Grain Size Analysis

SINBAD project document 2014-01

Date: 17-04-2014

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Summary

In this report an overview is given of the results that were acquired with the grain size analysis. The grain size analysis is part of the experiments that were conducted in the CIEM wave flume at the UPC in Barcelona. The grain sizes are determined for the suction samples and for the bed samples that were taken during the experiments in November, December and January. The analysis is based on the D_{50} grain size that was obtained by the Beckman Coulter LS 13 320. This machine sends laser pulses through a sand sample. For each measurement, a sample was brought in a flow of water that circulates through the machine and passes a sample cell. The laser beam was aimed at the sample cell and the amount of laser diffractions by the sand particles determine the grain size distribution. If too little sediment is present in the system, the obscuration and therefore the reliability of the measurement decreases. The obscuration is determined by the amount of sand that can be measured by the Laser diffraction system. In this report RB-data with an obscuration >4% was said to be reliable and for INB-conditions it is stated at >1%. Data that was lower than these values was ignored in the analysis.

With INB-conditions five types of wave groups were measured at the same location and for each wave group one measurement was analyzed. The results show that sediments are strongly sorted near the bed. Higher in the water column grains of ±100 um were found, while the initial (reference) grain size was 246 um. After the INB-measurements, also four bed samples were collected at 30 cm depth from which a new reference D_{50} of 290 um was calculated. For the experiments with regular breaking waves, the largest particles were measured in the breaker zone (±320 um). For the RB1-conditions little sediment sorting occurred in the breaker zone, but on top of the breaker bar there was more sorting. In the shoaling zone, little sediment sorting was found and the grains were small (200-220 um) for both the RB1- as the RB2-conditions. In the surf zone however, larger particles (±260 um) were measured and the sand was well mixed.

The grain sizes of the suction samples have been compared to the bed samples at the same location. The results show that for the RB1-measurements the bed samples are comparable to the suction samples. Only in the surf zone the suction samples become (±15%) smaller than the bed samples. Also the influence of the fine sand in the D_{50} of the suction samples becomes larger. These results may indicate that fine sediment is transported away from the surf zone during a measurement. For both RB1- and RB2-conditions the grain size of the bed samples show a larger range (e.g. rb1: ±230-310 um) than for the suction sample's grain size (e.g. rb1: ±235-285 um). It is possible that with the use of the volume meter some larger sand particles were lost, what causes the smaller range for the suction samples. When the ratio suction sample/bed sample is observed, it can be seen that the grain sizes are comparable from the shoaling zone until the breaker zone. In the surf zone the grains in the bed become larger. It is assumed that the suction samples have the most influence on this divergating trend, because the obscuration of the bed samples was better and the suction samples do not show uniform distributions in each zone. In order to obtain more information of the horizontal sediment sorting it is recommended to perform more measurements and to use information of flow velocities.

To conclude, the β-calibration factor could be calculated for each sample, because the D_{50} was measured for each nozzle. When the effect on the concentrations of this new β-factor was calculated, it was found to be small enough to fall within the measuring error.

Enschede, April 2014
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Table of contents

1. Introduction

This report is written for the SandT-Pro campaign funded by the European Union through the HydralabIV program. The report gives an overview of the results that are generated concerning the grain size distribution under regular breaking and irregular non-breaking waves. The sand samples that have been analyzed are collected with the Transverse Suction System and the bed samples are taken manually after each measuring condition. Results are shown and described for the following conditions:

a. Regular Breaking waves (RB1):
   The experiments conducted in November and December 2013
b. Regular Breaking waves (RB2):
   The experiments conducted in January 2014
c. Irregular Non-Breaking (INB):
   The experiments conducted in November and December 2013
d. Bed samples that were taken after the RB1 and RB2 measurements.

In order to know how the data was generated, the second chapter describes the measuring method and the functioning of the Laser diffraction system. In the chapters that follow, the results will be discussed by the use of figures and tables. With the figures a description of the results and a discussion is given. Because many data is analyzed, the appendices include an overview per measurement that is used to support the conclusions. At the end of the report an overview of the conclusions and results will be given.

