

**DAMAGE PROGRESSION AND STABILIZATION OF LOW  
CRESTED RUBBLE MOUNDS UNDER BREAKING WAVES**

by

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## **ABSTRACT**

The rehabilitation timing of a damaged rubble mound structure depends on the remaining capacity of the deteriorated structure. A laboratory experiment was conducted in a wave flume to measure the remaining capacity of a low-crested rubble mound inside the surf zone on a sand beach. The formation of a bar and trough feature modified wave conditions at the toe of the structure. Wave transmission over and through the structure increased with the lowering of the mound crest. The mound with a double armor layer on smaller core stones was exposed to irregular wave action lasting 22.2 hours. Some of the core stone was visible through holes of the thinned armor layer but remained in place. The crest lowering reduced wave action on the damaged mound. On the other hand, the mound with a single armor layer did not stabilize itself because of the core stone removal after 7.8 hours. The rubble mound structure was resilient as long as the core stone was protected.

## **Chapter 1**

### **INTRODUCTION**

New coastal structures design was investigated extensively, and design formulas were presented in the Coastal Engineering Manual (USACE 2003). The recent progress of coastal structure design was summarized in the report by Kobayashi (2015). On the other hand, the rehabilitation of damaged or aged rubble mound structures has not been studied in systematic manners. This study was motivated by the risk assessment of damaged Point Judith breakwaters in Rhode Island performed by Melby et al. (2015). The three breakwaters provide shelter for refuge, a commercial harbor and a sandy, recreational shoreline. The old rubble mound breakwaters were constructed between 1891 and 1914 before the expertise of coastal engineering was established. The breakwaters were rehabilitated a number of times. The cross-sectional areas became relatively large and complicated because of additional rock placement after past damage. The cross-sectional area of a new structure is generally minimized to reduce the construction cost. The deformed rubble mound structure may be damaged more gradually than the corresponding new structure. This study attempts to quantify the remaining capacity of a rubble mound breakwater with a damaged and lowered crest at the beginning of a storm. The remaining capacity will determine the timing of the next rehabilitation.

Damaged breakwaters with lowered crests are similar to low-crested detached breakwaters built in shallow water for beach stabilization and shore protection. A large number of detached breakwaters were constructed in the world. A design manual was published in Japan by the Ministry of Construction (1992). Lamberti et al. (2005) described study sites in Europe monitored during the DELOS (Environmental Design of Low Crested Coastal Defense Structures) project. Detached breakwaters are normally exposed to depth-limited breaking waves in shallow water during storms. Burcharth et al. (2006) recommended low-crested breakwater design of no or little cumulative damage. Bathymetric surveys during the DELOS project indicated significant bathymetric changes that were not included in design formulas derived from fixed-bed experiments.

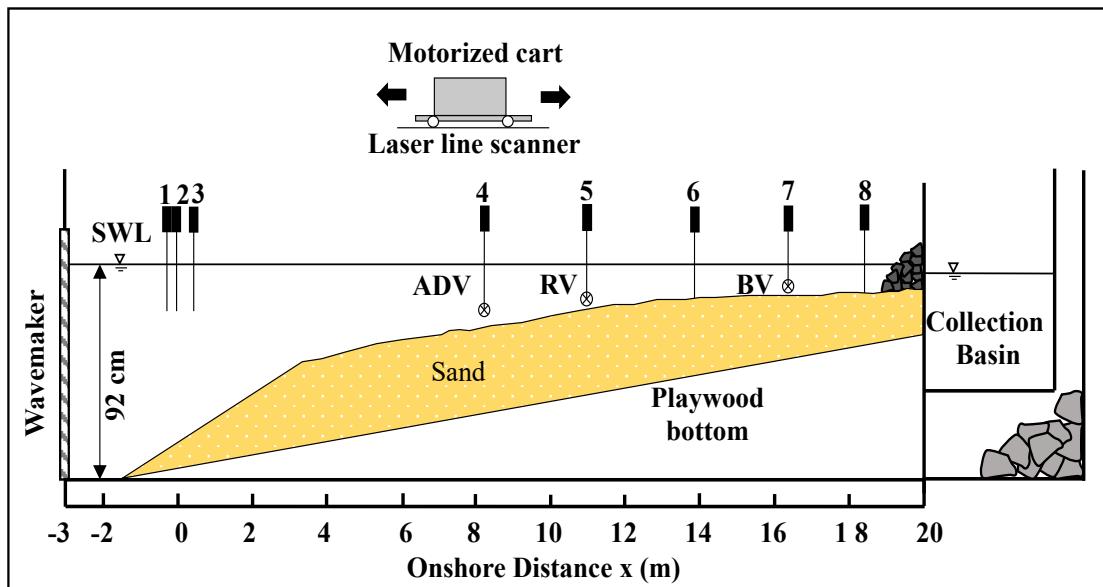
A laboratory experiment was conducted in a wave flume to quantify the remaining capacity of a rubble mound structure built inside the surf zone on a nearly equilibrium sand beach. The rubble mound consisted of a core and an armor layer of a traditional two-layer thickness. The mound in the double layer test was exposed to irregular wave action of approximately 42,000 waves lasting 22.2 hours. The mound crest was damaged and the displaced armor stones were deposited on the seaward and landward slopes. The core stones were visible through holes of the thinned armor layer, but the core stones were not removed. The lowered crest near the still water level (SWL) became stabilized unlike the damage progression measured by Melby and Kobayashi (2011) for conventional rubble mound breakwaters with crests well above the SWL. A single layer test was performed to examine the effect of the armor layer thickness on the

damage progression and stabilization. The removal of core stones through large holes of the eroded single layer occurred after irregular wave action of about 15,000 waves lasting 7.8 hours. The experiment, data analysis, beach profile evolution effect on wave transformation, deforming structure effect on wave transmission, and crest lowering effect on damage progression are presented in the following.

## Chapter 2

### EXPERIMENT

An experiment was conducted in a wave flume that was 23 m long, 1.15 m wide, and 1.5 high as shown in Fig. 2.1 for a test with no structure. The experiment facility and instrument were explained by Yuksel and Kobayashi (2020). Wave gauges and Velocimeters locations are listed in Table 2.1. The sand beach on a plywood slope of 1/30 (vertical /horizontal) consisted of well-sorted fine sand with a median diameter of 0.018 cm. The sand characteristics are listed in Table 2.2.



**Figure 2.1** Experimental setup at start of N test with no structure

**Table 2.1** Wave Gauge Locations (WG1-WG8) and Velocimeter Locations (ADV; Red- Vectrino, RV; Blue Vectrino, BV)

Wave Gauge	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
x (m)	0	0.25	0.95	8.4	11	13.8	16.3	18.3

Velocity Gauge				ADV	RV		BV	
x (m)				8.4	11		16.3	
y (m)				0.15	0.15		0	
z (m)				-2d/3	-2d/3		-2d/3	

x = onshore coordinate with x = 0 at WG1

y = alongshore coordinate with y = 0 at the middle of the flume

z = vertical coordinate with z = 0 at SWL

d = local water depth at the start of each run

**Table 2.2** Characteristics and Photo of Sand, white stones, Green stones, Blue stones, and Combined (Green plus Blue)

	Sand	White Stones	Green Stones	Blue Stones	Green and Blue Combined
Dn50 (cm)	0.018	2.11	3.52	3.81	3.65
Density (g/cm3)	2.60	2.70	2.94	3.06	3.00
Porosity	0.4	0.44	0.44	0.44	0.44



This small-scale experiment was not intended to reproduce specific prototype conditions. The fine sand was observed to be transported offshore as suspended load and onshore as bed load. A 400-s run of irregular waves with a Texel, Marsen, and Arsloe (TMA) spectrum was generated by a piston-type wave maker in water depth of 0.92 m on a horizontal concrete bottom. The spectral significant wave height and peak period were 0.2 m and 2.6 s so as to create a relatively wide surf zone seaward of a wave absorbing slope constructed of large rock in front of the impermeable vertical wall of the collection basin for wave overtopping. No wave overtopping of the vertical wall occurred in this experiment.

Eight wave gauges (WG1-WG8) were used to measure the cross-shore variation of the free surface elevation for each run. The onshore coordinate  $x$  starts from  $x = 0$  at WG1 and extends to  $x = 18.3$  m at WG8 located 0.3 m seaward of the rock slope. The vertical coordinate  $z$  is positive upward with  $z = 0$  at the still water level (SWL) of the 0.92 m depth in Fig. 2.1. The free surface elevations measured at WG1-WG3, located at  $x = 0.0, 0.25$ , and  $0.95$  m, respectively, were used to separate incident and reflected waves at the location of  $x = 0$  for each 400-s run. The separation method based on linear wave theory was explained by Kobayashi et al. (1990). The relatively steep slope of about 1/10 seaward of  $x = 5$  m in Fig. 2.1 was artificial and necessary because of the limited flume length. Large waves in the incident irregular waves started breaking in the vicinity of  $x = 6$  m. WG4 at  $x = 8.4$  m and WG5 at  $x = 11.0$  m were located inside the surf zone. WG6 was placed at  $x = 13.8$  m where the toe of a rubble mound was located in a test with a structure. WG7 at  $x = 16.3$  m and WG8 at  $x = 18.3$  m measured

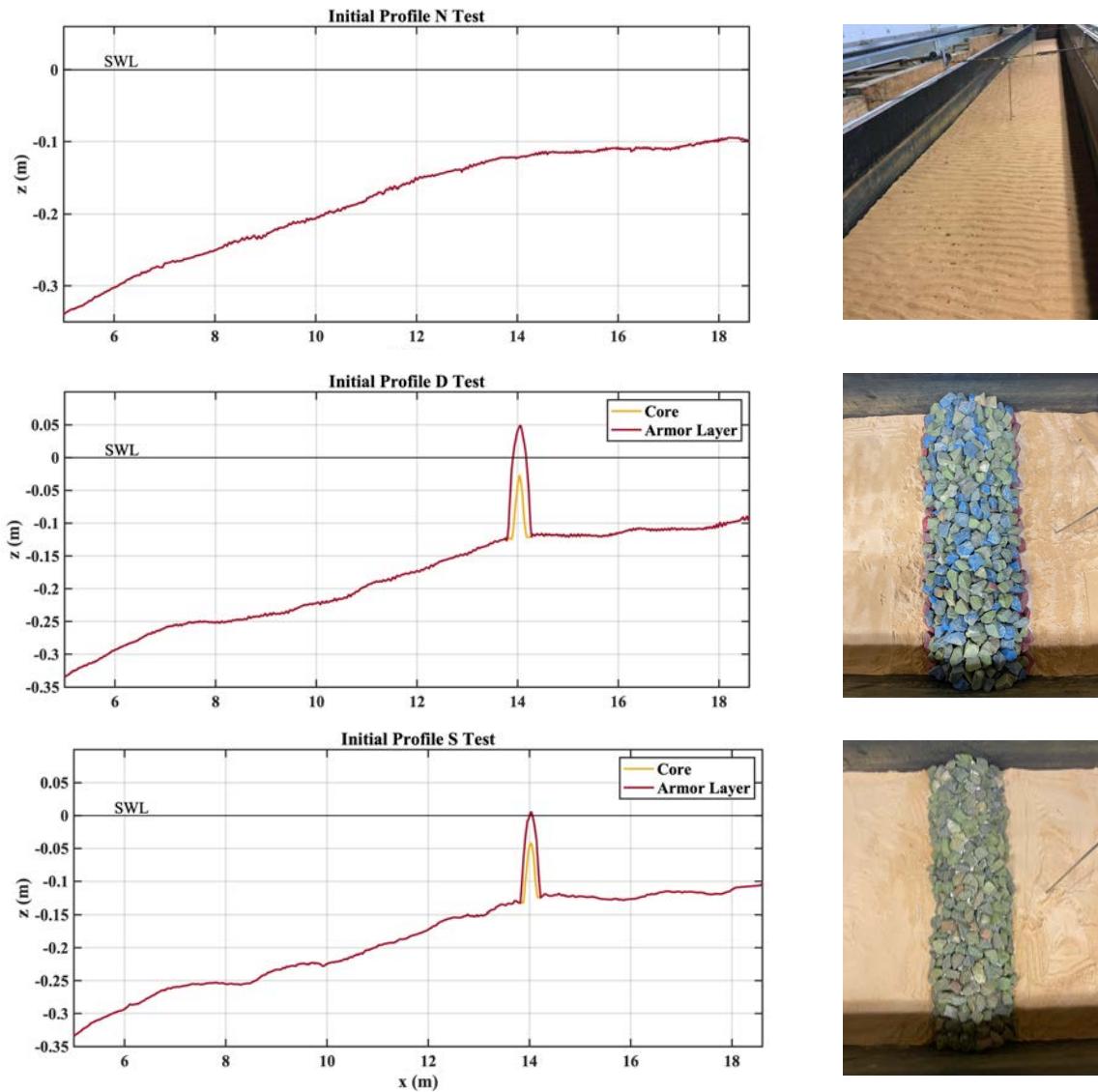
transmitted waves in the structure test. The fluid velocities at the cross-shore locations of WG4, WG5 and WG7 were measured at an elevation above the bed of one-third of the local water depth by one acoustic Doppler velocimeter (ADV) and two Vectrinos (Nortek, Rud, Norway) indicated by RV and BV in Fig. 2.1. The beach profile was measured using a laser line scanner system mounted on a motorized cart before each test and after noticeable profile changes. Three-dimensional bathymetry data were averaged alongshore to obtain the average beach profile.

Table 2.3 summarizes the sequence of three tests in the experiment. The initial profiles for N, D, and S Test are represented in Fig. 2.2 with the photos. The initial profile of the no (N) structure test depicted on Fig. 2.1 was exposed to 20 runs where the numeral after the letter N corresponds to the run number starting from the first run N1. Each run lasted 400 s and contained more than 200 waves. The initial profile N0 was regarded to be nearly equilibrium under the generated waves. The measured profiles N10 and N20 after 10 and 20 runs are compared with the initial profile N0 in the next section.

**Table 2.3**

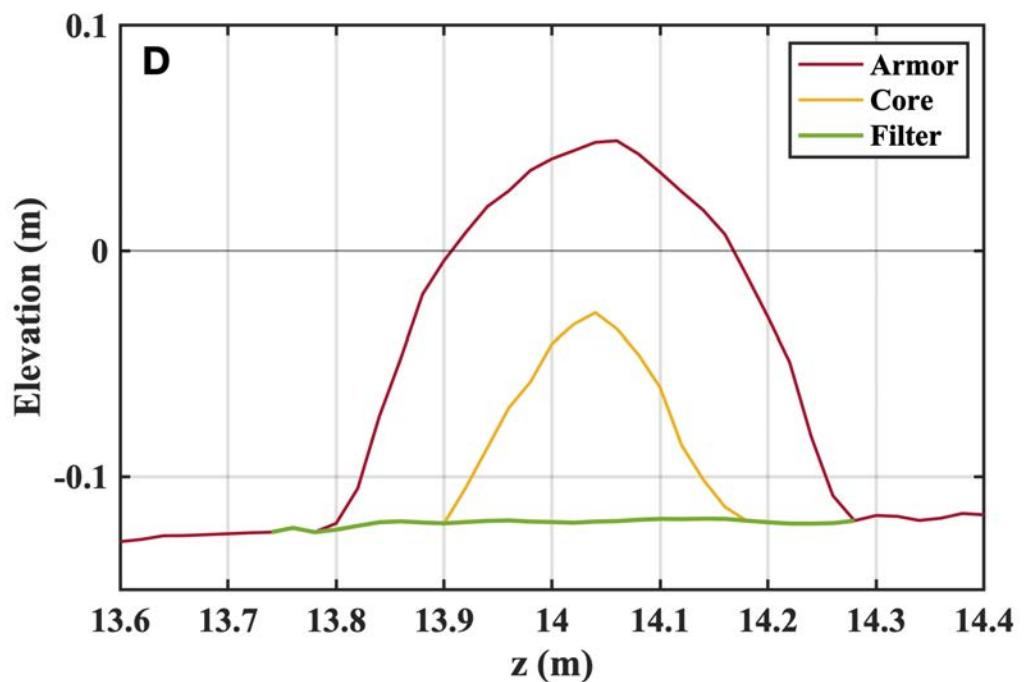
Sequence of N, D, and S Consisting of 310 Runs with Each Run Lasting 400s

Description	Runs	SWL (cm)	Duration (s)
No structure	N1 - 20	0	8,000
Double armor layer after SWL lowering	D1 - 150 D151 - 200	0 -2	60,000 20,000
after D structure removal	D201 - 210	0	4,000
Single armor layer after S structure removal	S1 - 70 S71 - 80	0	28,000 4,000



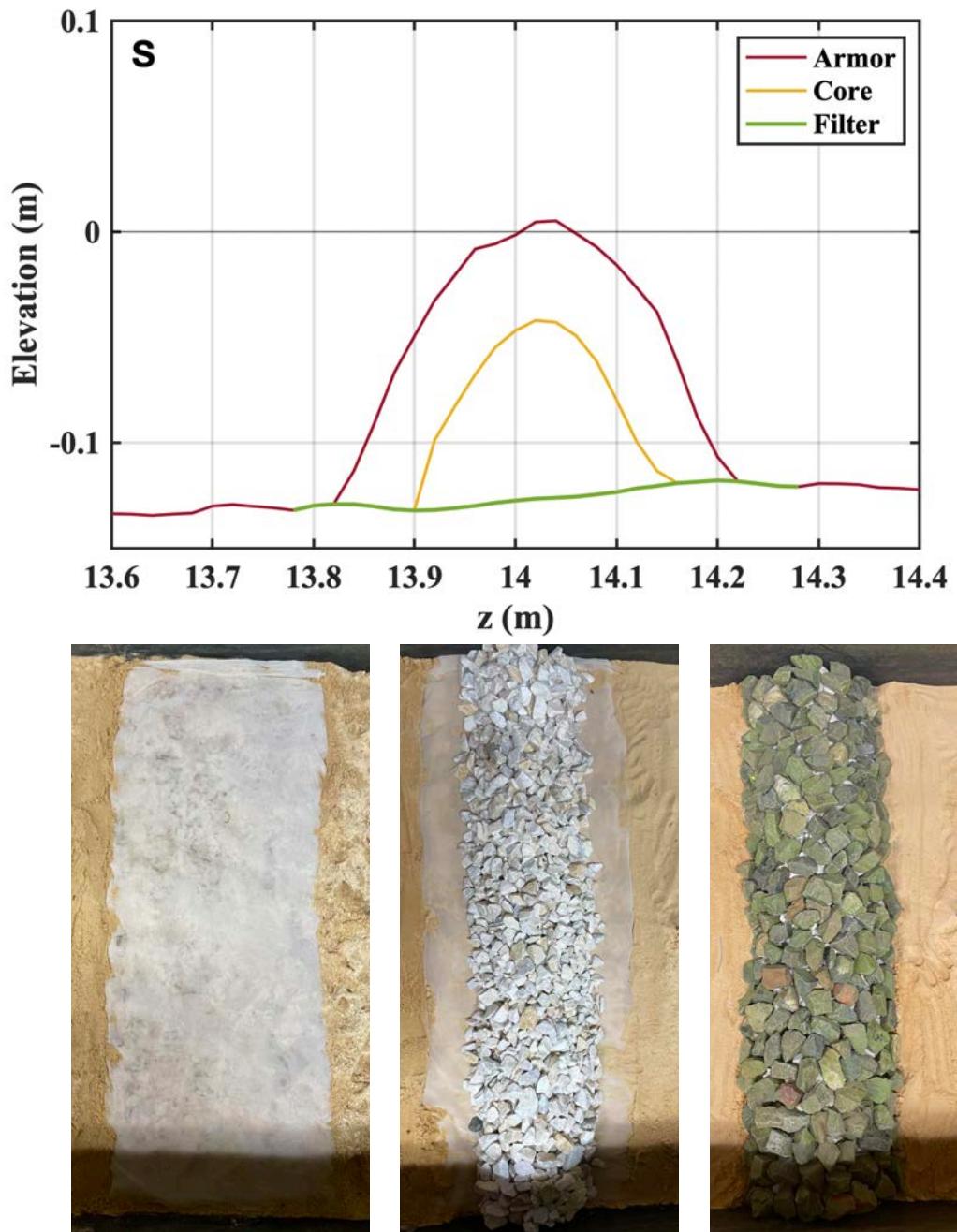
**Figure 2.2** Initial profiles and photos of No structure (N), Double-layer (D), and Single-layer (S) tests with Still Water Level (SWL) of 92 cm in the wave flume

A rubble mound structure was built on the profile of N20 in the zone of  $x = 13.74$  – 14.28 m. White core stones were placed on a filter of polyester fabric mesh with an opening of 0.074 mm. The double (D) armor layer placed on the core was in a two-layer thickness shown in Fig. 2.3. The characteristics of the core and D armor stones are listed in Table 2.2. The blue and green stones used by Yuksel and Kobayashi (2020) were reused in the D test where the green stone was 54% in volume. The nominal stone diameter was 3.65 cm. The filter edges in Fig. 2.3 were buried 0.1 m into the sand to minimize sand undermining below the filter. The armor stones were piled steeply to allow some stone movement and stabilization that might mimic aging processes crudely. The beach and mound profile were measured 13 times during D1-D150. The initial mound crest of the profile D0 was at the elevation of  $z = 4.9$  cm. The crest was lowered and became more resistant to wave action. The crest of the profile D150 was at  $z = 0.4$  cm above the SWL set at the datum  $z = 0$  in Fig. 2.3. The SWL was lowered by 2 cm during D151-D200 so as to increase wave action on the crest. The lowered crest was damaged somewhat but became stable. The mound of D200 was removed and wave transmission in the absence of the D mound was measured during D201-D210 with the SWL at  $z = 0$  in order to estimate the mound effect on wave height reduction.



**Figure 2.3** Initial rubble mound profile in D test with photos showing the placement of filter, white core stones, and double-layer (blue and green)

After the D test, the beach profile was rebuilt to be almost the same as the profile of N20 at the beginning of the D test (Fig. 2.2). The elevation difference was within 1 cm. The filter and the core stones used in the D test were placed in the same zone of  $x = 13.74 - 14.28$  m. The stone in the single (S) armor layer was the green stone in the D test. The nominal stone diameter was 3.52 cm (Table 2.2). The core stone with the nominal diameter of 2.11 cm may be dislodged more readily from holes of the damaged single armor layer. The SWL was kept at the datum  $z = 0$ . The initial profile of the S mound in Fig. 2.4 was exposed to the same wave action as in D1-D150. The crest elevation was lowered gradually from  $z = 0.5$  cm for S0 to  $z = -3.3$  cm for S70. The core stones of S70 were visible along the entire length of the mound crest. Several core stones were dislodged and deposited on the sand surface. The mound of S70 was removed and wave transformation was measured during S70-S80 with no structure. It is noted that the two Vectrinos (RV and BV in Fig. 2.1) were out of order during the S test.

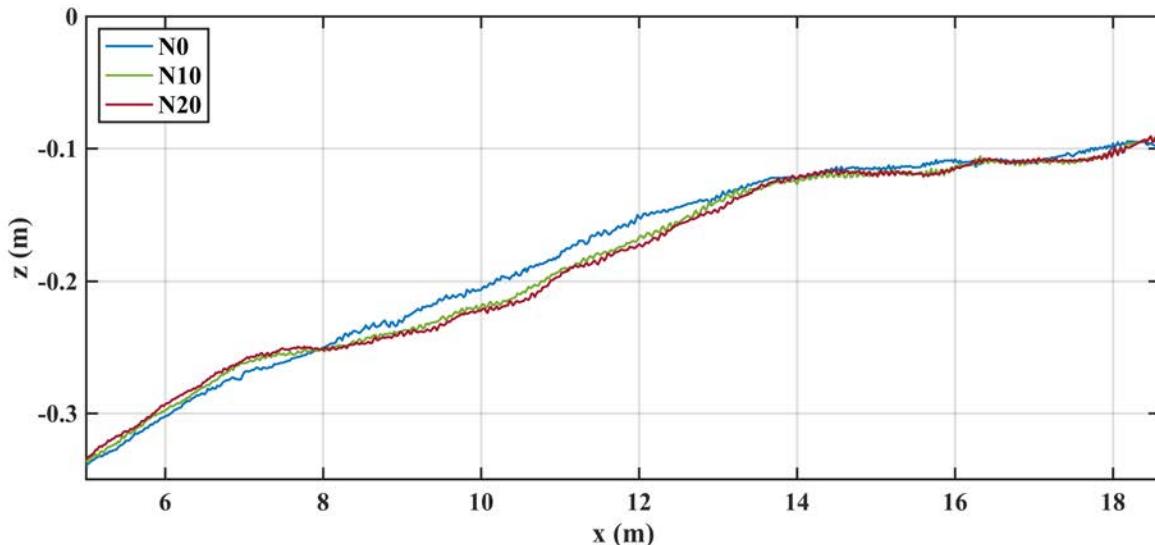


**Figure 2.4** Initial rubble mound profile in S test with photos showing the placement of filter, white core stones, and single-layer (green) stones

## Chapter 3

### NO STRUCTURE (N) TEST

The N test was conducted to create an equilibrium profile of the fine sand (Table 2.2) under the specified waves generated in the wave flume. Fig. 3.1 shows the measured sand beach profiles of N0, N10, and N20 in the zone of  $x = 5.0\text{-}18.6\text{ m}$  where  $x = 5.0\text{ m}$  was the seaward limit of the motorized cart movement in Fig. 2.1. The initial profile (N0) was eroded in the zone of  $x = 8\text{-}14\text{ m}$  up to 2 cm after 10 runs (N10). Additional 10 runs were generated to reduce the profile change to less than 1 cm from N10 to N20. The profile of N20 was used as the initial profile of the D structure test so as to measure the profile evolution induced by the presence of the D structure.

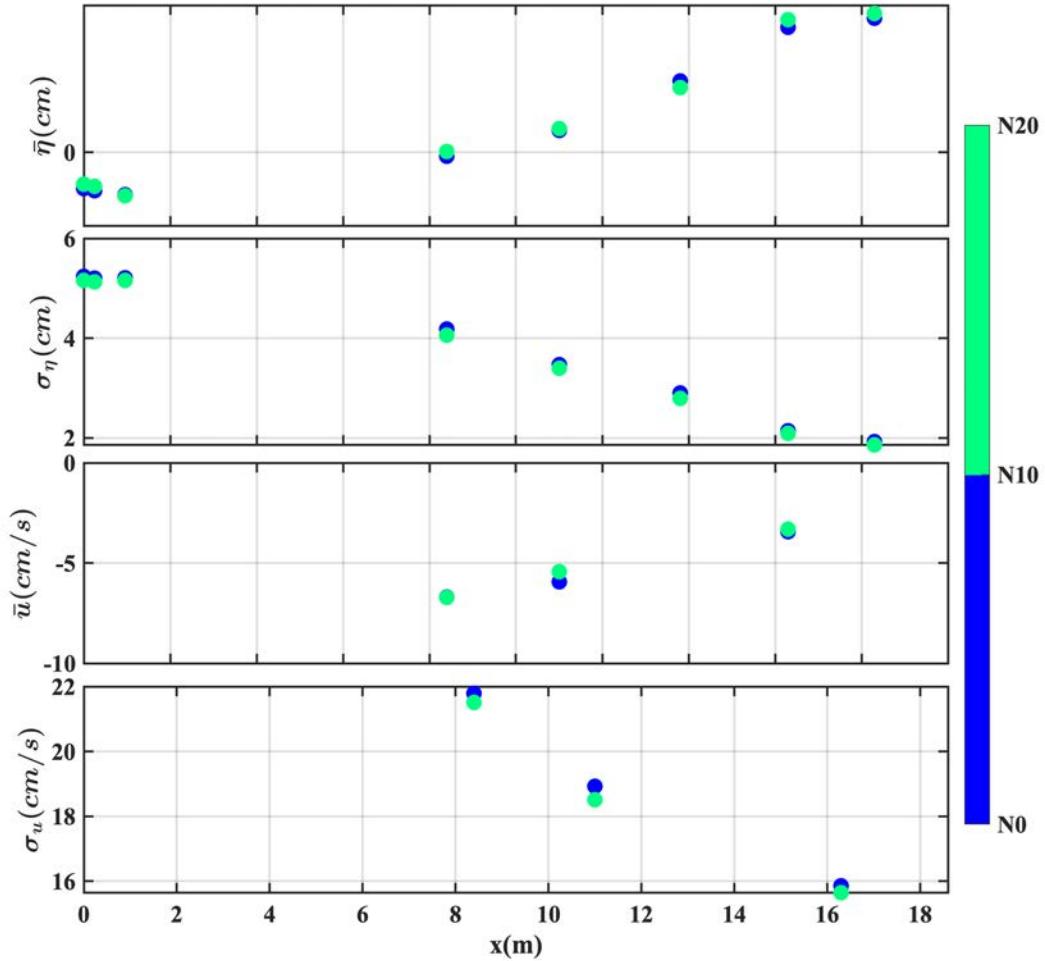


**Figure 3.1** Initial profile (N0) and measured profiles (N10 and N20) after 10 and 20 runs in N test where the numeral after N indicates the number of runs with each run lasting 400s

The time series obtained by the eight wave gauges and three velocimeters in Fig. 2.1 were analyzed for each the 20 runs. The incident and reflected waves were estimated using WG1 – WG3 ( $x = 0.0 – 0.95$  m) outside the surf zone. The spectral significant wave height  $H_{mo}$  and peak period  $T_p$  of the incident waves at  $x = 0$  were 21 cm and 2.6 s, respectively. The mean period  $T_m$  was 1.8 s and the number of waves in each 400-s run was approximately 220 (Table 3.1). The wave reflection coefficient, defined as the ratio between the values of  $H_{mo}$  for the reflected and incident waves, was 0.14 for the experimental setup with no structure in Fig. 2.1.

The mean and standard deviation of the free surface elevation  $\eta$  above the SWL were calculated to examine the cross-shore wave transformation on the beach profile in Fig. 3.1. The average values of  $\bar{\eta}$ ,  $\sigma_\eta$ ,  $\bar{u}$ , and  $\sigma_u$  in the N1-N10, and N11-N20 intervals are plotted in Fig. 3.2 for the onshore distance  $x = 0-18.6$  m, and listed in Tables 3.2, 3.3, and 3.4. The mean water level  $\bar{\eta}$  was slightly negative (wave setdown) at WG1-WG3 and approximately zero at WG4 ( $x = 8.4$  m) in the outer surf zone. The positive  $\bar{\eta}$  (wave setup) at WG5-WG8 ( $x = 11.0 – 18.3$  m) increased landward in the surf zone and was approximately 0.9 cm at WG8. The free surface standard deviation  $\sigma_\eta$  may be related to the local significant wave height  $H_{mo} = 4\sigma_\eta$ . The values of  $\sigma_\eta$  were approximately 5.2 cm at WG1-WG3 and decreased monotonically from WG4 – WG8 inside the surf zone. The values of  $\sigma_\eta$  for the 20 runs were approximately 1.9 cm at WG8. The average values of  $\bar{\eta}$  and  $\sigma_\eta$  during the profile measurement intervals of N1-N10 and N11-N20 were calculated to examine the change of  $\bar{\eta}$  and  $\sigma_\eta$  which might have

been caused by the profile changes in Fig. 3.1. The averaged values changed by 0.1 cm or less. These changes were comparable to the free surface elevation measurement error of 0.1 cm.



**Figure 3.2** Average values of mean and standard deviation of free surface elevation  $\eta$  and cross-shore velocity  $u$  for N1-N10 and N11-N20 runs in N test

The velocities were measured at  $x = 8.4$ ,  $11.0$ , and  $16.3$  m inside the surf zone. The measured alongshore and vertical velocity were small in comparison to the cross-shore velocities  $u$ . The mean horizontal velocity  $\bar{u}$  was negative (offshore) because of the wave-induced offshore return current. The velocity standard deviation  $\sigma_u$  represents the wave-induced oscillatory velocity and decreased with the decrease of the wave height in the surf zone. The average values of  $\bar{u}$  and  $\sigma_u$  were calculated for the two intervals of N1 – N10 and N11 – N20. The average offshore current ( $-\bar{u}$ ) was  $6.7$ ,  $5.7$ , and  $3.4$  cm/s at  $x = 8.4$ ,  $11.0$ , and  $16.3$  m, respectively. The corresponding value of  $\sigma_u$  was  $21.7$ ,  $18.7$ , and  $15.8$  cm/s at  $x = 8.4$ ,  $11.0$ , and  $16.3$  m, respectively. The velocity differences between the two intervals were within the velocity measurement error of about  $1$  cm/s.

