SUMMARY OF VELOCITY MEASUREMENTS AT DHI

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1. INTRODUCTION

A series of comprehensive velocity measurements was carried out on the three dimensional model of the berm breakwater at the Danish Hydraulic Institute (DHI) in September 1995. Those measurements were a part of the research on berm breakwaters within the MAST II programme sponsored by the Commission of the European Communities.

The major part of previous research on berm breakwaters has concentrated on the reshaping of a trunk section and stone movements exposed to perpendicular waves. Research at the DHI has been undertaken to study the effect of oblique waves on the reshaping and longshore transport of the trunk and roundhead of the berm breakwater. Since the main cause for these processes is the velocity field around the structure, the velocity measurements have been taken with the aim of studying and analysing the velocity field on the trunk and, especially, around the roundhead under wave attack. Regular waves were used for most of the experiments with one run using irregular waves.

2. MODEL SET-UP AND TEST PROGRAMME

2.1. Establishing the model

A model test programme for the velocity measurements of a trunk and roundhead of the berm breakwater under the influence of the waves was carried out in the wave basin at the Danish Hydraulic Institute (DHI). The three dimensional structure of the berm breakwater was about 19m long, but the tests were concentrated on the top part of the trunk and the rounhead, approximately 7.5m long and 5m width.

The berm breakwater profile used for the trunk section is shown in ***Figure 1***. The rounhead was made by rotating the profile around the centreline.

The specific weight of the stones of the armour layer was 2.68 kg/dm^3, porosity 0.40. Nominal diameter of 50% for the core was 0.010 m and nominal diameter of 50% for the stone armour was 0.023 m. The seaward slope was 1:1.1 and water depth in front of the slopes was 0.50 m. The width of the berm was 0.65 m. The grid for the points, where the velocities were measured, was established to cover the rounhead region. Five verticals were defined at horizontal separations of 0.15 m, starting from the still water level on the slope and continuing in the seaward direction. At each vertical velocities were measured at intervals of 0.10 m below the still water level. The lowest locations are at a smaller increment because of the wish to measure velocities at the point closest to the slope.

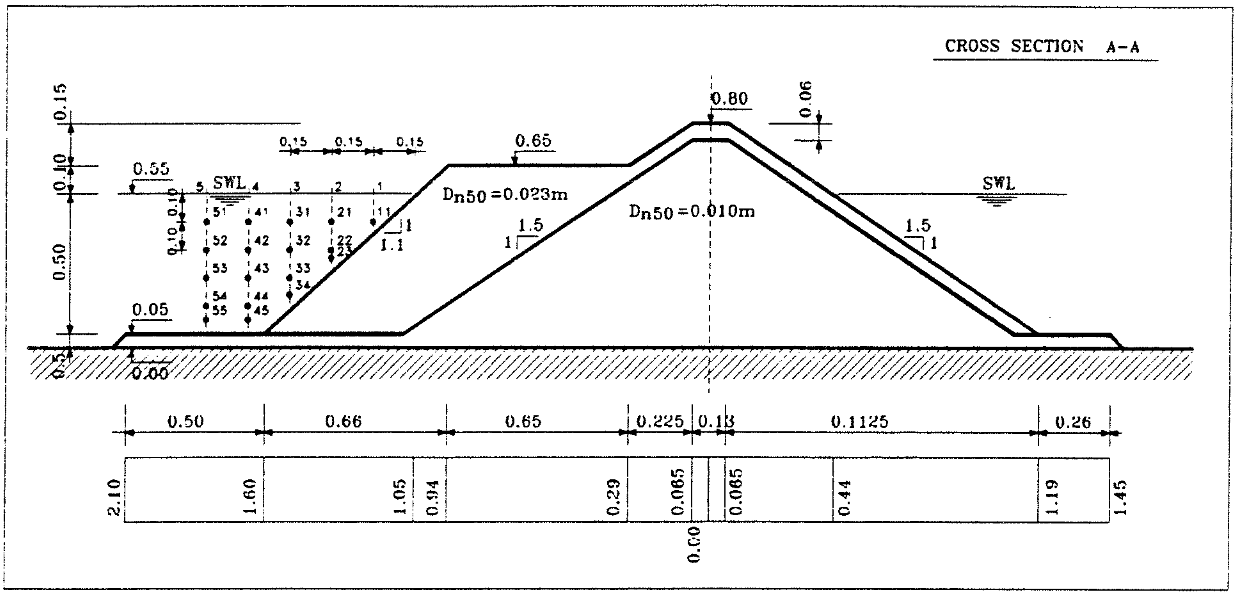

Figure 1. Characteristic cross section of the tested berm breakwater

The velocity measurements were made using ultrasonic equipment which was able to measure the velocities at the specified point in three directions: x, y and z. The equipment had to be under the water during the whole wave cycle and the distance between the measuring points and the bed is about 0.06 m. Therefore, the points for measuring velocities could not be closer to the water surface or to the bed than those chosen.

The plan positions of the profiles for measuring velocities are shown in ***Figure 2***.

The profiles were specified to cover the field around the roundhead and one control profile was chosen on the trunk of the structure (number 2.5). The profiles on the roundhead were numbered: -90, -45, -15, 0, 15, 45, and 90, corresponding to degrees rotation from the trunk axis, anticlockwise. All other profiles shown in ***Figure 2*** were used to enable the description of the berm breakwater before and after the reshaping procedure caused by the waves.

2.1. Measuring procedure

The berm breakwater structure was imposed to the influence of regular waves. Wave height was H=0.136 m and period T=1.32 s to allow comparison with the irregular waves (significant wave height Hs=0.136 m, mean wave period Tm=1.32 s and Ho=3.5) which were used for the previous tests of reshaping the structure at DHI.

At the beginning, the profiles of the berm breakwater were measured by laser profiler, every 0.50 m on the trunk and every 0.10 m on the roundhead, in order to obtain the initial state of the structure. Those profiles were later transformed by MIKE 11 programme of DHI to form 32 profiles (from 145 to 0.5) as shown in ***Figure 2***.