2. Research questions

In this research, it is ought to find how the grain size is distributed under (breaking) waves. The measuring and analyzing of the grain sizes can give new insights in the movement of sand particles under breaking or non-breaking waves. In order to find relationships and analyze the results, four research questions have been drawn:

a. How is the grain size distributed over the height in the water column?
b. Does sorting take place in the horizontal plane?
c. In what way do the D_{50} of the bed samples relate to the D_{50} of the suction samples?
d. What is the influence on Bosman's β-calibration factor when the measured D_{50} per sample is used instead of a fixed D_{50}?

These questions form a guideline for the report and in the following chapters it is intended to find answers.

In this report sometimes a reference is given to the *"Data Overview"* or "*the Manual"*. The *"Data Overview"* is the file "*Overview_data_per_measurement_(figures).pdf* " and with "t*he Manual"* the manual of the Laser diffraction system is meant. Both files can be found in the same folder as where this report is saved.

3. Instrumentation, experimental conditions and error definition

3.1. Instrumentation

The Transverse Suction System (TSS):
The Transverse Suction System was used to collect water and sediment at different elevations in the water column. A suction nozzle was positioned at seven elevations and the cross-shore position in the flume was adjusted every run. Pumps pumped up water and sediment into large buckets, from which the water was drained directly after the run. The amount of the remaining sand was measured with the volume meter and after it was dried, it was put in a plastic bag for the grain size measurements.

Bed sample collection:
Bed samples are obtained after each measuring condition, i.e. RB1-, RB2- and INB-conditions. After the water was drained from the flume, the top layer of the bed was put in an aluminum cup. It was tried to sample an average of the ripple sample in order to generate better results.

The laser diffraction system:
The grain size measurements are conducted with the Beckman Coulter LS 13 320. This machine uses the diffraction of a laser to measure the grain sizes and computes the grain size distribution. The samples were obtained in the CIEM wave flume, where the artificial beach was prepared with well sorted sand. The collected sand samples were transferred from the plastic bags to a tube, which was then put in the auto preparation system (photos are shown in Appendix I).

The auto preparation system consists of 30 slots for sand samples, a small container of water, a pump and various sensors. Sensors measure and control the amount of water in the system. Automatically the machine empties the tube in the water and the pump circulates the suspended sediment through the system. When too much sand is suspended in the water, the machine automatically filters the water until the optimal concentration is reached. From the auto preparation system the sand is transported to the laser system, where the sand passes two sample cells. Two types of grain size measurements are performed there. In the first measurement a laser beam is sent through a Fourier lens that focusses the beam through the sample cell (see Figure 1). Then depending on the size of a particle the beam is diffracted differently. The different refractions are measured by a detector, which transforms the signals into a grain size distribution. The second measurement is consists of polarized intensity differential scattering (PIDS). This technique uses polarization and the different wave lengths of light. Polarized light waves are waves that are limited to vibrations in a single plane (horizontal or vertical). The polarized light then passes a color filter that filters certain wave lengths. Because of the polarization and the color filter the refraction of light by the sand particles can be determined very precisely. This part of the machine can measure particles in the 0.04 um to 0.4 um range.

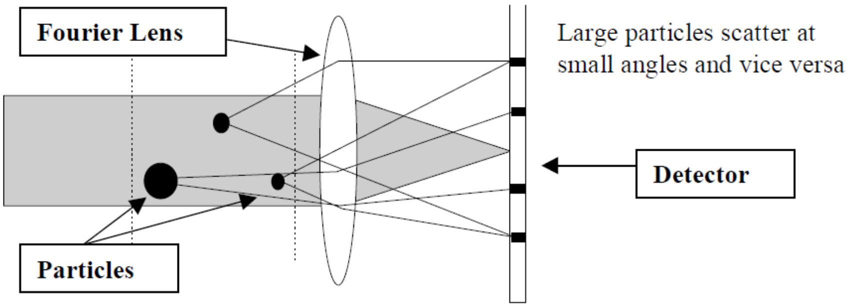

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Figure 1: Schematic overview of the functioning of the Fourier Lens

In total three measurements are taken per sample and the results in this report are based on the average of these three measurements. After a run the machine presented a large amount of results and an example of these results are given in Appendix II. In total the machine measured 203 sand samples and three test-runs are conducted to see if the machine was measuring correctly. Data points that give unreliable information have been removed. The PIDS are not taken into account in this report, because the measuring-range is too small in comparison to the error that occurred in the sample collection. More information about the PIDS and the instrument can be found in Chapters 2 and 3 of the machine's manual.