**Table 3.1** Incident Wave Characteristics for 20 Runs in N Test

Run	H <sub>mo</sub> (cm)	H <sub>rms</sub> (cm)	H <sub>s</sub> (cm)	T <sub>p</sub> (s)	T <sub>s</sub> (s)	T <sub>m</sub> (s)	R	N. Waves
1	21.77	15.39	21.02	2.62	2.14	1.80	0.14	222
2	21.58	15.26	20.96	2.62	2.14	1.78	0.14	225
3	21.52	15.22	20.79	2.62	2.13	1.77	0.14	226
4	21.45	15.16	20.69	2.62	2.12	1.79	0.14	224
5	21.54	15.23	20.80	2.62	2.14	1.80	0.14	222
6	21.07	14.90	20.47	2.62	2.16	1.83	0.14	219
7	21.15	14.96	20.46	2.62	2.16	1.79	0.13	223
8	21.17	14.97	20.41	2.62	2.10	1.77	0.14	226
9	21.12	14.93	20.41	2.62	2.16	1.78	0.14	225
10	21.14	14.95	20.35	2.62	2.12	1.78	0.14	225
Average	<b>21.35</b>	<b>15.10</b>	<b>20.64</b>	<b>2.62</b>	<b>2.14</b>	<b>1.79</b>	<b>0.14</b>	<b>2237</b>
11	21.01	14.86	20.39	2.62	2.12	1.82	0.14	220
12	21.18	14.98	20.57	2.62	2.13	1.82	0.14	220
13	21.15	14.95	20.45	2.62	2.16	1.82	0.14	220
14	21.18	14.98	20.39	2.62	2.12	1.79	0.13	223
15	21.17	14.97	20.41	2.62	2.12	1.79	0.13	223
16	21.18	14.98	20.38	2.62	2.14	1.80	0.14	222
17	21.15	14.95	20.46	2.62	2.14	1.80	0.14	222
18	21.11	14.93	20.46	2.62	2.15	1.82	0.14	220
19	21.10	14.92	20.41	2.62	2.12	1.81	0.14	221
20	21.11	14.93	20.36	2.62	2.11	1.80	0.14	222
Average	<b>21.13</b>	<b>14.94</b>	<b>20.43</b>	<b>2.62</b>	<b>2.13</b>	<b>1.81</b>	<b>0.14</b>	<b>2213</b>

**Table 3.2** Mean Free Surface Elevation (cm) at Eight Wave Gauges for 20 Runs in N Test

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>1</b>	-0.18	-0.22	-0.32	-0.07	0.16	0.59	0.87	0.90
<b>2</b>	-0.28	-0.30	-0.32	-0.04	0.17	0.52	0.88	0.94
<b>3</b>	-0.24	-0.30	-0.27	-0.06	0.14	0.53	0.87	0.92
<b>4</b>	-0.28	-0.26	-0.27	-0.05	0.17	0.55	0.85	0.97
<b>5</b>	-0.26	-0.27	-0.31	-0.03	0.15	0.54	0.87	0.94
<b>6</b>	-0.25	-0.28	-0.30	-0.01	0.14	0.39	0.72	0.81
<b>7</b>	-0.26	-0.26	-0.26	-0.01	0.14	0.43	0.86	0.94
<b>8</b>	-0.23	-0.25	-0.28	-0.02	0.14	0.44	0.88	0.93
<b>9</b>	-0.25	-0.24	-0.26	0.02	0.13	0.46	0.85	0.90
<b>10</b>	-0.24	-0.23	-0.30	0.00	0.16	0.42	0.84	0.88
<b>Average</b>	<b>-0.25</b>	<b>-0.26</b>	<b>-0.29</b>	<b>-0.03</b>	<b>0.15</b>	<b>0.49</b>	<b>0.85</b>	<b>0.91</b>
<b>11</b>	-0.17	-0.24	-0.34	0.01	0.16	0.44	0.81	0.92
<b>12</b>	-0.22	-0.21	-0.30	0.01	0.14	0.46	0.90	0.95
<b>13</b>	-0.23	-0.23	-0.28	-0.01	0.17	0.49	0.95	0.96
<b>14</b>	-0.21	-0.23	-0.30	-0.01	0.14	0.45	0.91	0.94
<b>15</b>	-0.21	-0.23	-0.29	0.02	0.19	0.45	0.91	0.95
<b>16</b>	-0.17	-0.24	-0.34	0.01	0.16	0.44	0.81	0.92
<b>17</b>	-0.21	-0.23	-0.30	0.00	0.15	0.43	0.92	0.96
<b>18</b>	-0.26	-0.22	-0.27	0.02	0.13	0.44	0.92	0.95
<b>19</b>	-0.25	-0.24	-0.26	0.00	0.16	0.39	0.96	0.94
<b>20</b>	-0.24	-0.24	-0.27	0.01	0.20	0.42	0.92	0.97
<b>Average</b>	<b>-0.22</b>	<b>-0.23</b>	<b>-0.30</b>	<b>0.00</b>	<b>0.16</b>	<b>0.44</b>	<b>0.90</b>	<b>0.95</b>

**Table 3.3** Free Surface Standard Deviation (cm) at Eight Wave Gauges for 20 Runs in N Test

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>1</b>	5.34	5.31	5.28	4.27	3.56	2.88	2.18	1.97
<b>2</b>	5.34	5.28	5.31	4.27	3.50	2.95	2.16	1.98
<b>3</b>	5.28	5.22	5.24	4.25	3.50	2.98	2.16	1.95
<b>4</b>	5.27	5.21	5.24	4.23	3.49	2.96	2.16	1.94
<b>5</b>	5.28	5.23	5.26	4.26	3.50	2.97	2.16	1.95
<b>6</b>	5.16	5.15	5.14	4.12	3.43	2.85	2.13	1.90
<b>7</b>	5.19	5.16	5.16	4.11	3.42	2.84	2.13	1.88
<b>8</b>	5.19	5.17	5.17	4.10	3.44	2.85	2.12	1.89
<b>9</b>	5.17	5.17	5.15	4.11	3.44	2.85	2.13	1.88
<b>10</b>	5.18	5.17	5.15	4.10	3.42	2.87	2.13	1.88
<b>Average</b>	<b>5.24</b>	<b>5.21</b>	<b>5.21</b>	<b>4.18</b>	<b>3.47</b>	<b>2.90</b>	<b>2.15</b>	<b>1.92</b>
<b>11</b>	5.13	5.10	5.16	4.07	3.40	2.76	2.10	1.88
<b>12</b>	5.16	5.16	5.18	4.09	3.43	2.78	2.10	1.87
<b>13</b>	5.17	5.15	5.18	4.04	3.40	2.79	2.10	1.86
<b>14</b>	5.18	5.16	5.18	4.08	3.41	2.81	2.11	1.88
<b>15</b>	5.18	5.16	5.17	4.05	3.40	2.79	2.11	1.88
<b>16</b>	5.13	5.10	5.16	4.07	3.40	2.76	2.10	1.88
<b>17</b>	5.17	5.12	5.16	4.04	3.39	2.79	2.09	1.84
<b>18</b>	5.17	5.13	5.15	4.06	3.38	2.79	2.09	1.85
<b>19</b>	5.16	5.12	5.14	4.04	3.38	2.81	2.08	1.85
<b>20</b>	5.18	5.12	5.15	4.04	3.40	2.81	2.09	1.84
<b>Average</b>	<b>5.16</b>	<b>5.13</b>	<b>5.16</b>	<b>4.06</b>	<b>3.40</b>	<b>2.79</b>	<b>2.10</b>	<b>1.86</b>

**Table 3.4** Mean Horizontal Velocity and Standard Deviation at Three  
Velocimeters for 20 Runs in N test

	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
Run	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
1	-5.59	23.45	-6.37	18.89	-3.07	15.80
2	-6.02	21.96	-6.08	19.20	-2.87	16.26
3	-6.11	21.70	NR	NR	NR	NR
4	-7.58	21.57	-5.48	18.87	-3.45	15.98
5	-6.61	21.82	-6.22	19.30	-3.35	15.79
6	-6.95	21.51	-5.99	18.75	-3.83	15.97
7	-6.86	21.26	-5.82	18.78	-3.98	15.58
8	-6.70	21.32	-5.87	18.87	-3.34	15.73
9	-7.34	21.66	-6.19	18.80	-4.21	15.91
10	-7.11	21.72	-5.43	18.83	-2.76	15.70
Average	<b>-6.69</b>	<b>21.80</b>	<b>-5.94</b>	<b>18.92</b>	<b>-3.43</b>	<b>15.86</b>
11	-6.34	21.77	-5.72	18.62	-2.97	15.53
12	-7.23	21.41	-3.61	19.36	-3.36	17.61
13	-7.11	21.50	-5.54	18.20	-3.77	15.70
14	-6.42	21.78	-5.78	18.82	-4.02	15.23
15	-6.53	21.30	-5.63	18.29	-3.14	15.70
16	-6.34	21.77	-5.34	18.50	-3.07	15.01
17	-7.48	21.40	-5.58	18.31	-3.42	14.87
18	-7.26	21.32	NR	NR	NR	NR
19	-5.64	21.72	-6.12	18.26	-2.75	15.10
20	-6.79	21.20	-5.56	18.27	-3.28	16.08
Average	<b>-6.71</b>	<b>21.52</b>	<b>-5.43</b>	<b>18.52</b>	<b>-3.31</b>	<b>15.65</b>

NR means Not Reliable

**Table 3.5** Average Incident Wave Characteristics for N Test

Runs	H <sub>mo</sub> (cm)	H <sub>rms</sub> (cm)	H <sub>s</sub> (cm)	T <sub>p</sub> (s)	T <sub>s</sub> (s)	T <sub>m</sub> (s)	R	N. Cum.
<b>N1 - N10</b>	21.35	15.10	20.64	2.62	2.14	1.79	0.14	2237
<b>N11 -N20</b>	21.13	14.94	20.43	2.62	2.13	1.81	0.14	4450

**Table 3.6** Average Mean Free Surface Elevation (cm) for N Test

Runs	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>N1 - N10</b>	-0.25	-0.26	-0.29	-0.03	0.15	0.49	0.85	0.91
<b>N11 -N20</b>	-0.22	-0.23	-0.30	0.00	0.16	0.44	0.90	0.95

**Table 3.7** Average Free Surface Standard Deviation (cm) for N Test

Runs	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>N1 - N10</b>	5.24	5.21	5.21	4.18	3.47	2.90	2.15	1.92
<b>N11 -N20</b>	5.16	5.13	5.16	4.06	3.40	2.79	2.10	1.86

**Table 3.8** Average Mean Velocity and Standard Deviation for N Test

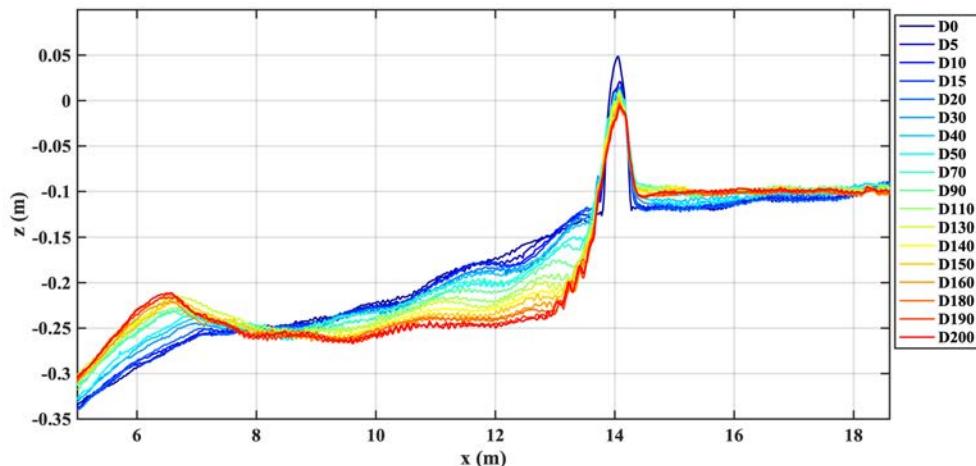
	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG7	
Runs	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>N1 - N10</b>	-6.69	21.80	-5.94	18.92	-3.43	15.86
<b>N11 -N20</b>	-6.71	21.52	-5.43	18.52	-3.31	15.65

## **Chapter 4**

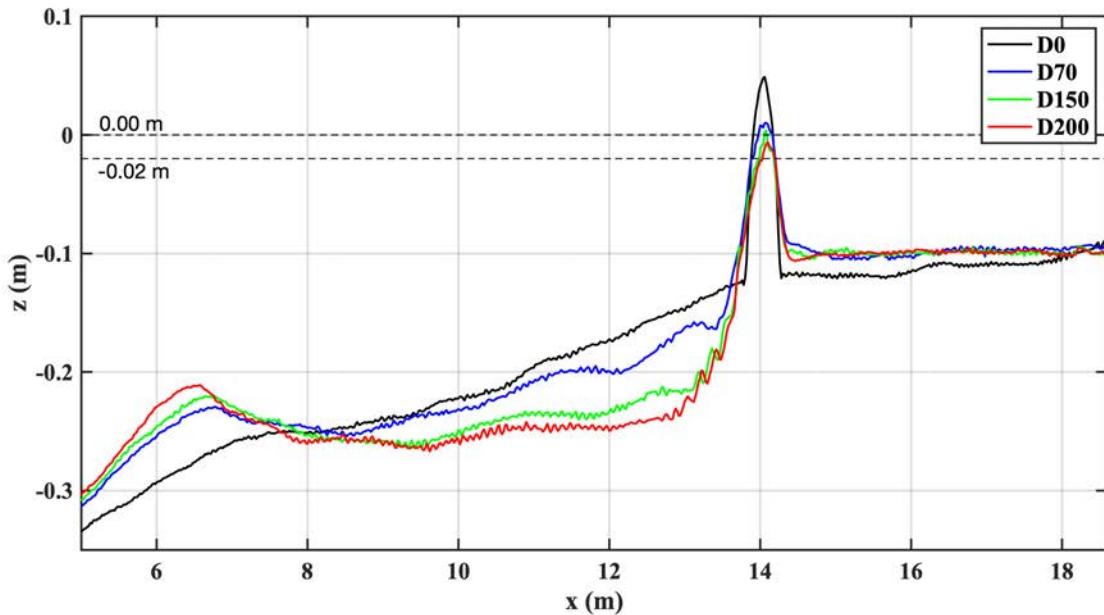
### **DOUBLE LAYER (D) TEST**

The D mound in Fig. 2.3 was built on the beach profile of N20 in the zone  $x = 13.74 - 14.28$  m with the mound toe located at WG6 in Fig. 2.1. The D test procedure was summarized in Table 2.3. The wave generation signal was kept the same for the N, D, and S tests. The mound and beach profiles were measured after 5, 10, 15, 20, 30, 40, 50, 70, 90, 110, 130, 140, and 150 runs. The initial mound deformation was caused by the dislocation of stones placed in unstable positions. The dislocated stones became more stable in their new positions. The profile measurement interval was increased on the basis of visual observations of the armor and core stones after each 400-s run. The failure of an armor layer is generally based on the visibility of underlayer stone through a hole in the armor layer exceeding the nominal armor stone diameter for conventional rubble mound structures with little wave overtopping (Melby and Kobayashi 1998). The observed holes were not circular but this criterion might have been exceeded after D130. Visible core stones were not removed through the holes after D150 with the mound crest at an elevation  $z = 0.4$  cm. The SWL was lowered from  $z = 0.0$  to  $z = -2$  cm in expectation for damage acceleration. The profile was measured after 160, 180, 190, and 200 runs. The holes were enlarged but the visible core stones were not removed through the enlarged holes. The D mound was removed after D200 and wave transformation in the absence of the D mound was measured for D201 – D210.

In Fig. 4.1 the measured 18 profiles were plotted together to visualize the overall profile evolution from D0 to D200. Fig. 4.2 shows only the four profiles of D0, D70, D150, and D200 for visual clarity. The initial profile of D0 seaward of the rubble mound was eroded during D1 to D200 lasting 80,000 s. Offshore sand transport resulted in the formation of a bar near  $x = 7$  m and deposition extending to the zone of  $x < 5$  m with no profile measurement. The slight profile change pattern from N0 to N20 in Fig. 3.1 may have continued after the placement of the D mound which limited the landward extent of erosion. The crest of the rubble mound was eroded, and the dislodged armor stones were deposited on the side slopes of the mound. The lower and wider mound became more stable. Onshore sand transport through and over the porous mound caused sand deposition of about 1 cm landward of the mound. The bathymetric changes observed in the D test were more pronounced than expected from prototype bathymetric changes (e.g., Ministry of Construction 1992; Burcharth et al. 2006) perhaps because of the two-dimensional experiment under constant wave conditions.



**Figure 4.1** Measured 18 profiles starting from the initial profile (D0) to the final profile (D200) in D test



**Figure 4.2** Measured profile evolution from D0 to D70, D150, and D200 where SWL = 0.0 m for D0 to D150 and SWL = -0.02 m for D151 to D200

The time series measured in each of the 210 runs in the D test were analyzed in Appendix A. The analyzed values were averaged for each of the 18 intervals consisting of 5, 10 or 20 runs in the D test. The average value of the incident significant wave height  $H_{mo}$  at  $x = 0$  decreased gradually from 21 cm to 19 cm during the D test (Table 4.1). The wave maker piston, which was repaired just before the experiment, may have adjusted itself before the consistent wave generation in the S test. The wave height decrease of about 10% was utilized to examine the wave height effect on wave transformation. The spectral peak period of 2.6 s remained the same during the experiment. The wave reflection coefficient was in the range of 0.16-0.18 for D1-D200

and 0.14 for D201-D210 after the removal of the D mound. The D mound did not increase wave reflection much because of the intense wave breaking seaward of the mound and wave transmission over the mound. The bar and trough during D201-D210 did not change the wave reflection coefficient of 0.14 during N1-N20.

**Table 4.1** Average Incident Wave Characteristics for D Test

Runs	$H_{mo}$ (cm)	$H_{rms}$ (cm)	$H_s$ (cm)	$T_p$ (s)	$T_s$ (s)	$T_m$ (s)	$R$	N. Cum.
<b>D1 - D5</b>	21.15	14.96	20.57	2.62	2.15	1.84	0.17	1085
<b>D6 - D10</b>	21.16	14.96	20.56	2.62	2.13	1.84	0.17	2174
<b>D11 - D15</b>	21.17	14.97	20.56	2.62	2.13	1.84	0.16	3259
<b>D16 - D20</b>	21.22	15.00	20.60	2.62	2.12	1.83	0.16	4352
<b>D21 - D30</b>	20.85	14.74	20.30	2.62	2.13	1.84	0.16	6525
<b>D 31 - D40</b>	20.99	14.84	20.35	2.62	2.12	1.83	0.16	8707
<b>D41 - D50</b>	20.73	14.66	20.15	2.62	2.15	1.84	0.17	10877
<b>D51 - D70</b>	20.53	14.52	19.94	2.61	2.15	1.84	0.17	15224
<b>D71 - D90</b>	20.43	14.45	19.84	2.62	2.17	1.85	0.17	19112
<b>D91 -D110</b>	20.37	14.41	19.76	2.62	2.17	1.85	0.18	23443
<b>D111 - D130</b>	19.76	13.97	19.12	2.62	2.17	1.84	0.18	27568
<b>D131 - D140</b>	19.86	14.05	19.19	2.62	2.15	1.84	0.18	29739
<b>D141 - D150</b>	19.59	13.85	18.94	2.62	2.17	1.84	0.18	31917
<b>D151 - D160</b>	19.75	13.97	19.12	2.62	2.14	1.79	0.18	34154
<b>D161 - D180</b>	19.47	13.77	18.85	2.62	2.16	1.82	0.18	38122
<b>D181 - D190</b>	19.34	13.67	18.65	2.62	2.17	1.81	0.18	40108
<b>D191 - D200</b>	19.02	13.45	18.37	2.62	2.16	1.81	0.18	42094
<b>D201 - D210</b>	19.10	13.50	18.37	2.62	2.14	1.73	0.14	44401

For D151-D200, SWL=-0.02 m. For D201-D210, after the D structure removal.

**Table 4.2** Average Mean Free Surface Elevation (cm) for D Test

Runs	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>D1 - D5</b>	-0.39	-0.40	-0.47	-0.16	0.00	0.25	2.71	2.69
<b>D6 - D10</b>	-0.38	-0.40	-0.46	-0.12	0.07	0.22	2.65	2.61
<b>D11 - D15</b>	-0.37	-0.38	-0.44	-0.20	0.10	0.19	2.51	2.48
<b>D16 - D20</b>	-0.37	-0.37	-0.44	-0.17	0.08	0.17	2.53	2.49
<b>D21 - D30</b>	-0.38	-0.38	-0.44	-0.18	0.07	0.12	2.57	2.51
<b>D 31 - D40</b>	-0.41	-0.39	-0.43	-0.14	0.07	0.11	2.68	2.55
<b>D41 - D50</b>	-0.40	-0.39	-0.45	-0.13	0.07	0.06	2.63	2.56
<b>D51 - D70</b>	-0.39	-0.41	-0.43	-0.06	0.06	0.03	2.76	2.76
<b>D71 - D90</b>	-0.37	-0.37	-0.44	-0.09	0.09	0.01	2.65	2.60
<b>D91 - D110</b>	-0.39	-0.39	-0.43	-0.01	0.08	-0.04	2.77	2.69
<b>D111 - D130</b>	-0.38	-0.39	-0.40	-0.08	0.06	-0.09	2.54	2.46
<b>D131 - D140</b>	-0.38	-0.39	-0.43	-0.04	0.07	-0.10	2.74	2.60
<b>D141 - D150</b>	-0.37	-0.38	-0.43	-0.05	0.08	-0.10	2.64	2.66
<b>D151 - D160</b>	-0.57	-0.60	-0.56	-0.06	0.02	-0.15	3.74	3.49
<b>D161 - D180</b>	-0.39	-0.45	-0.42	0.04	0.06	-0.13	3.34	3.28
<b>D181 - D190</b>	-0.40	-0.44	-0.43	0.05	0.09	-0.12	3.25	3.23
<b>D191 - D200</b>	-0.39	-0.45	-0.42	0.06	0.09	-0.11	3.19	3.05
<b>D201 - D210</b>	-0.21	-0.21	-0.26	0.09	0.21	0.06	0.74	0.93

For D151-D200, SWL=-0.02 m. For D201-D210, after the D structure removal.

**Table 4.3** Average Free Surface Standard Deviation (cm) for D Test

Runs	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>D1 - D5</b>	5.20	5.19	5.14	4.07	3.42	3.00	1.43	1.38
<b>D6 - D10</b>	5.21	5.15	5.15	4.01	3.45	3.00	1.44	1.38
<b>D11 - D15</b>	5.19	5.17	5.15	4.03	3.42	3.00	1.46	1.41
<b>D16 - D20</b>	5.24	5.20	5.12	4.02	3.41	3.04	1.49	1.43
<b>D21 - D30</b>	5.13	5.09	5.08	3.94	3.38	3.12	1.50	1.45
<b>D 31 - D40</b>	5.18	5.12	5.08	3.86	3.30	3.10	1.46	1.44
<b>D41 - D50</b>	5.09	5.03	5.05	3.84	3.32	3.26	1.53	1.52
<b>D51 - D70</b>	5.02	5.00	5.01	3.77	3.30	3.32	1.52	1.49
<b>D71 - D90</b>	5.01	4.96	4.98	3.74	3.27	3.39	1.58	1.55
<b>D91 -D110</b>	5.02	4.98	4.94	3.69	3.23	3.40	1.56	1.51
<b>D111 - D130</b>	4.86	4.82	4.81	3.60	3.20	3.49	1.62	1.56
<b>D131 - D140</b>	4.89	4.84	4.84	3.59	3.19	3.46	1.61	1.54
<b>D141 - D150</b>	4.86	4.79	4.80	3.55	3.17	3.46	1.61	1.44
<b>D151 - D160</b>	4.91	4.93	4.78	3.34	2.93	3.16	1.23	1.01
<b>D161 - D180</b>	4.81	4.82	4.65	3.36	2.98	3.30	1.38	1.30
<b>D181 - D190</b>	4.84	4.86	4.65	3.36	2.97	3.33	1.40	1.29
<b>D191 - D200</b>	4.76	4.77	4.62	3.28	2.93	3.29	1.36	1.25
<b>D201 - D210</b>	4.67	4.65	4.66	3.48	3.11	3.11	2.16	1.69

For D151-D200, SWL=-0.02 m. For D201-D210, after the D structure removal.

**Table 4.4** Average Mean Velocity and Standard Deviation for D Test

Runs	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG7	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>D1 - D5</b>	-6.99	21.68	-5.80	18.84	-2.00	10.87
<b>D6 - D10</b>	-7.06	21.54	-5.26	18.44	-1.66	10.27
<b>D11 - D15</b>	-6.89	21.45	-5.02	17.71	-1.66	10.52
<b>D16 - D20</b>	-7.08	21.33	-5.27	18.25	-2.26	11.24
<b>D21 - D30</b>	-7.56	20.80	-5.26	18.33	-2.37	10.58
<b>D31 - D40</b>	-7.32	20.44	-4.85	17.77	-2.38	11.34
<b>D41 - D50</b>	-7.26	20.31	-4.32	17.76	-2.38	10.97
<b>D51 - D70</b>	-7.09	19.84	-3.65	16.93	-2.46	11.02
<b>D71 - D90</b>	-7.39	19.48	-3.33	16.83	-2.33	10.67
<b>D91 - D110</b>	-7.79	19.23	-3.09	16.85	-1.90	9.57
<b>D111 - D130</b>	-7.25	19.20	-3.16	17.22	-1.51	8.73
<b>D131 - D140</b>	-7.54	18.69	-2.97	17.01	-2.34	11.19
<b>D141 - D150</b>	-7.52	19.01	-2.64	16.40	-2.55	11.67
<b>D151 - D160</b>	-7.16	18.13	-2.82	17.11	-1.34	10.57
<b>D161 - D180</b>	-6.92	18.10	-1.53	15.29	-1.74	10.77
<b>D181 - D190</b>	-6.99	18.11	-1.73	15.03	-1.63	10.73
<b>D191 - D200</b>	-6.81	17.63	-1.75	14.88	-1.70	10.55
<b>D201 - D210</b>	-6.95	17.68	-3.59	15.97	-5.21	17.00

For D151-D200, SWL=-0.02 m. For D201-D210, after the D structure removal.

Water depth (cm) below SWL at Wave Gauge Locations for D Test  
**Table 4.5** where SWL = 0.0 cm for D0 to D150 and SWL = -2 cm for D151 to D200

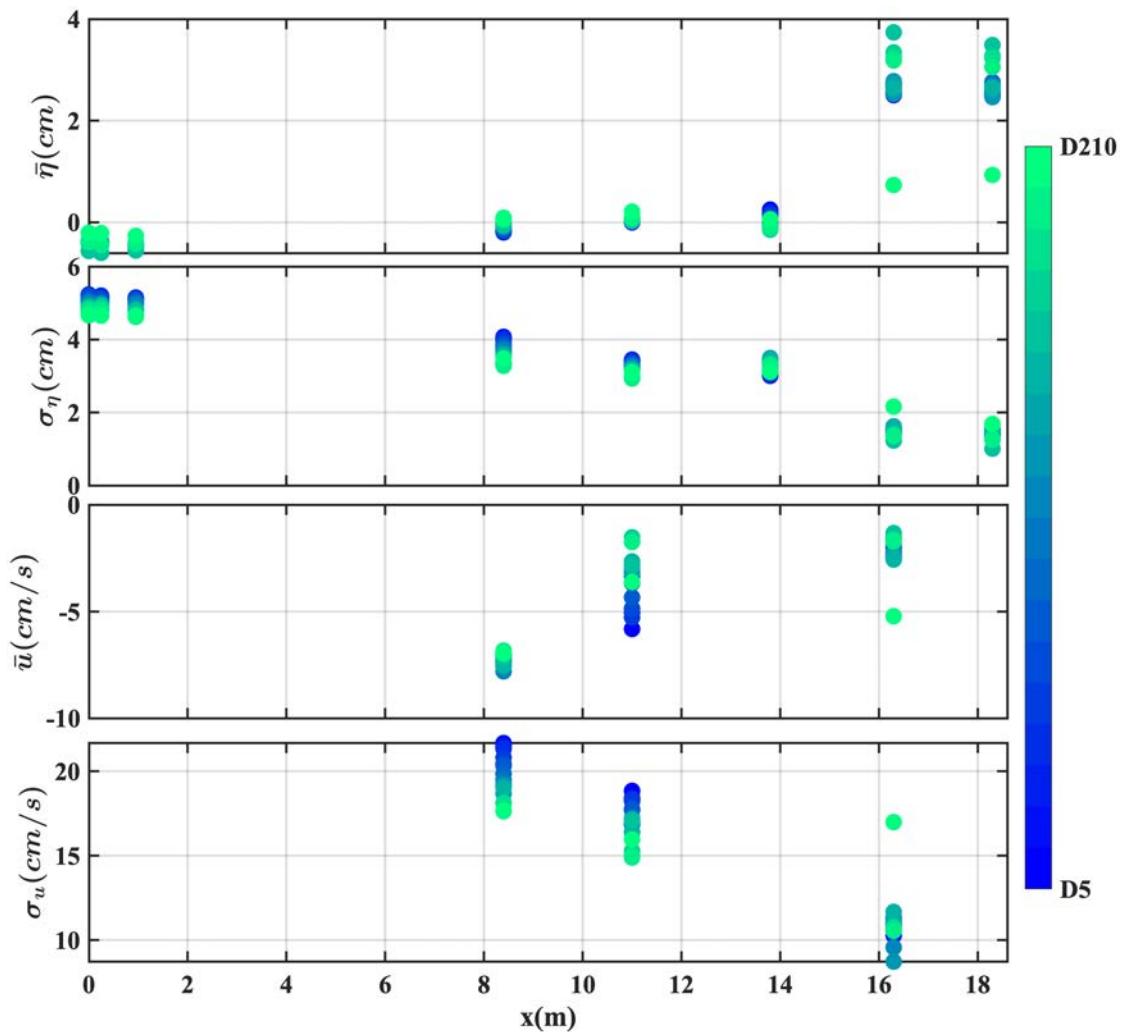
<b>Run</b>	<b>SWL (cm)</b>	<b>Offshore (cm)</b>	<b>WG1/2/3 (cm)</b>	<b>WG4 (cm)</b>	<b>WG5 (cm)</b>	<b>WG6 (cm)</b>	<b>WG7 (cm)</b>	<b>WG8 (cm)</b>
<b>D0</b>	0	92	83	24.77	19.62	12.53	10.80	9.79
<b>D5</b>	0	92	83	24.68	19.89	11.54	11.00	9.84
<b>D10</b>	0	92	83	25.18	19.97	11.20	10.99	9.67
<b>D15</b>	0	92	83	24.75	20.25	10.23	10.64	9.51
<b>D20</b>	0	92	83	25.04	20.58	9.45	10.87	9.81
<b>D30</b>	0	92	83	25.04	20.65	9.01	10.56	9.53
<b>D40</b>	0	92	83	25.35	20.84	10.11	10.17	9.19
<b>D50</b>	0	92	83	26.08	21.54	9.74	10.78	9.84
<b>D70</b>	0	92	83	25.24	20.80	10.00	10.14	9.35
<b>D90</b>	0	92	83	25.62	21.20	9.80	10.15	9.31
<b>D110</b>	0	92	83	25.85	21.65	11.48	9.86	9.74
<b>D130</b>	0	92	83	25.25	22.26	10.29	9.74	9.75
<b>D140</b>	0	92	83	25.44	22.95	11.68	9.96	10.02
<b>D150</b>	0	92	79	25.67	23.47	11.00	10.11	9.59
<b>D160</b>	-2	90	79	23.87	22.07	9.32	8.23	7.74
<b>D180</b>	-2	90	79	23.44	21.74	9.84	8.04	7.98
<b>D190</b>	-2	90	79	24.13	22.61	10.30	8.10	7.82
<b>D200</b>	-2	90	79	23.52	22.53	9.64	7.98	7.70

The average values of  $\bar{\eta}$ ,  $\sigma_\eta$ ,  $\bar{u}$ , and  $\sigma_u$  in the 18 intervals are listed in Tables 4.2, 4.3, 4.4, and are plotted in Fig. 4.3 for the onshore distance  $x = 0\text{-}18.6$  m. The deviations among the 18 values at the given  $x$  were caused by the wave height decrease of about 10%, the beach and mound profile evolution, and the SWL lowering by 2 cm during D151-D200, and the mound removal after D200. The cross-shore variation of the mean water level  $\bar{\eta}$  above the SWL did not change much during D1-D150. The data points in Fig. 4.3 are plotted in sequence of D5 (dark) to D210 (light), resulting in the hiding of

darker data points underneath lighter points. The values of  $\bar{\eta}$  at WG7 ( $x = 16.3$  m) and WG8 ( $x = 18.3$  m) landward of the D mound increased during D151-D200 probably because of the increased ponding landward of their higher mound crest above the lowered SWL. The values of  $\bar{\eta}$  at  $x = 16.3$  m and 18.3 m were reduced to about 0.8 cm during D201-D210 after the D mound removal. This wave setup was similar to the corresponding setup of about 0.9 cm during N1-N20.

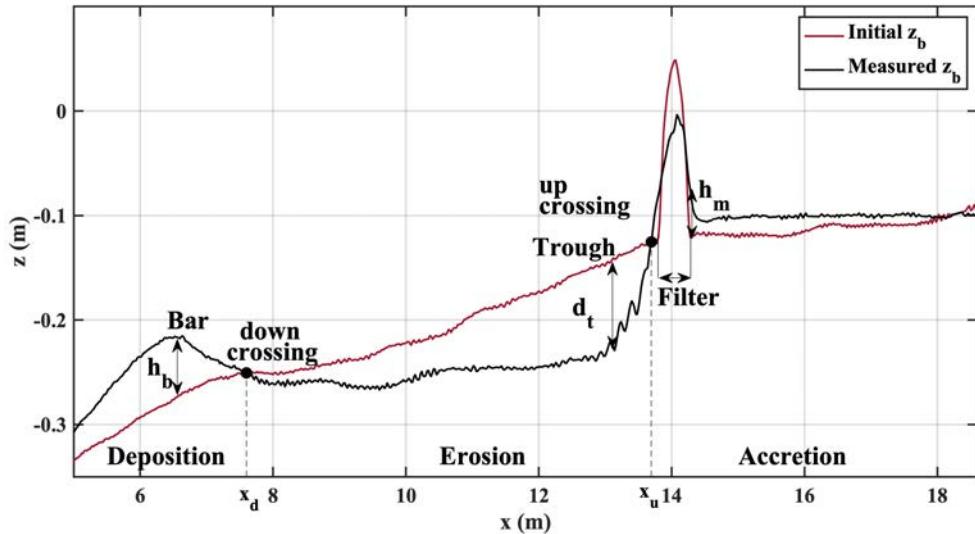
The free surface standard deviation  $\sigma_\eta$  at WG1 – WG5 decreased with the decrease of  $H_{mo}$  at  $x = 0$  by about 10%. The measured  $\sigma_\eta$  at WG<sub>j</sub> at  $j = 1-8$  is used to estimate the local significant wave height  $H_j = 4\sigma_\eta$  at WG<sub>j</sub>. This estimation neglects reflected waves. The values of  $H_I$  at  $x = 0$  is compared with the incident wave height  $H_{mo}$  at  $x = 0$  where linear wave theory may be accurate enough to separate incident and reflected waves using WG1 – WG3. The values of  $H_I/H_{mo}$  were in the range of 0.98-1.00 in this experiment. Reflected waves inside the surf zone were not measured in this experiment. On the other hand, the values of  $\sigma_\eta$  at WG6 ( $x = 13.8$  m) increased in spite of the decrease of  $H_{mo}$  probably because of the trough deepening seaward of WG6 in Fig.4.1. The values of  $\sigma_\eta$  at WG7 and WG8 decreased during D151-D200 because of the higher mound crest above the lower SWL and increased during D201-D210 after the D mound removal. The increased values of  $\sigma_\eta$  were about 1.9 cm and similar to those of N1-N20. The offshore mean current ( $-\bar{u}$ ) of about 7 cm/s at  $x = 8.4$  m contributed to the formation of a bar near  $x = 7$  m. This offshore current at  $x = 11.0$  m decreased noticeably with the trough deepening. The offshore current at  $x = 16.3$  m

increased clearly after the D mound removal. The horizontal velocity standard deviation  $\sigma_u$  decreased (increased) with the decrease (increase) of  $\sigma_\eta$  as expected from linear irregular wave theory (e.g. Kobayashi 2016).



**Figure 4.3** Average values of mean and standard deviation of free surface elevation  $\eta$  and cross-shore velocity  $u$  for 18 intervals during Test D where the last interval of D201-D210 occurred after the D structure removal

Fig. 4.4 is used to characterize the bar and trough profile on the seaward beach and the accreted profile on the landward beach. The measured bottom elevation  $z_b(t, x)$  for the given time  $t$  is compared with the initial profile elevation  $z_b(t=0, x)$ . The rubble mound was placed in the filter zone of  $x = 13.74-14.28$  m. In the seaward zone of  $x < 13.74$ , the locations of zero elevation change at the given  $t$  are identified in Fig. 4.4 where  $x_d$  and  $x_u$  are the cross-shore locations of zero down-crossing and up-crossing points, respectively. The deposition zone of  $x < x_d$  was limited to  $x > 5$  m for lack of data. The bar crest height  $h_b$  is defined as the largest deposition height. The erosion zone of  $x_d < x < x_u$  is represented by the trough depth  $d_t$  defined as the maximum erosion depth below the initial profile. In the landward accretion zone of  $x = 14.28-18.6$  m, the accretion height decreased landward and the maximum accretion height  $h_m$  at  $x = 14.28$  m is presented in the following.

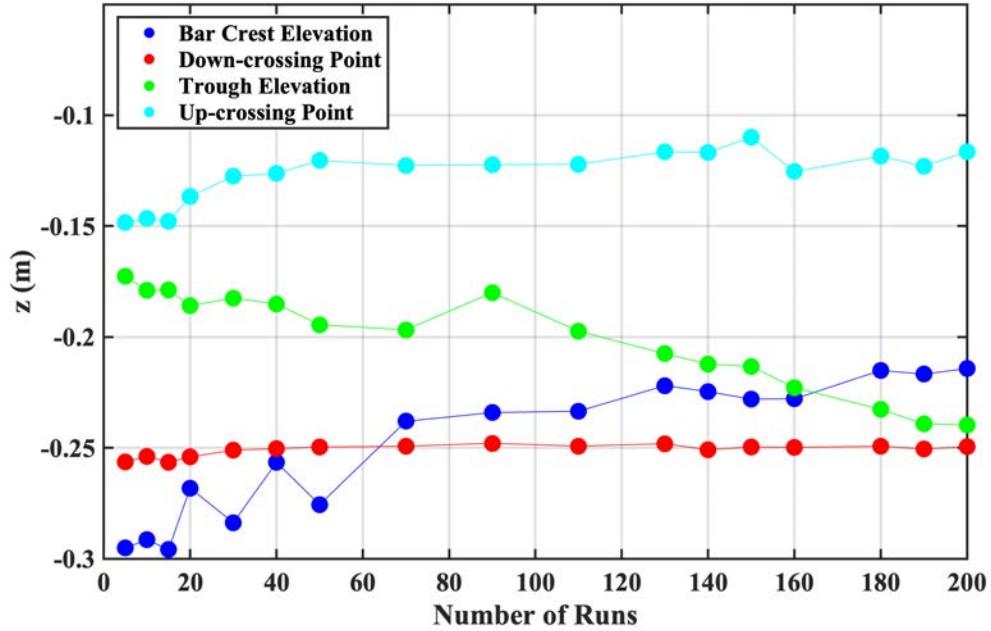


**Fig. 4.4.** Characterization of bar and trough formation on seaward beach and sand accretion on landward beach

The bar crest elevation, down-crossing point, beach trough elevation, and up-crossing point are listed in Table 4.6 and plotted Fig. 4.5 varying with the number of runs.