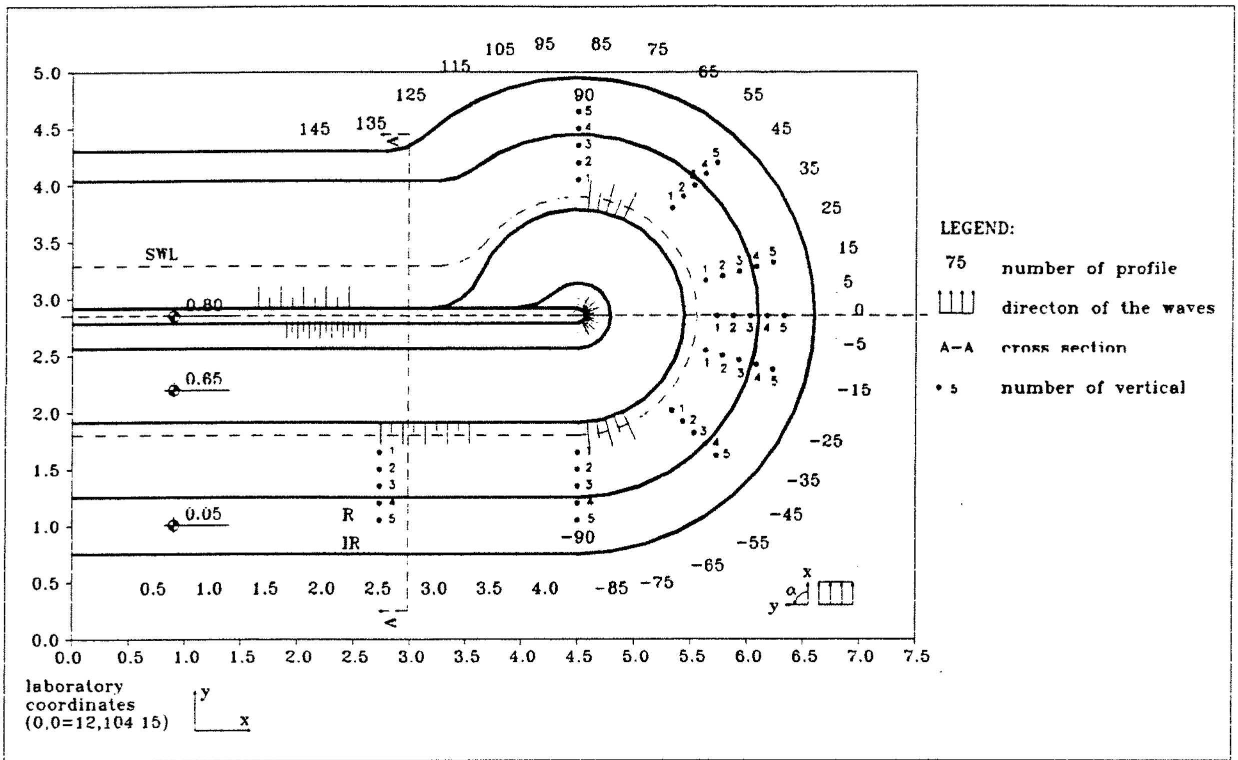

Figure 2. *Plan view of the berm breakwater*

The berm breakwater was reshaped by the total of 2000 regular waves. Significant reshaping was observed as a reshaping of about 0.15 m of the berm. Subsequently, the profiles were measured using the same procedure as before, to obtain the reshaped state of the structure.

Then, the structure was influenced by slightly smaller regular waves of the wave height H=0.117 m and period T=1.22 s to avoid the further movement of the stones and enable the measurement of the velocities without damaging the equipment. Those waves were chosen to allow comparison with the irregular waves (Hs=0.117 m, Tm=1.22 s and Ho=3.0) which were used for the previous tests of reshaping the structure at DHI.

The velocities were measured in 7 profiles on the roundhead (-90, -45, -15, 0, 15, 45 and 90) and 1 profile on the trunk (2.5=R). For each profile about 15 points were measured with the grid shown in ***Figure 1***. The signal for every point was recorded by ultrasonic equipment for 1 minute, which is approximately 50 wave periods.

Having obtained velocities of the regular waves, the irregular waves were introduced. The waves chosen were from PM spectrum, Hs=0.117 m, Tm=1.2 2s and Ho=3.0, as for previous experiments on the berm breakwater model at DHI. The velocities were measured on the trunk profile (2.5=IR) in 14 points. The signal for every point was recorded by ultrasonic equipment for 10 minutes, which was considered long enough.

Finally, the profiles were measured, with the same procedure as before, to obtain the state of the structure after all measurements of the velocities.

3. RESULTS

The velocities of the regular waves were measured in 113 points on the rounhead and 14 points on the trunk of the berm breakwater. The velocities of the irregular waves were measured in 14 points on the trunk. All velocity data are in the ASCII files with four columns: time and velocities in x, y and z direction. As shown in ***Figure 2***, x direction is the direction of the waves, y direction is down the structure and z direction is vertical.

An example of the velocity data is given in ***Table 1***. It shows just a part of the vx, vy and vz data between the 25[th] and 30[th] second of the time series for one profile and the calculated resultant v velocity and appropriate angle.

profile	vertical	point
R(30)	2	22
measured velocities (m/s)		

