.000	0.10
	Pwave [kW/m]	0.000	1.560	4.750	9.729	16.136	25.671	37.493	21.564	
	P*prob	0.000	0.112	0.063	0.087	0.035	0.034	0.006	0.002	0.34
		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5	
	Hs [m]		0.74	1.23	1.50	2.02	2.53	3.34		
	Tp [s]		6.00	6.57	7.00	7.29	8.20	9.10		
W	Dir.		285.0	292.8	290.0	294.3	300.0	302.0		SUM
	Prob.	0.000	0.346	0.063	0.043	0.051	0.007	0.006	0.000	0.52
	Pwave [kW/m]	0.000	1.406	4.231	6.711	12.650	22.417	43.203	0.000	
	P*prob	0.000	0.486	0.268	0.287	0.651	0.167	0.250	0.000	2.11
		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5	
	Hs [m]		0.83	1.38	1.89	2.45	2.83	3.40	4.17	
	Tp [s]		5.74	6.23	6.59	7.05	7.59	8.10	9.39	
NW	Dir.		317.6	319.0	318.9	322.0	320.0	327.0	324.5	SUM
	Prob.	0.000	0.161	0.048	0.030	0.017	0.009	0.004	0.003	0.27
	Pwave [kW/m]	0.000	1.689	5.073	10.018	18.052	25.896	39.919	69.537	
	P*prob	0.000	0.273	0.241	0.296	0.305	0.236	0.146	0.189	1.69
		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5	
	Hs [m]	0.46	0.62	1.25						
	Tp [s]	10.10	5.23	6.29						
SW	Dir.	302.1	279.1	288.0						SUM
	Prob.	0.00	0.061	0.002	0.000	0.000	0.000	0.000	0.000	0.07
	Pwave [kW/m]	0.915	0.847	4.162	0.000	0.000	0.000	0.000	0.000	
	P*prob	0.000	0.052	0.008	0.000	0.000	0.000	0.000	0.000	0.06
		<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5	
	Hs [m]		0.517							
	Tp [s]		5.161							
S	Dir.		289.6							SUM
	Prob.	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.02
	Pwave [kW/m]	0.000	0.589	0.000	0.000	0.000	0.000	0.000	0.000	
	P*prob	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.01
	SUM-Prob.	0.005	0.661	0.126	0.081	0.070	0.018	0.010	0.003	0.974
	SUM-P*prob	0.000	0.935	0.579	0.671	0.991	0.436	0.402	0.190	4.204

Figure 9. Wave Climate in Point 2 = 4.20 kW/m.

TABLE 3. WAVE CLIMATE IN POINT 1 = 5.86 KW/M.

	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5
H_s [m]	0.83	1.18	1.83	2.3	2.81	3.29	3.78
T_p [s]	5.55	7.11	6.74	7.04	7.55	7.79	9.39
Prob	0.60	0.14	0.10	0.06	0.05	0.03	0.00
P_{wave} [kW/m]	1.65	4.24	9.60	15.86	25.43	35.84	57.15
P* prob	0.99	0.59	0.93	0.97	1.33	0.90	0.16

TABLE 4. WAVE CLIMATE IN POINT 3 = 4.56 KW/M.

	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	>3.5
H_s [m]	0.80	1.29	1.72	2.16	2.63	3.13	3.75
T_p [s]	5.83	6.46	6.78	6.79	7.61	4.12	9.21
Prob	0.67	0.101	0.081	0.08	0.03	0.01	0.01
P_{wave} [kW/m]	1.59	4.60	8.5	13.46	22.47	17.22	55.3
P* prob	1.06	0.46	0.69	1.05	0.63	0.19	0.47

V. RATIO BETWEEN AVERAGE AND EXTREME WAVE HEIGHTS

From the results collected until now, it is possible to present a ratio between the average and the extreme wave heights at the three locations selected within the DanWEC in the proximity of the Hantholm harbour and at the buoy.

The average wave height is defined for each wave climate as:

$$H_{Pmean} = \sqrt{\frac{P_{wave}}{0.49 \times T_m}} \tag{6}$$

Where T_m is the average wave climate period (= 5.67s, 7.31 s, 6.19 s and 6.61 s for the buoy, point 1, 2 and 3 respectively) and P_{wave} the wave power calculated like in Eq. 4 [kW/m].

The extreme wave heights are the ones already presented in Table 2. In Table 5 the results are summarized for the buoy and points 1, 2 and 3 considering two different extreme wave heights. Based on this definition, we can see that for the specific case the extreme wave heights are between 3.9 and 6.8 times higher than average wave heights for the 4 points taken into consideration in this study.

If we consider the H_{pmean} to be related to the income that a developer may expect from the performance of its device while $H_{extreme}$ related to the cost of the device, we could assume that we want the ratio H_{pmean}/ $H_{extreme}$ to be as big as possible. In this optic, it seems reasonable to prefer point 1 or the buoy location to points 2 and 3. It is indeed possible to say that passing from point 3 to point 1 there is 73% gain considering 1st$H_{extreme}$ as the design wave height and 77% when considering 2nd$H_{extreme}$. A gain of 73% on this ration could with some reason be considered as an economical gain equal to 73%.

TABLE 5. SUMMARY OF AVERAGE AND TWO EXTREME WAVE HEIGHTS FOR WAVE CLIMATES AT POINT 1, 2 AND 3.

	Buoy	Point 1	Point 2	Point 3
H_{pmean} [m]	1.54	1.28	1.18	1.19
1st $H_{extreme}$ [m]	8.6	5.0	7.4	8.1
2nd $H_{extreme}$ [m]	7	4.3	7.0	7.2
H_{pmean}/1st $H_{extreme}$	0.18	0.26	0.16	0.15
H_{pmean}/2nd $H_{extreme}$	0.22	0.30	0.17	0.17

VI. CONCLUSIONS

The wave climate at location has been extensively studied to taking the directionality into account. The main wave direction is West direction. The wave climate offshore the Hanstholm harbor is 6.55 kW/m with 98% of the energy flux associated to the sectors N, NW and W.

The offshore extreme wave analysis has been performed on direct wave measurements available from a buoy (non directional) outside Hanstholm harbour at d=20 m. water depth. The study resulted in a Hs50=8.0 m.

Wave transformation from offshore to 3 different close to shore locations has been conducted with MILDwave for wave conditions representative of the scatter diagram and of the extreme waves, with different wave periods and a set up of +1.2 m for extreme conditions. The average wave power associated to the different points is 5.86 kW/m for pint 1, 4.20 kW/m for point 2 and 4.56 kW/m for point 3.

The average wave height = H_{pmean} has been defined as the wave height that provides the average wave power when multiplied by the average period of a specific wave climate in the wave power equation. It is suggested that H_{pmean} is proportional to the expected income while $H_{extreme}$ is proportional to the cost of the installation. It is therefore suggested the ration H_{pmean}/ $H_{extreme}$ is a valuable indicator of the convenience of a location for wave energy installation.

In the case understudy, after comparison of the 4 different H_{pmean}/ $H_{extreme}$ it can be concluded that the choice of point 1 and 2 can result in a gain up to 73% on point 3. It is suggested that the gain is proportional to an economic gain.

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