**Table 4.6** Measured Locations of Bar Crest, Down-crossing Point, Trough, and Up-crossing Point during D test

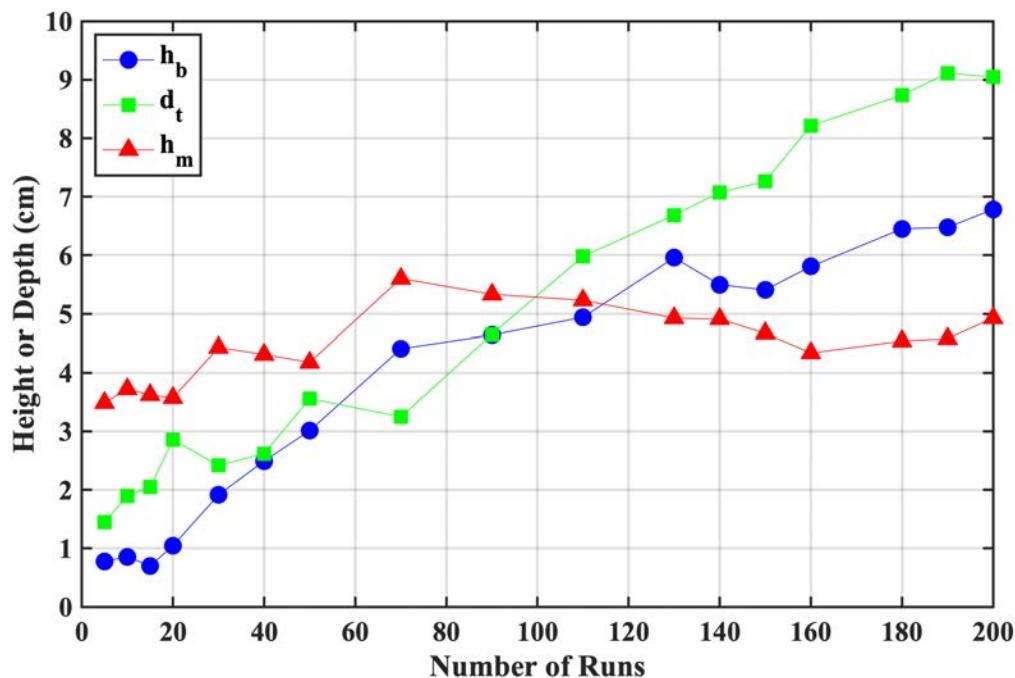
	Bar Crest Elevation		Down-Crossing		Beach Trough Elevation		Up-Crossing	
Runs	xc (m)	zc (m)	xd (m)	zd (m)	xt (m)	zt (m)	xu (m)	zu (m)
<b>D5</b>	5.80	-0.30	7.18	-0.26	12.46	-0.17	12.92	-0.15
<b>D10</b>	5.86	-0.29	7.40	-0.25	12.42	-0.18	13.00	-0.15
<b>D15</b>	5.80	-0.30	7.14	-0.26	12.48	-0.18	13.00	-0.15
<b>D20</b>	6.46	-0.27	7.28	-0.25	12.50	-0.19	13.22	-0.14
<b>D30</b>	5.80	-0.28	8.18	-0.25	12.48	-0.18	13.54	-0.13
<b>D40</b>	6.38	-0.26	7.64	-0.25	12.44	-0.19	13.62	-0.13
<b>D50</b>	5.72	-0.28	7.66	-0.25	12.44	-0.19	13.66	-0.12
<b>D70</b>	6.34	-0.24	8.30	-0.25	12.28	-0.20	13.62	-0.12
<b>D90</b>	6.40	-0.23	7.96	-0.25	13.40	-0.18	13.66	-0.12
<b>D110</b>	6.32	-0.23	7.78	-0.25	13.26	-0.20	13.68	-0.12
<b>D130</b>	6.38	-0.22	8.22	-0.25	13.12	-0.21	13.68	-0.12
<b>D140</b>	6.44	-0.22	7.88	-0.25	13.16	-0.21	13.70	-0.12
<b>D150</b>	6.34	-0.23	7.86	-0.25	13.12	-0.21	13.70	-0.11
<b>D160</b>	6.22	-0.23	7.64	-0.25	13.12	-0.22	13.68	-0.13
<b>D180</b>	6.44	-0.22	7.66	-0.25	13.02	-0.23	13.70	-0.12
<b>D190</b>	6.38	-0.22	7.60	-0.25	12.86	-0.24	13.70	-0.12
<b>D200</b>	6.34	-0.21	7.62	-0.25	12.84	-0.24	13.70	-0.12



**Figure 4.5** Elevation of bar crest, down-crossing point, trough, and up-crossing point varying with the number of runs during D test

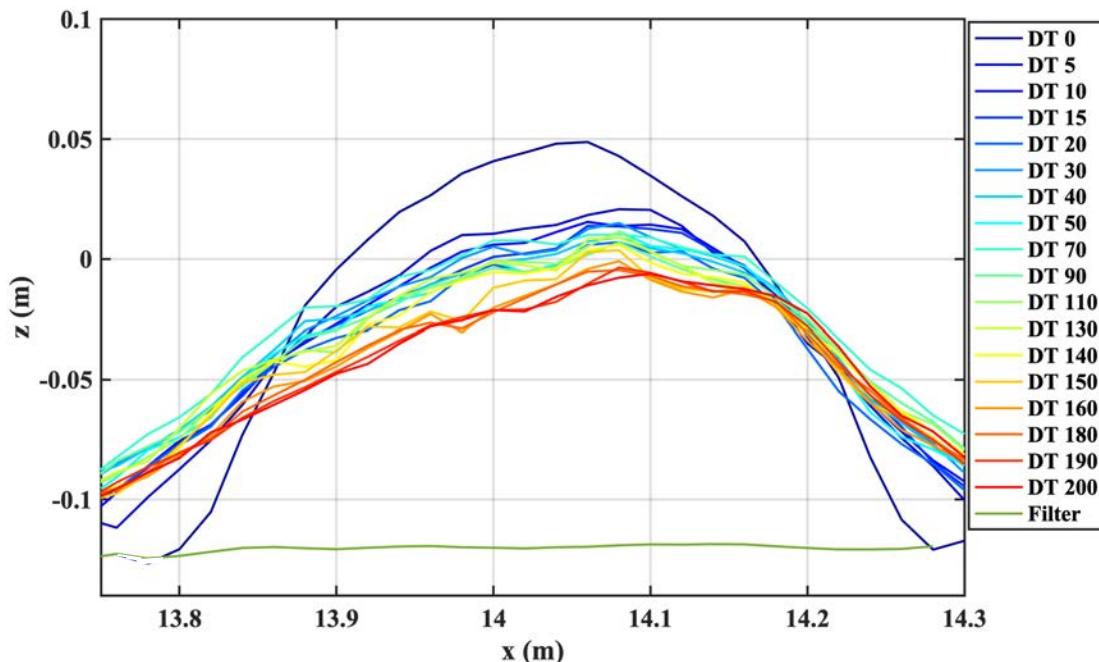
Fig. 4.6 shows the bar crest height  $h_b$ , the trough depth  $d_t$ , and the maximum height  $h_m$  of landward accretion increasing with the number of runs with each run lasting 400 s in the D test. The bar height  $h_b$  and the trough depth  $d_t$  increased steadily to 6.8 and 9.0 cm, respectively, after 200 runs. The cross-shore locations  $x_d$  and  $x_u$  (Fig. 4.4) did not change much in Fig. 4.5. The bar crest elevation was raised with the increase of the bar height  $h_b$ . The trough elevation was lowered with the increase of the trough depth  $d_t$ . The bar area in the zone of  $x < x_d$  increased with the increase of  $h_b$  because of sand deposition in the entire bar zone. The eroded area in the zone of  $x_d < x < x_u$  increased with the increase of the trough depth  $d_t$  because of sand erosion in the entire trough zone. On the other hand, the maximum height  $h_m$  of landward accretion increased

quickly from D0 to D5 because of dislodged armor stone deposition on the landward side of the D mound. The fluctuation of  $h_m$  during D6-D200 may have been caused by the armor stone movement and sand accretion or erosion. The average height of sand accretion in the landward zone of  $x = 14.28\text{-}18.6\text{ m}$  increased to 1.0 cm during D0 – D40 and fluctuated in the range of 0.6-1.4 cm. Sediment dynamics were different on the seaward and landward beaches.

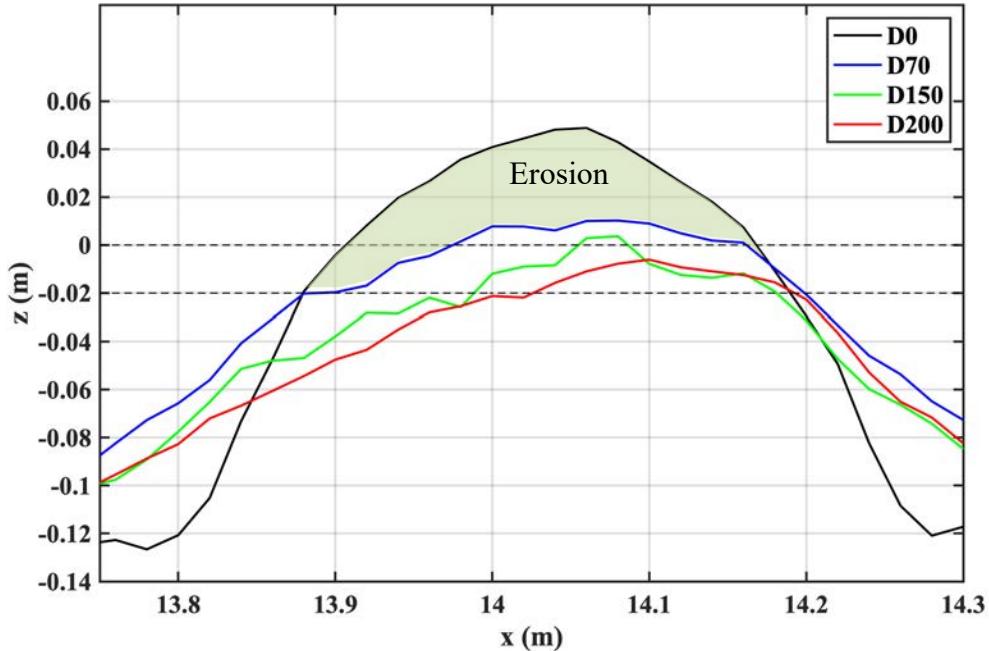


**Fig. 4.6.** Bar crest height  $h_b$ , trough depth  $d_t$ , and maximum height  $h_m$  of landward accretion increasing with number of runs during Test D

The measured 18 mound profiles were analyzed to understand the process of damage progression and stabilization on the low-crested rubble mound (Fig. 4.7). Fig. 4.8 depicts only the four profiles of D0, D70, D150, and D200 for visual clarity. The mound crest was eroded, and the side slopes became gentler. The lowered and wider crest near SWL = 0.0 was surprisingly stable. The SWL was lowered from 0.0 to -0.02 m after D150 in order to expose the crest to more direct wave action during wave uprush. The mean water level  $\bar{\eta}$  at WG7 and WG8 (Fig. 4.3) increased during D151-D200. The increased ponding water level may have increased seaward flow during wave downrush. The SWL lowering lead to the crest lowering and stabilization before D200.



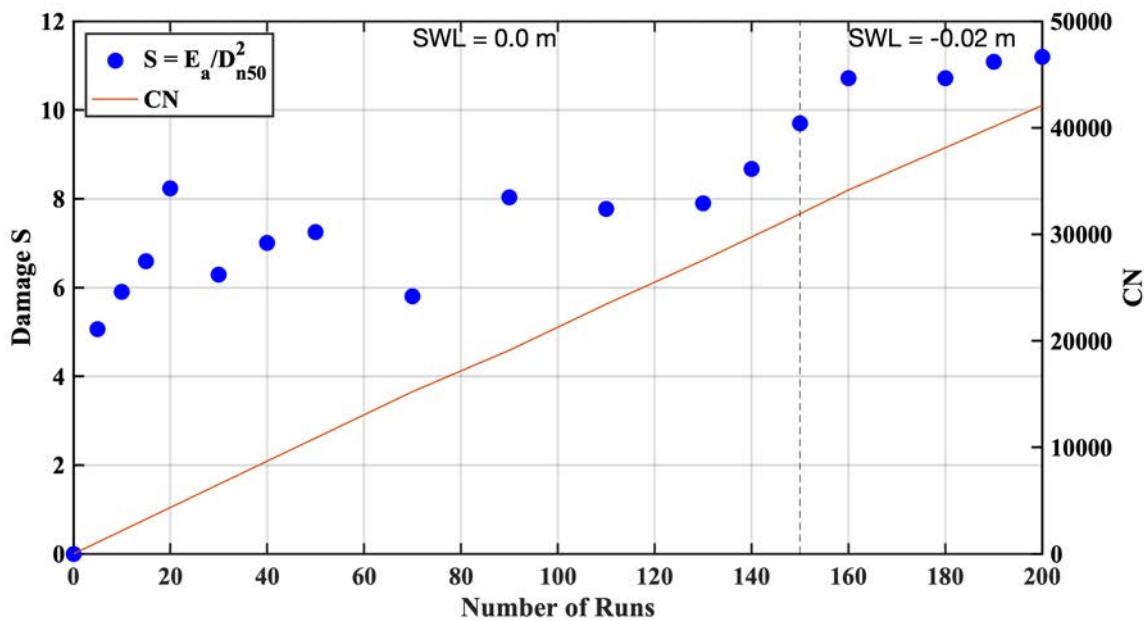
**Figure 4.7** Measured 18 profiles of deforming rubble mound above filter during D test



**Figure 4.8** Rubble mound crest lowering from D0 to D70, D150, and D200 where SWL = 0.0 for D1 - D150 and SWL= -0.02 m for D151 – D200

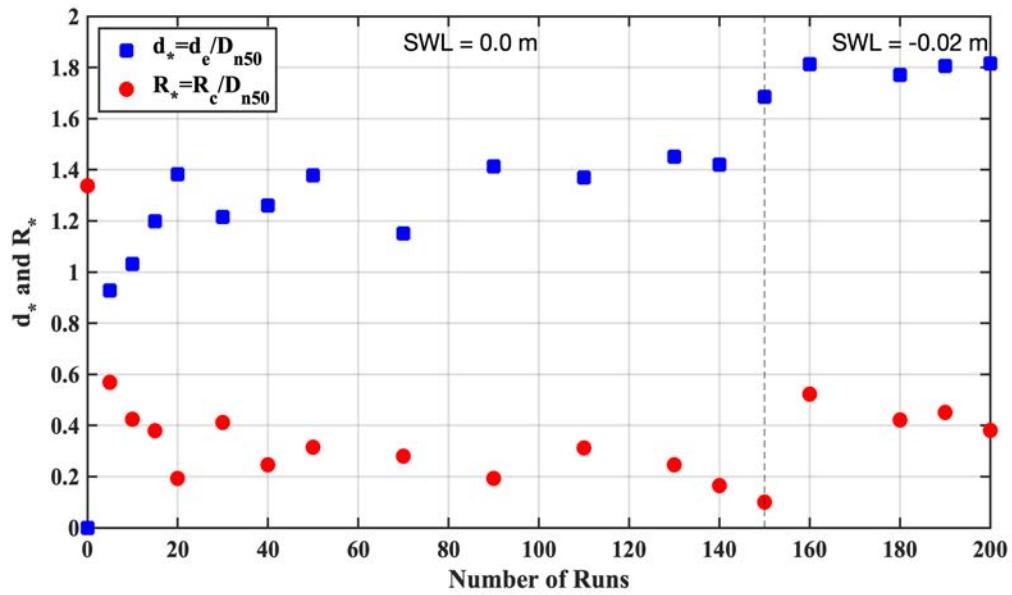
The mound surface elevation  $z_b(t, x)$  measured at the given time  $t$  is compared with the initial elevation  $z_b(t=0, x)$  to identify the eroded mound zone of  $z_b(t, x) < z_b(t=0, x)$  and calculate the eroded area  $E_a$  and damage  $S = E_a/D_{n50}^2$  with the nominal stone diameter  $D_{n50} = 3.65$  cm in the D test (Table 2.2). Fig. 4.9 shows the damage  $S$  and the cumulative number  $CN$  of waves in the incident wave time series at  $x = 0$  as the function of the number of 400-s runs. The damage  $S$  increased from 0.0 for D0 to 5.1, 5.9, 6.6, and 8.2 for D5, D10, D15, and D20, respectively. The damage fluctuated until  $S = 8.7$  for D140 and  $S = 9.7$  for D150. After the SWL lowering to -0.02 m,  $S = 10.7, 10.7, 11.1$ , and 11.2 for D160, D180, D190, and D200. The cumulative number of waves increased linearly up to 42,000 for D200 with the number of runs because of the

repeatability of the wave generation apart from the gradual wave height decrease of 10% during D1 to D200. Melby and Kobayashi (1998) measured damage progression of a conventional rubble mound structure with little wave overtopping for the duration of 28.5 h consisting of about 60,000 waves. The damage increased steadily but the rate of the damage increase was reduced probably because the damaged slope became gentler. The damage fluctuation or stabilization between D20 and D140 in Fig. 4.9 may be more related to the crest lowering and stabilization of reef (low-crested stone mound) breakwaters investigated by Ahrens (1989).



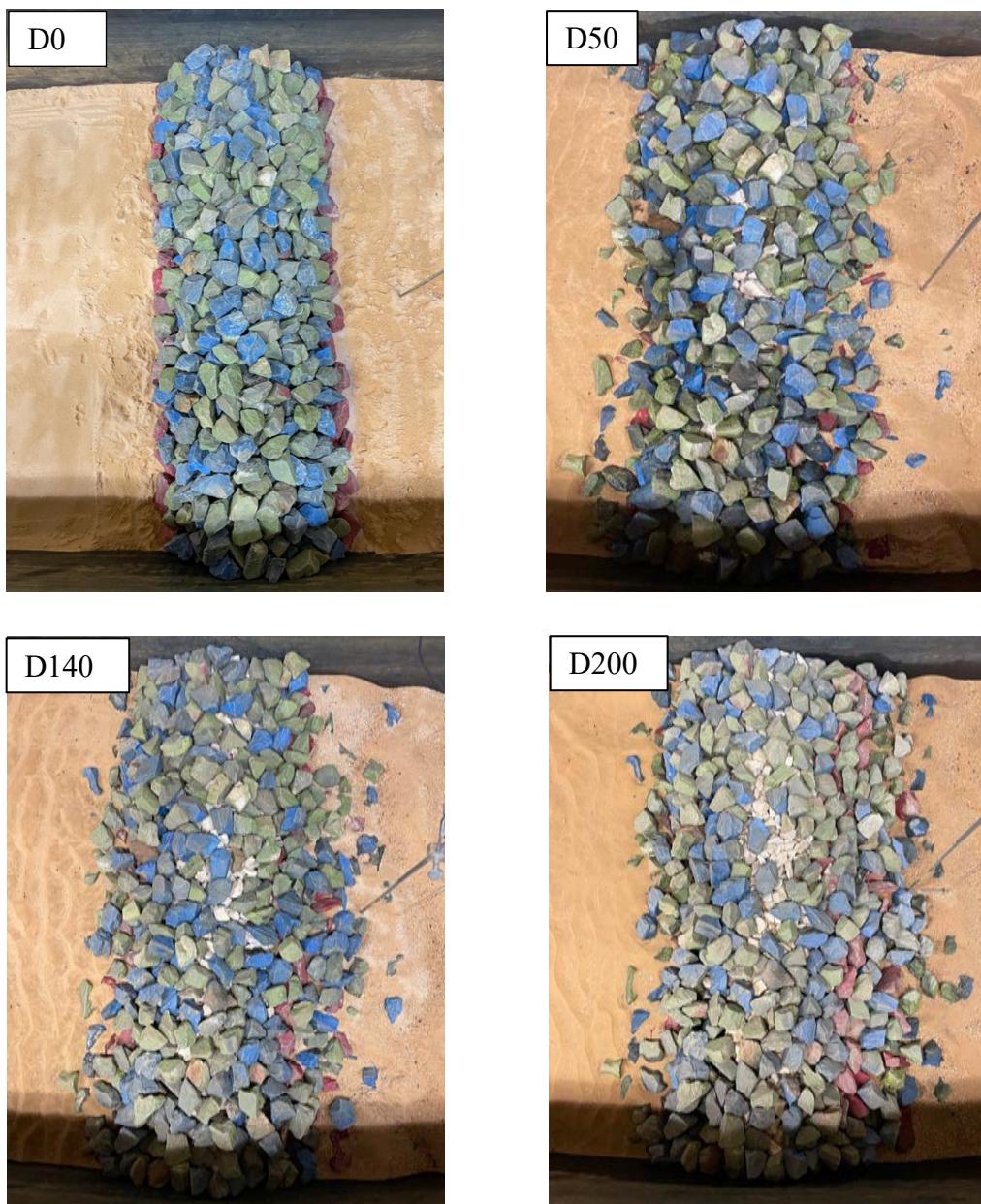
**Figure 4.9** Armor layer damage S (normalized eroded area) and cumulative number CN of waves varying with the number of runs during D test with nominal armor stone diameter  $D_{n50}=3.65\text{cm}$

The crest lowering is caused by erosion of the mound surface elevation  $z_b$ . The vertical erosion depth  $d_e$  at the given time  $t$  is defined as the maximum elevation difference between  $z_b(t=0, x)$  and  $z_b(t, x)$  in the eroded mound zone. The normalized depth of  $d_* = d_e/D_{n50}$  is plotted as the function of the number of runs in Fig. 4.10. The temporal variation of  $S$  and  $d_*$  in Figs. 4.9 and 4.10 are similar because the width of the eroded mound zone in Fig. 4.8 did no increase much. The value of  $d_*$  increased from 0.0 for D0 to 0.9 for D5 and gradually to 1.8 for D200 where the double layer thickness corresponds to  $d_*=2$ . On the other hand, the crest height  $R_c$  is defined as the maximum crest elevation above the SWL. The normalized height of  $R_* = R_c/D_{n50}$  is plotted in Fig. 4.10 where the SWL was lowered from 0.0 to -0.02 m after D150. The value of  $R_*$  increased because of the SWL lowering.



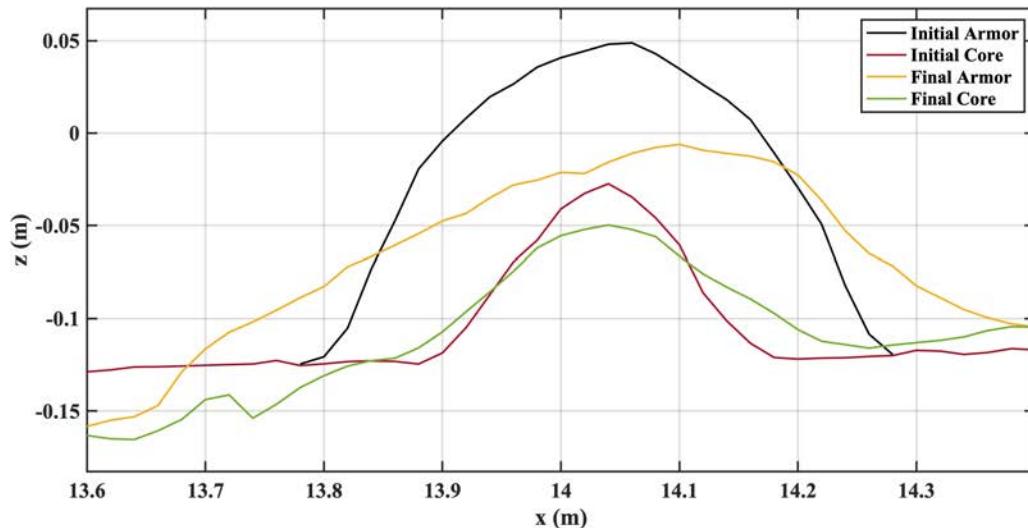
**Fig. 4.10.** Armor layer erosion depth  $d_e$  and crest elevation  $R_c$  above SWL normalized by  $D_{n50}=3.65$  cm varying with number of runs during Test D

White core stones were visible through a few small holes in the armor layer of D50. The size and the number of holes increased in the photo of D140. The size of the largest hole exceeded the stone diameter of  $D_{n50} = 3.65$  cm (Table 2.2) after D200, Fig. 4.11, but the deformed mound appeared to be fairly stable in spite of the armor layer erosion of  $d_* = 1.8$ . The interior conditions below the mound profile of D200 were examined by measuring the profiles after removing the armor stones, core stones, sand, and filter one by one as was done by Yuksel and Kobayashi (2020).



**Figure 4.11** Photographic damage progression starting from the intact armor layer (D0), visible white core stones (D50), gradual enlargement of white stone holes (D140), and the final armor layer with fairly stable white stone holes (D200)

Fig. 4.12 compares the initial and final profiles of the armor and core stone surfaces. The dislodged armor stones were transported seaward and landward, resulting in the stabilization of the deformed mound. The deformed core surface included sand because of sand transport and deposition inside the porous structure. The armor layer thickness was reduced by the mound crest erosion, but the reduction was mitigated by the core crest lowering. After the removal of the core stones, the thickness and mass of sand remaining on the filter in the zone of  $x = 13.74$ - $14.28$  m were measured to estimate the sand layer thickness of approximately 0.8 cm which was consistent with the sand accretion height of about 1 cm in the landward zone of  $x = 14.28$ - $18.6$  m. The filter settlement was as large as 1.4 cm at its seaward edge because of toe scour induced by the trough formation in Fig. 4.2.

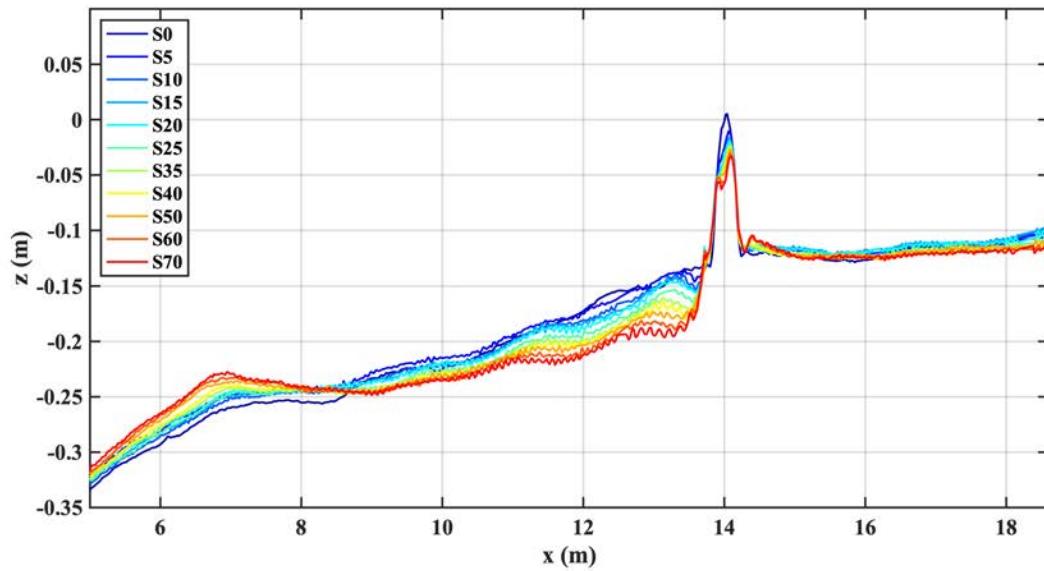


**Figure 4.12** Initial (D0) surface elevation of the armor layer and core in comparison with final (D200) surface elevations before and after the armor

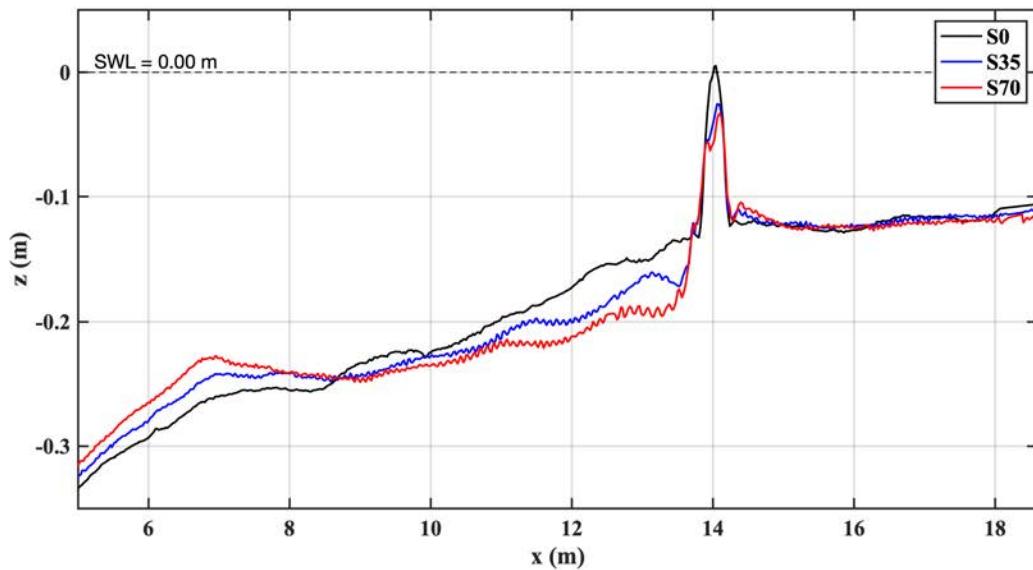
## **Chapter 5**

### **SINGLE LAYER (S) TEST**

The beach profile was rebuilt after D test so that the initial profile of the S test was almost (within 1 cm) the same as the initial profile of the D test. The same filter and core stone were placed in the same zone as in the D test. Only the green stone (54% in volume) of the blue and green stones in the D armor layer was used to build the single armor layer. Consequently, the initial mound of S0 was lower and narrower than the D mound in Fig. 2.4. The S mound and beach profiles were measured after 5, 10, 15, 20, 25, 35, 40, 50, 60, and 70 runs (Fig 5.1). Fig. 5.2 shows only the three profiles of S0, S35, and S70 for visual clarity. The mound and beach profile evolution during 70 runs in the S test was similar to those during 200 runs in the D test. The details were different, but the bar and trough formation was repeatable. The runs of S71-S80 were conducted after the removal of the mound of S70. The S test procedure was summarized in Table 2.3. The SWL was at  $z = 0.0$  during the entire S test.

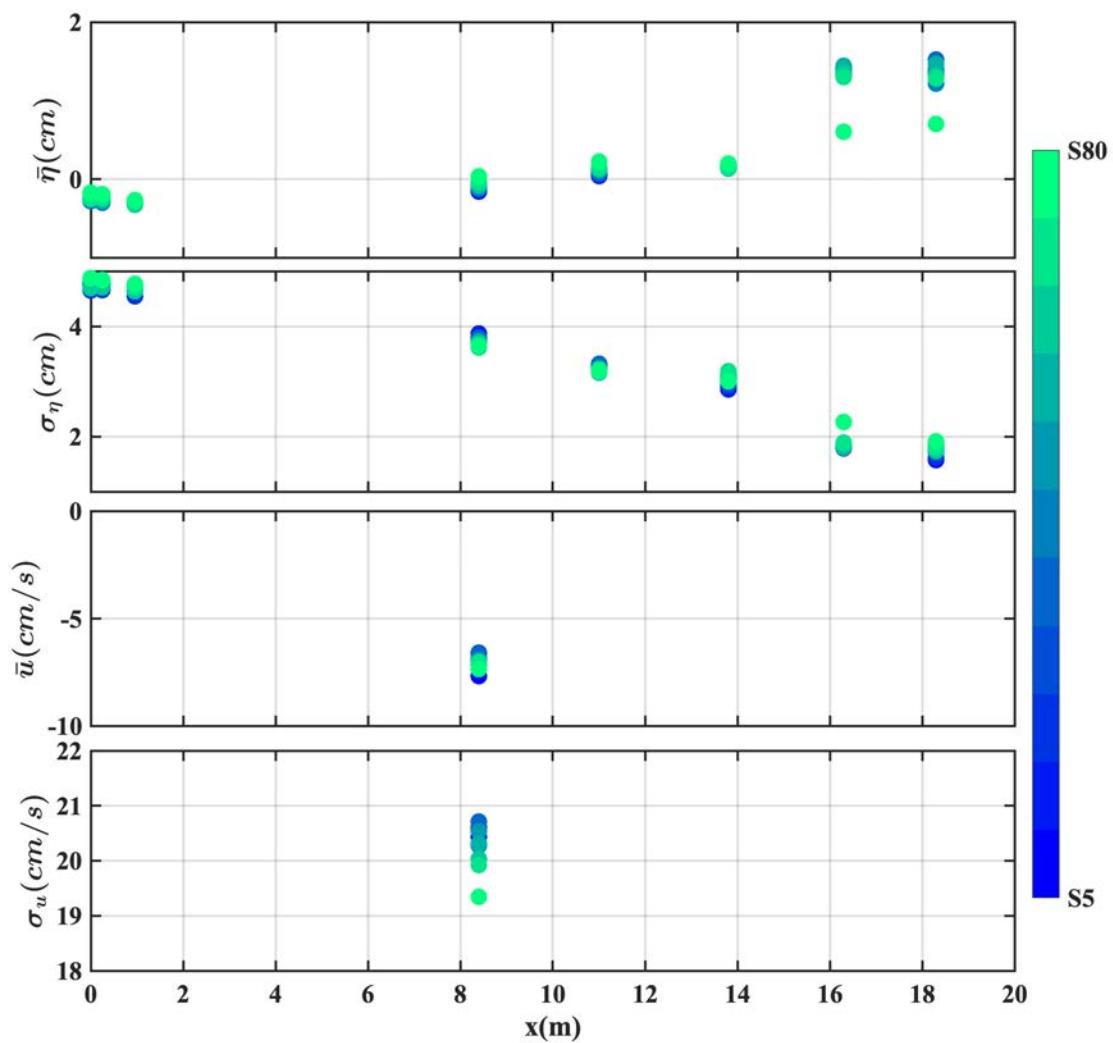


**Fig. 5.1** Measured 11 profiles starting from the initial profile (S0) to the final profile (S70) in S test



**Fig 5.2** Measured profile evolution from S0 to S35 and S70 where SWL = 0.00 m for S test

The measured time series of the free surface elevation  $\eta$  and horizontal velocity  $u$  were analyzed and tabulated in Appendix B where the velocimeters at WG5 and WG7 in Fig. 2.1 were not operational during the S test. The average values during the 11 intervals based on the profile measurements were used to examine the cross-shore wave transformation. The incident significant wave height  $H_{mo}$  at  $x = 0$  was 19.4 cm within 2% deviations. The spectral peak period  $T_p = 2.6$  s and the mean period  $T_m = 1.8$  s remained the same as in the D test. The wave reflection coefficient at  $x = 0$  was 0.15 or 0.16 for S1-S70 and 0.14 for S71-S80. The reflection coefficient was increased by 0.01-0.02 by the S mound in comparison to the increase by 0.02-0.04 by the D mound. The cross-shore variations of the mean and standard deviation of  $\eta$  and  $u$  for the 11 intervals are plotted in Fig. 5.3. The average values of  $\bar{\eta}$ ,  $\sigma_\eta$ ,  $\bar{u}$ , and  $\sigma_u$  in the 11 intervals are listed in Tables 5.2, 5.3, 5.4. The notable differences between the D mound and the lower S mound were observed at WG7 and WG8 landward of the mound. The mean water level  $\bar{\eta}$  was reduced more than 1 cm because of the reduced ponding in the S test. The standard deviation  $\sigma_\eta$  increased by 0.2-0.3 cm because of the increased of wave transmission in the S test.