t	vx	vy	vz	$v=(vx^2+vy^2)^{0.5}$	α
25.0823	0.184417	0.050295	0.155676	0.19115	15
25.1818	0.213157	0.02874	0.062271	0.21509	8
25.2813	0.203577	-0.01198	-0.0503	0.20393	-3
25.3809	0.081431	-0.01677	-0.12215	0.08314	-12
25.4804	-0.04551	-0.02635	-0.16765	0.05258	-150
25.5799	-0.17244	-0.0479	-0.18921	0.17897	-164
25.6795	-0.20597	-0.02874	-0.20118	0.20797	-172
25.779	-0.24669	-0.00958	-0.10299	0.24687	-178
25.8785	-0.1461	0.00479	-0.00958	0.14617	178
25.9781	-0.06467	0.067061	0.184417	0.09316	134
26.0776	0.03832	0.0479	0.229922	0.06134	51
26.1771	0.182021	0.0479	0.208367	0.18822	15
26.2767	0.196392	0.03353	0.107776	0.19923	10
26.3762	0.244292	-0.02395	-0.0024	0.24546	-6
26.4757	0.126936	-0.01916	-0.10538	0.12837	-9
26.5753	-0.00719	-0.01437	-0.16286	0.01607	-117
26.6748	-0.11257	-0.04072	-0.18921	0.11970	-160
26.7743	-0.20358	-0.05748	-0.21795	0.21154	-164
26.8739	-0.25387	0.055086	-0.22513	0.25978	168
26.9734	-0.24669	0.081431	0.04311	0.25978	162
27.0729	-0.13652	0.100591	0.126936	0.16957	144
27.1725	0.007185	0.040715	0.237107	0.04134	80
27.272	0.150886	0.01916	0.294587	0.15210	7
27.3715	0.225132	0.062271	0.124541	0.23359	15
27.4711	0.277822	-0.01198	0.00958	0.27808	-2
27.5706	0.186812	-0.02635	-0.11257	0.18866	-8
27.6701	0.050295	-0.04311	-0.21076	0.06624	-41
27.7697	-0.07904	-0.06946	-0.18681	0.10522	-139
27.8692	-0.1916	-0.06227	-0.22274	0.20147	-162
27.9687	-0.25387	0	-0.18442	0.25387	-180
28.0683	-0.26585	0.081431	-0.11257	0.27804	163
28.1678	-0.16526	0.093406	0.062271	0.18983	151
28.2673	-0.03593	0.067061	0.208367	0.07608	118
28.3668	0.110171	-0.01437	0.344883	0.11110	-7
28.4664	0.210762	0.0479	0.177231	0.21614	13
28.5659	0.285007	-0.00719	0.050295	0.28510	-1
28.6654	0.177231	-0.04551	-0.06946	0.18298	-14
28.765	0.107776	-0.06467	-0.13173	0.12569	-31
28.8645	-0.01437	-0.02635	-0.19679	0.03001	-119
28.964	-0.15328	-0.03114	-0.19679	0.15641	-169
29.0636	-0.22753	-0.02395	-0.12933	0.22878	-174
29.1631	-0.2419	-0.0024	-0.08622	0.24191	-179
29.2626	-0.17484	0.064666	0.04311	0.18641	160
29.3622	-0.05509	0.124541	0.222737	0.13618	114
29.4617	0.069456	0.05269	0.246687	0.08718	37
29.5612	0.170046	0.045505	0.237107	0.17603	15

29.6608	0.217947	0.02395	0.117356	0.21926	6
29.7603	0.234712	-0.02156	0.026345	0.23570	-5
29.8598	0.136516	-0.01916	-0.08622	0.13785	-8
29.9594	-0.0024	-0.01198	-0.14131	0.01221	-101

***Table 1**. An example of the velocity data*

Three series of profiles were measured with 32 profiles for each series: before reshaping, after measuring the velocities for regular waves and after measuring the velocities of irregular waves.

For example, profile number 2.5 (the approximate location at which velocities were measured on the trunk), is given in ***Figure 3***.

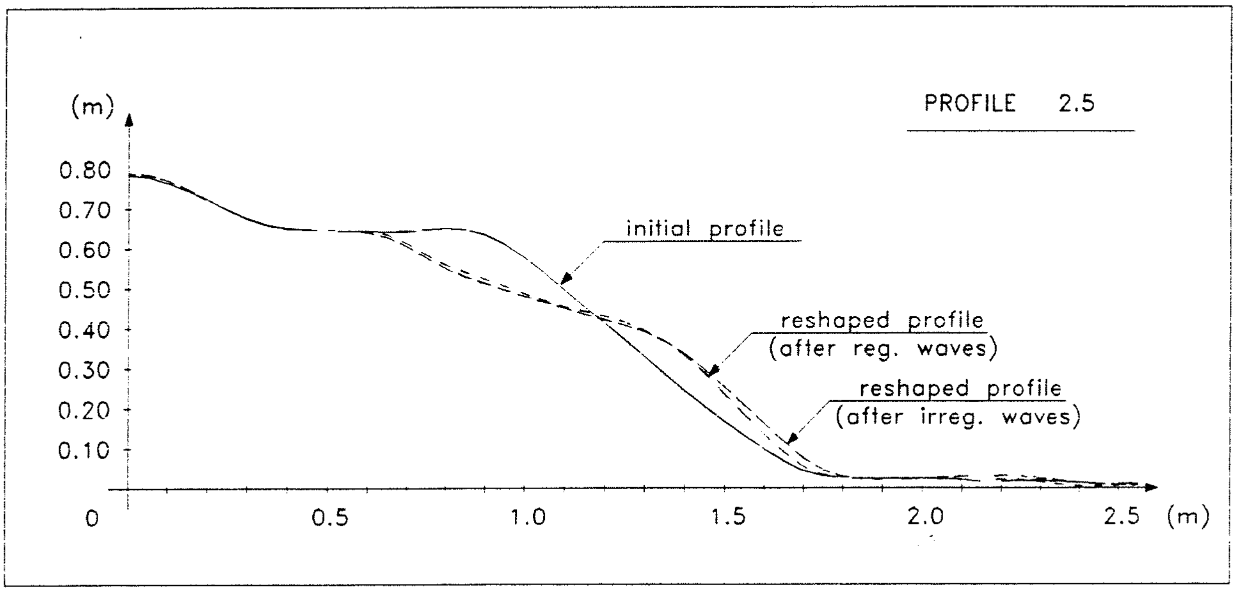

***Figure 3**. An example of the measured profiles*

The exact positions for the points where the velocities were measured are given in ***Table 2***, ***3*** and ***4***.

profile	vertical	point	measured co-ord. (m)			laboratory co-ord. (m)		
			xm	ym	zm	x	y	z
R (30)	1	11	14.5	1.74		14.73	105.8	
	2	21	14.5	1.59	0.995	14.73	105.65	0.45
		22	14.5	1.59	0.935	14.73	105.65	0.39
	3	31	14.5	1.44	0.995	14.73	105.5	0.45
		32	14.5	1.44	0.895	14.73	105.5	0.35
		33	14.5	1.44	0.805	14.73	105.5	0.26
	4	41	14.5	1.29	0.995	14.73	105.35	0.45
		42	14.5	1.29	0.895	14.73	105.35	0.35
		43	14.5	1.29	0.795	14.73	105.35	0.25
		44	14.5	1.29	0.695	14.73	105.35	0.15
		45	14.5	1.29	0.63	14.73	105.35	0.085
	5	51	14.5	1.14	0.995	14.73	105.2	0.45
		52	14.5	1.14	0.895	14.73	105.2	0.35
		53	14.5	1.14	0.795	14.73	105.2	0.25
		54	14.5	1.14	0.695	14.73	105.2	0.15
		55	14.5	1.14	0.605	14.73	105.2	0.06

IR (40)	1	11	14.5	1.74		14.73	105.8	
	2	21	14.5	1.59	0.995	14.73	105.65	0.45
		22	14.5	1.59	0.92	14.73	105.65	0.375
	3	31	14.5	1.44	0.995	14.73	105.5	0.45
		32	14.5	1.44	0.895	14.73	105.5	0.35
		33	14.5	1.44	0.82	14.73	105.5	0.275
	4	41	14.5	1.29	0.995	14.73	105.35	0.45
		42	14.5	1.29	0.895	14.73	105.35	0.35
		43	14.5	1.29	0.795	14.73	105.35	0.25
		44	14.5	1.29	0.695	14.73	105.35	0.15
	5	51	14.5	1.14	0.995	14.73	105.2	0.45
		52	14.5	1.14	0.895	14.73	105.2	0.35
		53	14.5	1.14	0.795	14.73	105.2	0.25
		54	14.5	1.14	0.695	14.73	105.2	0.15
		55	14.5	1.14	0.61	14.73	105.2	0.065
-90 (1)	1	11	16.27	1.74	0.995	16.5	105.8	0.45
	2	21	16.27	1.59	0.995	16.5	105.65	0.45
		22	16.27	1.59	0.92	16.5	105.65	0.375
	3	31	16.27	1.44	0.995	16.5	105.5	0.45
		32	16.27	1.44	0.895	16.5	105.5	0.35
		33	16.27	1.44	0.8	16.5	105.5	0.255
	4	41	16.27	1.29	0.995	16.5	105.35	0.45
		42	16.27	1.29	0.895	16.5	105.35	0.35
		43	16.27	1.29	0.795	16.5	105.35	0.25
		44	16.27	1.29	0.695	16.5	105.35	0.15
		45	16.27	1.29	0.64	16.5	105.35	0.095
	5	51	16.27	1.14	0.995	16.5	105.2	0.45
		52	16.27	1.14	0.895	16.5	105.2	0.35
		53	16.27	1.14	0.795	16.5	105.2	0.25
		54	16.27	1.14	0.695	16.5	105.2	0.15
		55	16.27	1.14	0.61	16.5	105.2	0.065

Table 2. *Laboratory co-ordinates of the points for velocity measurements for the profiles R, IR and -90*

profile	vertical	point	measured co-ord. (m)			laboratory co-ord. (m)		
			xm	ym	zm	x	y	z
-45 (5)	1	11	17.1	2.11	0.995	17.33	106.17	0.45
	2	21	17.2	2.01	0.995	17.43	106.07	0.45
		22	17.2	2.01	0.9	17.43	106.07	0.355
	3	31	17.3	1.91	0.995	17.53	105.97	0.45
		32	17.3	1.91	0.895	17.53	105.97	0.35
		33	17.3	1.91	0.795	17.53	105.97	0.25
	4	41	17.4	1.81	0.995	17.63	105.87	0.45
		42	17.4	1.81	0.895	17.63	105.87	0.35
		43	17.4	1.81	0.795	17.63	105.87	0.25
		44	17.4	1.81	0.695	17.63	105.87	0.15
	5	51	17.5	1.71	0.995	17.73	105.77	0.45
		52	17.5	1.71	0.895	17.73	105.77	0.35
		53	17.5	1.71	0.795	17.73	105.77	0.25
		54	17.5	1.71	0.695	17.73	105.77	0.15
		55	17.5	1.71	0.62	17.73	105.77	0.075
-15 (20)	1	11	17.4	2.63		17.63	106.69	
	2	21	17.55	2.59	0.995	17.78	106.65	0.45
		22	17.55	2.59	0.895	17.78	106.65	0.35
	3	31	17.7	2.55	0.995	17.93	106.61	0.45

		32	17.7	2.55	0.895	17.93	106.61	0.35
		33	17.7	2.55	0.795	17.93	106.61	0.25
	4	41	17.85	2.51	0.995	18.08	106.57	0.45
		42	17.85	2.51	0.895	18.08	106.57	0.35
		43	17.85	2.51	0.795	18.08	106.57	0.25
		44	17.85	2.51	0.695	18.08	106.57	0.15
	5	51	18	2.47	0.995	18.23	106.53	0.45
		52	18	2.47	0.895	18.23	106.53	0.35
		53	18	2.47	0.795	18.23	106.53	0.25
		54	18	2.47	0.695	18.23	106.53	0.15
		55	18	2.47	0.61	18.23	106.53	0.065
0 (4)	1	11	17.5	2.94	0.995	17.73	107	0.45
	2	21	17.65	2.94	0.995	17.88	107	0.45
		22	17.65	2.94	0.895	17.88	107	0.35
		23	17.65	2.94	0.87	17.88	107	0.325
	3	31	17.8	2.94	0.995	18.03	107	0.45
		32	17.8	2.94	0.895	18.03	107	0.35
		33	17.8	2.94	0.795	18.03	107	0.25
		34	17.8	2.94	0.74	18.03	107	0.195
	4	41	17.95	2.94	0.995	18.18	107	0.45
		42	17.95	2.94	0.895	18.18	107	0.35
		43	17.95	2.94	0.795	18.18	107	0.25
		44	17.95	2.94	0.695	18.18	107	0.15
		45	17.95	2.94	0.64	18.18	107	0.095
	5	51	18.1	2.94	0.995	18.33	107	0.45
		52	18.1	2.94	0.895	18.33	107	0.35
		53	18.1	2.94	0.795	18.33	107	0.25
		54	18.1	2.94	0.695	18.33	107	0.15
		55	18.1	2.94	0.62	18.33	107	0.075