**Figure 5.3** Average values of mean and standard deviation of free surface elevation  $\eta$  and cross-shore velocity  $u$  for 11 intervals during S test where the last interval of S71 – S80 occurred after the S structure removal

**Table 5.1** Average Incident Wave Characteristics for S Test

<b>Runs</b>	<b>Hmo (cm)</b>	<b>Hrms (cm)</b>	<b>Hs (cm)</b>	<b>Tp (s)</b>	<b>Ts (s)</b>	<b>Tm (s)</b>	<b>R</b>	<b>N. Cum</b>
<b>S1 - S5</b>	19.26	13.62	18.55	2.62	2.15	1.74	0.15	1151
<b>S6 -S10</b>	19.42	13.73	18.68	2.62	2.14	1.80	0.15	2263
<b>S11 -S15</b>	18.89	13.36	18.19	2.62	2.15	1.80	0.15	3373
<b>S16 - S20</b>	19.42	13.73	18.77	2.62	2.16	1.81	0.15	4476
<b>S21 - S25</b>	19.42	13.74	18.72	2.62	2.16	1.80	0.15	5588
<b>S26 - S35</b>	19.24	13.61	18.58	2.62	2.15	1.82	0.15	7791
<b>S36 - S40</b>	19.34	13.68	18.72	2.62	2.16	1.82	0.16	8890
<b>S41 - S50</b>	19.59	13.85	18.93	2.62	2.15	1.82	0.15	11079
<b>S51 - S60</b>	19.07	13.48	18.47	2.62	2.17	1.83	0.16	13271
<b>S61 - S70</b>	19.65	13.89	18.95	2.62	2.15	1.81	0.16	15479
<b>S71 - S80</b>	19.76	13.97	19.10	2.62	2.16	1.84	0.14	17674

For S71-80, after the S structure removal

**Table 5.2** Average Mean Free Surface Elevation (cm) for S Test

<b>Runs</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>S1 - S5</b>	-0.24	-0.25	-0.31	-0.16	0.04	0.16	1.39	1.38
<b>S6 -S10</b>	-0.28	-0.29	-0.31	-0.14	0.05	0.18	1.41	1.40
<b>S11 -S15</b>	-0.23	-0.24	-0.30	-0.14	0.06	0.15	1.33	1.34
<b>S16 - S20</b>	-0.28	-0.30	-0.31	-0.12	0.06	0.18	1.37	1.35
<b>S21 - S25</b>	-0.24	-0.24	-0.28	-0.12	0.09	0.14	1.31	1.52
<b>S26 - S35</b>	-0.28	-0.30	-0.31	-0.11	0.10	0.15	1.37	1.22
<b>S36 - S40</b>	-0.25	-0.26	-0.31	-0.09	0.13	0.15	1.43	1.39
<b>S41 - S50</b>	-0.24	-0.27	-0.33	-0.08	0.13	0.15	1.44	1.47
<b>S51 - S60</b>	-0.24	-0.25	-0.32	-0.07	0.13	0.13	1.35	1.32
<b>S61 - S70</b>	-0.25	-0.25	-0.30	-0.04	0.15	0.15	1.30	1.28
<b>S71 - S80</b>	-0.17	-0.19	-0.27	0.04	0.22	0.20	0.60	0.70

For S71-80, after the S structure removal

**Table 5.3** Average Free Surface Standard Deviation (cm) for S Test

<b>Runs</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>S1 - S5</b>	4.75	4.75	4.63	3.81	3.32	2.91	1.80	1.58
<b>S6 -S10</b>	4.79	4.70	4.74	3.87	3.30	2.85	1.79	1.76
<b>S11 -S15</b>	4.65	4.66	4.55	3.72	3.27	2.91	1.78	1.61
<b>S16 - S20</b>	4.76	4.76	4.71	3.80	3.31	2.95	1.81	1.71
<b>S21 - S25</b>	4.78	4.79	4.68	3.77	3.32	3.00	1.86	1.86
<b>S26 - S35</b>	4.72	4.70	4.68	3.73	3.26	3.03	1.82	1.77
<b>S36 - S40</b>	4.74	4.73	4.69	3.70	3.22	3.05	1.80	1.73
<b>S41 - S50</b>	4.85	4.79	4.72	3.72	3.23	3.09	1.81	1.82
<b>S51 - S60</b>	4.69	4.71	4.64	3.61	3.16	3.13	1.84	1.75
<b>S61 - S70</b>	4.87	4.84	4.71	3.68	3.21	3.19	1.89	1.79
<b>S71 - S80</b>	4.88	4.84	4.77	3.64	3.18	3.00	2.26	1.91

For S71-80, after the S structure removal

**Table 5.4** Average Mean Velocity and Standard Deviation for S Test

<b>Run</b>	<b>2D AVD at WG4</b>	
	<b><math>\bar{u}</math> (cm/s)</b>	<b><math>\sigma_u</math> (cm/s)</b>
<b>S1 - S5</b>	-7.68	20.44
<b>S6 -S10</b>	-6.86	20.62
<b>S11 -S15</b>	-6.59	20.58
<b>S16 - S20</b>	-6.61	20.58
<b>S21 - S25</b>	-6.63	20.71
<b>S26 - S35</b>	-6.94	20.28
<b>S36 - S40</b>	-6.93	20.54
<b>S41 - S50</b>	-7.00	20.31
<b>S51 - S60</b>	-7.17	20.03
<b>S61 - S70</b>	-7.03	19.92
<b>S71 - S80</b>	-7.34	19.34

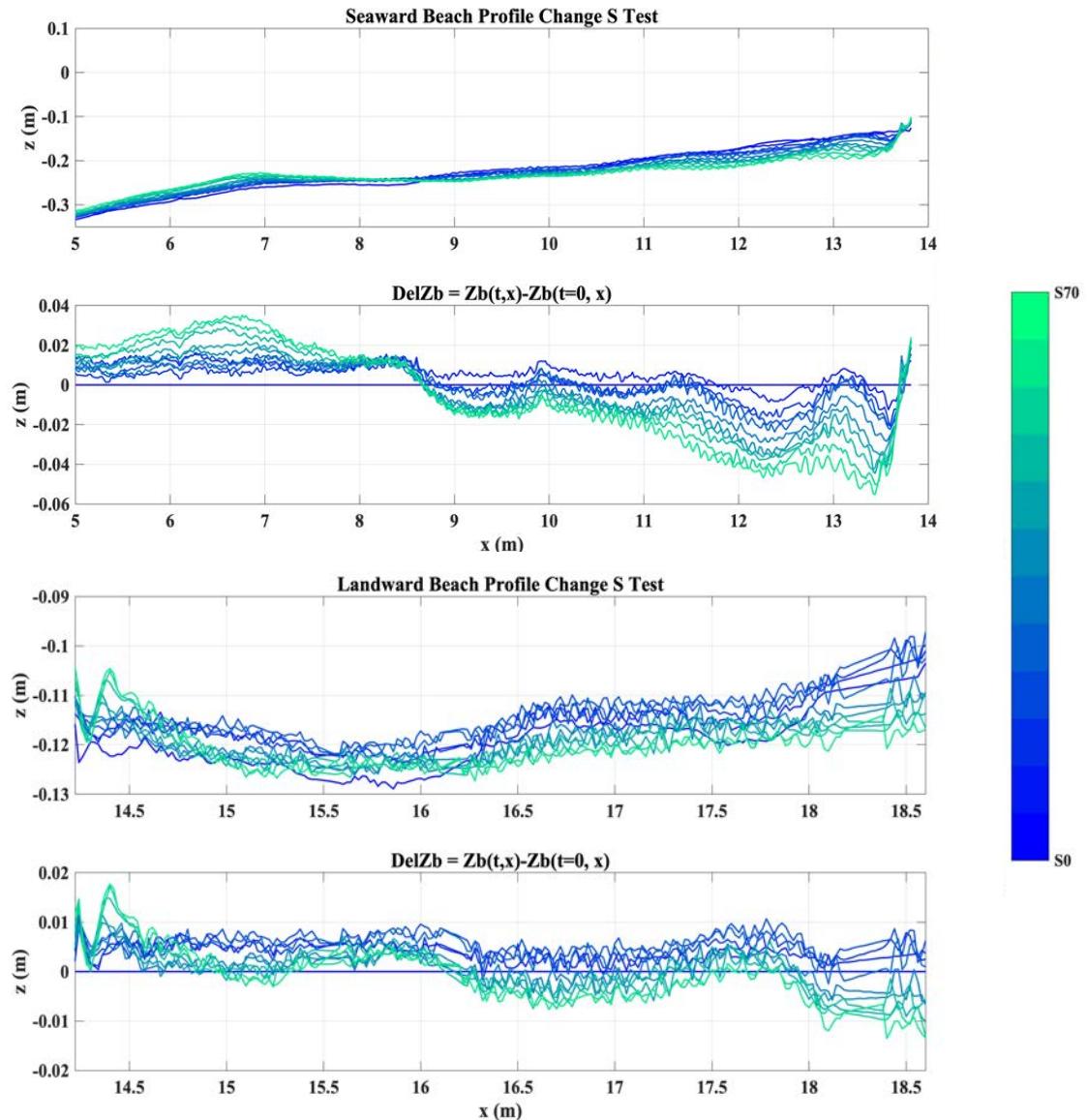
For S71-80, after the S structure removal

**Table 5.5** Water Depth (cm) below SWL at Wave Gauge Locations for S Test where SWL = 0.0 cm

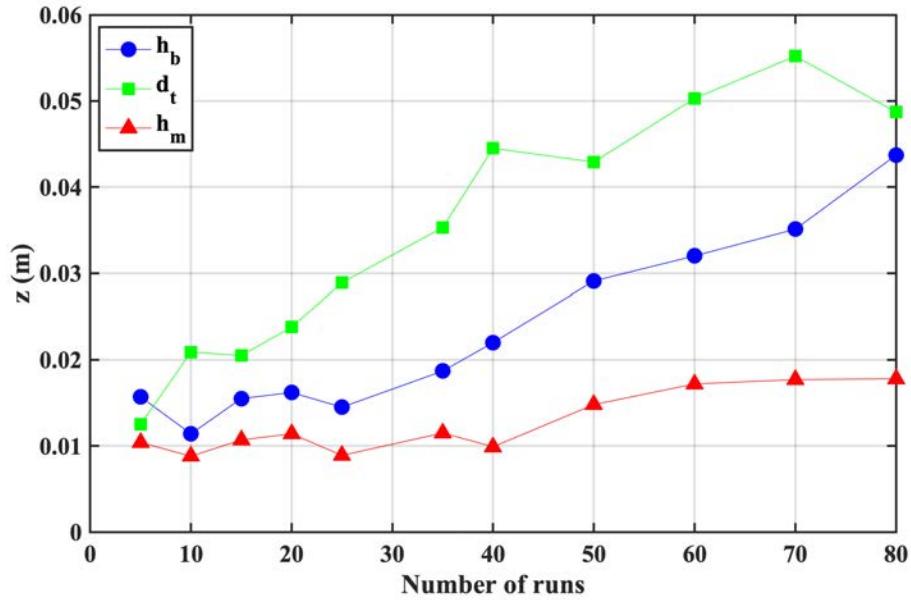
Run	SWL (cm)	Offshore (cm)	WG1/2/3 (cm)	WG4 (cm)	WG5 (cm)	WG6 (cm)	WG7 (cm)	WG8 (cm)
S0	0	92	79	25.44	19.74	13.01	12.18	10.80
S5	0	92	79	24.03	19.39	13.45	11.81	10.56
S10	0	92	79	24.36	19.84	12.72	12.01	10.42
S15	0	92	79	24.24	19.96	12.75	11.63	10.26
S20	0	92	79	24.17	20.12	12.81	11.79	10.85
S25	0	92	79	24.47	20.66	13.01	12.40	11.21
S35	0	92	79	24.60	21.37	12.67	12.41	11.34
S40	0	92	79	24.25	21.29	13.27	12.44	11.62
S50	0	92	79	24.10	21.13	13.93	12.47	11.54
S60	0	92	79	24.38	21.51	13.48	12.49	11.71
S70	0	92	79	24.16	21.61	13.16	12.37	11.53

The bar and trough formation and landward sand accretion are analyzed and plotted in Fig. 5.4. Fig. 5.5 shows the bar crest height  $h_b$ , the trough depth  $d_t$ , and the maximum height  $h_m$  of landward accretion increasing with the number of runs with each run lasting 400 s in the S test. The bar crest height  $h_b$  increased from  $h_b = 0$  for S0 to  $h_b = 3.5$  cm for S70 in comparison to  $h_b = 4.4$  cm for D70. The trough depth  $d_t$  increased to  $d_t = 5.5$  cm for S70 in comparison to  $d_t = 3.2$  cm for D70. The maximum height  $h_m$  of landward accretion was  $h_m = 1.8$  cm for S70 and smaller than  $h_m = 5.6$  cm for D70 because dislodged armor stones were deposited more on the seaward side of the submerged S mound. The average height of sand accretion in the landward zone of  $x = 14.28-18.6$  m was 0.2 cm for S70 in comparison to 1.3 cm for D70. In Table 5.6 is listed

the bar crest elevation, down-crossing point, beach trough elevation, and up-crossing point, plotted in Fig 5.6 showing the evolution during the number of runs.



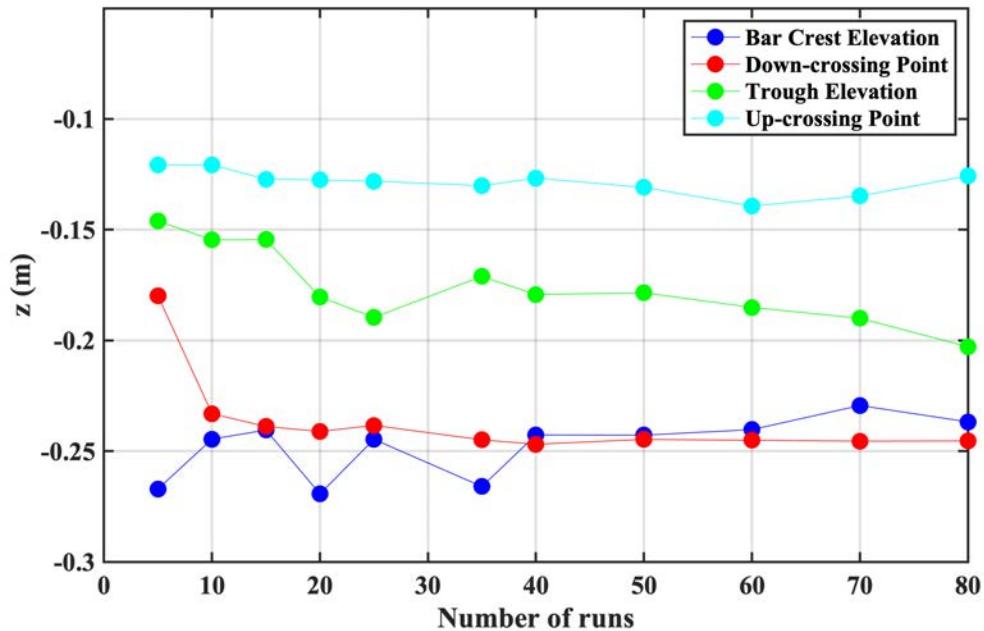
**Figure 5.4** Characterization of bar and trough formation on seaward beach and sand accretion on landward beach



**Fig. 5.5** Bar crest height  $h_b$ , trough depth  $d_t$ , and maximum height  $h_m$  of landward accretion increasing with number of runs during Test S

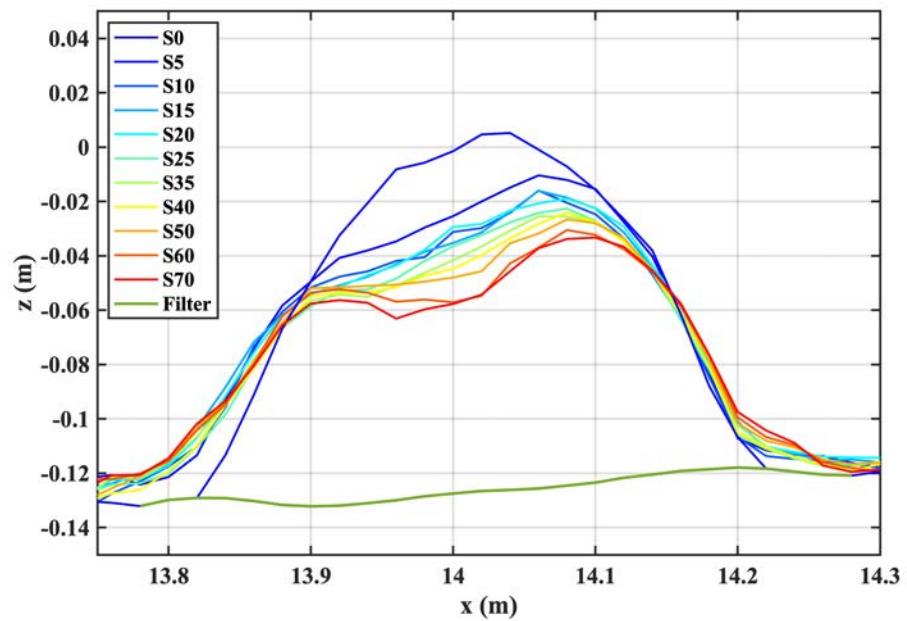
**Table 5.6** Measured Locations of Bar Crest, Down-crossing Point, Trough, and Up-crossing Point during S test

Runs	Bar Crest Elevation		Down-Crossing		Beach Trough Elevation		Up-Crossing	
	$x_c$ (m)	$z_c$ (m)	$x_d$ (m)	$z_d$ (m)	$x_t$ (m)	$z_t$ (m)	$x_u$ (m)	$z_u$ (m)
S1 - S5	6.32	-0.27	11.76	-0.18	13.58	-0.15	13.70	-0.12
S6 - S10	8.28	-0.24	8.86	-0.23	13.60	-0.15	13.76	-0.12
S11 - S15	8.28	-0.24	8.78	-0.24	13.62	-0.15	13.70	-0.13
S16 - S20	6.26	-0.27	8.80	-0.24	12.38	-0.18	13.70	-0.13
S21 - S25	7.10	-0.24	8.66	-0.24	12.24	-0.19	13.70	-0.13
S26 - S35	6.28	-0.27	8.66	-0.24	13.50	-0.17	13.70	-0.13
S36 - S40	6.80	-0.24	8.68	-0.25	13.44	-0.18	13.70	-0.13
S41 - S50	6.58	-0.24	8.66	-0.24	13.42	-0.18	13.74	-0.13
S51 - S60	6.56	-0.24	8.66	-0.25	13.44	-0.19	13.70	-0.14
S61 - S70	6.76	-0.23	8.68	-0.25	13.44	-0.19	13.70	-0.13
S71 - S80	6.38	-0.24	8.64	-0.25	12.48	-0.20	13.82	-0.13

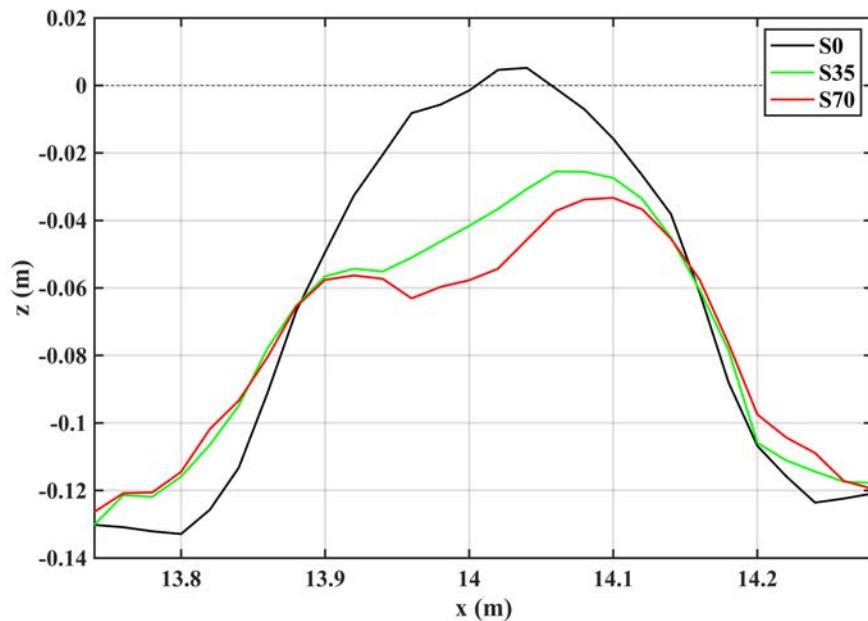


**Figure 5.6** Elevation of bar crest, down-crossing point, trough, and up-crossing point varying with the number of runs during S test

The measured 11 mound profiles were analyzed to examine damage progression on the lower and narrower mound in the S test (Fig. 5.7). Fig. 5.8 shows only the three profiles of S0, S35, and S70. The mound crest elevation  $R_c$  above the SWL was 0.5 cm for S0 and reduced to -1.0 cm for S5. The S mound was submerged during S5-S70 unlike the emerged D mound during D0-D200. Wave downrush and return flow on the submerged crest may have caused the seaward transport of dislodged armor stones.

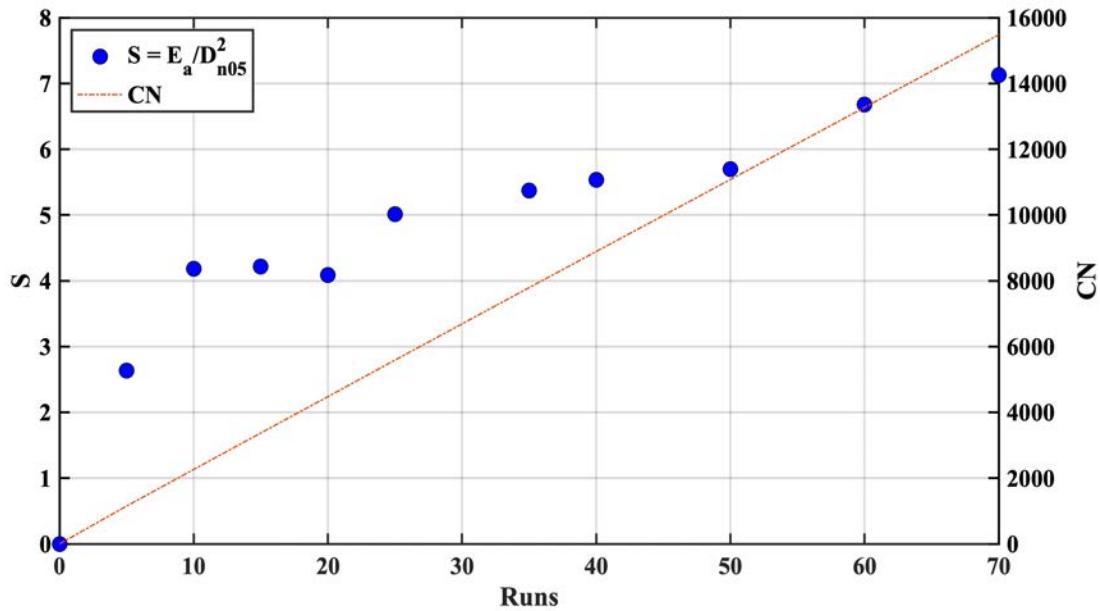


**Figure 5.7** Measured 11 profiles of deforming rubble mound above filter during S test



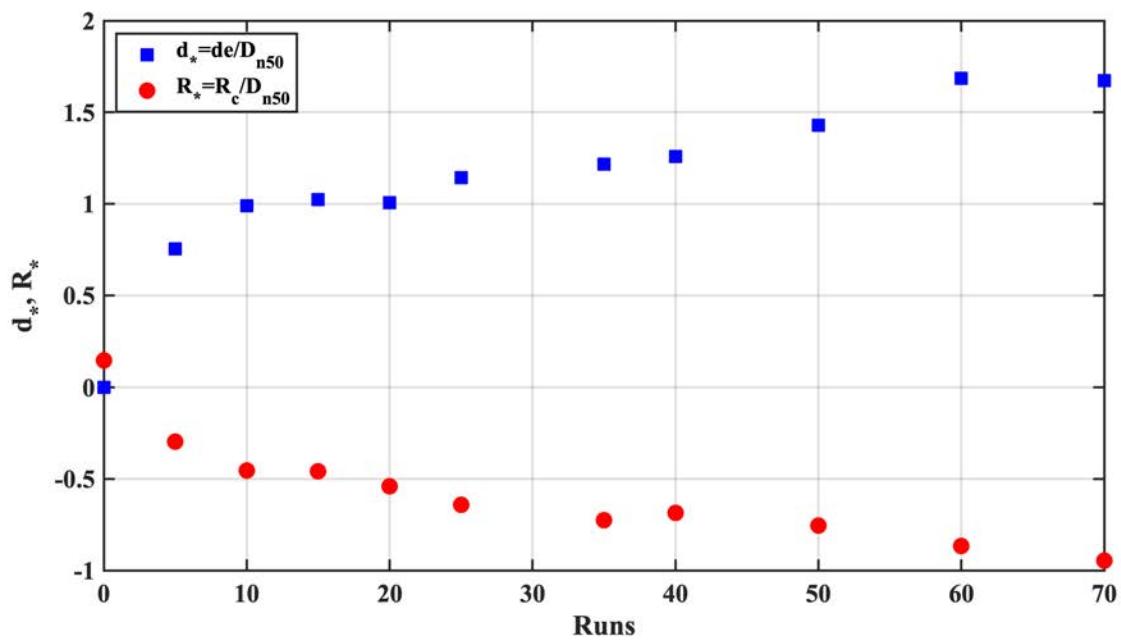
**Figure 5.8** Rubble mound crest lowering from S0 to S40, and S70 where SWL = 0.0 for S test

The eroded area and damage  $S$  were calculated for each mound profile. The damage increased to  $S = 2.6$  for S5 and  $S = 4.2$  for S10. The damage progressed slower after S10 and reached  $S = 7.1$  for S70 in comparison to  $S = 5.8$  for D70 (Fig. 5.9).

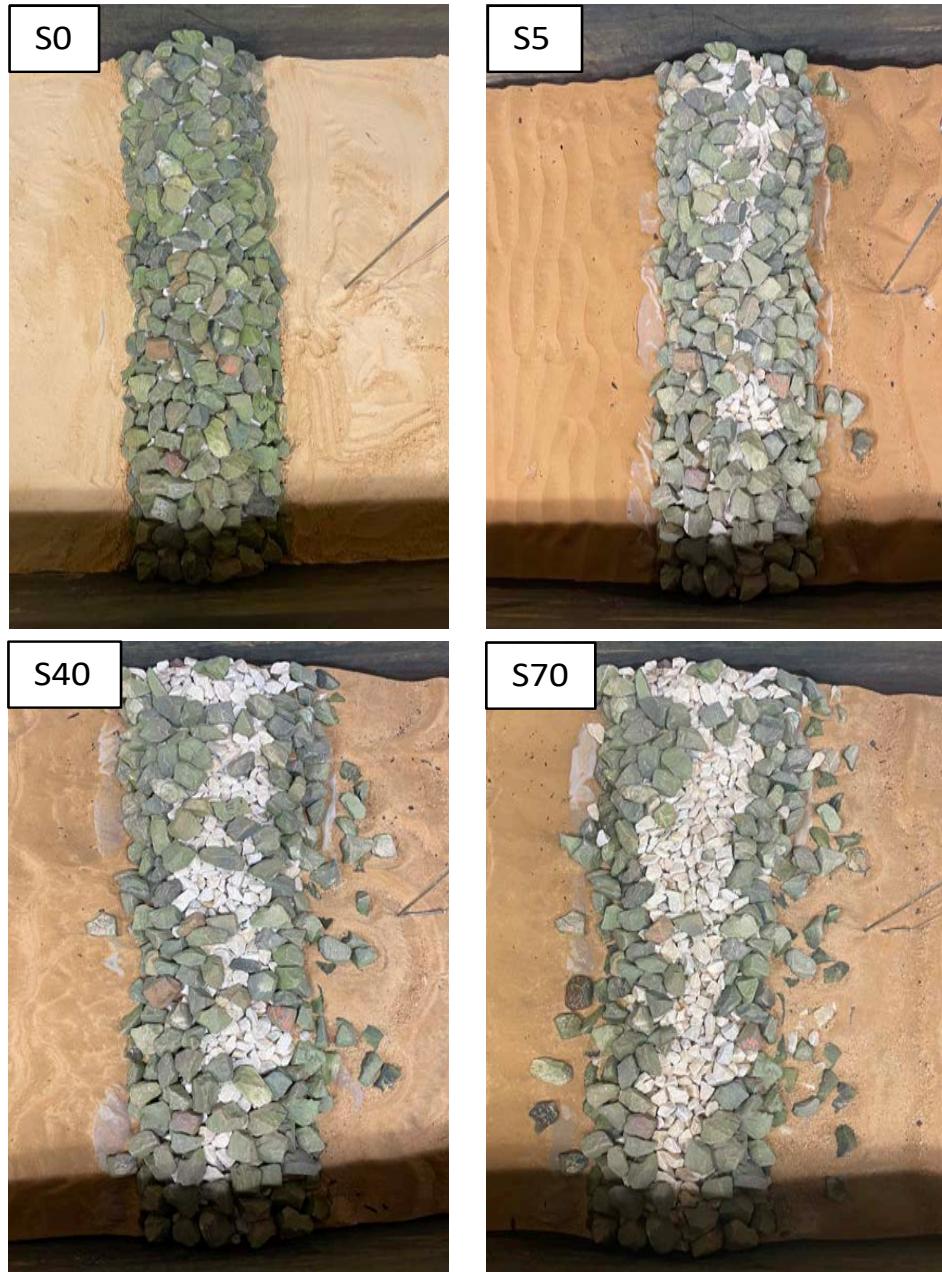


**Figure 5.9** Armor layer damage  $S$  (normalized eroded area) and cumulative number CN of waves varying with the number of runs during S test with nominal armor stone diameter  $D_{n50}=3.52\text{cm}$

The normalized erosion depth  $d_*$  and crest height  $R_*$  were plotted in Fig. 5.10. The value of  $d_*$  was 0.75 for S5 and increased to 1.67 for S70 in comparison to 1.15 for D70. The negative (submerged) value of  $R_*$  was -0.30 for S5 and decreased to -0.95 for S70. The positive (emerged) value of  $R_*$  was 0.57 for D5 and 0.28 for D70. The crest erosion and lowering progressed faster for the single armor layer. The double armor layer had a larger remaining capacity after its initial damage. Fig. 5.11 shows the photos of the damage during S0, S5, S40, and S70.

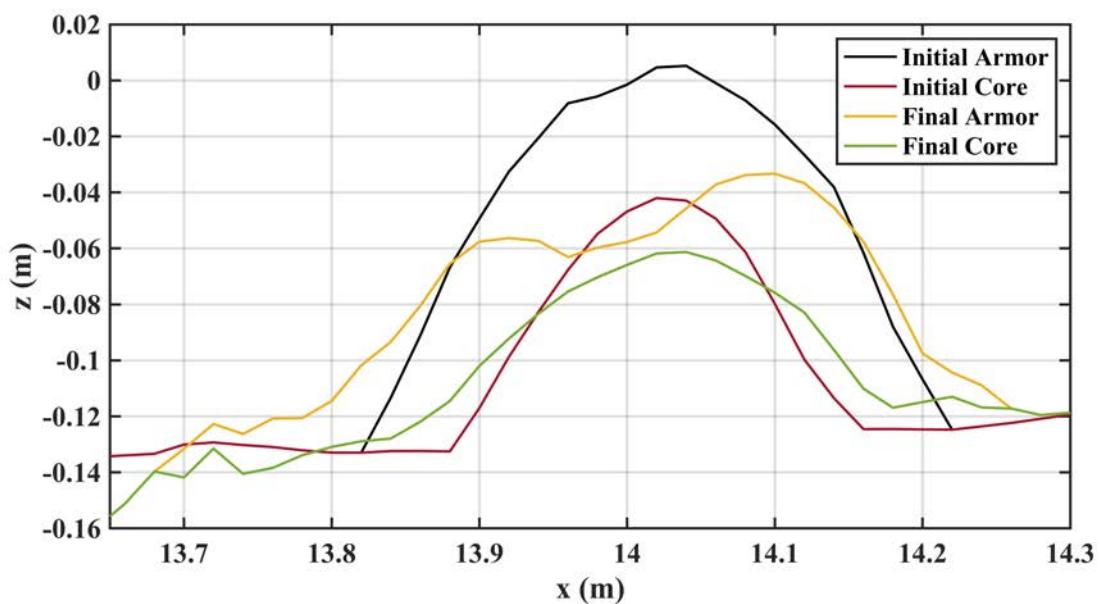


**Figure 5.10** Armor layer erosion depth  $d_e$  and crest elevation  $R_c$  above SWL normalized by  $D_{n50}=3.52\text{cm}$  varying with the number of runs



**Figure 5.11** Photographic damage progression starting from the intact armor layer (S0), visible white core stones (S5), gradual enlargement of white stone holes (S40), and the final armor layer with removed white stone (S70)

Fig. 5.12 shows the initial (S0) surface elevations of the armor layer and core in comparison with the final (S70) surface elevations before and after the S armor stone removal. The armor layer thickness is the vertical distance between the armor stone and core stone surfaces. The final armor layer thickness was much less than the nominal armor stone diameter of 3.52 cm above the core crest in the vicinity of  $x = 14$  m. The white core stones were visible in the wide zone of the armor layer thickness less than 2 cm. This wide zone was almost continuous in the alongshore direction. Several core stones were removed and deposited on the sand surface. Nevertheless, the S mound did not fail rapidly probably because the mound crest was sufficiently submerged. The deposited sand layer thickness on the filter was about 1.1 cm. The filter settlement was 1.1 cm at its seaward edge. It is noted that the core mound deformation cannot be predicted at the moment. The final armor stone surface elevation was below the initial core stone surface in Fig. 5.12 (failure) but above this initial surface in Fig. 4.12 (no failure). This simple failure criterion may be useful if the armor stone surface deformation is predicted using numerical models (e.g., Kobayashi et al. 2010; Garcia and Kobayashi 2015).



**Figure 5.12** Initial (S0) surface elevation of the armor layer and core in comparison with final (S70) surface elevations before and after the armor stone removal

## **Chapter 6**

### **SYNTESYS OF N, D, AND S TESTS**

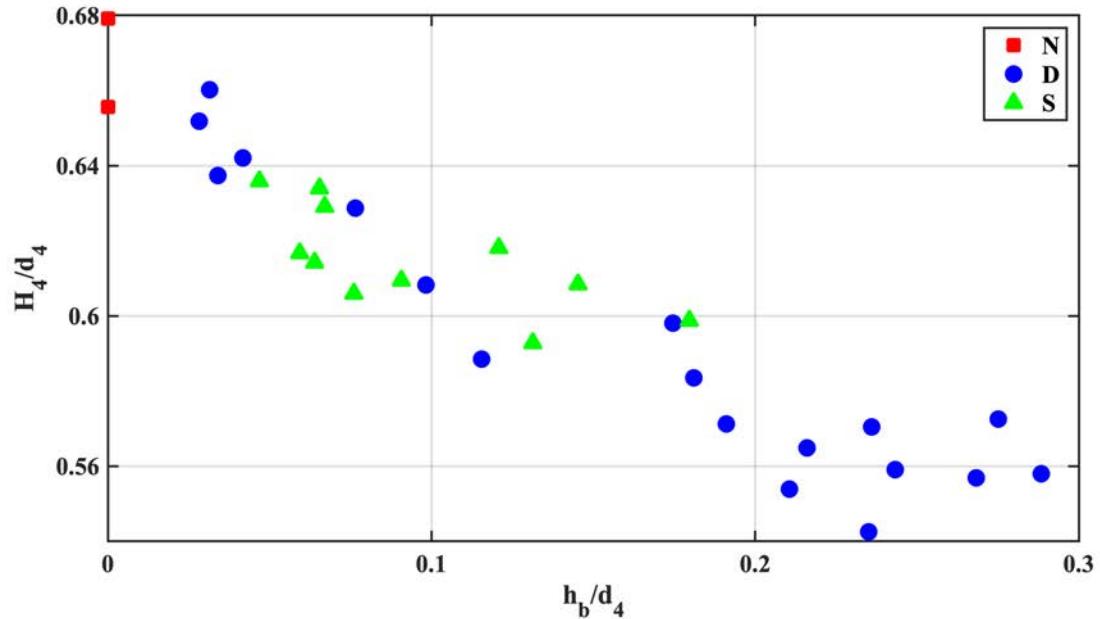
The data of the N, D, and S tests are combined and interpreted for practical applications.

The effects of the bar and trough formation seaward of a coastal structure are not taken into account at present. Available formulas for wave transformation over and through porous rubble mound structures (e.g., Van der Meer et al. 2005; Goda and Ahrens 2008) were developed for intact trapezoidal structures on fixed horizontal bottoms. Existing stability formulas for intact low-crested rubble mound breakwaters (e.g., Kramer and Burcharth 2003; Burcharth et al. 2006) need to be adjusted for the application to damaged breakwaters with lowered crests.

#### **6.1 Bar and Trough Effects on Wave Shoaling and Breaking**

Depth-limited wave breaking at WG4-WG6 in Fig. 2.1 is examined using the significant wave height  $H_j = 4\sigma_\eta$  at  $WG_j$  in the still water depth  $d_j$ . The incident significant wave height  $H_{mo}$  at  $x=0$  was almost (within 2% difference) the same as the significant wave height  $H_I$  at WG1 ( $x=0.0$ ). For the 310 runs (N, D, S tests),  $H_{mo}$  was in the range of 19-21 cm. Large waves broke on the bar (Figs. 4.1 and 5.1) seaward of WG4 ( $x = 8.4$  m) in the water depth  $d_4$  in the range of 23-26 cm for the 2, 18, and 11 intervals in the N, D, and S tests. Fig. 6.1 shows the average values of  $H_4/d_4$  for the 31 intervals which

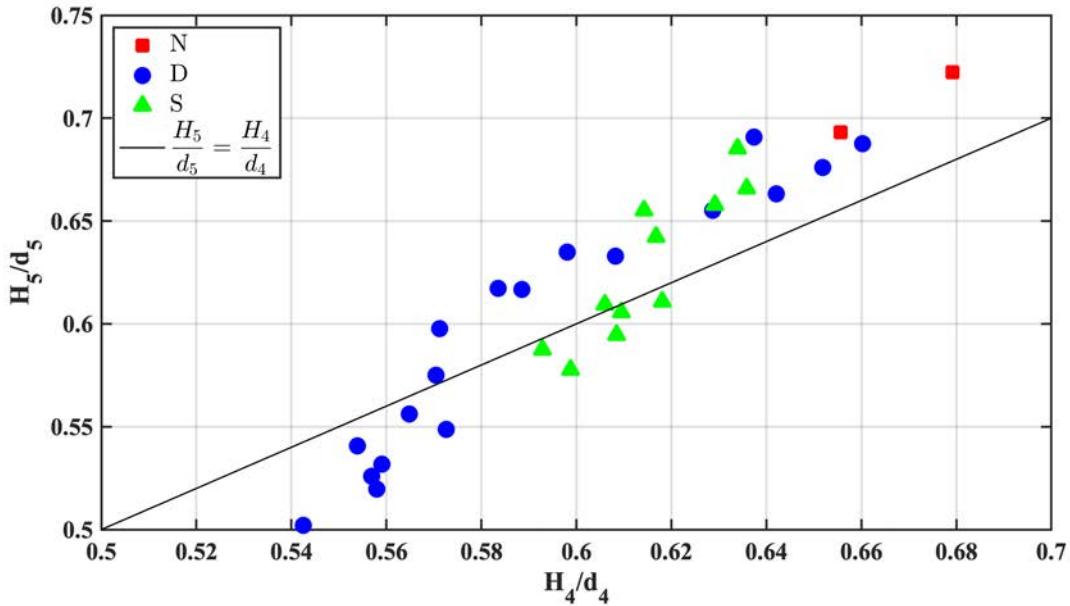
decreased with the increase of the normalized bar height  $h_b/d_4$ . For the two intervals in the N test (Fig. 3.1),  $h_b = 0$  before the bar formation. For the 29 intervals in the D and S tests,  $h_b = 0.8\text{-}6.8$  cm. The increase of wave breaking with the bar height increase reduced the wave height  $H_4$  landward of the bar. The values of  $H_4/d_4$  were in the range of 0.54-0.68. The breaker ratio parameter used in the numerical model CSHORE was calibrated in the range of 0.5-1.0 (Kobayashi 2016).