Table 3. *Laboratory co-ordinates of the points for velocity measurements for the profiles -45, -15 and 0*

profile	**vertical**	**point**	**measured co-ord. (m)**			**laboratory co-ord. (m)**		
			xm	**ym**	**zm**	**x**	**y**	**z**
15 (10)	1	11	17.4	3.25		17.63	107.31	
	2	21	17.55	3.29	0.995	17.78	107.35	0.45
		22	17.55	3.29	0.9	17.78	107.35	0.355
	3	31	17.7	3.33	0.995	17.93	107.39	0.45
		32	17.7	3.33	0.895	17.93	107.39	0.35
		33	17.7	3.33	0.795	17.93	107.39	0.25
	4	41	17.85	3.37	0.995	18.08	107.43	0.45
		42	17.85	3.37	0.895	18.08	107.43	0.35
		43	17.85	3.37	0.795	18.08	107.43	0.25
		44	17.85	3.37	0.695	18.08	107.43	0.15
		45	17.85	3.37	0.65	18.08	107.43	0.105
	5	51	18	3.41	0.995	18.23	107.47	0.45
		52	18	3.41	0.895	18.23	107.47	0.35
		53	18	3.41	0.795	18.23	107.47	0.25
		54	18	3.41	0.695	18.23	107.47	0.15
		55	18	3.41	0.61	18.23	107.47	0.065
45 (3)	1	11	17.1	3.89	0.995	17.33	107.95	0.45
	2	21	17.2	3.99	0.995	17.43	108.05	0.45
		22	17.2	3.99	0.895	17.43	108.05	0.35
		23	17.2	3.99	0.86	17.43	108.05	0.315

	3	31	17.3	4.09	0.995	17.53	108.15	0.45
		32	17.3	4.09	0.895	17.53	108.15	0.35
		33	17.3	4.09	0.795	17.53	108.15	0.25
	4	41	17.4	4.19	0.995	17.63	108.25	0.45
		42	17.4	4.19	0.895	17.63	108.25	0.35
		43	17.4	4.19	0.795	17.63	108.25	0.25
		44	17.4	4.19	0.695	17.63	108.25	0.15
	5	51	17.5	4.29	0.995	17.73	108.35	0.45
		52	17.5	4.29	0.895	17.73	108.35	0.35
		53	17.5	4.29	0.795	17.73	108.35	0.25
		54	17.5	4.29	0.695	17.73	108.35	0.15
		55	17.5	4.29	0.61	17.73	108.35	0.065
90 (2)	1	11	16.27	4.14	0.995	16.5	108.2	0.45
	2	21	16.27	4.29	0.995	16.5	108.35	0.45
		22	16.27	4.29	0.895	16.5	108.35	0.35
		23	16.27	4.29	0.85	16.5	108.35	0.305
	3	31	16.27	4.44	0.995	16.5	108.5	0.45
		32	16.27	4.44	0.895	16.5	108.5	0.35
		33	16.27	4.44	0.795	16.5	108.5	0.25
		34	16.27	4.44	0.72	16.5	108.5	0.175
	4	41	16.27	4.59	0.995	16.5	108.65	0.45
		42	16.27	4.59	0.895	16.5	108.65	0.35
		43	16.27	4.59	0.795	16.5	108.65	0.25
		44	16.27	4.59	0.695	16.5	108.65	0.15
		45	16.27	4.59	0.655	16.5	108.65	0.11
	5	51	16.27	4.74	0.995	16.5	108.8	0.45
		52	16.27	4.74	0.895	16.5	108.8	0.35
		53	16.27	4.74	0.795	16.5	108.8	0.25
		54	16.27	4.74	0.695	16.5	108.8	0.15
		55	16.27	4.74	0.61	16.5	108.8	0.065

***Table 4.** Laboratory co-ordinates of the points for velocity measurements for the profiles 15, 45 and 90*

4. PRELIMINARY ANALYSIS OF SELECTED DATA

A considerable amount of analysis is possible with these results from the velocity measurements. One initial aspect was to consider the velocity field around the roundhead close to the rock surface. These velocities are the most interesting due to the fact that they are causing the movement of the stones on the slope.

At the beginning, the maximum velocities were calculated for the points on the bottom of the slope within the 7 profiles around the rounhead and 1 profile on the trunk. Maximum velocity is the velocity vector defined from v_x and v_y vectors with the maximum absolute value. Positive maximum velocity means that velocity is in the direction of the waves (angle $\alpha=0^0$ to 90^0 and $\alpha=0^0$ to -90^0) and maximum negative velocity means that velocity is in the contra direction of the waves (angle $\alpha=90^0$ to 180^0 and $\alpha=-90^0$ to -180^0), as shown in ***Figure 2***. The results are shown in ***Table 5***.

	vertical	point	laboratory co-ord. (m)			velocity (m/s)		angle (⁰)	
			x	y	z	v(+)	v(-)	α(+)	α(-)
R (30)	1	11	14.73	105.8					
	2	22	14.73	105.65	0.39	0.28510	0.27840	-1	163
	3	33	14.73	105.5	0.26	0.14023	0.18934	8	-178
	4	45	14.73	105.35	0.085	0.03964	0.20594	65	-171
	5	55	14.73	105.2	0.06	0.12682	0.12837	11	-171
-90 (1)	1	11	16.5	105.8	0.45	0.60107	0.46286	5	177
	2	22	16.5	105.65	0.375	0.39094	0.25762	-4	174
	3	33	16.5	105.5	0.255	0.13207	0.19547	4	-173
	4	45	16.5	105.35	0.095	0.06471	0.12092	2	-172
	5	55	16.5	105.2	0.065	0.11041	0.13311	-4	172
-45 (5)	1	11	17.33	106.17	0.45	0.50175	0.47632	7	-147
	2	22	17.43	106.07	0.355	0.28292	0.22081	13	167
	3	33	17.53	105.97	0.25	0.15569	0.19692	1	162
	4	44	17.63	105.87	0.15	0.10301	0.16966	-1	161
	5	55	17.73	105.77	0.075	0.11110	0.13480	7	171
-15 (20)	1	11	17.63	106.69					
	2	22	17.78	106.65	0.35				
	3	33	17.93	106.61	0.25	0.24232	0.12233	-3	-157
	4	44	18.08	106.57	0.15	0.12252	0.13769	4	167
	5	55	18.23	106.53	0.065	0.10105	0.10947	5	170
0 (4)	1	11	17.73	107	0.45	1.02248	0.26277	18	-138
	2	23	17.88	107	0.325	0.15457	0.15925	13	-168
	3	34	18.03	107	0.195	0.10907	0.16636	19	-173
	4	45	18.18	107	0.095	0.09643	0.12299	14	-173
	5	55	18.33	107	0.075	0.10711	0.11041	10	-176
15 (10)	1	11	17.63	107.31					
	2	22	17.78	107.35	0.355	0.19388	0.17470	27	-151
	3	33	17.93	107.39	0.25	0.11891	0.12539	19	-151
	4	45	18.08	107.43	0.105	0.10497	0.08705	27	-172
	5	55	18.23	107.47	0.065	0.07498	0.10398	27	-172
45 (3)	1	11	17.33	107.95	0.45	0.18318	0.17875	64	-125
	2	23	17.43	108.05	0.315	0.11426	0.11893	57	-115
	3	33	17.53	108.15	0.25	0.07845	0.11348	59	-136
	4	44	17.63	108.25	0.15	0.05075	0.08678	71	-152
	5	55	17.73	108.35	0.065	0.03986	0.07076	57	-156
90 (2)	1	11	16.5	108.2	0.45	0.07918	0.08942	-87	-110
	2	23	16.5	108.35	0.305	0.06950	0.06576	-88	-100
	3	34	16.5	108.5	0.175				
	4	45	16.5	108.65	0.11		0.06227		-113
	5	55	16.5	108.8	0.065		0.05988		-127

Table 5. *Maximum bed velocities, positive (+) and negative (-), within the profiles*

Velocity field for the maximum positive velocities around the rounhead (1m=1m/s), close to the rock surface, is shown on ***Figure 4***.

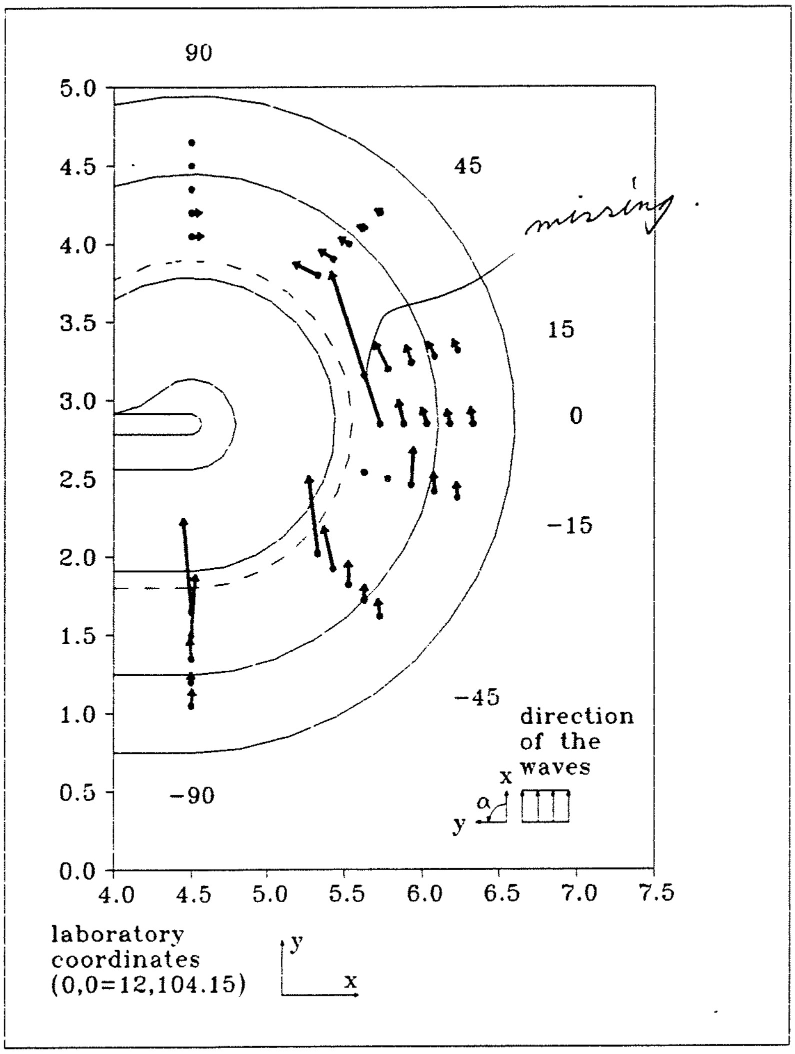

***Figure 4.** Maximum positive velocity field on the roundhead, close to the rock surface*

Obviously, the highest values of the velocities are closer to the SWL (still water level). Deeper in the water the values are smaller. The biggest values within the same arc around the rounhead are at the top of the structure (profile 0) and after profile 45 probably due to the refraction of the waves there are no positive velocities - the current has completely opposite direction. Generally, the angle of the velocity vector is compatible to the shape of the rounhead.

The velocity field for the maximum negative velocities around the rounhead (1m=1m/s), close to the rock surface is shown on ***Figure 5***.

Obviously, the highest values of the velocities are closer to the SWL (still water level). Deeper in the water the values are smaller. The biggest values within the same arc around the rounhead are near the profile -45. Generally, the angle of the velocity vector is compatible to the shape of the rounhead except for the points close to the surface where is that angle much more perpendicular to the structure.