**Figure 6.1** Ratio of significant wave height  $H_4$  and still water depth  $d_4$  at WG4 decreasing with increase of bar height  $h_b$  divided by  $d_4$

The wave height  $H_5$  at WG5 ( $x = 11.0$  m) was measured in the still water depth  $d_5$  of 19-23 cm in the trough zone. The values of  $H_5/d_5$  and  $H_4/d_4$  in each of the 31 intervals are compared in Fig. 6.2. The still water depth was essentially the same as the mean water depth including wave setup or setdown at WG4 and WG5. The values of

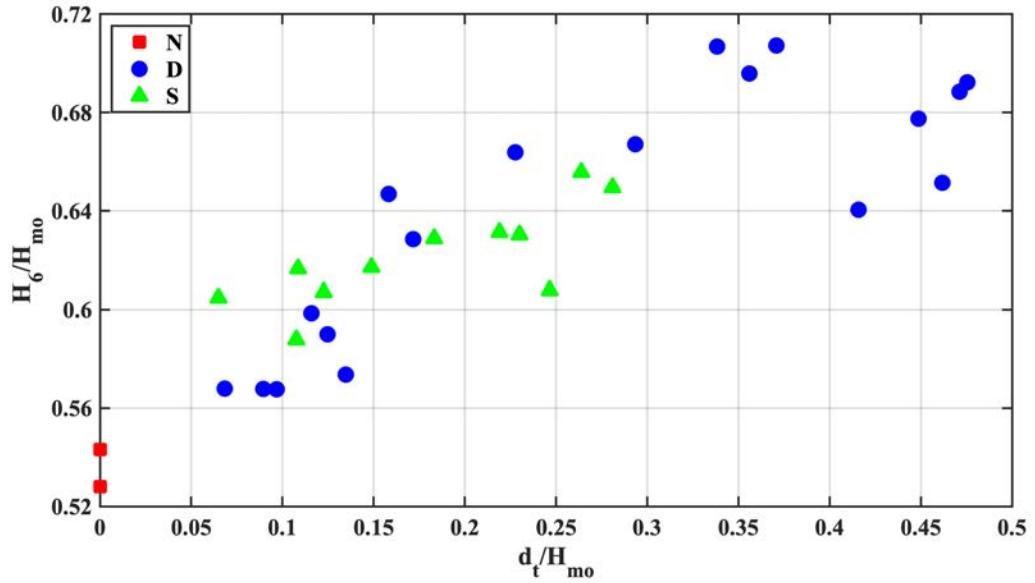
$H_5/d_5$  were in the wider range of 0.50-0.72. The difference between  $H_5/d_5$  and  $H_4/d_4$  was less than 0.06. The assumption of constant  $H_4/d_4$  and  $H_5/d_5$  in the trough zone may be acceptable for engineering applications.



**Figure 6.2** Ratio of significant wave height  $H_5$  and still water depth  $d_5$  at WG5 in comparison to ratio  $H_4/d_4$

WG6 ( $x = 13.8$  m) was located at the toe of the rubble mound in the D and S tests. The still water depth  $d_6$  was affected by the deposition of dislodged armor stones and sand erosion or deposition. For the two intervals in the N test,  $d_6 = 12.6$  cm. For the 17 intervals during D1-D200,  $d_6 = 9.0\text{-}11.5$  cm but  $d_6 = 16.3$  cm for D201-D210 after the D mound removal. For the 10 intervals during S1-S70,  $d_6 = 12.7\text{-}13.9$  cm but  $d_6 = 15.6$  cm for S71-S80 after the S mound removal. The values of  $H_6/d_6$  for the 31 intervals were in the range of 0.76-1.38. The bottom slope in front of WG6 became too steep to

assume constant  $H_6/d_6$  after the deep trough formation in Figs. 4.1 and 5.1. The incident significant wave height  $H_{mo}$  at  $x= 0$  is used to obtain the wave height ratio  $H_6/H_{mo}$  and examine the bar and trough effect on  $H_6/H_{mo}$ . The bar height effect on wave breaking is apparent in Fig. 6.1. Wave breaking in the trough zone was reduced with the increase of the trough depth  $d_t$  where  $d_t = 0$  for the two intervals in the N test. For the 29 intervals in the D and S tests,  $d_t = 1.3\text{-}9.1$  cm. Fig. 6.3 shows the values of  $H_6/H_{mo}$  in the range of 0.53-0.71 increasing with the increase of  $d_t/H_{mo}$ . The scatter of the 31 data points may be reduced by including the bar height effect, but the bar height and the trough depth are related as shown in Fig. 4.6 and 5.5. The bar and trough formation under the given  $H_{mo}$  resulted in the increase of the wave height  $H_6$  at the toe of the rubble mound in this experiment. This finding may be specific to the present experimental setup but the assumption of a fixed slope seaward of a rubble mound breakwater may lead to the underestimation of the wave height at the toe.



**Figure 6.3** Ratio of significant wave height  $H_6$  at WG6 and incident wave height  $H_{mo}$  at  $x = 0$  increasing with increase of trough depth  $dt$  divided by  $H_{mo}$

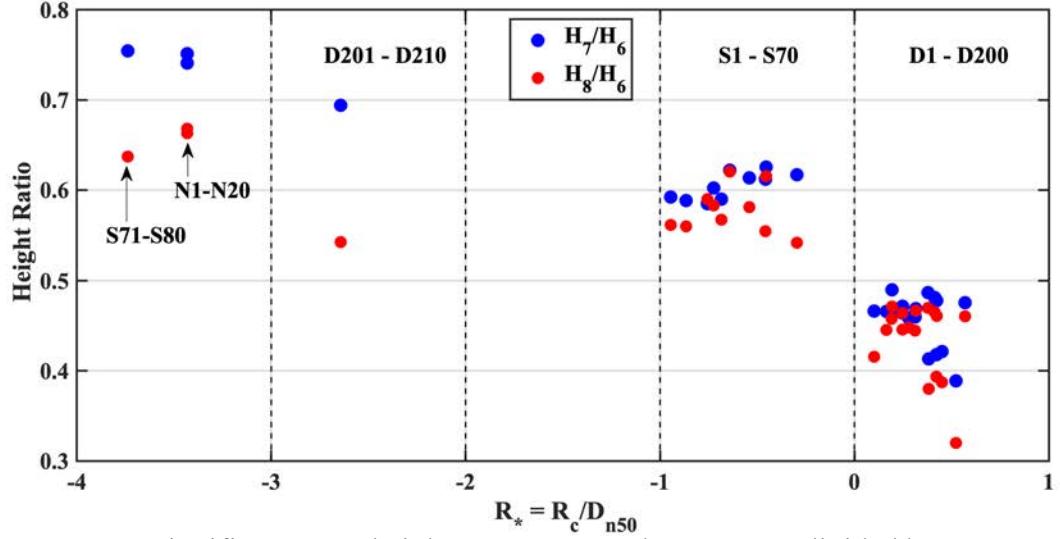
## 6.2 Mound crest lowering effect on wave transmission

WG7 ( $x = 16.3$  m) and WG8 ( $x = 18.3$  m) were located landward of the rubble mound in the D and S tests. Transmitted waves are represented by the significant wave heights  $H_7$  and  $H_8$  at WG7 and WG8. The wave height  $H_6$  at the toe of the rubble mound, which included reflected waves at the toe, is used as a surrogate of the incident wave height. The significant wave height decreased landward in the surf zone and  $H_6 > H_7 > H_8$  even in the absence of the rubble mound (N test). Wave transmission over and through a porous mound depends on the mound crest height  $R_c$  above the SWL (e.g., Van der Meer et al. 2005). For the cases of no mound (N test, D201-D210, and S71-S80), use is made of  $R_c = -d_6$  where the still water depth  $d_6$  corresponds to the wave height  $H_6$ . The nominal

stone diameter  $D_{n50}$  is used to calculate the normalized crest height  $R_c/D_{n50}$  where the D armor stone  $D_{n50}$  (Table 2.2) is used for the two intervals in the N test.

Fig. 6.4. shows the values of  $H_7/ H_6$  and  $H_8/ H_6$  for the emerged D mound (D1-D200), the submerged S mound (S1-S70), and the intervals of no mound with  $(R_c/D_{n50}) < -2.7$  (N1-N20, D201-D200, and S71-S80). For the emerged D mound,  $(R_c/D_{n50}) = 0.10-0.57$ ,  $(H_7/ H_6) = 0.39-0.49$ , and  $(H_8/ H_6) = 0.32-0.47$ . For the submerged S mound,  $(R_c/D_{n50}) = -0.95$  to  $-0.30$ ,  $(H_7/ H_6) = 0.59-0.63$ , and  $(H_8/ H_6) = 0.54-0.62$ . For the no mound intervals,  $(H_7/ H_6) = 0.69-0.76$ , and  $(H_8/ H_6) = 0.54-0.67$ . The wave height decay in the surf zone from  $x = 13.8$  m to  $x = 16.3$  and 18.3 m was appreciable even in the absence of the rubble mound. For actual applications, the required wave height reduction depends on the necessary functions of a coastal structure such as providing shelter for ships and a sandy shoreline (e.g., Melby et al. 2015). Available formulas for wave transmission over and through porous rubble mound structures on fixed horizontal bottoms are expected to overestimate the wave transmission coefficient for structures located inside the surf zone because the formulas do not account for the wave height decay in the surf zone with no structure. The data of D1-D200 in Fig. 6.4 are compared with the formula by Tomasicchio et al. (2011), who adjusted the formula by Goda and Ahrens (2008) using 33 data sets consisting of 3,327 data points. The wave height  $H_6$  is assumed to be the incident wave height. The average height of  $H_7$  and  $H_8$  is regarded as the transmitted wave height. The measured wave transmission coefficient given by  $(H_7 + H_8)/(2H_6)$  was in the range of 0.35-0.48 in comparison with the empirical transmission

coefficient in the range of 0.47-0.54. The overestimation of about 0.1 is within errors of available formulas.

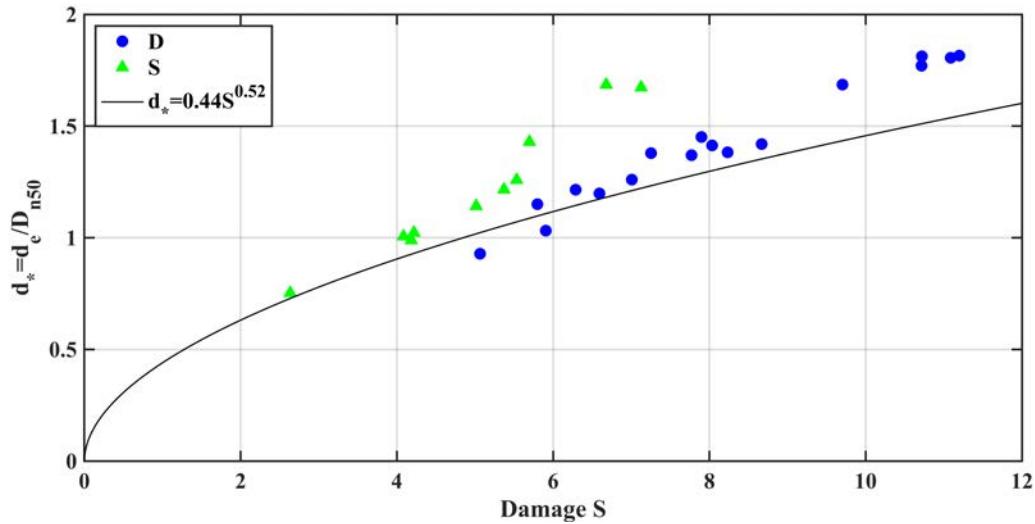


**Figure 6.4** Significant wave height  $H_7$  at WG7 and  $H_8$  at WG8 divided by  $H_6$  at WG6 varying with mound crest elevation  $R_c$  above SWL divided by nominal stone diameter  $D_{n50}$

### 6.3 Mound crest lowering and damage stabilization

The crests of the D and S mounds in Figs. 4.8 and 5.8 were eroded and lowered. The eroded area  $E_a$  and the maximum vertical erosion depth  $d_e$  were calculated for each damaged profile. The normalized values of  $S = E_a/D_{n50}^2$  and  $d_* = d_e/D_{n50}$  for the D test are plotted in Figs. 4.9 and 5.9, respectively. The values of  $S$  and  $d_*$  for the D and S tests are plotted in Fig. 6.5 and compared with the formula of  $d_* = 0.44S^{0.52}$  by Melby and Kobayashi (1998) who measured slope-normal erosion of conventional rubble mound structures with little wave overtopping. The damage  $S$  on the low-crested D and S mounds increased with the number of runs in Fig. 6.5. The measured  $d_*$  became larger

than the empirical  $d_*$  with the increase of  $S$  perhaps because of the core crest lowering and filter settlement discussed in relation to Figs. 4.12 and 5.12. The normalized crest height  $R_* = R_c/D_{n50}$  decreased with the increase of the damage  $S$  but increased by the SWL lowering during D151-D200 (Fig. 4.10). On the other hand, the normalized erosion depth is independent of the SWL.



**Figure 6.5** Normalized armor layer erosion depth  $d_*=d_e/D_{n50}$  increasing with damage  $S$  in comparison to formula for conventional rubble mound structures

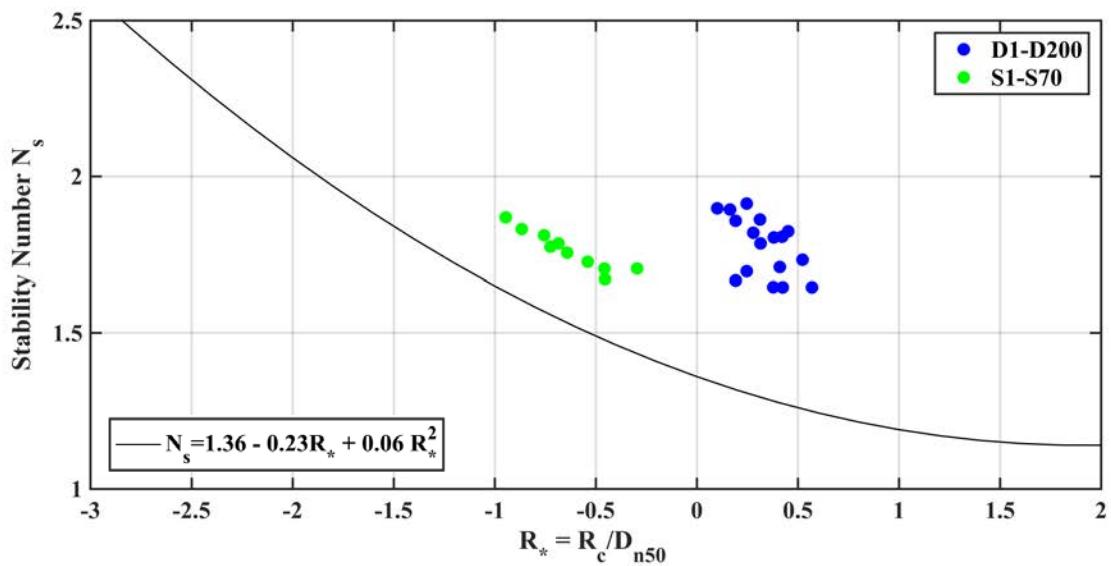
Kramer and Burcharth (2003) analyzed three data sets for the stability of low-crested rubble mound breakwaters and proposed the following formula for the stability

$$N_s = 1.36 - 0.23R_* + 0.06R_*^2 \quad \text{for } -3 < R_* < 2 \quad (1)$$

$$N_s = \frac{H_s}{(s-1)D_{n50}} \quad ; \quad s = \frac{\rho_s}{\rho_w} \quad ; \quad D_{n50} = \left( \frac{M_{50}}{\rho_s} \right)^{\frac{1}{3}} \quad (2)$$

where  $R_* = R_c/D_{n50}$ ;  $R_c$  = crest height above the SWL,  $H_s$  = incident significant wave height;  $s$  = specific gravity;  $\rho_s$  = stone density;  $\rho_w$  = water density;  $D_{n50}$  = nominal stone diameter; and  $M_{50}$  = median stone mass. The wave height  $H_s$  is approximated by the significant wave height  $H_6$  measured by WG6. Table 2.2 lists the values of  $D_{n50}$  and  $\rho_s$  of the D and S armor stones.

The values of  $N_s$  and  $R_*$  for the 17 intervals of D1-D200 and the 10 intervals of S1-S70 are plotted in Fig. 6.6 together with Eq. (1). For D1-D200,  $R_* = 0.10-0.57$ , and  $N_s = 1.65-1.91$ . For S1-S70,  $R_* = -0.95$  to  $-0.30$ , and  $N_s = 1.67-1.87$ . Fig. 6.6 implies that the criterion of the damage initiation was exceeded in the D and S tests. Eq. (1) intended for the design of a new structure gives the required stability number  $N_s$  for the specified value of  $R_*$  for allowable wave transmission as explained in relation to Fig. 6.5. For the assessment of an existing structure, Eq (1) may be used inversely to estimate the stable value of  $R_*$  for the given  $N_s$ . The value of  $R_*$  did not decrease steadily during the D test partly because of the lowered SWL = -0.02 m during D151-S200. During the S test,  $R_*$  decreased steadily (S data points moving to the left in Fig. 6.6) and may have been approaching a stable value where Eq. (1) predicts  $N_s = 1.65, 2.06$ , and  $2.59$  for  $R_* = -1, -2$ , and  $-3$ , respectively. The stability number  $N_s$  also increased during the S test because of the gradual increase of  $H_6$  by 10% caused by the bar and trough formation. It is noted that the stability number of the white core stone (Table 2.2) for the same  $H_6$  in Eq. (2) exceeds 2.59 corresponding to  $R_* = -3$  in Eq. (1). The severely damaged mound of S70 was deemed unstable after the extensive exposure of the core stone on the lowered crest.



**Figure 6.6** Stability number  $N_s$  based on wave height  $H_6$  as a function of  $R_*$  in comparison to no damage formula for low-crested breakwater inside surf zones

## **Chapter 7**

### **CONCLUSIONS**

The remaining capacity of a damaged rubble mound breakwater was investigated in a wave flume experiment. Three tests consisting of 310 runs with each run lasting 400 s were conducted on a sand beach to quantify the effect of beach profile evolution on wave shoaling and breaking seaward of a low-crested rubble mound consisting of core stone and an armor stone layer of a double or single layer thickness. The gradual formation of a bar in the outer breaker zone resulted in the gradual decrease (up to 0.1) of the ratio between the local significant wave height and the still water depth in the landward trough zone. The significant wave height at the toe of the mound located inside the surf zone was almost one half of the incident significant wave height of about 0.2 m outside the surf zone. The trough deepening (up to 0.09 m) in front of the mound resulted in the increase (about 10%) of the significant wave height at the toe. The wave height changes were less than the bottom elevation changes in this experiment.

The low crest of the rubble mound was damaged by breaking waves in the surf zone. The initial damage was caused mostly by the dislocation of stones placed in unstable positions. The dislodged stones were transported onshore by wave uprush over the crest and offshore by wave downrush and return flow over the low crest. The lowered and wider crest became more stable and the damage progression was slowed considerably. The core mound below the armor stone layer may have deformed itself to

stabilize the whole mound against breaking wave action. The remaining capacity of the double armor layer was larger than that of the single armor layer. The thinned armor layer could protect the core stone longer because of the initial thicker layer. The damage initiation criterion for intact low-crested rubble mounds proposed by Kramer and Burcharth (2003) was used to explain the stability increase with the lowering of the damaged crest elevation. The allowable crest lowering depends on the minimum thickness of the thinned armor layer for the core stone protection as well as tolerable wave transmission landward of the damaged rubble mound.

Wave transformation landward the toe of the rubble mound on the sloping beach was affected by wave breaking and energy dissipation on the sand beach as well as by wave transmission over and through the porous mound. The ratios between the wave heights on the landward and seaward sides of the mound were less than 0.5 for the emerged crest of the mound with the double armor layer and about 0.6 for the submerged crest of the mound with the single armor layer. The wave height ratios increased with the decrease of the mound crest height above the still water level as expected from available formulas for wave transmission over and through intact porous structures on fixed horizontal bottoms. The formulas do not include wave height decay inside the surf zone on a sloping bottom. In the present experiment, the wave height ratios were roughly 0.7 for the test with no structure and for the runs after the mound removal. In short, available formulas for waves transmission and armor layer response are insufficient for the assessment and rehabilitation of damaged rubble mound breakwaters.

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## Appendix A

### MEASURED HYDRODYNAMICS FOR 210 RUNS IN D TEST

**Table A.1** Incident Wave Characteristics for D Test

Run	$H_{mo}$ (cm)	$H_{rms}$ (cm)	$H_s$ (cm)	$T_p$ (s)	$T_s$ (s)	$T_m$ (s)	$R$	N. Wave
1	21.18	14.98	20.73	2.62	2.14	1.86	0.18	215
2	21.20	14.99	20.58	2.62	2.15	1.82	0.17	220
3	21.08	14.90	20.43	2.62	2.17	1.83	0.17	218
4	21.18	14.98	20.58	2.62	2.16	1.85	0.17	216
5	21.11	14.93	20.51	2.62	2.14	1.85	0.17	216
Average	<b>21.15</b>	<b>14.96</b>	<b>20.57</b>	<b>2.62</b>	<b>2.15</b>	<b>1.84</b>	<b>0.17</b>	<b>1085</b>
6	21.10	14.92	20.53	2.62	2.14	1.87	0.17	214
7	21.18	14.97	20.54	2.62	2.13	1.80	0.17	222
8	21.20	14.99	20.55	2.62	2.15	1.83	0.17	219
9	21.18	14.98	20.62	2.62	2.13	1.85	0.16	216
10	21.15	14.95	20.58	2.62	2.13	1.83	0.16	218
Average	<b>21.16</b>	<b>14.96</b>	<b>20.56</b>	<b>2.62</b>	<b>2.13</b>	<b>1.84</b>	<b>0.17</b>	<b>1089</b>
11	21.09	14.91	20.71	2.62	2.13	1.89	0.16	212
12	21.19	14.98	20.49	2.62	2.12	1.82	0.16	220
13	21.18	14.97	20.46	2.62	2.12	1.83	0.16	219
14	21.24	15.02	20.54	2.62	2.14	1.84	0.16	217
15	21.17	14.97	20.61	2.62	2.14	1.84	0.16	217
Average	<b>21.17</b>	<b>14.97</b>	<b>20.56</b>	<b>2.62</b>	<b>2.13</b>	<b>1.84</b>	<b>0.16</b>	<b>1085</b>
16	21.15	14.96	20.56	2.62	2.12	1.84	0.16	217
17	21.26	15.03	20.52	2.62	2.13	1.83	0.16	219
18	21.22	15.00	20.72	2.62	2.11	1.83	0.16	218
19	21.25	15.03	20.59	2.62	2.13	1.82	0.16	220
20	21.22	15.01	20.59	2.62	2.11	1.83	0.16	219
Average	<b>21.22</b>	<b>15.00</b>	<b>20.60</b>	<b>2.62</b>	<b>2.12</b>	<b>1.83</b>	<b>0.16</b>	<b>1093</b>

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>21</b>	20.79	14.70	20.27	2.62	2.15	1.85	0.15	216
<b>22</b>	20.85	14.75	20.30	2.62	2.13	1.83	0.16	218
<b>23</b>	20.82	14.72	20.25	2.62	2.11	1.83	0.16	218
<b>24</b>	20.87	14.76	20.32	2.62	2.11	1.84	0.16	217
<b>25</b>	20.91	14.78	20.34	2.62	2.13	1.84	0.16	217
<b>26</b>	20.89	14.77	20.26	2.62	2.12	1.81	0.16	221
<b>27</b>	20.89	14.77	20.40	2.62	2.16	1.85	0.16	216
<b>28</b>	20.83	14.73	20.26	2.62	2.13	1.85	0.16	216
<b>29</b>	20.85	14.75	20.34	2.62	2.13	1.84	0.17	217
<b>30</b>	20.81	14.72	20.23	2.62	2.10	1.84	0.16	217
<b>Average</b>	<b>20.85</b>	<b>14.74</b>	<b>20.30</b>	<b>2.62</b>	<b>2.13</b>	<b>1.84</b>	<b>0.16</b>	<b>2173</b>
<b>31</b>	20.97	14.82	20.32	2.62	2.12	1.82	0.16	220
<b>32</b>	21.02	14.87	20.47	2.62	2.13	1.83	0.16	218
<b>33</b>	21.02	14.86	20.37	2.62	2.11	1.85	0.16	216
<b>34</b>	21.01	14.85	20.32	2.62	2.14	1.82	0.16	220
<b>35</b>	21.04	14.87	20.42	2.62	2.12	1.84	0.16	217
<b>36</b>	20.97	14.83	20.30	2.62	2.12	1.83	0.16	219
<b>37</b>	20.97	14.82	20.33	2.62	2.14	1.84	0.16	217
<b>38</b>	20.97	14.83	20.28	2.62	2.13	1.82	0.16	220
<b>39</b>	20.94	14.80	20.30	2.62	2.12	1.84	0.16	217
<b>40</b>	20.97	14.83	20.40	2.62	2.13	1.83	0.16	218
<b>Average</b>	<b>20.99</b>	<b>14.84</b>	<b>20.35</b>	<b>2.62</b>	<b>2.12</b>	<b>1.83</b>	<b>0.16</b>	<b>2182</b>
<b>41</b>	20.75	14.67	20.20	2.62	2.14	1.85	0.16	216
<b>42</b>	20.75	14.67	20.14	2.62	2.12	1.84	0.16	217
<b>43</b>	20.75	14.67	20.24	2.62	2.16	1.83	0.16	218
<b>44</b>	20.78	14.69	20.27	2.62	2.16	1.87	0.17	214
<b>45</b>	20.78	14.69	20.11	2.62	2.16	1.85	0.16	216
<b>46</b>	20.79	14.70	20.25	2.62	2.15	1.84	0.17	217
<b>47</b>	20.70	14.64	20.15	2.62	2.15	1.85	0.17	216
<b>48</b>	20.68	14.62	19.98	2.62	2.13	1.81	0.17	221
<b>49</b>	20.66	14.61	20.05	2.62	2.17	1.84	0.17	217
<b>50</b>	20.69	14.63	20.10	2.62	2.16	1.83	0.17	218
<b>Average</b>	<b>20.73</b>	<b>14.66</b>	<b>20.15</b>	<b>2.62</b>	<b>2.15</b>	<b>1.84</b>	<b>0.17</b>	<b>2170</b>

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>51</b>	20.86	14.75	20.24	2.62	2.12	1.85	0.17	216
<b>52</b>	20.79	14.70	20.09	2.62	2.14	1.83	0.17	218
<b>53</b>	20.81	14.71	20.23	2.62	2.14	1.85	0.17	216
<b>54</b>	20.80	14.71	20.31	2.62	2.15	1.83	0.17	219
<b>55</b>	20.76	14.68	20.15	2.62	2.11	1.83	0.17	218
<b>56</b>	20.75	14.67	20.22	2.62	2.16	1.85	0.17	216
<b>57</b>	20.75	14.67	20.09	2.62	2.15	1.83	0.17	218
<b>58</b>	20.78	14.70	20.15	2.62	2.13	1.85	0.17	216
<b>59</b>	20.69	14.63	20.04	2.62	2.15	1.83	0.17	218
<b>60</b>	20.74	14.66	20.18	2.62	2.16	1.85	0.17	216
<b>61</b>	20.96	14.82	20.24	2.62	2.14	1.83	0.17	219
<b>62</b>	20.93	14.80	20.32	2.62	2.15	1.83	0.17	218
<b>63</b>	15.85	11.21	15.53	2.41	2.12	1.77	0.19	226
<b>64</b>	20.77	14.68	20.20	2.62	2.17	1.86	0.17	215
<b>65</b>	20.79	14.70	20.08	2.62	2.15	1.82	0.17	220
<b>66</b>	20.74	14.66	20.23	2.62	2.17	1.87	0.17	214
<b>67</b>	20.72	14.65	20.07	2.62	2.16	1.83	0.17	219
<b>68</b>	20.69	14.63	20.14	2.62	2.15	1.85	0.17	216
<b>69</b>	20.70	14.64	20.17	2.62	2.18	1.87	0.17	214
<b>70</b>	20.71	14.64	20.10	2.62	2.19	1.86	0.17	215
<b>Average</b>	<b>20.53</b>	<b>14.52</b>	<b>19.94</b>	<b>2.61</b>	<b>2.15</b>	<b>1.84</b>	<b>0.17</b>	<b>4347</b>

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>71</b>	20.44	14.46	19.78	2.62	2.16	1.83	0.17	218
<b>72</b>	20.55	14.53	20.02	2.62	2.16	1.85	0.17	216
<b>73</b>	20.52	14.51	19.77	2.62	2.14	1.81	0.17	221
<b>74</b>	20.47	14.48	19.90	2.62	2.18	1.86	0.17	215
<b>75</b>	20.52	14.51	20.08	2.62	2.19	1.88	0.17	213
<b>76</b>	20.42	14.44	19.76	2.62	2.17	1.84	0.17	217
<b>77</b>	NR	NR	NR	NR	NR	NR	NR	217*
<b>78</b>	20.37	14.40	19.79	2.62	2.15	1.86	0.17	215
<b>79</b>	20.39	14.42	19.90	2.62	2.18	1.87	0.17	214
<b>80</b>	NR	NR	NR	NR	NR	NR	NR	216*
<b>81</b>	20.36	14.40	19.81	2.62	2.18	1.87	0.17	214
<b>82</b>	20.34	14.38	19.79	2.62	2.17	1.88	0.17	213
<b>83</b>	20.32	14.37	19.62	2.62	2.16	1.85	0.17	216
<b>84</b>	20.31	14.36	19.59	2.62	2.18	1.83	0.17	218
<b>85</b>	20.54	14.53	19.95	2.62	2.17	1.86	0.17	215
<b>86</b>	20.52	14.51	19.93	2.62	2.17	1.83	0.17	218
<b>87</b>	20.46	14.47	20.00	2.62	2.19	1.86	0.18	215
<b>88</b>	20.39	14.42	19.73	2.62	2.16	1.83	0.17	218
<b>89</b>	20.38	14.41	19.78	2.62	2.18	1.83	0.17	218
<b>90</b>	20.45	14.46	19.96	2.62	2.18	1.87	0.17	214
<b>Average</b>	<b>20.43</b>	<b>14.45</b>	<b>19.84</b>	<b>2.62</b>	<b>2.17</b>	<b>1.85</b>	<b>0.17</b>	<b>4321</b>

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>91</b>	20.55	14.53	20.08	2.62	2.13	1.84	0.18	217
<b>92</b>	20.61	14.58	20.09	2.62	2.17	1.86	0.17	215
<b>93</b>	20.54	14.52	19.97	2.62	2.18	1.86	0.17	215
<b>94</b>	20.45	14.46	19.70	2.62	2.17	1.82	0.18	220
<b>95</b>	20.45	14.46	19.88	2.62	2.16	1.85	0.18	216
<b>96</b>	20.41	14.43	19.81	2.62	2.17	1.85	0.18	216
<b>97</b>	20.40	14.43	19.80	2.62	2.17	1.86	0.18	215
<b>98</b>	20.41	14.43	19.72	2.62	2.15	1.83	0.18	219
<b>99</b>	20.43	14.45	19.83	2.62	2.16	1.85	0.17	216
<b>100</b>	20.36	14.40	19.69	2.62	2.16	1.85	0.18	216
<b>101</b>	20.38	14.41	19.65	2.62	2.18	1.86	0.18	215
<b>102</b>	20.32	14.37	19.76	2.62	2.17	1.85	0.18	216
<b>103</b>	20.27	14.33	19.64	2.62	2.18	1.84	0.18	217
<b>104</b>	20.34	14.39	19.74	2.62	2.18	1.84	0.18	217
<b>105</b>	20.26	14.33	19.64	2.62	2.18	1.84	0.18	217
<b>106</b>	20.28	14.34	19.77	2.62	2.16	1.85	0.18	216
<b>107</b>	20.26	14.32	19.66	2.62	2.16	1.83	0.18	218
<b>108</b>	20.22	14.30	19.57	2.62	2.16	1.84	0.18	217
<b>109</b>	20.31	14.36	19.67	2.62	2.17	1.84	0.18	217
<b>110</b>	20.21	14.29	19.57	2.62	2.17	1.85	0.18	216
<b>Average</b>	<b>20.37</b>	<b>14.41</b>	<b>19.76</b>	<b>2.62</b>	<b>2.17</b>	<b>1.85</b>	<b>0.18</b>	<b>4331</b>

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>111</b>	19.62	13.87	19.04	2.62	2.17	1.83	0.18	219
<b>112</b>	19.56	13.83	18.95	2.62	2.16	1.84	0.18	217
<b>113</b>	19.46	13.76	18.79	2.62	2.18	1.84	0.18	217
<b>114</b>	19.88	14.06	19.19	2.62	2.16	1.84	0.18	217
<b>115</b>	19.80	14.00	19.22	2.62	2.16	1.85	0.18	216
<b>116</b>	19.76	13.97	19.15	2.62	2.14	1.86	0.18	215
<b>117</b>	19.75	13.97	19.14	2.62	2.18	1.84	0.18	217
<b>118</b>	19.77	13.98	19.06	2.62	2.18	1.82	0.18	220
<b>119</b>	19.73	13.95	19.18	2.62	2.19	1.83	0.18	219
<b>120</b>	19.74	13.96	19.22	2.62	2.15	1.88	0.18	213
<b>121</b>	19.86	14.04	19.13	2.62	2.17	1.83	0.18	218
<b>122</b>	NR	NR	NR	NR	NR	NR	NR	217*
<b>123</b>	19.90	14.07	19.30	2.62	2.17	1.86	0.18	215
<b>124</b>	19.93	14.09	19.19	2.62	2.16	1.82	0.18	220
<b>125</b>	19.88	14.06	19.23	2.62	2.18	1.86	0.18	215
<b>126</b>	19.80	14.00	19.14	2.62	2.20	1.84	0.18	217
<b>127</b>	19.76	13.97	19.07	2.62	2.17	1.83	0.18	219
<b>128</b>	19.73	13.95	19.09	2.62	2.16	1.86	0.18	215
<b>129</b>	19.74	13.95	19.17	2.62	2.17	1.85	0.18	216
<b>130</b>	19.70	13.93	19.03	2.62	2.16	1.82	0.19	220
<b>Average</b>	<b>19.76</b>	<b>13.97</b>	<b>19.12</b>	<b>2.62</b>	<b>2.17</b>	<b>1.84</b>	<b>0.18</b>	<b>4342</b>
<b>131</b>	19.88	14.06	19.20	2.62	2.14	1.83	0.18	219
<b>132</b>	19.98	14.13	19.35	2.62	2.14	1.84	0.18	217
<b>133</b>	19.94	14.10	19.21	2.62	2.15	1.84	0.18	217
<b>134</b>	19.93	14.09	19.22	2.62	2.15	1.83	0.18	219
<b>135</b>	19.82	14.01	19.19	2.62	2.15	1.83	0.18	218
<b>136</b>	19.81	14.01	19.09	2.62	2.15	1.85	0.18	216
<b>137</b>	19.84	14.03	19.11	2.62	2.16	1.86	0.18	215
<b>138</b>	19.80	14.00	19.12	2.62	2.15	1.85	0.18	216
<b>139</b>	19.71	13.94	19.07	2.62	2.16	1.84	0.18	217
<b>140</b>	19.94	14.10	19.34	2.62	2.16	1.84	0.18	217
<b>Average</b>	<b>19.86</b>	<b>14.05</b>	<b>19.19</b>	<b>2.62</b>	<b>2.15</b>	<b>1.84</b>	<b>0.18</b>	<b>2171</b>

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>141</b>	19.69	13.92	19.06	2.62	2.17	1.81	0.18	221
<b>142</b>	19.69	13.92	19.06	2.62	2.17	1.87	0.18	214
<b>143</b>	19.71	13.94	19.05	2.62	2.18	1.80	0.18	222
<b>144</b>	19.64	13.89	18.94	2.62	2.15	1.83	0.18	219
<b>145</b>	19.58	13.85	19.03	2.62	2.16	1.86	0.18	215
<b>146</b>	19.56	13.83	18.93	2.62	2.18	1.85	0.18	216
<b>147</b>	19.53	13.81	18.88	2.62	2.15	1.83	0.18	219
<b>148</b>	19.44	13.75	18.80	2.62	2.17	1.86	0.17	215
<b>149</b>	19.44	13.75	18.80	2.62	2.17	1.82	0.17	220
<b>150</b>	19.59	13.85	18.88	2.62	2.16	1.84	0.18	217
<b>Average</b>	<b>19.59</b>	<b>13.85</b>	<b>18.94</b>	<b>2.62</b>	<b>2.17</b>	<b>1.84</b>	<b>0.18</b>	<b>2178</b>
<b>151</b>	19.85	14.04	19.30	2.62	2.13	0.18	1.82	220
<b>152</b>	19.86	14.05	19.19	2.62	2.13	0.18	1.74	230
<b>153</b>	19.86	14.05	19.19	2.62	2.13	0.18	1.75	229
<b>154</b>	19.71	13.94	19.12	2.62	2.13	0.18	1.78	225
<b>155</b>	19.77	13.98	19.18	2.62	2.16	0.18	1.79	224
<b>156</b>	19.53	13.81	18.91	2.62	2.16	0.18	1.76	227
<b>157</b>	19.74	13.96	19.08	2.62	2.15	0.18	1.80	222
<b>158</b>	19.74	13.96	19.08	2.62	2.15	0.18	1.83	218
<b>159</b>	19.72	13.95	19.12	2.62	2.16	0.18	1.83	219
<b>160</b>	19.75	13.97	19.06	2.62	2.14	0.18	1.79	223
<b>Average</b>	<b>19.75</b>	<b>13.97</b>	<b>19.12</b>	<b>2.62</b>	<b>2.14</b>	<b>0.18</b>	<b>1.79</b>	<b>2237</b>
<b>161</b>	19.43	13.74	18.92	2.62	2.14	1.85	0.18	216
<b>162</b>	19.64	13.89	18.99	2.62	2.16	1.83	0.18	219
<b>163</b>	19.72	13.95	19.05	2.62	2.16	1.82	0.18	220
<b>164</b>	NR	NR	NR	NR	NR	NR	NR	218*
<b>165</b>	NR	NR	NR	NR	NR	NR	NR	221*
<b>166</b>	19.49	13.78	18.89	2.62	2.15	1.83	0.18	221
<b>167</b>	19.55	13.82	18.94	2.62	2.15	1.81	0.18	221
<b>168</b>	19.51	13.80	18.94	2.62	2.16	1.82	0.18	220
<b>169</b>	19.43	13.74	18.73	2.62	2.16	1.79	0.18	223
<b>170</b>	19.58	13.85	18.99	2.62	2.13	1.83	0.18	218

**Table A.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math> (cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math> (s)</b>	<b><math>T_m</math> (s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>171</b>	19.49	13.78	18.94	2.62	2.19	1.80	0.19	222
<b>172</b>	19.49	13.78	18.94	2.62	2.19	1.83	0.19	219
<b>173</b>	19.42	13.73	18.72	2.62	2.18	1.79	0.18	223
<b>174</b>	19.39	13.71	18.83	2.62	2.14	1.83	0.19	219
<b>175</b>	19.37	13.70	18.70	2.62	2.15	1.80	0.18	222
<b>176</b>	19.39	13.71	18.83	2.62	2.14	1.83	0.19	219
<b>177</b>	19.39	13.71	18.58	2.62	2.14	1.79	0.18	224
<b>178</b>	19.43	13.74	18.84	2.62	2.17	1.83	0.19	219
<b>179</b>	19.33	13.67	18.60	2.62	2.13	1.79	0.19	224
<b>180</b>	19.37	13.70	18.80	2.62	2.15	1.83	0.19	219
<b>Average</b>	<b>19.47</b>	<b>13.77</b>	<b>18.85</b>	<b>2.62</b>	<b>2.16</b>	<b>1.82</b>	<b>0.18</b>	<b>4407</b>
<b>181</b>	19.30	13.65	18.61	2.62	2.15	1.78	0.18	225
<b>182</b>	19.45	13.75	18.68	2.62	2.14	1.80	0.18	222
<b>183</b>	19.57	13.84	18.92	2.62	2.17	1.83	0.18	219
<b>184</b>	19.40	13.72	18.80	2.62	2.20	1.84	0.18	217
<b>185</b>	19.41	13.72	18.78	2.62	2.17	1.83	0.18	219
<b>186</b>	19.32	13.66	18.55	2.62	2.17	1.81	0.18	221
<b>187</b>	19.28	13.63	18.60	2.62	2.14	1.80	0.18	222
<b>188</b>	NR	NR	NR	NR	NR	NR	NR	221*
<b>189</b>	19.15	13.54	18.39	2.62	2.18	1.80	0.18	222
<b>190</b>	19.17	13.56	18.55	2.62	2.17	1.83	0.18	219
<b>Average</b>	<b>19.34</b>	<b>13.67</b>	<b>18.65</b>	<b>2.62</b>	<b>2.17</b>	<b>1.81</b>	<b>0.18</b>	<b>2207</b>
<b>191</b>	19.16	13.55	18.47	2.62	2.16	1.78	0.18	225
<b>192</b>	19.25	13.61	18.72	2.62	2.14	1.81	0.18	221
<b>193</b>	19.18	13.56	18.51	2.62	2.16	1.83	0.18	218
<b>194</b>	19.19	13.57	18.55	2.62	2.16	1.82	0.18	220
<b>195</b>	19.05	13.47	18.31	2.62	2.18	1.83	0.18	219
<b>196</b>	19.01	13.44	18.22	2.62	2.17	1.81	0.18	221
<b>197</b>	NR	NR	NR	NR	NR	NR	NR	221*
<b>198</b>	18.79	13.29	18.17	2.62	2.15	1.83	0.18	219
<b>199</b>	18.79	13.29	18.17	2.62	2.15	1.81	0.18	221
<b>200</b>	18.79	13.29	18.17	2.62	2.15	1.80	0.18	222
<b>Average</b>	<b>19.02</b>	<b>13.45</b>	<b>18.37</b>	<b>2.62</b>	<b>2.16</b>	<b>1.81</b>	<b>0.18</b>	<b>2207</b>

**Table A.1** Continued

Run	$H_{mo}$ (cm)	$H_{rms}$ (cm)	$H_s$ (cm)	$T_p$ (s)	$T_s$ (s)	$T_m$ (s)	$R$	N. Wave
<b>201</b>	18.85	13.33	18.23	2.62	2.15	1.75	0.13	229
<b>202</b>	18.98	13.42	18.26	2.62	2.14	1.72	0.13	233
<b>203</b>	19.11	13.52	18.43	2.62	2.16	1.73	0.13	231
<b>204</b>	19.34	13.67	18.49	2.62	2.15	1.73	0.14	231
<b>205</b>	19.28	13.64	18.49	2.62	2.12	1.74	0.13	230
<b>206</b>	19.16	13.55	18.45	2.62	2.15	1.72	0.14	232
<b>207</b>	19.12	13.52	18.33	2.62	2.13	1.72	0.14	232
<b>208</b>	19.12	13.52	18.38	2.62	2.14	1.75	0.14	228
<b>209</b>	19.00	13.43	18.33	2.62	2.13	1.76	0.14	227
<b>210</b>	19.00	13.43	18.30	2.62	2.13	1.71	0.13	234
<b>Average</b>	<b>19.10</b>	<b>13.50</b>	<b>18.37</b>	<b>2.62</b>	<b>2.14</b>	<b>1.73</b>	<b>0.14</b>	<b>2307</b>

\* The number of waves estimated as the average value in the proceeding runs after averaging.