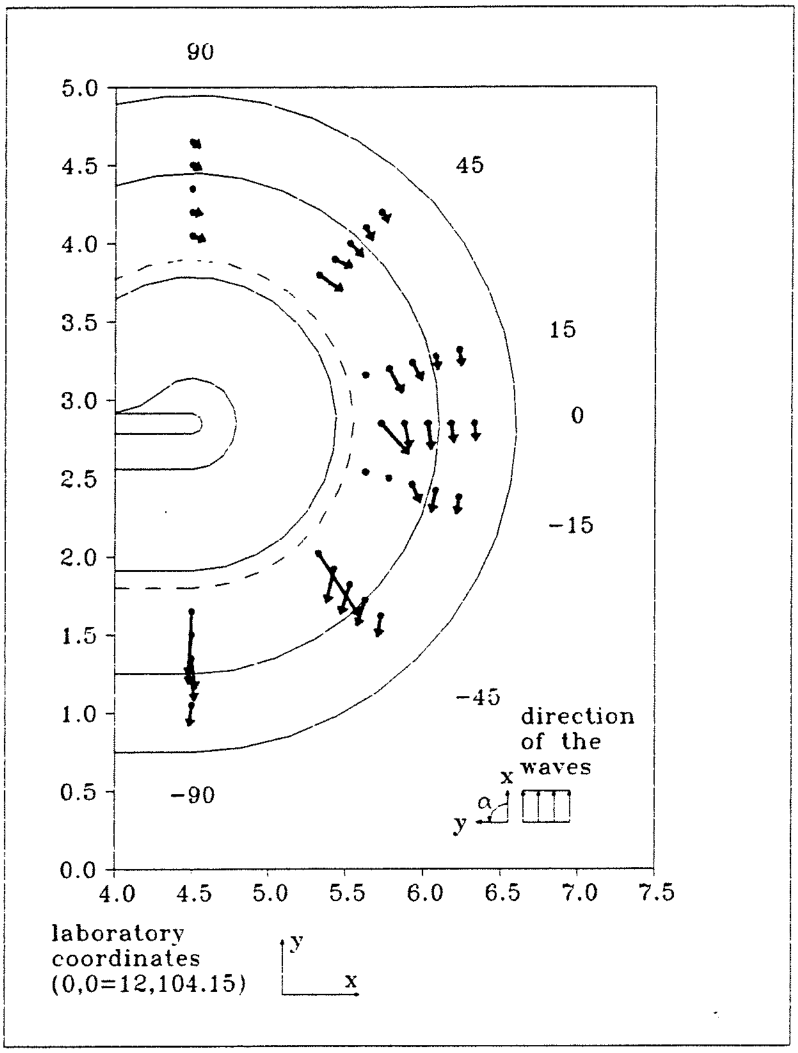

Figure 5. *Maximum negative velocity field on the roundhead, close to the rock surface*

Knowing some of the velocities on the bed within the same arc (***Table 6***), it was possible to plot those velocities and to find trend curve (polynomial) to connect those points. Obviously, at this stage of the analysis the polynomial curves for maximum velocities may not be valid.

vertical	profile	β (°)	L_{arc}(m)	velocity (m/s)		angle (°)	
				v(+)	v(-)	α(+)	α(-)
1	-90	0	0.00	0.60107	0.46286	5	177
	-45	45	0.94	0.50175	0.47632	7	-147
	-15	75	1.57				
	0	90	1.88	1.02248	0.26277	18	-138
	15	105	2.20				
	45	135	2.83	0.18318	0.17875	64	-125
	90	180	3.77	0.07918	0.08942	-87	-110
2	-90	0	0.00	0.39094	0.25762	-4	174
	-45	45	1.06	0.28292	0.22081	13	167
	-15	75	1.77				
	0	90	2.12	0.15457	0.15925	13	-168
	15	105	2.47	0.19388	0.17470	27	-151
	45	135	3.18	0.11426	0.11893	57	-115
	90	180	4.24	0.06950	0.06576	-88	-100
3	-90	0	0.00	0.13207	0.19547	4	-173

	-45	45	1.18	0.15569	0.19692	1	162
	-15	75	1.96	0.24232	0.12233	-3	-157
	0	90	2.36	0.10907	0.16636	19	-173
	15	105	2.75	0.11891	0.12539	19	-151
	45	135	3.53	0.07845	0.11348	59	-136
	90	180	4.71				
4	**-90**	0	0.00	0.06471	0.12092	2	-172
	-45	45	1.30	0.10301	0.16966	-1	161
	-15	75	2.16	0.12252	0.13769	4	167
	0	90	2.59	0.09643	0.12299	14	-173
	15	105	3.02	0.10497	0.08705	27	-172
	45	135	3.89	0.05075	0.08678	71	-152
	90	180	5.18		0.06227		-113
5	**-90**	0	0.00	0.11041	0.13311	-4	172
	-45	45	1.41	0.11110	0.13480	7	171
	-15	75	2.36	0.10105	0.10947	5	170
	0	90	2.83	0.10711	0.11041	10	-176
	15	105	3.30	0.07498	0.10398	27	-172
	45	135	4.24	0.03986	0.07076	57	-156
	90	180	5.65		0.05988		-127

Table 6. *Maximum bed velocities (+) and (-) along the same arc*

The maximum positive bed velocities along the same arc (constant distance from the centre of the structure) are shown in ***Figure 6***. Obviously, the highest values of the velocities are closer to the SWL (still water level). Deeper in the water the values are smaller and more stable. The biggest values within the same arc around the rounhead are near the top of the structure (profile 0). Again, the plot suggests that the positive velocities after profile 45 do not exist, especially for the points close to the SWL.