**Table A.2** Mean Free Surface Elevation (cm) for D Test

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>1</b>	-0.39	-0.41	-0.54	-0.17	0.02	0.23	2.78	2.78
<b>2</b>	-0.40	-0.39	-0.43	-0.15	0.00	0.27	2.72	2.65
<b>3</b>	-0.37	-0.38	-0.48	-0.15	-0.01	0.26	2.70	2.67
<b>4</b>	-0.37	-0.39	-0.45	-0.17	0.00	0.27	2.68	2.67
<b>5</b>	-0.39	-0.40	-0.46	-0.18	0.00	0.21	2.66	2.65
<b>Average</b>	<b>-0.39</b>	<b>-0.40</b>	<b>-0.47</b>	<b>-0.16</b>	<b>0.00</b>	<b>0.25</b>	<b>2.71</b>	<b>2.69</b>
<b>6</b>	-0.36	-0.43	-0.50	-0.12	0.06	0.20	2.66	2.61
<b>7</b>	-0.39	-0.42	-0.44	-0.14	0.04	0.19	2.64	2.63
<b>8</b>	-0.38	-0.40	-0.47	-0.11	0.11	0.20	2.63	2.59
<b>9</b>	-0.42	-0.39	-0.46	-0.12	0.11	0.28	2.65	2.58
<b>10</b>	-0.37	-0.37	-0.42	-0.11	0.06	0.22	2.64	2.62
<b>Average</b>	<b>-0.38</b>	<b>-0.40</b>	<b>-0.46</b>	<b>-0.12</b>	<b>0.07</b>	<b>0.22</b>	<b>2.65</b>	<b>2.61</b>
<b>11</b>	-0.34	-0.38	-0.46	-0.23	0.05	0.18	2.46	2.43
<b>12</b>	-0.34	-0.36	-0.46	-0.19	0.14	0.27	2.50	2.46
<b>13</b>	-0.38	-0.40	-0.44	-0.18	0.09	0.19	2.49	2.47
<b>14</b>	-0.39	-0.39	-0.39	-0.21	0.09	0.20	2.54	2.55
<b>15</b>	-0.39	-0.38	-0.45	-0.19	0.11	0.12	2.54	2.49
<b>Average</b>	<b>-0.37</b>	<b>-0.38</b>	<b>-0.44</b>	<b>-0.20</b>	<b>0.10</b>	<b>0.19</b>	<b>2.51</b>	<b>2.48</b>
<b>16</b>	-0.34	-0.35	-0.44	-0.16	0.09	0.15	2.51	2.44
<b>17</b>	-0.34	-0.35	-0.46	-0.17	0.10	0.23	2.52	2.48
<b>18</b>	-0.37	-0.36	-0.43	-0.17	0.07	0.17	2.56	2.53
<b>19</b>	-0.39	-0.39	-0.41	-0.17	0.06	0.15	2.50	2.49
<b>20</b>	-0.41	-0.40	-0.43	-0.18	0.07	0.13	2.54	2.51
<b>Average</b>	<b>-0.37</b>	<b>-0.37</b>	<b>-0.44</b>	<b>-0.17</b>	<b>0.08</b>	<b>0.17</b>	<b>2.53</b>	<b>2.49</b>

**Table A.2** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>21</b>	-0.34	-0.35	-0.44	-0.16	0.09	0.15	2.51	2.44
<b>22</b>	-0.37	-0.39	-0.42	-0.18	0.09	0.16	2.50	2.50
<b>23</b>	-0.38	-0.36	-0.41	-0.19	0.06	0.12	2.57	2.50
<b>24</b>	-0.39	-0.39	-0.43	-0.21	0.08	0.09	2.50	2.47
<b>25</b>	-0.38	-0.38	-0.42	-0.17	0.06	0.10	2.59	2.52
<b>26</b>	-0.38	-0.42	-0.45	-0.18	0.05	0.18	2.56	2.50
<b>27</b>	-0.38	-0.38	-0.43	-0.20	0.06	0.09	2.60	2.49
<b>28</b>	-0.39	-0.40	-0.46	-0.17	0.04	0.12	2.58	2.53
<b>29</b>	-0.41	-0.39	-0.43	-0.15	0.09	0.09	2.64	2.54
<b>30</b>	-0.40	-0.38	-0.45	-0.16	0.04	0.12	2.64	2.57
<b>Average</b>	<b>-0.38</b>	<b>-0.38</b>	<b>-0.44</b>	<b>-0.18</b>	<b>0.07</b>	<b>0.12</b>	<b>2.57</b>	<b>2.51</b>
<b>31</b>	-0.37	-0.40	-0.48	-0.15	0.10	0.15	3.01	2.53
<b>32</b>	-0.40	-0.37	-0.46	-0.15	0.06	0.15	2.60	2.52
<b>33</b>	-0.38	-0.37	-0.44	-0.16	0.08	0.11	2.66	2.55
<b>34</b>	-0.42	-0.41	-0.42	-0.14	0.09	0.08	2.69	2.58
<b>35</b>	-0.42	-0.41	-0.43	-0.15	0.09	0.12	2.60	2.56
<b>36</b>	-0.41	-0.40	-0.40	-0.13	0.08	0.08	2.62	2.53
<b>37</b>	-0.42	-0.40	-0.46	-0.13	0.07	0.14	2.66	2.51
<b>38</b>	-0.41	-0.40	-0.41	-0.14	0.05	0.07	2.69	2.52
<b>39</b>	-0.42	-0.39	-0.44	-0.15	0.05	0.13	2.65	2.59
<b>40</b>	-0.43	-0.41	-0.39	-0.13	0.07	0.09	2.65	2.57
<b>Average</b>	<b>-0.41</b>	<b>-0.39</b>	<b>-0.43</b>	<b>-0.14</b>	<b>0.07</b>	<b>0.11</b>	<b>2.68</b>	<b>2.55</b>
<b>41</b>	-0.40	-0.42	-0.53	-0.11	0.11	0.06	2.58	2.57
<b>42</b>	-0.36	-0.40	-0.45	-0.12	0.03	0.10	2.61	2.54
<b>43</b>	-0.38	-0.38	-0.46	-0.14	0.06	0.02	2.60	2.53
<b>44</b>	-0.41	-0.38	-0.45	-0.13	0.08	0.06	2.64	2.54
<b>45</b>	-0.41	-0.39	-0.44	-0.14	0.09	0.10	2.68	2.58
<b>46</b>	-0.41	-0.40	-0.43	-0.13	0.10	0.06	2.65	2.55
<b>47</b>	-0.41	-0.40	-0.45	-0.13	0.06	0.11	2.61	2.56
<b>48</b>	-0.40	-0.38	-0.44	-0.13	0.04	-0.01	2.61	2.59
<b>49</b>	-0.40	-0.40	-0.45	-0.11	0.06	0.03	2.63	2.57
<b>50</b>	-0.40	-0.39	-0.44	-0.12	0.09	0.04	2.67	2.52
<b>Average</b>	<b>-0.40</b>	<b>-0.39</b>	<b>-0.45</b>	<b>-0.13</b>	<b>0.07</b>	<b>0.06</b>	<b>2.63</b>	<b>2.56</b>

**Table A.2** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>51</b>	-0.40	-0.42	-0.46	-0.11	0.09	0.09	2.74	2.64
<b>52</b>	-0.40	-0.41	-0.45	-0.11	0.06	0.11	2.74	2.51
<b>53</b>	-0.40	-0.41	-0.44	-0.10	0.03	-0.03	2.72	2.39
<b>54</b>	-0.41	-0.38	-0.44	-0.11	0.09	0.06	2.77	3.28
<b>55</b>	-0.39	-0.41	-0.42	-0.08	0.10	0.02	2.74	3.70
<b>56</b>	-0.40	-0.41	-0.42	-0.10	0.09	0.07	2.72	3.19
<b>57</b>	-0.41	-0.41	-0.42	-0.09	0.11	0.04	2.73	2.75
<b>58</b>	-0.40	-0.41	-0.42	-0.08	0.03	0.05	2.73	2.73
<b>59</b>	-0.40	-0.41	-0.43	-0.08	0.10	0.05	2.75	2.61
<b>60</b>	-0.37	-0.38	-0.42	-0.10	0.08	0.07	2.73	2.74
<b>61</b>	-0.40	-0.42	-0.46	-0.07	0.07	0.01	2.72	2.66
<b>62</b>	-0.43	-0.45	-0.49	0.00	0.05	0.04	2.82	2.85
<b>63</b>	-0.27	-0.29	-0.33	-0.20	-0.18	-0.24	2.54	2.46
<b>64</b>	-0.39	-0.41	-0.47	0.00	0.07	0.04	2.83	2.17
<b>65</b>	-0.42	-0.43	-0.43	0.00	0.08	0.08	2.80	2.77
<b>66</b>	-0.39	-0.42	-0.43	0.02	0.10	0.02	2.79	2.77
<b>67</b>	-0.41	-0.40	-0.42	-0.01	0.08	0.00	2.83	2.76
<b>68</b>	-0.41	-0.42	-0.41	0.00	0.07	0.00	2.84	2.71
<b>69</b>	-0.39	-0.40	-0.45	-0.01	0.08	0.05	2.81	2.77
<b>70</b>	-0.40	-0.42	-0.43	0.02	0.06	0.03	2.82	2.78
<b>Average</b>	<b>-0.39</b>	<b>-0.41</b>	<b>-0.43</b>	<b>-0.06</b>	<b>0.06</b>	<b>0.03</b>	<b>2.76</b>	<b>2.76</b>

**Table A.2** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>71</b>	-0.32	-0.38	-0.48	-0.13	0.01	-0.07	2.54	2.54
<b>72</b>	-0.34	-0.32	-0.46	-0.07	0.11	0.06	2.62	2.50
<b>73</b>	-0.33	-0.34	-0.44	-0.10	0.08	0.05	2.58	2.54
<b>74</b>	-0.33	-0.37	-0.43	-0.08	0.10	0.01	2.63	2.58
<b>75</b>	-0.37	-0.38	-0.45	-0.09	0.07	0.04	2.61	2.59
<b>76</b>	-0.38	-0.34	-0.45	-0.08	0.10	0.05	2.62	2.56
<b>77</b>	NR	NR	NR	NR	NR	NR	NR	NR
<b>78</b>	-0.38	-0.36	-0.42	-0.09	0.09	-0.04	2.60	2.59
<b>79</b>	-0.37	-0.38	-0.43	-0.08	0.08	0.03	2.64	2.53
<b>80</b>	NR	NR	NR	NR	NR	NR	NR	NR
<b>81</b>	-0.38	-0.36	-0.43	-0.09	0.10	0.03	2.64	2.56
<b>82</b>	-0.37	-0.36	-0.42	-0.07	0.09	0.03	2.67	2.59
<b>83</b>	-0.38	-0.39	-0.43	-0.10	0.10	-0.01	2.57	2.67
<b>84</b>	-0.38	-0.40	-0.43	-0.08	0.11	0.03	2.64	2.63
<b>85</b>	-0.42	-0.42	-0.52	-0.12	0.07	0.01	2.70	2.68
<b>86</b>	-0.41	-0.41	-0.41	-0.08	0.08	-0.01	2.74	2.69
<b>87</b>	-0.36	-0.40	-0.42	-0.04	0.08	0.00	2.70	2.66
<b>88</b>	-0.40	-0.39	-0.44	-0.09	0.08	0.00	2.74	2.63
<b>89</b>	-0.37	-0.37	-0.42	-0.07	0.08	-0.02	2.71	2.66
<b>90</b>	-0.36	-0.39	-0.42	-0.07	0.08	-0.01	2.72	2.66
<b>Average</b>	<b>-0.37</b>	<b>-0.37</b>	<b>-0.44</b>	<b>-0.09</b>	<b>0.09</b>	<b>0.01</b>	<b>2.65</b>	<b>2.60</b>

**Table A.2** Continued

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>91</b>	-0.40	-0.40	-0.48	-0.08	0.11	0.01	2.77	2.64
<b>92</b>	-0.39	-0.38	-0.47	-0.07	0.07	-0.05	2.74	2.67
<b>93</b>	-0.39	-0.40	-0.43	-0.04	0.08	-0.03	2.72	2.70
<b>94</b>	-0.37	-0.40	-0.44	-0.01	0.09	-0.05	2.74	2.68
<b>95</b>	-0.40	-0.37	-0.45	-0.05	0.05	-0.10	2.75	2.68
<b>96</b>	-0.39	-0.39	-0.42	-0.03	0.07	-0.01	2.75	2.67
<b>97</b>	-0.36	-0.39	-0.41	0.00	0.09	-0.07	2.76	2.68
<b>98</b>	-0.37	-0.40	-0.48	-0.02	0.11	-0.05	2.81	2.66
<b>99</b>	-0.37	-0.40	-0.41	-0.03	0.09	0.03	2.77	2.71
<b>100</b>	-0.40	-0.42	-0.41	0.00	0.10	-0.02	2.80	2.72
<b>101</b>	-0.40	-0.38	-0.40	0.01	0.08	-0.04	2.78	2.72
<b>102</b>	-0.37	-0.37	-0.43	0.03	0.10	-0.07	2.81	2.73
<b>103</b>	-0.38	-0.40	-0.41	0.01	0.06	-0.09	2.78	2.71
<b>104</b>	-0.40	-0.40	-0.42	-0.02	0.09	-0.01	2.79	2.70
<b>105</b>	-0.36	-0.39	-0.42	0.00	0.10	-0.07	2.74	2.74
<b>106</b>	-0.38	-0.40	-0.42	0.00	0.09	-0.04	2.79	2.71
<b>107</b>	-0.40	-0.38	-0.42	0.00	0.06	-0.08	2.79	2.71
<b>108</b>	-0.40	-0.37	-0.42	0.00	0.08	-0.04	2.80	2.69
<b>109</b>	-0.39	-0.38	-0.43	-0.01	0.07	-0.02	2.80	2.67
<b>110</b>	-0.39	-0.41	-0.43	0.04	0.08	-0.03	2.77	2.70
<b>Average</b>	<b>-0.39</b>	<b>-0.39</b>	<b>-0.43</b>	<b>-0.01</b>	<b>0.08</b>	<b>-0.04</b>	<b>2.77</b>	<b>2.69</b>

**Table A.2** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>111</b>	-0.36	-0.45	-0.46	-0.08	0.07	-0.09	2.39	2.35
<b>112</b>	-0.36	-0.39	-0.39	-0.08	0.05	-0.14	2.46	2.34
<b>113</b>	-0.35	-0.35	-0.38	-0.11	0.07	-0.12	2.43	2.35
<b>114</b>	-0.34	-0.38	-0.41	-0.09	0.08	-0.10	2.50	2.40
<b>115</b>	-0.36	-0.37	-0.40	-0.10	0.04	-0.03	2.45	2.43
<b>116</b>	-0.39	-0.38	-0.39	-0.07	0.08	-0.13	2.46	2.36
<b>117</b>	-0.37	-0.37	-0.39	-0.11	0.07	-0.03	2.52	2.42
<b>118</b>	-0.36	-0.38	-0.40	-0.10	0.06	-0.06	2.48	2.42
<b>119</b>	-0.39	-0.39	-0.39	-0.09	0.08	-0.11	2.47	2.39
<b>120</b>	-0.38	-0.39	-0.38	-0.01	0.07	-0.13	2.52	2.40
<b>121</b>	-0.41	-0.38	-0.45	-0.06	0.07	-0.10	2.56	2.51
<b>122</b>	-0.39	-0.41	-0.37	-0.09	0.07	-0.04	2.61	2.56
<b>123</b>	-0.38	-0.38	-0.40	-0.08	0.08	-0.10	2.59	2.54
<b>124</b>	-0.39	-0.38	-0.41	-0.08	0.06	-0.09	2.63	2.56
<b>125</b>	-0.39	-0.40	-0.41	-0.09	0.05	-0.11	2.60	2.55
<b>126</b>	-0.40	-0.40	-0.41	-0.08	0.08	-0.10	2.60	2.54
<b>127</b>	-0.40	-0.40	-0.41	-0.07	0.06	-0.10	2.61	2.52
<b>128</b>	-0.40	-0.39	-0.40	-0.08	0.04	-0.10	2.60	2.52
<b>129</b>	-0.40	-0.40	-0.43	-0.07	0.05	-0.10	2.61	2.54
<b>130</b>	-0.41	-0.39	-0.38	-0.09	0.05	-0.11	2.60	2.54
<b>Average</b>	<b>-0.38</b>	<b>-0.39</b>	<b>-0.40</b>	<b>-0.08</b>	<b>0.06</b>	<b>-0.09</b>	<b>2.54</b>	<b>2.46</b>
<b>131</b>	-0.40	-0.43	-0.48	-0.10	0.09	-0.08	2.68	2.69
<b>132</b>	-0.38	-0.40	-0.43	-0.03	0.09	-0.13	2.76	2.71
<b>133</b>	-0.37	-0.39	-0.43	-0.03	0.05	-0.07	2.74	2.71
<b>134</b>	-0.37	-0.37	-0.41	-0.06	0.09	-0.10	2.73	2.72
<b>135</b>	-0.38	-0.38	-0.42	-0.03	0.06	-0.05	2.74	2.68
<b>136</b>	-0.39	-0.38	-0.40	-0.05	0.05	-0.07	2.72	2.71
<b>137</b>	-0.39	-0.36	-0.42	-0.06	0.07	-0.13	2.75	2.68
<b>138</b>	-0.40	-0.39	-0.43	-0.05	0.09	-0.17	2.73	2.65
<b>139</b>	-0.40	-0.41	-0.41	-0.06	0.04	-0.07	2.75	1.85
<b>140</b>	-0.38	-0.39	-0.47	0.02	0.07	-0.12	2.81	2.60
<b>Average</b>	<b>-0.38</b>	<b>-0.39</b>	<b>-0.43</b>	<b>-0.04</b>	<b>0.07</b>	<b>-0.10</b>	<b>2.74</b>	<b>2.60</b>

**Table A.2** Continued

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>141</b>	-0.38	-0.37	-0.41	-0.01	0.06	-0.07	2.63	2.50
<b>142</b>	-0.37	-0.38	-0.48	-0.06	0.09	-0.09	2.62	2.86
<b>143</b>	-0.37	-0.37	-0.41	-0.07	0.07	-0.07	2.67	2.58
<b>144</b>	-0.36	-0.36	-0.42	-0.04	0.09	-0.13	2.58	2.62
<b>145</b>	-0.39	-0.39	-0.42	-0.04	0.08	-0.12	2.66	2.53
<b>146</b>	-0.39	-0.39	-0.40	-0.05	0.07	-0.13	2.62	2.75
<b>147</b>	-0.37	-0.36	-0.43	-0.04	0.09	-0.10	2.66	2.63
<b>148</b>	-0.37	-0.38	-0.42	-0.06	0.07	-0.08	2.64	2.75
<b>149</b>	-0.33	-0.37	-0.44	-0.04	0.09	-0.09	2.64	2.68
<b>150</b>	-0.39	-0.39	-0.43	-0.05	0.07	-0.13	2.62	NR
<b>Average</b>	<b>-0.37</b>	<b>-0.38</b>	<b>-0.43</b>	<b>-0.05</b>	<b>0.08</b>	<b>-0.10</b>	<b>2.64</b>	<b>2.66</b>
<b>151</b>	-0.63	-0.71	-0.60	-0.15	-0.04	-0.23	3.56	3.35
<b>152</b>	-0.65	-0.75	-0.61	-0.14	-0.01	-0.22	3.73	3.58
<b>153</b>	-0.66	-0.66	-0.59	-0.18	0.01	-0.17	3.98	3.68
<b>154</b>	-0.66	-0.67	-0.63	-0.14	-0.06	-0.17	4.12	3.83
<b>155</b>	-0.74	-0.71	-0.68	-0.12	-0.04	-0.16	4.17	3.93
<b>156</b>	-0.66	-0.68	-0.66	-0.05	0.00	-0.12	4.24	4.02
<b>157</b>	-0.41	-0.42	-0.46	-0.01	0.08	-0.08	3.40	3.12
<b>158</b>	-0.44	-0.50	-0.45	0.07	0.09	-0.10	3.41	3.16
<b>159</b>	-0.40	-0.48	-0.45	0.05	0.11	-0.09	3.33	3.10
<b>160</b>	-0.41	-0.47	-0.43	0.05	0.10	-0.14	3.41	3.14
<b>Average</b>	<b>-0.57</b>	<b>-0.60</b>	<b>-0.56</b>	<b>-0.06</b>	<b>0.02</b>	<b>-0.15</b>	<b>3.74</b>	<b>3.49</b>
<b>161</b>	-0.38	-0.49	-0.45	0.04	0.10	-0.13	3.35	3.23
<b>162</b>	-0.38	-0.42	-0.45	0.06	0.06	-0.07	3.34	3.24
<b>163</b>	-0.39	-0.42	-0.44	0.08	0.11	-0.12	3.39	3.17
<b>164</b>	-0.28	-0.34	-0.31	-0.18	-0.18	-0.35	3.05	2.64
<b>165</b>	NR	NR	NR	NR	NR	NR	NR	NR
<b>166</b>	-0.41	-0.48	-0.44	0.04	0.07	-0.11	3.36	3.54
<b>167</b>	-0.41	-0.48	-0.42	0.04	0.06	-0.09	3.38	3.23
<b>168</b>	-0.42	-0.47	-0.41	0.03	0.10	-0.11	3.37	3.19
<b>169</b>	-0.43	-0.47	-0.42	0.07	0.08	-0.13	3.33	3.40

**Table A.2** Continued

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>170</b>	-0.42	-0.49	-0.42	0.04	0.07	-0.11	3.35	3.30
<b>171</b>	-0.41	-0.45	-0.45	0.06	0.08	-0.12	3.39	3.36
<b>172</b>	-0.40	-0.46	-0.42	0.03	0.09	-0.13	3.34	3.33
<b>173</b>	-0.42	-0.47	-0.42	0.03	0.07	-0.12	3.36	3.33
<b>174</b>	-0.38	-0.41	-0.42	0.03	0.07	-0.14	3.33	3.34
<b>175</b>	-0.42	-0.47	-0.42	0.05	0.03	-0.14	3.36	3.32
<b>176</b>	-0.36	-0.42	-0.42	0.05	0.08	-0.11	3.37	3.36
<b>177</b>	-0.39	-0.43	-0.44	0.06	0.07	-0.12	3.35	3.34
<b>178</b>	-0.38	-0.44	-0.42	0.06	0.09	-0.12	3.40	3.32
<b>179</b>	-0.41	-0.45	-0.43	0.08	0.08	-0.13	3.40	3.32
<b>180</b>	-0.39	-0.47	-0.41	0.08	0.08	-0.12	3.34	3.35
<b>Average</b>	<b>-0.39</b>	<b>-0.45</b>	<b>-0.42</b>	<b>0.04</b>	<b>0.06</b>	<b>-0.13</b>	<b>3.34</b>	<b>3.28</b>
<b>181</b>	-0.40	-0.40	-0.48	0.01	0.07	-0.08	3.54	2.35
<b>182</b>	-0.38	-0.47	-0.42	0.03	0.12	-0.09	3.24	4.38
<b>183</b>	-0.39	-0.45	-0.42	0.07	0.09	-0.14	3.27	2.95
<b>184</b>	-0.39	-0.45	-0.42	0.07	0.08	-0.09	3.20	3.28
<b>185</b>	-0.42	-0.45	-0.42	0.07	0.08	-0.11	3.22	3.71
<b>186</b>	-0.42	-0.47	-0.42	0.02	0.05	-0.14	3.20	2.72
<b>187</b>	-0.40	-0.42	-0.43	0.06	0.09	-0.12	3.20	3.25
<b>188</b>	NR	NR	NR	NR	NR	NR	NR	NR
<b>189</b>	-0.38	-0.46	-0.43	0.05	0.09	-0.13	3.18	3.21
<b>190</b>	-0.39	-0.43	-0.41	0.05	0.10	-0.15	3.16	3.19
<b>Average</b>	<b>-0.40</b>	<b>-0.44</b>	<b>-0.43</b>	<b>0.05</b>	<b>0.09</b>	<b>-0.12</b>	<b>3.25</b>	<b>3.23</b>
<b>191</b>	-0.38	-0.44	-0.45	0.07	0.12	-0.17	3.22	3.20
<b>192</b>	-0.38	-0.45	-0.45	0.02	0.08	-0.09	3.22	2.85
<b>193</b>	-0.42	-0.46	-0.41	0.07	0.11	-0.08	3.19	3.21
<b>194</b>	-0.41	-0.46	-0.41	0.07	0.09	-0.09	3.20	3.16
<b>195</b>	-0.40	-0.45	-0.43	0.07	0.12	-0.11	3.17	3.18
<b>196</b>	-0.36	-0.45	-0.42	0.06	0.12	-0.10	3.16	3.16
<b>197</b>	NR	NR	NR	NR	NR	NR	NR	NR
<b>198</b>	-0.39	-0.43	-0.40	0.05	0.05	-0.13	3.15	2.96
<b>199</b>	-0.38	-0.47	-0.41	0.08	0.08	-0.09	3.19	2.91
<b>200</b>	-0.36	-0.44	-0.41	0.04	0.08	-0.09	3.19	2.84
<b>Average</b>	<b>-0.39</b>	<b>-0.45</b>	<b>-0.42</b>	<b>0.06</b>	<b>0.09</b>	<b>-0.11</b>	<b>3.19</b>	<b>3.05</b>

**Table A.2** Continued

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>201</b>	-0.21	-0.25	-0.28	0.06	0.20	0.02	0.64	0.91
<b>202</b>	-0.19	-0.18	-0.23	0.12	0.24	0.08	0.94	0.91
<b>203</b>	-0.23	-0.24	-0.29	-0.01	0.21	0.05	0.69	0.81
<b>204</b>	-0.22	-0.23	-0.26	0.12	0.22	0.08	0.75	0.92
<b>205</b>	-0.18	-0.20	-0.28	0.11	0.20	0.09	0.70	0.95
<b>206</b>	-0.23	-0.19	-0.26	0.11	0.22	0.03	0.72	0.96
<b>207</b>	-0.18	-0.18	-0.26	0.11	0.21	0.08	0.77	0.95
<b>208</b>	-0.21	-0.20	-0.26	0.11	0.20	0.05	0.68	0.97
<b>209</b>	-0.20	-0.21	-0.26	0.08	0.20	0.09	0.74	0.96
<b>210</b>	-0.21	-0.22	-0.25	0.10	0.20	NR	0.75	0.96
<b>Average</b>	<b>-0.21</b>	<b>-0.21</b>	<b>-0.26</b>	<b>0.09</b>	<b>0.21</b>	<b>0.06</b>	<b>0.74</b>	<b>0.93</b>

**Table A.3** Free Surface Standard Deviation (cm) for D Test

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
<b>1</b>	5.21	5.19	5.17	4.07	3.41	3.01	1.43	1.37
<b>2</b>	5.20	5.19	5.17	4.08	3.42	3.00	1.40	1.38
<b>3</b>	5.20	5.20	5.09	4.07	3.43	2.99	1.44	1.39
<b>4</b>	5.19	5.20	5.15	4.07	3.42	3.01	1.43	1.38
<b>5</b>	5.18	5.18	5.14	4.07	3.43	3.01	1.44	1.40
<b>Average</b>	<b>5.20</b>	<b>5.19</b>	<b>5.14</b>	<b>4.07</b>	<b>3.42</b>	<b>3.00</b>	<b>1.43</b>	<b>1.38</b>
<b>6</b>	5.19	5.13	5.15	4.03	3.44	3.00	1.43	1.39
<b>7</b>	5.21	5.16	5.16	4.02	3.45	3.00	1.43	1.37
<b>8</b>	5.22	5.16	5.14	4.00	3.46	2.99	1.44	1.38
<b>9</b>	5.23	5.16	5.14	4.02	3.46	3.01	1.44	1.39
<b>10</b>	5.21	5.16	5.13	4.00	3.44	3.02	1.45	1.39
<b>Average</b>	<b>5.21</b>	<b>5.15</b>	<b>5.15</b>	<b>4.01</b>	<b>3.45</b>	<b>3.00</b>	<b>1.44</b>	<b>1.38</b>
<b>11</b>	5.19	5.13	5.15	4.03	3.44	3.00	1.43	1.39
<b>12</b>	5.19	5.18	5.16	4.04	3.44	3.00	1.47	1.41
<b>13</b>	5.18	5.18	5.15	4.03	3.41	2.99	1.48	1.42
<b>14</b>	5.21	5.20	5.17	4.03	3.41	3.01	1.47	1.41
<b>15</b>	5.18	5.18	5.15	4.03	3.42	3.03	1.47	1.42
<b>Average</b>	<b>5.19</b>	<b>5.17</b>	<b>5.15</b>	<b>4.03</b>	<b>3.42</b>	<b>3.00</b>	<b>1.46</b>	<b>1.41</b>
<b>16</b>	5.22	5.17	5.13	4.03	3.42	3.03	1.47	1.42
<b>17</b>	5.24	5.21	5.13	4.02	3.42	3.05	1.49	1.45
<b>18</b>	5.24	5.20	5.13	4.02	3.41	3.04	1.50	1.43
<b>19</b>	5.24	5.21	5.12	4.01	3.39	3.05	1.49	1.44
<b>20</b>	5.25	5.21	5.11	4.00	3.41	3.05	1.50	1.43
<b>Average</b>	<b>5.24</b>	<b>5.20</b>	<b>5.12</b>	<b>4.02</b>	<b>3.41</b>	<b>3.04</b>	<b>1.49</b>	<b>1.43</b>

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>21</b>	5.22	5.17	5.13	4.03	3.42	3.03	1.47	1.42
<b>22</b>	5.12	5.07	5.08	3.94	3.38	3.09	1.51	1.44
<b>23</b>	5.12	5.07	5.08	3.94	3.38	3.08	1.52	1.45
<b>24</b>	5.13	5.08	5.08	3.95	3.37	3.11	1.49	1.45
<b>25</b>	5.14	5.09	5.09	3.91	3.36	3.12	1.50	1.45
<b>26</b>	5.13	5.09	5.06	3.90	3.37	3.13	1.50	1.46
<b>27</b>	5.13	5.08	5.07	3.93	3.40	3.15	1.50	1.45
<b>28</b>	5.12	5.08	5.06	3.92	3.39	3.14	1.51	1.47
<b>29</b>	5.12	5.08	5.04	3.93	3.38	3.18	1.51	1.47
<b>30</b>	5.11	5.08	5.06	3.90	3.36	3.17	1.51	1.46
<b>Average</b>	<b>5.13</b>	<b>5.09</b>	<b>5.08</b>	<b>3.94</b>	<b>3.38</b>	<b>3.12</b>	<b>1.50</b>	<b>1.45</b>
<b>31</b>	5.16	5.11	5.10	3.90	3.28	3.04	1.46	1.42
<b>32</b>	5.18	5.12	5.11	3.85	3.30	3.05	1.46	1.42
<b>33</b>	5.19	5.13	5.10	3.87	3.32	3.07	1.47	1.43
<b>34</b>	5.19	5.12	5.09	3.89	3.30	3.07	1.46	1.43
<b>35</b>	5.19	5.13	5.10	3.82	3.29	3.09	1.45	1.44
<b>36</b>	5.19	5.12	5.08	3.85	3.29	3.10	1.47	1.43
<b>37</b>	5.19	5.12	5.07	3.86	3.28	3.12	1.46	1.44
<b>38</b>	5.17	5.12	5.07	3.86	3.29	3.13	1.45	1.45
<b>39</b>	5.17	5.11	5.07	3.85	3.30	3.14	1.45	1.46
<b>40</b>	5.18	5.12	5.06	3.81	3.31	3.14	1.46	1.46
<b>Average</b>	<b>5.18</b>	<b>5.12</b>	<b>5.08</b>	<b>3.86</b>	<b>3.30</b>	<b>3.10</b>	<b>1.46</b>	<b>1.44</b>
<b>41</b>	5.08	5.03	5.08	3.82	3.32	3.19	1.51	1.48
<b>42</b>	5.09	5.03	5.08	3.84	3.31	3.23	1.52	1.50
<b>43</b>	5.09	5.04	5.06	3.86	3.31	3.25	1.52	1.51
<b>44</b>	5.09	5.05	5.06	3.86	3.31	3.25	1.52	1.52
<b>45</b>	5.11	5.04	5.05	3.84	3.32	3.24	1.53	1.51
<b>46</b>	5.10	5.04	5.07	3.83	3.33	3.27	1.53	1.51
<b>47</b>	5.08	5.03	5.04	3.84	3.33	3.27	1.54	1.54
<b>48</b>	5.08	5.03	5.03	3.82	3.31	3.26	1.53	1.54
<b>49</b>	5.08	5.03	5.03	3.84	3.32	3.30	1.54	1.54
<b>50</b>	5.09	5.03	5.03	3.82	3.34	3.31	1.54	1.54
<b>Average</b>	<b>5.09</b>	<b>5.03</b>	<b>5.05</b>	<b>3.84</b>	<b>3.32</b>	<b>3.26</b>	<b>1.53</b>	<b>1.52</b>