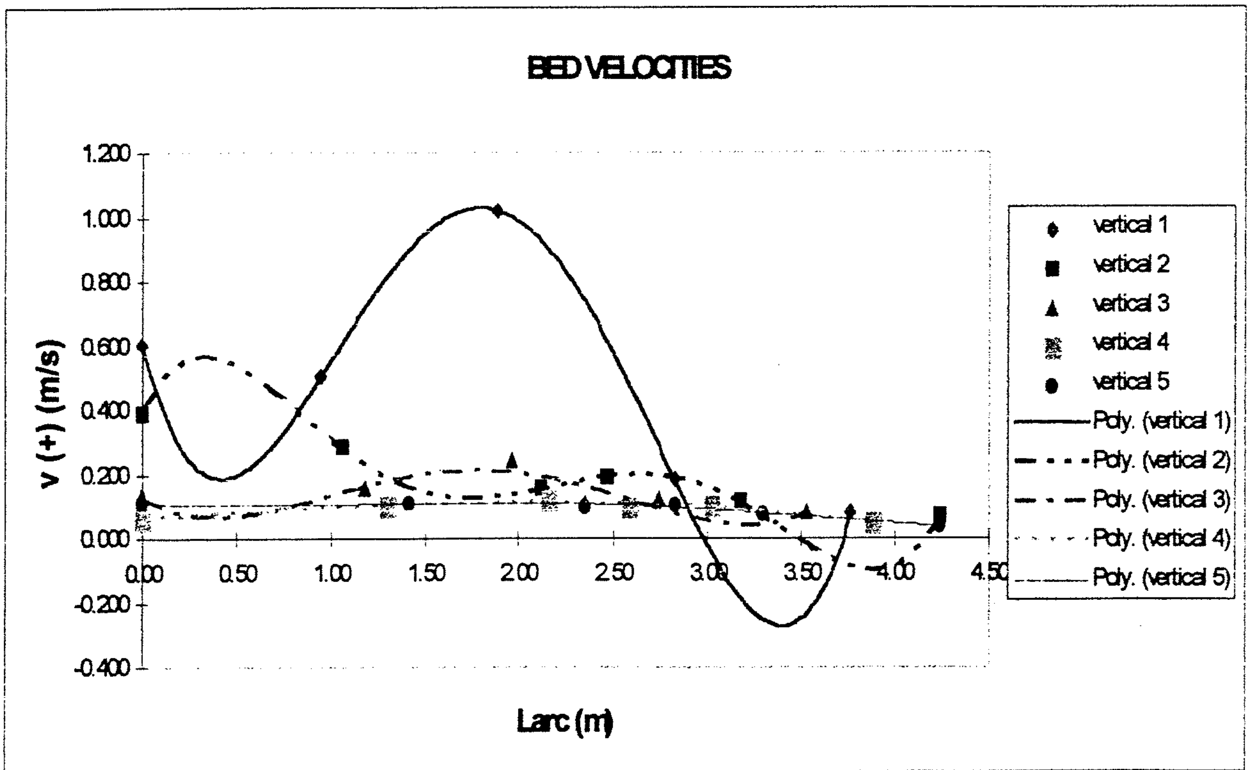

Figure 6. *Maximum positive velocities on the bed of the slope along the same arc*

The maximum negative bed velocities along the same arc (distance from the centre of the structure) are shown in ***Figure** 7*. Obviously, the highest values of the velocities are closer to the SWL (still water level). Deeper in the water the values are smaller and more stable. The biggest values within the same arc around the rounhead are near the profile -45.

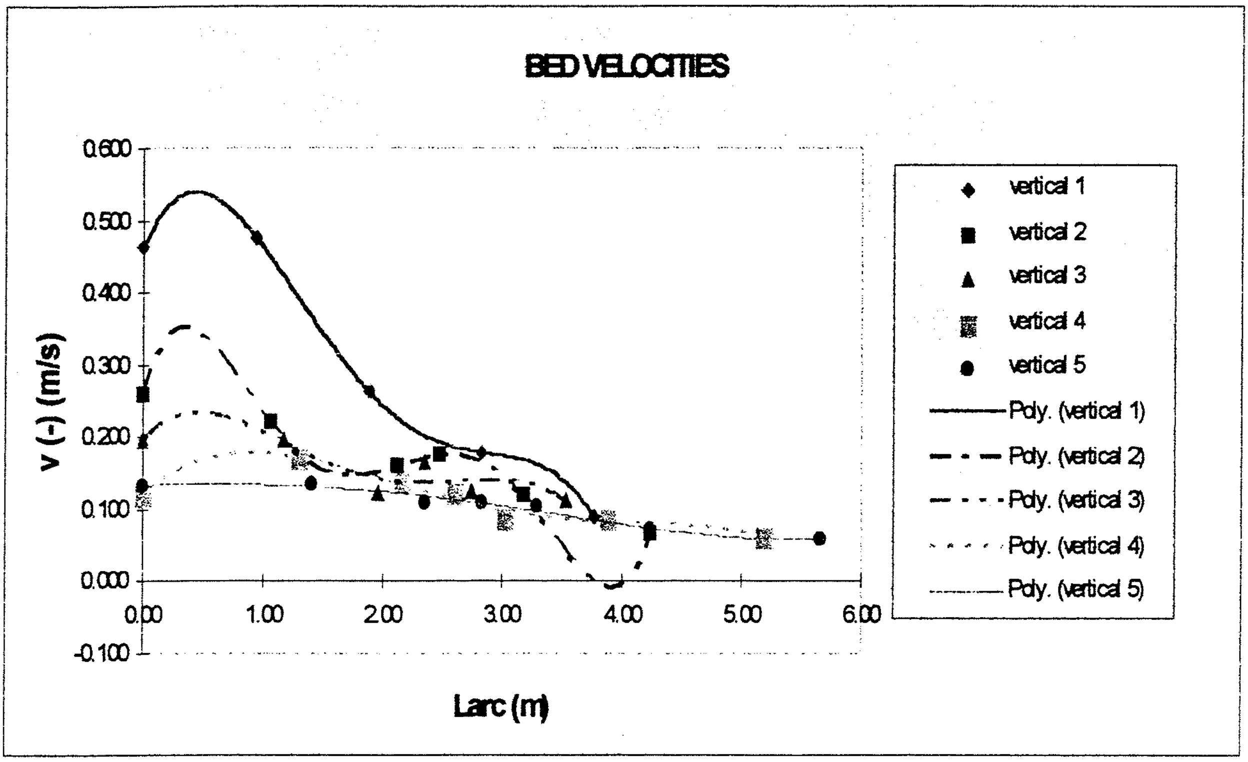

***Figure** 7. Maximum negative velocities on the bed of the slope along the same arc*

SUMMARY

Based on the limited data analysed thus far it can be seen that coherent velocity fields were recorded in the experiment.

The data illustrates well the areas subjected to maximum velocities under the tested wave conditions, which occurs near the still water level.

It is intended to use this velocity data as input to the reshaping numerical program, substituting it for the information on velocities which would have otherwise obtained from the run-up and backwash numerical model.

For negative (down-slope) velocities this approximation, mainly a two-dimensional assumption, is reasonably valid. However, for positive velocities the vector is almost normal to the maximum slope of the roundhead thus demonstrating that other solutions for stability in this part of the wave cycle will be necessary.