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>51</b>	5.09	5.08	5.09	3.81	3.33	3.29	1.52	1.39
<b>52</b>	5.07	5.06	5.08	3.83	3.34	3.29	1.53	1.39
<b>53</b>	5.08	5.07	5.07	3.82	3.32	3.29	1.52	1.29
<b>54</b>	5.09	5.06	5.07	3.82	3.32	3.31	1.52	1.55
<b>55</b>	5.08	5.05	5.06	3.83	3.33	3.31	1.53	1.52
<b>56</b>	5.07	5.05	5.06	3.82	3.33	3.32	1.53	1.52
<b>57</b>	5.08	5.05	5.06	3.79	3.33	3.33	1.52	1.53
<b>58</b>	5.08	5.06	5.08	3.82	3.32	3.31	1.55	1.52
<b>59</b>	5.06	5.04	5.03	3.81	3.31	3.33	1.53	1.52
<b>60</b>	5.07	5.04	5.05	3.80	3.31	3.34	1.54	1.53
<b>61</b>	5.13	5.10	5.10	3.79	3.32	3.34	1.54	1.52
<b>62</b>	5.13	5.10	5.10	3.78	3.29	3.34	1.51	1.50
<b>63</b>	3.87	3.89	3.90	3.43	3.24	3.17	1.47	1.44
<b>64</b>	5.09	5.07	5.06	3.74	3.30	3.32	1.51	1.46
<b>65</b>	5.09	5.07	5.06	3.79	3.29	3.31	1.52	1.51
<b>66</b>	5.09	5.06	5.05	3.76	3.28	3.32	1.52	1.51
<b>67</b>	5.09	5.05	5.05	3.76	3.29	3.36	1.52	1.52
<b>68</b>	5.07	5.04	5.05	3.77	3.26	3.37	1.53	1.51
<b>69</b>	5.08	5.04	5.04	3.72	3.26	3.38	1.52	1.51
<b>70</b>	5.08	5.04	5.04	3.78	3.27	3.36	1.52	1.52
<b>Average</b>	<b>5.02</b>	<b>5.00</b>	<b>5.01</b>	<b>3.77</b>	<b>3.30</b>	<b>3.32</b>	<b>1.52</b>	<b>1.49</b>

**Table A.3** Continued

Run	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8
71	5.00	4.95	5.00	3.74	3.28	3.38	1.57	1.58
72	5.04	4.99	5.02	3.74	3.27	3.40	1.58	1.58
73	5.03	4.97	5.01	3.77	3.27	3.36	1.58	1.57
74	5.02	4.96	5.01	3.74	3.27	3.37	1.58	1.54
75	5.02	4.98	5.02	3.76	3.29	3.39	1.58	1.56
76	5.01	4.96	4.99	3.76	3.28	3.37	1.58	1.56
77	NR							
78	5.00	4.95	4.97	3.75	3.27	3.38	1.58	1.55
79	5.00	4.95	4.97	3.77	3.28	3.39	1.59	1.55
80	NR							
81	5.00	4.95	4.97	3.72	3.27	3.40	1.58	1.56
82	4.99	4.94	4.97	3.76	3.26	3.40	1.57	1.57
83	4.98	4.93	4.95	3.75	3.26	3.39	1.58	1.56
84	4.99	4.94	4.95	3.74	3.27	3.40	1.59	1.55
85	5.05	5.01	5.00	3.71	3.27	3.41	1.57	1.55
86	5.04	5.00	5.00	3.70	3.27	3.40	1.58	1.54
87	5.02	4.97	4.97	3.71	3.26	3.41	1.57	1.54
88	5.00	4.97	4.97	3.71	3.25	3.40	1.57	1.52
89	5.01	4.96	4.96	3.73	3.27	3.39	1.57	1.53
90	5.03	4.98	4.98	3.73	3.27	3.40	1.55	1.53
Average	<b>5.01</b>	<b>4.96</b>	<b>4.98</b>	<b>3.74</b>	<b>3.27</b>	<b>3.39</b>	<b>1.58</b>	<b>1.55</b>

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>91</b>	5.05	5.01	4.98	3.74	3.25	3.36	1.56	1.50
<b>92</b>	5.08	5.03	5.00	3.73	3.23	3.38	1.56	1.51
<b>93</b>	5.06	5.03	4.99	3.71	3.23	3.38	1.57	1.51
<b>94</b>	5.04	4.99	4.96	3.69	3.26	3.39	1.56	1.52
<b>95</b>	5.03	4.99	4.97	3.73	3.27	3.39	1.56	1.52
<b>96</b>	5.03	4.99	4.95	3.70	3.25	3.41	1.56	1.52
<b>97</b>	5.04	4.99	4.95	3.69	3.23	3.40	1.56	1.51
<b>98</b>	5.03	4.98	4.95	3.67	3.24	3.40	1.56	1.53
<b>99</b>	5.04	5.00	4.96	3.70	3.23	3.39	1.56	1.52
<b>100</b>	5.03	4.98	4.94	3.68	3.25	3.40	1.56	1.52
<b>101</b>	5.03	4.99	4.94	3.71	3.24	3.40	1.56	1.50
<b>102</b>	5.02	4.96	4.94	3.67	3.21	3.41	1.56	1.51
<b>103</b>	4.99	4.96	4.92	3.67	3.23	3.43	1.57	1.50
<b>104</b>	5.01	4.98	4.94	3.68	3.22	3.41	1.56	1.51
<b>105</b>	5.00	4.95	4.92	3.68	3.24	3.39	1.56	1.50
<b>106</b>	4.99	4.96	4.92	3.68	3.23	3.40	1.57	1.51
<b>107</b>	4.99	4.94	4.91	3.69	3.22	3.39	1.56	1.50
<b>108</b>	4.98	4.94	4.91	3.67	3.23	3.39	1.55	1.50
<b>109</b>	5.00	4.97	4.92	3.67	3.22	3.41	1.58	1.51
<b>110</b>	4.98	4.94	4.90	3.68	3.22	3.42	1.58	1.51
<b>Average</b>	<b>5.02</b>	<b>4.98</b>	<b>4.94</b>	<b>3.69</b>	<b>3.23</b>	<b>3.40</b>	<b>1.56</b>	<b>1.51</b>

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>111</b>	4.82	4.78	4.78	3.65	3.22	3.48	1.62	1.56
<b>112</b>	4.81	4.76	4.77	3.61	3.21	3.48	1.62	1.57
<b>113</b>	4.80	4.75	4.75	3.59	3.21	3.48	1.64	1.58
<b>114</b>	4.89	4.85	4.86	3.63	3.21	3.50	1.64	1.57
<b>115</b>	4.87	4.82	4.83	3.62	3.21	3.49	1.64	1.57
<b>116</b>	4.87	4.82	4.81	3.63	3.22	3.49	1.63	1.56
<b>117</b>	4.85	4.81	4.83	3.60	3.22	3.50	1.64	1.57
<b>118</b>	4.87	4.82	4.81	3.62	3.24	3.50	1.64	1.57
<b>119</b>	4.85	4.81	4.81	3.62	3.22	3.52	1.64	1.57
<b>120</b>	4.85	4.82	4.81	3.62	3.23	3.49	1.65	1.58
<b>121</b>	4.88	4.84	4.83	3.59	3.19	3.47	1.59	1.54
<b>122</b>	4.90	4.87	4.84	3.59	3.17	3.50	1.62	1.55
<b>123</b>	4.90	4.86	4.84	3.61	3.19	3.50	1.61	1.54
<b>124</b>	4.91	4.86	4.85	3.61	3.20	3.51	1.61	1.55
<b>125</b>	4.90	4.86	4.83	3.57	3.19	3.50	1.60	1.55
<b>126</b>	4.88	4.83	4.81	3.57	3.18	3.47	1.60	1.53
<b>127</b>	4.87	4.82	4.81	3.59	3.18	3.49	1.61	1.55
<b>128</b>	4.87	4.82	4.79	3.58	3.17	3.50	1.61	1.54
<b>129</b>	4.86	4.82	4.80	3.56	3.16	3.48	1.60	1.54
<b>130</b>	4.85	4.81	4.78	3.57	3.17	3.48	1.60	1.55
<b>Average</b>	<b>4.86</b>	<b>4.82</b>	<b>4.81</b>	<b>3.60</b>	<b>3.20</b>	<b>3.49</b>	<b>1.62</b>	<b>1.56</b>
<b>131</b>	4.87	4.83	4.86	3.60	3.22	3.46	1.61	1.57
<b>132</b>	4.91	4.86	4.87	3.61	3.21	3.46	1.62	1.57
<b>133</b>	4.90	4.85	4.87	3.61	3.20	3.45	1.62	1.56
<b>134</b>	4.91	4.86	4.86	3.60	3.24	3.46	1.62	1.56
<b>135</b>	4.88	4.83	4.83	3.59	3.16	3.44	1.61	1.56
<b>136</b>	4.87	4.83	4.82	3.58	3.17	3.46	1.60	1.56
<b>137</b>	4.88	4.84	4.84	3.57	3.20	3.46	1.62	1.54
<b>138</b>	4.88	4.83	4.82	3.59	3.17	3.46	1.60	1.56
<b>139</b>	4.86	4.81	4.80	3.59	3.19	3.47	1.61	1.49
<b>140</b>	4.92	4.88	4.83	3.58	3.16	3.44	1.59	1.43
<b>Average</b>	<b>4.89</b>	<b>4.84</b>	<b>4.84</b>	<b>3.59</b>	<b>3.19</b>	<b>3.46</b>	<b>1.61</b>	<b>1.54</b>

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>141</b>	4.89	4.80	4.83	3.58	3.16	3.44	1.61	1.45
<b>142</b>	4.90	4.83	4.84	3.56	3.18	3.46	1.63	1.43
<b>143</b>	4.89	4.81	4.82	3.57	3.17	3.45	1.62	1.38
<b>144</b>	4.87	4.80	4.80	3.58	3.17	3.45	1.61	1.37
<b>145</b>	4.86	4.79	4.79	3.55	3.17	3.46	1.61	1.39
<b>146</b>	4.85	4.77	4.80	3.55	3.16	3.46	1.62	1.39
<b>147</b>	4.84	4.77	4.79	3.52	3.18	3.47	1.62	1.39
<b>148</b>	4.83	4.76	4.76	3.54	3.18	3.48	1.60	1.40
<b>149</b>	4.85	4.77	4.78	3.54	3.18	3.48	1.62	1.38
<b>150</b>	4.83	4.76	4.77	3.55	3.18	3.49	1.61	1.81
<b>Average</b>	<b>4.86</b>	<b>4.79</b>	<b>4.80</b>	<b>3.55</b>	<b>3.17</b>	<b>3.46</b>	<b>1.61</b>	<b>1.44</b>
<b>151</b>	4.96	4.99	4.82	3.35	2.98	3.23	1.29	1.11
<b>152</b>	4.94	5.00	4.83	3.30	2.94	3.18	1.23	1.04
<b>153</b>	4.89	4.95	4.83	3.28	2.87	3.11	1.14	0.95
<b>154</b>	4.85	4.91	4.82	3.28	2.85	3.06	1.08	0.88
<b>155</b>	4.82	4.86	4.79	3.25	2.81	3.02	1.02	0.83
<b>156</b>	4.78	4.81	4.74	3.24	2.78	2.98	0.98	0.80
<b>157</b>	4.96	4.93	4.76	3.41	3.02	3.28	1.39	1.14
<b>158</b>	4.97	4.97	4.75	3.43	3.05	3.26	1.39	1.13
<b>159</b>	4.95	4.96	4.75	3.43	3.02	3.26	1.39	1.12
<b>160</b>	4.97	4.97	4.75	3.40	3.01	3.26	1.38	1.12
<b>Average</b>	<b>4.91</b>	<b>4.93</b>	<b>4.78</b>	<b>3.34</b>	<b>2.93</b>	<b>3.16</b>	<b>1.23</b>	<b>1.01</b>
<b>161</b>	4.85	4.87	4.72	3.39	2.99	3.27	1.39	1.34
<b>162</b>	4.91	4.92	4.76	3.38	2.99	3.27	1.40	1.35
<b>163</b>	4.92	4.93	4.79	3.39	2.99	3.29	1.39	1.26
<b>164</b>	3.70	3.73	3.65	3.10	2.91	3.19	1.29	1.08
<b>165</b>	NR							
<b>166</b>	4.88	4.88	4.70	3.39	2.98	3.29	1.39	1.33
<b>167</b>	4.90	4.91	4.73	3.39	2.98	3.29	1.38	1.25
<b>168</b>	4.90	4.90	4.71	3.38	2.98	3.31	1.39	1.27
<b>169</b>	4.87	4.87	4.71	3.39	3.00	3.31	1.39	1.28

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>170</b>	4.88	4.89	4.70	3.37	2.99	3.30	1.39	1.32
<b>171</b>	4.88	4.89	4.71	3.37	2.99	3.31	1.38	1.32
<b>172</b>	4.86	4.86	4.68	3.35	2.97	3.30	1.39	1.32
<b>173</b>	4.87	4.88	4.70	3.36	2.97	3.30	1.38	1.33
<b>174</b>	4.86	4.87	4.69	3.36	2.99	3.30	1.38	1.32
<b>175</b>	4.85	4.86	4.69	3.34	2.99	3.31	1.37	1.32
<b>176</b>	4.86	4.87	4.67	3.36	2.98	3.32	1.38	1.32
<b>177</b>	4.85	4.87	4.68	3.37	2.99	3.33	1.37	1.32
<b>178</b>	4.87	4.87	4.69	3.37	2.99	3.33	1.39	1.32
<b>179</b>	4.84	4.85	4.67	3.35	2.98	3.34	1.38	1.32
<b>180</b>	4.86	4.87	4.67	3.35	2.99	3.31	1.39	1.31
<b>Average</b>	<b>4.81</b>	<b>4.82</b>	<b>4.65</b>	<b>3.36</b>	<b>2.98</b>	<b>3.30</b>	<b>1.38</b>	<b>1.30</b>
<b>181</b>	4.82	4.84	4.66	3.31	2.97	3.31	1.42	1.21
<b>182</b>	4.86	4.88	4.69	3.37	2.98	3.31	1.41	1.55
<b>183</b>	4.88	4.88	4.69	3.35	2.98	3.33	1.41	1.21
<b>184</b>	4.85	4.88	4.67	3.54	2.98	3.34	1.40	1.24
<b>185</b>	4.85	4.87	4.66	3.34	2.97	3.35	1.40	1.52
<b>186</b>	4.84	4.86	4.64	3.33	2.96	3.34	1.40	1.22
<b>187</b>	4.83	4.85	4.63	3.34	2.97	3.32	1.40	1.22
<b>188</b>	NR							
<b>189</b>	4.80	4.82	4.60	3.32	2.97	3.32	1.39	1.22
<b>190</b>	4.79	4.83	4.60	3.32	2.98	3.34	1.39	1.21
<b>Average</b>	<b>4.84</b>	<b>4.86</b>	<b>4.65</b>	<b>3.36</b>	<b>2.97</b>	<b>3.33</b>	<b>1.40</b>	<b>1.29</b>
<b>191</b>	4.77	4.80	4.64	3.30	2.95	3.32	1.36	1.31
<b>192</b>	4.80	4.81	4.66	3.30	2.95	3.31	1.37	1.36
<b>193</b>	4.79	4.80	4.64	3.28	2.94	3.29	1.36	1.31
<b>194</b>	4.79	4.81	4.64	3.28	2.93	3.31	1.37	1.31
<b>195</b>	4.77	4.73	4.63	3.28	2.93	3.29	1.36	1.31
<b>196</b>	4.74	4.76	4.60	3.27	2.92	3.29	1.35	1.30
<b>197</b>	NR							
<b>198</b>	4.70	4.71	4.55	3.26	2.90	3.27	1.36	1.19
<b>199</b>	4.74	4.76	4.59	3.29	2.92	3.27	1.35	1.18
<b>200</b>	4.73	4.75	4.59	3.26	2.90	3.28	1.36	0.99
<b>Average</b>	<b>4.76</b>	<b>4.77</b>	<b>4.62</b>	<b>3.28</b>	<b>2.93</b>	<b>3.29</b>	<b>1.36</b>	<b>1.25</b>

**Table A.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>201</b>	4.59	4.58	4.63	3.47	3.11	3.18	2.15	1.70
<b>202</b>	4.64	4.61	4.65	3.45	3.12	3.13	2.17	1.71
<b>203</b>	4.68	4.67	4.66	3.47	3.10	3.11	2.18	1.66
<b>204</b>	4.73	4.73	4.71	3.48	3.10	3.09	2.18	1.66
<b>205</b>	4.72	4.72	4.71	3.48	3.11	3.09	2.16	1.70
<b>206</b>	4.69	4.67	4.68	3.50	3.12	3.09	2.15	1.70
<b>207</b>	4.67	4.65	4.67	3.47	3.11	3.10	2.16	1.70
<b>208</b>	4.67	4.65	4.67	3.49	3.12	3.10	2.14	1.68
<b>209</b>	4.64	4.62	4.64	3.47	3.12	3.10	2.16	1.68
<b>210</b>	4.64	4.63	4.63	3.47	3.12	3.10	2.14	1.68
<b>Average</b>	<b>4.67</b>	<b>4.65</b>	<b>4.66</b>	<b>3.48</b>	<b>3.11</b>	<b>3.11</b>	<b>2.16</b>	<b>1.69</b>

**Table A.4** Mean cross-shore  $\bar{u}$  and standard deviation  $\sigma_u$  of the 2D ADV co-located with WG4 at  $x=8.40$  m, Red Vectrino co-located with WG5 at  $x= 11$  m and Blue Vectrino co-located with WG7 at  $x= 16.30$  m

Run	2D ADV at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>1</b>	-7.32	21.88	-6.12	19.13	-1.71	11.07
<b>2</b>	-6.10	21.52	-5.81	18.66	-2.37	11.09
<b>3</b>	-7.80	21.68	-6.25	18.72	-2.43	10.76
<b>4</b>	-6.68	21.52	-5.46	18.61	NR	NR
<b>5</b>	-7.06	21.81	-5.38	19.10	-1.48	10.57
<b>Average</b>	<b>-6.99</b>	<b>21.68</b>	<b>-5.80</b>	<b>18.84</b>	<b>-2.00</b>	<b>10.87</b>
<b>6</b>	-6.25	21.43	-5.51	18.65	-1.49	10.57
<b>7</b>	-7.59	21.42	-4.67	18.41	-1.60	10.25
<b>8</b>	-7.10	21.74	-5.35	18.31	-1.77	10.10
<b>9</b>	-6.26	21.54	-5.32	18.31	-1.98	10.23
<b>10</b>	-8.12	21.59	-5.46	18.50	-1.45	10.22
<b>Average</b>	<b>-7.06</b>	<b>21.54</b>	<b>-5.26</b>	<b>18.44</b>	<b>-1.66</b>	<b>10.27</b>
<b>11</b>	-6.25	21.43	-3.42	15.43	-1.43	10.59
<b>12</b>	-6.69	21.53	-5.76	18.44	-1.95	10.56
<b>13</b>	-7.62	21.36	-5.08	18.29	-2.05	10.44
<b>14</b>	-7.04	21.58	-5.68	18.21	-1.60	10.38
<b>15</b>	-6.87	21.36	-5.18	18.18	-1.27	10.62
<b>Average</b>	<b>-6.89</b>	<b>21.45</b>	<b>-5.02</b>	<b>17.71</b>	<b>-1.66</b>	<b>10.52</b>
<b>16</b>	-6.68	21.41	-5.62	18.37	-2.55	12.79
<b>17</b>	-6.77	21.41	-5.13	18.19	-2.88	12.10
<b>18</b>	-7.37	21.16	-4.84	18.36	-2.38	11.02
<b>19</b>	-7.81	21.46	-5.27	18.17	-1.98	10.29
<b>20</b>	-6.74	21.19	-5.48	18.18	-1.52	10.02
<b>Average</b>	<b>-7.08</b>	<b>21.33</b>	<b>-5.27</b>	<b>18.25</b>	<b>-2.26</b>	<b>11.24</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>21</b>	-6.68	21.41	-4.47	18.20	-1.64	10.84
<b>22</b>	-7.53	20.90	-5.65	18.01	-2.38	11.03
<b>23</b>	-7.99	20.91	-5.13	18.04	-2.36	10.45
<b>24</b>	-8.90	20.65	-4.78	17.86	-2.00	10.49
<b>25</b>	-7.21	20.93	-4.53	17.94	-2.19	10.59
<b>26</b>	-7.34	20.68	-8.21	20.70	-2.32	10.50
<b>27</b>	-7.94	20.81	NR	NR	NR	NR
<b>28</b>	-7.42	20.31	NR	NR	NR	NR
<b>29</b>	-6.80	20.72	-4.49	17.95	-3.19	10.44
<b>30</b>	-7.80	20.69	-4.80	17.96	-2.87	10.26
<b>Average</b>	<b>-7.56</b>	<b>20.80</b>	<b>-5.26</b>	<b>18.33</b>	<b>-2.37</b>	<b>10.58</b>
<b>31</b>	-7.27	20.79	-5.22	17.99	-2.47	10.31
<b>32</b>	-6.95	20.44	-4.82	17.74	-2.23	10.52
<b>33</b>	-7.26	20.58	-4.80	17.74	-2.59	12.34
<b>34</b>	-7.90	20.84	-5.15	17.82	-2.45	12.05
<b>35</b>	-7.11	20.72	-5.22	17.77	-2.34	10.56
<b>36</b>	-8.26	20.62	-4.30	17.70	-1.91	9.83
<b>37</b>	-7.54	20.68	NR	NR	NR	NR
<b>38</b>	-7.18	18.98	NR	NR	NR	NR
<b>39</b>	NR	NR	-4.18	17.74	-2.67	12.93
<b>40</b>	-6.38	20.29	-5.08	17.69	-2.40	12.15
<b>Average</b>	<b>-7.32</b>	<b>20.44</b>	<b>-4.85</b>	<b>17.77</b>	<b>-2.38</b>	<b>11.34</b>
<b>41</b>	-7.78	20.62	-6.42	21.06	-2.47	10.23
<b>42</b>	-7.96	20.36	-3.68	16.89	-1.67	9.97
<b>43</b>	-6.76	20.69	-3.11	16.92	-1.15	10.56
<b>44</b>	-7.03	20.10	-4.44	16.77	-2.11	11.82
<b>45</b>	-7.09	20.50	-4.79	16.75	-3.24	12.66
<b>46</b>	-7.25	20.07	-4.91	16.97	-3.35	12.22
<b>47</b>	-7.47	20.16	-4.67	22.02	-3.19	11.27
<b>48</b>	-7.08	20.17	-3.70	16.79	-2.35	10.53
<b>49</b>	-7.34	20.52	-3.67	16.68	-2.34	10.26
<b>50</b>	-6.84	19.97	-3.81	16.75	-1.97	10.21
<b>Average</b>	<b>-7.26</b>	<b>20.31</b>	<b>-4.32</b>	<b>17.76</b>	<b>-2.38</b>	<b>10.97</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>51</b>	-6.75	20.11	-4.32	16.88	-1.82	10.20
<b>52</b>	-7.10	20.31	NR	NR	NR	NR
<b>53</b>	-7.16	20.07	-3.54	16.80	-3.06	11.27
<b>54</b>	-7.83	19.88	-3.67	16.81	-2.33	10.98
<b>55</b>	-7.00	20.05	-4.39	16.85	-2.11	11.24
<b>56</b>	-6.88	20.07	-3.82	16.72	NR	NR
<b>57</b>	NR	NR	-4.16	16.72	NR	NR
<b>58</b>	-7.39	20.03	-3.98	16.77	-2.65	10.26
<b>59</b>	-6.36	19.78	-3.40	16.66	-2.41	12.01
<b>60</b>	-6.17	20.13	-3.98	16.85	-2.31	12.86
<b>61</b>	-7.65	19.87	NR	NR	NR	NR
<b>62</b>	-7.74	20.01	-3.89	17.44	-2.12	10.07
<b>63</b>	-4.34	18.66	-2.17	15.87	-1.30	9.25
<b>64</b>	-8.63	19.97	-3.23	17.37	-2.02	10.65
<b>65</b>	-7.27	19.83	-3.38	17.10	-2.89	11.67
<b>66</b>	-7.56	19.89	-4.12	17.02	-3.21	11.60
<b>67</b>	-7.51	19.61	-3.22	17.32	-3.02	10.67
<b>68</b>	-7.41	19.72	NR	NR	NR	NR
<b>69</b>	-7.03	19.47	-3.42	17.30	NR	NR
<b>70</b>	-6.91	19.43	-3.41	17.40	-3.14	11.56
<b>Average</b>	<b>-7.09</b>	<b>19.84</b>	<b>-3.65</b>	<b>16.93</b>	<b>-2.46</b>	<b>11.02</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>71</b>	-6.99	19.60	-3.92	17.06	-2.45	11.17
<b>72</b>	-7.31	19.75	-3.43	17.03	-2.12	10.60
<b>73</b>	-7.31	19.66	-3.38	16.93	-2.67	11.19
<b>74</b>	-7.03	19.49	-3.32	16.91	-1.75	10.54
<b>75</b>	-8.06	19.62	-3.34	16.81	NR	NR
<b>76</b>	-7.12	19.64	-3.97	17.14	-1.87	10.27
<b>77</b>	NR	NR	NR	NR	NR	NR
<b>78</b>	-7.55	19.48	-3.64	16.85	NR	NR
<b>79</b>	-7.93	19.66	-3.60	16.86	-2.69	10.83
<b>80</b>	-4.10	18.34	-2.30	16.44	-2.51	10.17
<b>81</b>	NR	NR	NR	NR	NR	NR
<b>82</b>	-7.39	19.72	-3.83	17.15	NR	NR
<b>83</b>	-6.74	19.51	-2.91	16.86	-1.46	10.78
<b>84</b>	-6.79	19.49	NR	NR	NR	NR
<b>85</b>	-8.30	19.41	-3.56	16.79	-2.49	11.38
<b>86</b>	-7.18	19.38	-3.53	16.60	-2.30	10.46
<b>87</b>	-7.43	19.46	-2.60	16.59	-2.06	11.04
<b>88</b>	-8.32	19.49	-3.09	16.88	-2.85	11.01
<b>89</b>	-8.97	19.61	-2.71	16.56	-3.03	9.27
<b>90</b>	-8.42	19.25	-3.57	16.72	NR	NR
<b>Average</b>	<b>-7.39</b>	<b>19.48</b>	<b>-3.33</b>	<b>16.83</b>	<b>-2.33</b>	<b>10.67</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>91</b>	-7.24	19.71	-3.32	16.85	-2.57	10.22
<b>92</b>	-7.06	19.35	-2.65	16.76	NR	NR
<b>93</b>	-7.84	19.18	-4.12	16.66	-2.82	7.60
<b>94</b>	-7.31	19.08	-3.64	16.78	NR	NR
<b>95</b>	-8.05	19.40	-2.92	16.69	-2.35	14.98
<b>96</b>	-7.20	19.12	-3.04	16.64	-1.26	8.38
<b>97</b>	-8.78	19.30	-2.58	16.71	-1.81	8.92
<b>98</b>	-8.48	19.09	-2.95	16.88	-1.08	9.09
<b>99</b>	-6.79	19.25	-3.56	16.80	-1.78	9.21
<b>100</b>	-6.41	19.38	-3.31	16.72	-2.49	9.29
<b>101</b>	-7.73	19.27	NR	NR	NR	NR
<b>102</b>	-8.29	19.25	-2.93	16.73	-0.66	9.07
<b>103</b>	-7.87	19.07	-2.29	16.80	-2.90	11.49
<b>104</b>	-8.25	19.26	-3.62	16.77	NR	NR
<b>105</b>	-8.13	19.30	-2.91	17.01	NR	NR
<b>106</b>	-8.42	19.05	-2.50	17.10	-1.64	8.02
<b>107</b>	-8.92	19.02	-3.05	17.04	-1.09	9.58
<b>108</b>	-7.61	18.89	NR	NR	NR	NR
<b>109</b>	-8.25	19.31	-2.65	17.08	-2.25	8.52
<b>110</b>	-7.18	19.31	-3.63	17.24	NR	NR
<b>Average</b>	<b>-7.79</b>	<b>19.23</b>	<b>-3.09</b>	<b>16.85</b>	<b>-1.90</b>	<b>9.57</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vetrino at WG5		Blue Vetrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>111</b>	-6.54	19.61	-3.68	17.36	NR	NR
<b>112</b>	-6.96	19.31	-3.17	17.01	NR	NR
<b>113</b>	-5.85	19.39	-3.14	17.17	-2.04	9.31
<b>114</b>	-7.72	19.41	-3.31	17.31	NR	NR
<b>115</b>	-7.89	19.31	-2.98	17.17	NR	NR
<b>116</b>	-8.11	19.12	-3.22	17.57	-1.72	8.35
<b>117</b>	-7.72	19.34	-2.78	17.08	-0.97	6.85
<b>118</b>	-6.89	19.06	-3.82	17.10	NR	NR
<b>119</b>	-7.45	19.22	-3.23	17.20	-2.32	9.40
<b>120</b>	-7.31	19.21	-3.52	17.28	NR	NR
<b>121</b>	-7.28	18.92	-3.52	17.35	-1.84	9.28
<b>122</b>	-7.79	19.21	-2.69	17.27	NR	NR
<b>123</b>	-7.19	19.12	-3.21	17.28	-0.53	8.29
<b>124</b>	-6.96	19.02	-3.46	17.18	-1.97	10.09
<b>125</b>	-7.43	19.00	-2.91	17.19	-2.50	9.68
<b>126</b>	-7.23	19.16	-2.97	17.30	-1.92	8.86
<b>127</b>	-7.18	19.24	NR	NR	-0.62	7.61
<b>128</b>	-6.05	19.22	NR	NR	-1.36	9.27
<b>129</b>	-7.45	18.97	-2.65	17.07	-0.82	7.51
<b>130</b>	-8.08	19.15	-2.62	17.15	-0.96	9.05
<b>Average</b>	<b>-7.25</b>	<b>19.20</b>	<b>-3.16</b>	<b>17.22</b>	<b>-1.51</b>	<b>8.73</b>
<b>131</b>	-7.24	19.09	-3.50	17.19	-2.13	12.26
<b>132</b>	NR	NR	-3.47	17.14	-2.15	11.58
<b>133</b>	-8.43	19.00	-2.45	16.97	-1.66	11.12
<b>134</b>	-7.37	19.13	-2.05	16.69	-2.23	11.12
<b>135</b>	-7.85	18.78	-3.20	17.03	-2.37	10.99
<b>136</b>	-8.27	19.12	-2.97	17.19	-2.53	10.91
<b>137</b>	-4.94	16.13	NR	NR	NR	NR
<b>138</b>	-7.46	18.95	NR	NR	-2.83	11.24
<b>139</b>	-8.19	19.15	-2.88	16.86	-2.79	10.82
<b>140</b>	-8.17	18.83	-3.23	16.99	-2.34	10.67
<b>Average</b>	<b>-7.54</b>	<b>18.69</b>	<b>-2.97</b>	<b>17.01</b>	<b>-2.34</b>	<b>11.19</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
141	-7.80	19.21	-2.57	16.50	-2.34	11.46
142	-7.45	19.17	-2.55	16.46	-2.87	11.50
143	-6.79	19.13	NR	NR	NR	NR
144	-6.92	19.13	NR	NR	-3.20	11.65
145	-7.98	19.03	-2.17	16.39	-2.76	11.62
146	-7.96	19.05	-2.68	16.27	-2.36	11.64
147	-7.00	19.04	-2.73	16.35	-2.02	12.23
148	-7.88	18.87	-3.13	16.45	-2.76	11.64
149	-7.70	18.67	NR	NR	NR	NR
150	-7.72	18.80	NR	NR	-2.11	11.65
Average	<b>-7.52</b>	<b>19.01</b>	<b>-2.64</b>	<b>16.40</b>	<b>-2.55</b>	<b>11.67</b>
151	NR	NR	NR	NR	NR	NR
152	-7.80	18.30	-5.69	19.67	-0.87	9.63
153	-7.01	17.94	-5.95	21.48	-0.82	9.62
154	NR	NR	NR	NR	NR	NR
155	-6.10	17.50	-2.95	17.62	-0.86	9.30
156	-7.05	17.25	-0.90	15.38	-1.05	8.95
157	-7.83	18.66	-1.60	15.81	-1.76	15.14
158	-6.70	18.47	-2.02	15.68	-1.90	10.49
159	-7.66	18.53	-1.77	15.70	-1.82	10.06
160	-7.10	18.40	-1.66	15.54	-1.63	11.40
Average	<b>-7.16</b>	<b>18.13</b>	<b>-2.82</b>	<b>17.11</b>	<b>-1.34</b>	<b>10.57</b>
161	-7.45	18.36	-1.79	15.41	-1.56	10.80
162	-6.96	18.34	-0.93	15.29	-1.54	11.66
163	-6.58	18.34	-1.93	15.48	-2.39	11.84
164	-4.81	17.50	-1.02	14.60	-2.45	10.05
165	NR	NR	-2.08	15.49	-2.08	10.42
166	-7.26	18.16	-1.61	15.58	-1.54	10.58
167	-7.53	17.90	-1.54	15.50	-1.97	10.58
168	-7.55	18.38	-1.62	15.46	-1.70	10.17
169	-6.45	18.15	NR	NR	-1.89	10.14

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>170</b>	-7.59	18.19	NR	NR	-1.59	10.57
<b>171</b>	-6.69	17.91	-1.58	15.18	-1.27	11.15
<b>172</b>	-6.61	18.20	-1.44	15.40	NR	NR
<b>173</b>	-7.64	18.02	NR	NR	NR	NR
<b>174</b>	-7.26	17.89	-0.89	15.26	-2.20	11.69
<b>175</b>	-5.84	18.42	-1.53	15.21	-1.93	11.62
<b>176</b>	-7.41	18.06	-1.95	15.29	-1.67	10.92
<b>177</b>	-7.48	17.97	-1.02	15.16	-1.07	10.33
<b>178</b>	-5.71	18.14	-1.88	15.36	-1.15	10.42
<b>179</b>	-7.25	18.06	-1.64	15.24	NR	NR
<b>180</b>	-7.51	17.89	-1.65	15.01	-1.53	10.17
<b>Average</b>	<b>-6.92</b>	<b>18.10</b>	<b>-1.53</b>	<b>15.29</b>	<b>-1.74</b>	<b>10.77</b>
<b>181</b>	-6.98	17.90	-1.68	15.13	-1.36	10.58
<b>182</b>	-7.04	18.38	-1.50	14.76	-1.14	10.94
<b>183</b>	-7.55	18.03	-2.02	15.13	-1.58	11.15
<b>184</b>	-6.76	18.38	-2.02	14.96	-1.81	11.14
<b>185</b>	NR	NR	-1.63	15.05	-1.36	10.77
<b>186</b>	-7.09	18.02	-2.14	15.23	-1.81	10.86
<b>187</b>	-7.86	18.01	NR	NR	NR	NR
<b>188</b>	NR	NR	NR	NR	NR	NR
<b>189</b>	-8.10	18.09	-1.52	14.98	-2.18	10.20
<b>190</b>	-4.50	18.06	-1.30	NR	-1.78	10.21
<b>Average</b>	<b>-6.99</b>	<b>18.11</b>	<b>-1.73</b>	<b>15.03</b>	<b>-1.63</b>	<b>10.73</b>
<b>191</b>	-5.93	15.58	-1.68	15.13	-1.36	10.58
<b>192</b>	-7.59	17.73	-1.50	14.76	-1.14	10.94
<b>193</b>	-7.04	18.08	-2.02	15.13	NR	NR
<b>194</b>	-7.15	18.07	-2.02	14.96	-1.81	11.14
<b>195</b>	-7.90	17.57	-1.63	15.05	-1.36	10.77
<b>196</b>	-6.85	17.76	-2.14	15.23	-1.81	10.86
<b>197</b>	NR	NR	NR	NR	NR	NR
<b>198</b>	-6.63	17.88	-1.17	13.82	-2.20	9.66
<b>199</b>	-5.97	18.09	-1.52	14.98	-2.18	10.20
<b>200</b>	-6.23	17.95	-2.02	14.91	-1.78	10.21
<b>Average</b>	<b>-6.81</b>	<b>17.63</b>	<b>-1.75</b>	<b>14.88</b>	<b>-1.70</b>	<b>10.55</b>

**Table A.4** Continued

Run	2D AVD at WG4		Red Vectrino at WG5		Blue Vectrino at WG6	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>201</b>	-7.03	17.82	-3.10	15.13	NR	NR
<b>202</b>	-6.73	17.96	-3.20	15.04	NR	NR
<b>203</b>	-7.11	17.72	-1.87	14.55	-5.78	16.79
<b>204</b>	-7.74	17.53	-7.04	20.72	-6.08	16.97
<b>205</b>	-5.11	17.73	-3.15	14.70	-5.19	16.81
<b>206</b>	-7.42	17.61	-3.15	14.70	-5.19	16.81
<b>207</b>	-6.07	17.81	-1.96	14.60	-4.74	16.90
<b>208</b>	-7.74	17.64	-6.98	20.41	-5.19	17.14
<b>209</b>	-7.63	17.55	-3.04	14.89	-5.25	17.16
<b>210</b>	-6.92	17.41	-2.41	14.90	-4.28	17.40
<b>Average</b>	<b>-6.95</b>	<b>17.68</b>	<b>-3.59</b>	<b>15.97</b>	<b>-5.21</b>	<b>17.00</b>

## Appendix B

### MEASURED HYDRODYNAMICS FOR 80 RUNS IN S TEST

**Table B.1** Incident Wave Characteristics for S Test

Run	$H_{mo}$ (cm)	$H_{rms}$ (cm)	$H_s$ (cm)	$T_p$ (s)	$T_s$ (s)	$T_m$ (s)	$R$	N. Wave
<b>1</b>	18.86	13.33	18.24	2.62	2.17	1.78	0.16	225
<b>2</b>	19.27	13.62	18.58	2.62	2.16	1.72	0.15	232
<b>3</b>	19.50	13.79	18.79	2.62	2.15	1.72	0.15	232
<b>4</b>	19.39	13.71	18.59	2.62	2.12	1.75	0.15	229
<b>5</b>	19.27	13.63	18.54	2.62	2.14	1.72	0.15	233
<b>Average</b>	<b>19.26</b>	<b>13.62</b>	<b>18.55</b>	<b>2.62</b>	<b>2.15</b>	<b>1.74</b>	<b>0.15</b>	<b>1151</b>
<b>6</b>	19.30	13.64	18.59	2.62	2.15	1.80	0.15	222
<b>7</b>	19.45	13.75	18.66	2.62	2.13	1.79	0.15	223
<b>8</b>	19.55	13.82	18.77	2.62	2.13	1.79	0.15	224
<b>9</b>	19.45	13.75	18.78	2.62	2.15	1.83	0.15	219
<b>10</b>	19.37	13.70	18.59	2.62	2.15	1.79	0.15	224
<b>Average</b>	<b>19.42</b>	<b>13.73</b>	<b>18.68</b>	<b>2.62</b>	<b>2.14</b>	<b>1.80</b>	<b>0.15</b>	<b>1112</b>
<b>11</b>	18.58	13.14	18.04	2.62	2.18	1.81	0.15	221
<b>12</b>	18.77	13.27	18.08	2.62	2.17	1.79	0.15	224
<b>13</b>	19.02	13.45	18.30	2.62	2.15	1.80	0.15	222
<b>14</b>	19.03	13.46	18.23	2.62	2.13	1.80	0.15	222
<b>15</b>	19.03	13.46	18.31	2.62	2.15	1.81	0.15	221
<b>Average</b>	<b>18.89</b>	<b>13.36</b>	<b>18.19</b>	<b>2.62</b>	<b>2.15</b>	<b>1.80</b>	<b>0.15</b>	<b>1110</b>
<b>16</b>	19.22	13.59	18.48	2.62	2.16	1.79	0.15	223
<b>17</b>	19.42	13.74	18.79	2.62	2.16	1.79	0.15	223
<b>18</b>	19.47	13.77	18.71	2.62	2.15	1.81	0.15	221
<b>19</b>	19.50	13.79	18.90	2.62	2.16	1.83	0.15	218
<b>20</b>	19.48	13.77	18.97	2.62	2.15	1.83	0.15	218
<b>Average</b>	<b>19.42</b>	<b>13.73</b>	<b>18.77</b>	<b>2.62</b>	<b>2.16</b>	<b>1.81</b>	<b>0.15</b>	<b>1103</b>
<b>21</b>	19.21	13.58	18.63	2.62	2.17	1.83	0.15	219
<b>22</b>	19.44	13.74	18.76	2.62	2.16	1.82	0.15	220
<b>23</b>	19.57	13.84	18.88	2.62	2.16	1.79	0.16	223
<b>24</b>	19.48	13.78	18.66	2.62	2.15	1.78	0.15	225
<b>25</b>	19.43	13.74	18.67	2.62	2.16	1.78	0.15	225
<b>Average</b>	<b>19.42</b>	<b>13.74</b>	<b>18.72</b>	<b>2.62</b>	<b>2.16</b>	<b>1.80</b>	<b>0.15</b>	<b>1112</b>

**Table B.1** Continued

Run	$H_{mo}$ (cm)	$H_{rms}$ (cm)	$H_s$ (cm)	$T_p$ (s)	$T_s$ (s)	$T_m$ (s)	$R$	N. Wave
<b>26</b>	19.14	13.53	18.49	2.62	2.17	1.81	0.15	221
<b>27</b>	19.35	13.68	18.57	2.62	2.16	1.80	0.16	222
<b>28</b>	19.38	13.70	18.65	2.62	2.15	1.83	0.16	219
<b>29</b>	19.33	13.67	18.65	2.62	2.16	1.79	0.15	223
<b>30</b>	19.34	13.67	18.67	2.62	2.15	1.83	0.16	219
<b>31</b>	19.21	13.58	18.61	2.62	2.18	1.82	0.16	220
<b>32</b>	19.29	13.64	18.61	2.62	2.15	1.82	0.15	220
<b>33</b>	19.28	13.64	18.59	2.62	2.15	1.81	0.16	221
<b>34</b>	19.24	13.61	18.57	2.62	2.15	1.83	0.15	219
<b>35</b>	19.18	13.57	18.53	2.62	2.14	1.83	0.15	219
<b>Average</b>	<b>19.27</b>	<b>13.63</b>	<b>18.59</b>	<b>2.62</b>	<b>2.16</b>	<b>1.82</b>	<b>0.15</b>	<b>2203</b>
<b>36</b>	19.09	13.50	18.45	2.62	2.18	1.83	0.16	219
<b>37</b>	19.41	13.73	18.87	2.62	2.15	1.80	0.16	222
<b>38</b>	19.44	13.75	18.79	2.62	2.16	1.82	0.15	220
<b>39</b>	19.42	13.73	18.76	2.62	2.17	1.83	0.16	218
<b>40</b>	NR	NR	NR	NR	NR	NR	NR	220*
<b>Average</b>	<b>19.34</b>	<b>13.68</b>	<b>18.72</b>	<b>2.62</b>	<b>2.16</b>	<b>1.82</b>	<b>0.16</b>	<b>1099</b>
<b>41</b>	19.41	13.73	18.81	2.62	2.16	1.81	0.15	221
<b>42</b>	19.70	13.93	19.04	2.62	2.15	1.82	0.15	220
<b>43</b>	19.69	13.92	18.99	2.62	2.14	1.84	0.16	217
<b>44</b>	19.60	13.86	18.95	2.62	2.15	1.84	0.15	217
<b>45</b>	19.54	13.82	18.87	2.62	2.14	1.81	0.16	221
<b>46</b>	19.64	13.89	18.92	2.62	2.15	1.80	0.16	222
<b>47</b>	19.55	13.82	18.94	2.62	2.16	1.85	0.16	216
<b>48</b>	19.51	13.80	18.80	2.62	2.14	1.83	0.16	219
<b>49</b>	19.50	13.79	18.88	2.62	2.15	1.82	0.16	220
<b>50</b>	19.37	13.70	18.74	2.62	2.18	1.85	0.16	216
<b>Average</b>	<b>19.59</b>	<b>13.85</b>	<b>18.93</b>	<b>2.62</b>	<b>2.15</b>	<b>1.82</b>	<b>0.15</b>	<b>2189</b>

\*The number of waves estimated as the average value in the proceeding runs after averaging.

**Table B.1** Continued

<b>Run</b>	<b><math>H_{mo}</math> (cm)</b>	<b><math>H_{rms}</math>(cm)</b>	<b><math>H_s</math> (cm)</b>	<b><math>T_p</math> (s)</b>	<b><math>T_s</math>(s)</b>	<b><math>T_m</math>(s)</b>	<b><math>R</math></b>	<b>N. Wave</b>
<b>51</b>	18.56	13.12	17.96	2.62	2.18	1.81	0.16	221
<b>52</b>	19.03	13.45	18.50	2.62	2.16	1.84	0.16	217
<b>53</b>	19.20	13.57	18.53	2.62	2.17	1.81	0.16	221
<b>54</b>	19.27	13.63	18.68	2.62	2.17	1.84	0.15	217
<b>55</b>	19.28	13.64	18.68	2.62	2.19	1.83	0.16	218
<b>56</b>	19.14	13.54	18.47	2.62	2.17	1.82	0.16	220
<b>57</b>	19.31	13.65	18.73	2.62	2.17	1.82	0.16	220
<b>58</b>	19.38	13.70	18.83	2.62	2.20	1.84	0.16	217
<b>59</b>	19.27	13.63	18.62	2.62	2.17	1.82	0.15	220
<b>60</b>	19.28	13.63	18.61	2.62	2.14	1.81	0.16	221
<b>Average</b>	<b>19.07</b>	<b>13.48</b>	<b>18.47</b>	<b>2.62</b>	<b>2.17</b>	<b>1.83</b>	<b>0.16</b>	<b>2192</b>
<b>61</b>	19.52	13.81	18.81	2.62	2.15	1.80	0.16	222
<b>62</b>	19.55	13.82	18.94	2.62	2.15	1.82	0.16	220
<b>63</b>	19.79	13.99	19.03	2.62	2.14	1.80	0.16	222
<b>64</b>	19.74	13.96	19.06	2.62	2.16	1.81	0.16	221
<b>65</b>	19.63	13.88	18.88	2.62	2.15	1.80	0.16	222
<b>66</b>	19.38	13.70	18.62	2.62	2.14	1.80	0.16	222
<b>67</b>	19.54	13.82	18.86	2.62	2.18	1.83	0.16	218
<b>68</b>	19.50	13.79	18.81	2.62	2.15	1.81	0.16	221
<b>69</b>	19.49	13.78	18.80	2.62	2.18	1.81	0.16	221
<b>70</b>	19.46	13.76	18.87	2.62	2.19	1.83	0.16	219
<b>Average</b>	<b>19.65</b>	<b>13.89</b>	<b>18.95</b>	<b>2.62</b>	<b>2.15</b>	<b>1.81</b>	<b>0.16</b>	<b>2208</b>
<b>71</b>	19.55	13.82	18.82	2.62	2.16	1.82	0.14	220
<b>72</b>	19.80	14.00	19.14	2.62	2.15	1.85	0.14	216
<b>73</b>	19.86	14.04	19.28	2.62	2.18	1.85	0.13	216
<b>74</b>	19.77	13.98	19.18	2.62	2.16	1.85	0.14	216
<b>75</b>	19.81	14.00	19.09	2.62	2.15	1.80	0.13	222
<b>76</b>	19.67	13.91	18.90	2.62	2.15	1.79	0.13	223
<b>77</b>	19.71	13.94	18.95	2.62	2.14	1.81	0.14	221
<b>78</b>	19.67	13.91	18.93	2.62	2.15	1.83	0.13	218
<b>79</b>	19.69	13.92	18.93	2.62	2.15	1.81	0.14	221
<b>80</b>	19.55	13.82	18.78	2.62	2.15	1.80	0.14	222
<b>Average</b>	<b>19.76</b>	<b>13.97</b>	<b>19.10</b>	<b>2.62</b>	<b>2.16</b>	<b>1.84</b>	<b>0.14</b>	<b>2195</b>

**Table B.2** Mean Free Surface Elevation (cm) for S Test

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>1</b>	-0.28	-0.29	-0.38	-0.22	-0.02	0.12	1.40	1.36
<b>2</b>	-0.23	-0.26	-0.31	-0.15	0.04	0.13	1.36	1.34
<b>3</b>	-0.23	-0.23	-0.30	-0.14	0.06	0.22	1.39	1.35
<b>4</b>	-0.22	-0.23	-0.29	-0.16	0.05	0.14	1.38	1.36
<b>5</b>	-0.24	-0.23	-0.27	-0.11	0.06	0.18	1.41	1.49
<b>Average</b>	<b>-0.24</b>	<b>-0.25</b>	<b>-0.31</b>	<b>-0.16</b>	<b>0.04</b>	<b>0.16</b>	<b>1.39</b>	<b>1.38</b>
<b>6</b>	-0.31	-0.38	-0.40	-0.18	0.02	0.11	1.35	1.36
<b>7</b>	-0.28	-0.28	-0.28	-0.11	0.06	0.20	1.42	1.37
<b>8</b>	-0.30	-0.26	-0.29	-0.13	0.06	0.25	1.43	1.40
<b>9</b>	-0.28	-0.29	-0.29	-0.13	0.04	0.19	1.41	1.41
<b>10</b>	-0.24	-0.26	-0.28	-0.12	0.07	0.15	1.46	1.47
<b>Average</b>	<b>-0.28</b>	<b>-0.29</b>	<b>-0.31</b>	<b>-0.14</b>	<b>0.05</b>	<b>0.18</b>	<b>1.41</b>	<b>1.40</b>
<b>11</b>	-0.21	-0.24	-0.30	-0.19	0.00	0.16	1.32	1.32
<b>12</b>	-0.22	-0.21	-0.30	-0.13	0.07	0.15	1.27	1.30
<b>13</b>	-0.21	-0.22	-0.31	-0.13	0.09	0.13	1.35	1.41
<b>14</b>	-0.25	-0.27	-0.31	-0.10	0.06	0.17	1.35	NR
<b>15</b>	-0.25	-0.25	-0.28	-0.13	0.08	0.15	1.36	NR
<b>Average</b>	<b>-0.23</b>	<b>-0.24</b>	<b>-0.30</b>	<b>-0.14</b>	<b>0.06</b>	<b>0.15</b>	<b>1.33</b>	<b>1.34</b>
<b>16</b>	-0.31	-0.38	-0.35	-0.15	0.02	0.16	1.28	1.36
<b>17</b>	-0.29	-0.28	-0.30	-0.10	0.09	0.20	1.38	1.40
<b>18</b>	-0.29	-0.29	-0.28	-0.13	0.08	0.18	1.41	1.37
<b>19</b>	-0.27	-0.29	-0.32	-0.13	0.06	0.15	1.37	1.34
<b>20</b>	-0.24	-0.27	-0.28	-0.09	0.07	0.19	1.41	1.30
<b>Average</b>	<b>-0.28</b>	<b>-0.30</b>	<b>-0.31</b>	<b>-0.12</b>	<b>0.06</b>	<b>0.18</b>	<b>1.37</b>	<b>1.35</b>
<b>21</b>	-0.26	-0.30	-0.31	-0.12	0.06	0.14	1.30	1.55
<b>22</b>	-0.25	-0.23	-0.28	-0.12	0.09	0.13	1.29	1.66
<b>23</b>	-0.23	-0.22	-0.25	-0.10	0.10	0.17	1.33	NR
<b>24</b>	-0.21	-0.21	-0.29	-0.11	0.09	0.12	1.34	1.34
<b>25</b>	-0.26	-0.23	-0.27	-0.12	0.09	0.14	1.31	1.53
<b>Average</b>	<b>-0.24</b>	<b>-0.24</b>	<b>-0.28</b>	<b>-0.12</b>	<b>0.09</b>	<b>0.14</b>	<b>1.31</b>	<b>1.52</b>

**Table B.2** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>26</b>	-0.33	-0.38	-0.36	-0.13	0.05	0.09	1.28	1.25
<b>27</b>	-0.30	-0.31	-0.30	-0.12	0.10	0.18	1.36	1.32
<b>28</b>	-0.29	-0.32	-0.32	-0.13	0.10	0.13	1.35	1.30
<b>29</b>	-0.23	-0.26	-0.31	-0.12	0.13	0.16	1.37	1.32
<b>30</b>	-0.25	-0.29	-0.30	-0.13	0.11	0.13	1.35	1.26
<b>31</b>	-0.32	-0.33	-0.32	-0.10	0.09	0.14	1.39	1.09
<b>32</b>	-0.30	-0.31	-0.30	-0.12	0.10	0.16	1.40	1.13
<b>33</b>	-0.25	-0.25	-0.32	-0.07	0.10	0.16	1.41	1.18
<b>34</b>	-0.27	-0.29	-0.28	-0.10	0.12	0.19	1.39	1.12
<b>35</b>	-0.27	-0.29	-0.28	-0.11	0.11	0.16	1.41	1.19
<b>Average</b>	<b>-0.28</b>	<b>-0.30</b>	<b>-0.31</b>	<b>-0.11</b>	<b>0.10</b>	<b>0.15</b>	<b>1.37</b>	<b>1.22</b>
<b>36</b>	-0.24	-0.30	-0.33	-0.15	0.06	0.09	1.42	1.41
<b>37</b>	-0.24	-0.24	-0.35	-0.08	0.14	0.16	1.40	1.38
<b>38</b>	-0.27	-0.26	-0.29	-0.07	0.16	0.17	1.45	1.40
<b>39</b>	-0.26	-0.25	-0.30	-0.07	0.16	0.17	1.43	1.35
<b>40</b>	NR	NR	NR	NR	NR	NR	NR	NR
<b>Average</b>	<b>-0.25</b>	<b>-0.26</b>	<b>-0.31</b>	<b>-0.09</b>	<b>0.13</b>	<b>0.15</b>	<b>1.43</b>	<b>1.39</b>
<b>41</b>	-0.22	-0.29	-0.37	-0.10	0.13	0.17	1.44	1.48
<b>42</b>	-0.23	-0.26	-0.31	-0.07	0.15	0.18	1.45	1.50
<b>43</b>	-0.27	-0.27	-0.33	-0.08	0.13	0.15	1.43	1.43
<b>44</b>	-0.24	-0.27	-0.31	-0.07	0.12	0.15	1.47	1.49
<b>45</b>	-0.27	-0.27	-0.31	-0.07	0.14	0.12	1.43	1.45
<b>46</b>	-0.26	-0.27	-0.30	-0.06	0.15	0.17	1.48	1.42
<b>47</b>	-0.28	-0.29	-0.35	-0.06	0.16	0.18	1.47	NR
<b>48</b>	-0.27	-0.27	-0.31	-0.08	0.13	0.14	1.47	1.45
<b>49</b>	-0.24	-0.25	-0.22	-0.02	0.14	0.16	1.45	1.50
<b>50</b>	-0.26	-0.27	-0.34	-0.10	0.13	0.15	1.47	1.39
<b>Average</b>	<b>-0.24</b>	<b>-0.27</b>	<b>-0.33</b>	<b>-0.08</b>	<b>0.13</b>	<b>0.15</b>	<b>1.44</b>	<b>1.47</b>

**Table B.2** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>51</b>	-0.21	-0.30	-0.33	-0.12	0.11	0.08	1.33	NR
<b>52</b>	-0.22	-0.21	-0.32	-0.07	0.13	0.14	1.31	NR
<b>53</b>	-0.25	-0.23	-0.32	-0.06	0.14	0.12	1.34	NR
<b>54</b>	-0.26	-0.25	-0.29	-0.03	0.14	0.17	1.41	1.36
<b>55</b>	-0.28	-0.24	-0.32	-0.05	0.11	0.15	1.36	1.28
<b>56</b>	-0.26	-0.28	-0.30	-0.04	0.13	0.13	1.38	1.34
<b>57</b>	-0.25	-0.26	-0.31	-0.03	0.13	0.14	1.39	1.31
<b>58</b>	-0.25	-0.28	-0.31	-0.04	0.15	0.10	1.36	1.32
<b>59</b>	-0.27	-0.26	-0.30	-0.08	0.16	0.14	1.36	1.25
<b>60</b>	-0.27	-0.28	-0.28	-0.05	0.16	0.15	1.35	2.04
<b>Average</b>	<b>-0.24</b>	<b>-0.25</b>	<b>-0.32</b>	<b>-0.07</b>	<b>0.13</b>	<b>0.13</b>	<b>1.35</b>	<b>1.32</b>
<b>61</b>	-0.26	-0.27	-0.36	-0.05	0.11	0.14	1.21	1.30
<b>62</b>	-0.22	-0.22	-0.30	-0.05	0.17	0.17	1.33	1.25
<b>63</b>	-0.26	-0.24	-0.29	-0.04	0.16	0.15	1.32	1.31
<b>64</b>	-0.27	-0.24	-0.26	-0.02	0.17	0.15	1.33	1.31
<b>65</b>	-0.25	-0.26	-0.31	-0.02	0.15	0.14	1.31	1.23
<b>66</b>	-0.24	-0.25	-0.30	-0.06	0.17	0.14	1.31	1.25
<b>67</b>	-0.27	-0.26	-0.33	-0.05	0.17	0.16	1.32	1.27
<b>68</b>	-0.26	-0.24	-0.31	-0.05	0.16	0.11	1.31	1.21
<b>69</b>	-0.26	-0.26	-0.29	-0.04	0.15	0.11	1.30	1.28
<b>70</b>	-0.26	-0.25	-0.27	-0.07	0.15	0.12	1.28	1.22
<b>Average</b>	<b>-0.25</b>	<b>-0.25</b>	<b>-0.30</b>	<b>-0.04</b>	<b>0.15</b>	<b>0.15</b>	<b>1.30</b>	<b>1.28</b>
<b>71</b>	-0.14	-0.14	-0.29	0.04	0.20	0.19	0.58	0.66
<b>72</b>	-0.16	-0.19	-0.23	0.03	0.23	0.18	0.61	0.72
<b>73</b>	-0.16	-0.20	-0.24	0.04	0.23	0.22	0.57	0.72
<b>74</b>	-0.17	-0.21	-0.25	0.03	0.25	0.18	0.62	0.70
<b>75</b>	-0.21	-0.22	-0.31	0.05	0.21	0.23	0.63	0.72
<b>76</b>	-0.22	-0.19	-0.26	0.05	0.24	0.22	0.62	0.59
<b>77</b>	-0.19	-0.18	-0.26	0.06	0.24	0.20	0.63	0.70
<b>78</b>	-0.19	-0.21	-0.21	0.07	0.24	0.18	0.66	0.63
<b>79</b>	-0.21	-0.21	-0.22	0.06	0.24	0.24	0.63	0.64
<b>80</b>	-0.19	-0.20	-0.23	0.06	0.24	0.22	0.67	1.39
<b>Average</b>	<b>-0.17</b>	<b>-0.19</b>	<b>-0.27</b>	<b>0.04</b>	<b>0.22</b>	<b>0.20</b>	<b>0.60</b>	<b>0.70</b>

**Table B.3** Free Surface Standard Deviation (cm) for S Test

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>1</b>	4.66	4.66	4.55	3.76	3.29	2.91	1.77	1.56
<b>2</b>	4.77	4.75	4.63	3.81	3.34	2.90	1.79	1.54
<b>3</b>	4.81	4.81	4.68	3.83	3.33	2.91	1.81	1.53
<b>4</b>	4.78	4.78	4.66	3.81	3.33	2.91	1.80	1.54
<b>5</b>	4.76	4.76	4.62	3.83	3.32	2.93	1.82	1.72
<b>Average</b>	<b>4.75</b>	<b>4.75</b>	<b>4.63</b>	<b>3.81</b>	<b>3.32</b>	<b>2.91</b>	<b>1.80</b>	<b>1.58</b>
<b>6</b>	4.76	4.66	4.72	3.86	3.28	2.84	1.76	1.75
<b>7</b>	4.80	4.70	4.75	3.87	3.31	2.84	1.78	1.75
<b>8</b>	4.82	4.73	4.77	3.89	3.33	2.86	1.80	1.76
<b>9</b>	4.79	4.71	4.74	3.88	3.30	2.87	1.79	1.76
<b>10</b>	4.77	4.68	4.71	3.87	3.29	2.86	1.79	1.76
<b>Average</b>	<b>4.79</b>	<b>4.70</b>	<b>4.74</b>	<b>3.87</b>	<b>3.30</b>	<b>2.85</b>	<b>1.79</b>	<b>1.76</b>
<b>11</b>	4.57	4.57	4.49	3.66	3.24	2.88	1.77	1.67
<b>12</b>	4.63	4.63	4.52	3.71	3.28	2.91	1.77	1.75
<b>13</b>	4.69	4.69	4.58	3.73	3.28	2.91	1.78	1.76
<b>14</b>	4.69	4.70	4.57	3.75	3.26	2.93	1.79	1.33
<b>15</b>	4.68	4.70	4.58	3.76	3.29	2.93	1.79	1.55
<b>Average</b>	<b>4.65</b>	<b>4.66</b>	<b>4.55</b>	<b>3.72</b>	<b>3.27</b>	<b>2.91</b>	<b>1.78</b>	<b>1.61</b>
<b>16</b>	4.71	4.70	4.68	3.79	3.29	2.93	1.81	1.71
<b>17</b>	4.75	4.75	4.71	3.82	3.31	2.93	1.80	1.72
<b>18</b>	4.78	4.77	4.72	3.80	3.32	2.95	1.81	1.72
<b>19</b>	4.78	4.78	4.72	3.79	3.31	2.96	1.81	1.70
<b>20</b>	4.78	4.78	4.71	3.81	3.32	2.95	1.81	1.72
<b>Average</b>	<b>4.76</b>	<b>4.76</b>	<b>4.71</b>	<b>3.80</b>	<b>3.31</b>	<b>2.95</b>	<b>1.81</b>	<b>1.71</b>
<b>21</b>	4.72	4.73	4.64	3.79	3.30	2.99	1.87	1.92
<b>22</b>	4.78	4.80	4.68	3.76	3.32	3.00	1.87	2.09
<b>23</b>	4.81	4.82	4.70	3.78	3.33	2.99	1.86	1.68
<b>24</b>	4.80	4.81	4.69	3.77	3.33	3.01	1.86	1.75
<b>25</b>	4.79	4.79	4.67	3.77	3.31	3.00	1.86	1.86
<b>Average</b>	<b>4.78</b>	<b>4.79</b>	<b>4.68</b>	<b>3.77</b>	<b>3.32</b>	<b>3.00</b>	<b>1.86</b>	<b>1.86</b>

**Table B.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>26</b>	4.69	4.66	4.68	3.75	3.28	3.00	1.86	1.75
<b>27</b>	4.73	4.72	4.70	3.77	3.29	3.03	1.86	1.77
<b>28</b>	4.75	4.72	4.71	3.76	3.29	3.03	1.85	1.76
<b>29</b>	4.75	4.72	4.69	3.76	3.28	3.04	1.86	1.77
<b>30</b>	4.74	4.71	4.70	3.76	3.31	3.04	1.86	1.77
<b>31</b>	4.70	4.68	4.67	3.70	3.23	3.01	1.80	NR
<b>32</b>	4.72	4.71	4.68	3.71	3.22	3.04	1.78	NR
<b>33</b>	4.72	4.71	4.68	3.69	3.23	3.01	1.80	NR
<b>34</b>	4.72	4.70	4.67	3.70	3.21	3.04	1.78	NR
<b>35</b>	4.70	4.69	4.66	3.66	3.22	3.05	1.80	NR
<b>Average</b>	<b>4.72</b>	<b>4.70</b>	<b>4.68</b>	<b>3.73</b>	<b>3.26</b>	<b>3.03</b>	<b>1.82</b>	<b>1.77</b>
<b>36</b>	4.68	4.66	4.63	3.67	3.21	3.02	1.79	1.71
<b>37</b>	4.75	4.75	4.70	3.70	3.22	3.04	1.79	1.72
<b>38</b>	4.76	4.75	4.71	3.71	3.24	3.06	1.81	1.74
<b>39</b>	4.75	4.75	4.71	3.70	3.23	3.08	1.80	1.73
<b>40</b>	NR							
<b>Average</b>	<b>4.74</b>	<b>4.73</b>	<b>4.69</b>	<b>3.70</b>	<b>3.22</b>	<b>3.05</b>	<b>1.80</b>	<b>1.73</b>
<b>41</b>	4.80	4.74	4.70	3.72	3.21	3.08	1.80	1.83
<b>42</b>	4.88	4.81	4.75	3.73	3.23	3.09	1.81	1.83
<b>43</b>	4.88	4.81	4.74	3.72	3.24	3.08	1.81	1.81
<b>44</b>	4.86	4.80	4.70	3.74	3.22	3.10	1.81	1.82
<b>45</b>	4.84	4.78	4.69	3.71	3.23	3.11	1.81	1.83
<b>46</b>	4.86	4.80	4.73	3.69	3.23	3.11	1.81	1.83
<b>47</b>	4.84	4.78	4.71	3.69	3.22	3.10	1.84	1.83
<b>48</b>	4.84	4.78	4.69	3.68	3.23	3.11	1.82	1.83
<b>49</b>	4.83	4.77	4.69	3.69	3.22	3.11	1.82	1.83
<b>50</b>	4.80	4.74	4.66	3.67	3.21	3.10	1.83	1.83
<b>Average</b>	<b>4.85</b>	<b>4.79</b>	<b>4.72</b>	<b>3.72</b>	<b>3.23</b>	<b>3.09</b>	<b>1.81</b>	<b>1.82</b>

**Table B.3** Continued

<b>Run</b>	<b>WG1</b>	<b>WG2</b>	<b>WG3</b>	<b>WG4</b>	<b>WG5</b>	<b>WG6</b>	<b>WG7</b>	<b>WG8</b>
<b>51</b>	4.52	4.55	4.50	3.57	3.14	3.10	1.82	1.75
<b>52</b>	4.65	4.67	4.62	3.62	3.15	3.12	1.84	NR
<b>53</b>	4.68	4.72	4.65	3.63	3.15	3.12	1.83	1.76
<b>54</b>	4.72	4.73	4.66	3.65	3.17	3.14	1.84	1.76
<b>55</b>	4.72	4.74	4.66	3.64	3.15	3.14	1.84	1.74
<b>56</b>	4.69	4.72	4.62	3.60	3.17	3.11	1.83	1.73
<b>57</b>	4.72	4.75	4.67	3.60	3.17	3.12	1.84	1.74
<b>58</b>	4.76	4.77	4.67	3.62	3.18	3.13	1.85	1.76
<b>59</b>	4.72	4.74	4.66	3.60	3.16	3.15	1.85	1.75
<b>60</b>	4.72	4.75	4.65	3.61	3.14	3.12	1.85	1.75
<b>Average</b>	<b>4.69</b>	<b>4.71</b>	<b>4.64</b>	<b>3.61</b>	<b>3.16</b>	<b>3.13</b>	<b>1.84</b>	<b>1.75</b>
<b>61</b>	4.83	4.80	4.68	3.67	3.21	3.15	1.89	1.78
<b>62</b>	4.84	4.81	4.69	3.66	3.19	3.19	1.89	1.80
<b>63</b>	4.90	4.87	4.75	3.69	3.21	3.21	1.90	1.79
<b>64</b>	4.89	4.87	4.72	3.70	3.23	3.20	1.88	1.79
<b>65</b>	4.86	4.83	4.69	3.66	3.22	3.21	1.89	1.79
<b>66</b>	4.80	4.77	4.63	3.62	3.19	3.17	1.91	1.78
<b>67</b>	4.85	4.81	4.68	3.64	3.21	3.20	1.89	1.77
<b>68</b>	4.83	4.80	4.65	3.62	3.20	3.22	1.88	1.80
<b>69</b>	4.83	4.80	4.65	3.62	3.19	3.21	1.89	1.79
<b>70</b>	4.83	4.81	4.65	3.62	3.19	3.21	1.89	1.78
<b>Average</b>	<b>4.87</b>	<b>4.84</b>	<b>4.71</b>	<b>3.68</b>	<b>3.21</b>	<b>3.19</b>	<b>1.89</b>	<b>1.79</b>
<b>71</b>	4.81	4.78	4.74	3.63	3.16	3.01	2.26	1.91
<b>72</b>	4.89	4.85	4.78	3.64	3.19	3.01	2.27	1.92
<b>73</b>	4.91	4.87	4.79	3.66	3.21	3.00	2.27	1.91
<b>74</b>	4.88	4.85	4.77	3.63	3.17	2.98	2.27	1.91
<b>75</b>	4.89	4.85	4.78	3.65	3.19	3.01	2.25	1.91
<b>76</b>	4.87	4.82	4.74	3.61	3.20	3.00	2.25	NR
<b>77</b>	4.87	4.82	4.76	3.64	3.19	2.98	2.24	NR
<b>78</b>	4.86	4.82	4.75	3.60	3.19	2.97	2.24	NR
<b>79</b>	4.86	4.82	4.75	3.61	3.17	2.97	2.25	NR
<b>80</b>	4.84	4.79	4.72	3.58	3.18	2.96	2.25	1.88
<b>Average</b>	<b>4.88</b>	<b>4.84</b>	<b>4.77</b>	<b>3.64</b>	<b>3.18</b>	<b>3.00</b>	<b>2.26</b>	<b>1.91</b>

**Table B.4** Mean cross-shore  $\bar{u}$  and standard deviation  $\sigma_u$  of the 2D ADV co-located with WG4 at x=8.40 m, Red Vectrino and Blue Vectrino were not operational

Run	2D ADV at WG4	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>1</b>	-7.60	20.57
<b>2</b>	-7.48	20.31
<b>3</b>	-8.14	20.39
<b>4</b>	-7.82	20.47
<b>5</b>	-7.37	20.45
<b>Average</b>	<b>-7.68</b>	<b>20.44</b>
<b>6</b>	-7.35	20.44
<b>7</b>	-7.30	20.67
<b>8</b>	-6.95	20.79
<b>9</b>	-7.19	20.52
<b>10</b>	-5.52	20.65
<b>Average</b>	<b>-6.86</b>	<b>20.62</b>
<b>11</b>	-7.13	20.62
<b>12</b>	-6.01	20.38
<b>13</b>	-6.04	20.50
<b>14</b>	-6.57	20.72
<b>15</b>	-7.21	20.66
<b>Average</b>	<b>-6.59</b>	<b>20.58</b>
<b>16</b>	-6.23	20.61
<b>17</b>	-6.27	20.71
<b>18</b>	-6.62	20.64
<b>19</b>	-6.44	20.19
<b>20</b>	-7.48	20.74
<b>Average</b>	<b>-6.61</b>	<b>20.58</b>
<b>21</b>	-6.83	20.67
<b>22</b>	-6.46	20.59
<b>23</b>	-6.60	20.73
<b>24</b>	-6.50	20.68
<b>25</b>	-6.73	20.88
<b>Average</b>	<b>-6.63</b>	<b>20.71</b>

**Table B.4** Continued

Run	2D AVD at WG4	
	$\bar{u}$ (cm/s)	$\sigma_u$ (cm/s)
<b>26</b>	-6.07	20.78
<b>27</b>	-7.13	20.51
<b>28</b>	-6.81	20.46
<b>29</b>	-6.84	20.52
<b>30</b>	-6.62	20.45
<b>31</b>	-7.27	20.31
<b>32</b>	-7.41	20.13
<b>33</b>	-6.59	20.25
<b>34</b>	-6.80	20.34
<b>35</b>	-6.64	20.35
<b>Average</b>	<b>-6.94</b>	<b>20.28</b>
<b>36</b>	-6.56	20.31
<b>37</b>	-7.33	20.71
<b>38</b>	-6.99	20.65
<b>39</b>	-6.86	20.47
<b>40</b>	NR	NR
<b>Average</b>	<b>-6.93</b>	<b>20.54</b>
<b>41</b>	-7.37	20.49
<b>42</b>	-7.45	20.47
<b>43</b>	-6.67	20.25
<b>44</b>	-7.16	20.21
<b>45</b>	-6.35	20.14
<b>46</b>	-7.59	20.05
<b>47</b>	-6.13	19.94
<b>48</b>	-6.13	20.09
<b>49</b>	-6.18	20.15
<b>50</b>	-6.82	20.14
<b>Average</b>	<b>-7.00</b>	<b>20.31</b>

**Table B.4** Continued

Run	2D AVD at WG4	
	$u$ (cm/s)	$\sigma$ (cm/s)
51	NR	NR
52	-6.94	20.12
53	-7.14	19.92
54	-6.59	20.04
55	-8.01	20.05
56	-7.13	19.97
57	-6.40	20.03
58	-6.80	19.76
59	-7.44	20.13
60	-7.76	19.95
Average	<b>-7.17</b>	<b>20.03</b>
61	-7.62	20.14
62	-6.39	19.79
63	-7.60	20.09
64	-6.65	19.86
65	-6.88	19.73
66	-7.76	19.67
67	-7.49	19.94
68	-6.84	19.61
69	-6.44	19.66
70	-8.21	19.53
Average	<b>-7.03</b>	<b>19.92</b>
71	-7.78	19.18
72	-7.47	19.25
73	-7.32	19.49
74	-7.64	19.19
75	-6.47	19.60
76	-7.56	19.24
77	-7.81	19.20
78	-7.56	19.08
79	NR	NR
80	-6.89	19.12
Average	<b>-7.34</b>	<b>19.34</b>