3.2. Sample collection and error determination

During the sample collection at the CIEM wave flume in Barcelona and during the grain size measurements in Aberdeen errors could occur at different stages. By cleaning the data and by following certain procedures an attempt to reduce the error was made. In order to obtain an overview in the errors that occurred, the steps where errors could occur are described beneath.

Sample collection and errors

Before the analysis was done with the laser diffraction system, the samples were obtained during the experiments in Barcelona. The sampling consisted of many steps where errors could occur. As is described in the previous paragraph, the samples were collected in large buckets after which the water was drained by tilting the bucket. Suspended sand particles were difficult to see, so some particles could have been drained in this process. When the sample was transferred to the volume meter, it could have been left behind in the funnel or the buckets. Even though enough water was used to rinse the equipment, sand loss is inevitable. During these processes fine sand could have been lost. After the volume meter measurements samples were collected in aluminum cups. Because the tap on the volume meter spreads the water in all directions, sand loss occurred. The largest sand particles left the volume meter first, so with the collection of sand in the aluminum cups these larger particles could have been lost. While removing the water from the cup and in the transporting the dried sediment to the plastic bags some more (fine) sand was lost.

In order to perform the grain size measurements the samples were transferred from the plastic bags into tubes. Static forces in the plastic bag made it difficult to remove all the sediment from the bag. In the process of collecting the samples it is assumable that a part of the (finest) sand is lost and therefore it is possible that the results of the grain size analysis turn out to be higher than expected. On the other hand, the loss of the larger particles at the outlet of the volume meter could cause the grain sizes to become lower. Because fine sand could have been lost in more processes, it is assumed that the average grain sizes in this report are (somewhat) overestimated.

Obscuration

The laser diffraction system gives the best result when the obscuration is between 8% and 12%. The obscuration is measured by sensors in the machine and gives information about the concentration of sand in the sample. When more sand is present in the system, light will be blocked from the detectors and when the obscuration is lower less data is measured which can influence the reliability of the measurement.

Error prevention

In order to prevent or reduce the errors that are described above, some actions have been undertaken. To begin with, all the steps in the measuring process have been conducted with the highest possible precision. The intension was to maintain as much sediment as possible for the grain size analysis. Because in some conditions the pumped samples were very small the obscuration in the end was too low and therefore the measurement was not reliable. Runs 62 and 64 (RB2-conditions) and a few other data points were removed because the low obscuration showed a deviating grain size pattern. In order to create representative measurements, the samples were mixed properly before they were put in the laser diffraction system. When little sediment was present in the plastic bag, air was blown in the bag which made it easier to tap the sand to one corner. This corner was then removed and the sand was collected in the tube, ready for analysis.

As described in the previous paragraph, errors could occur in the process of measuring. Also, many samples consisted of little sediment, what caused the obscuration to be lower than 8%. In the manual is described that the most reliable data is generated between 8% and 12%. The samples with a lower obscuration often showed a good grain size distribution, so the boundary conditions for reliable data are changed per measuring condition.

- RB1- and RB2-conditions:
  For these measuring conditions the data was declared as unreliable when the obscuration was lower than 4%. Due to the changing conditions, each measurement is unique and therefore it is difficult to say if a single measurement gives a good result. When looking at the D_{50}-course of the uncorrected measurements, a large deviation can be found. When the obscuration is under 4%, the results are sometimes good and sometimes unreliable. Therefore the threshold was set at an obscuration of 4%.

- INB-conditions:
  For INB-conditions the obscuration was often very low. Less sediment was collected during the measurements and therefore the minimum obscuration was stated at 1%. This way the course of the D_{50} can be shown better and in the first 30 cm above the bed the measurements do not deviate as much as higher in the water column.

In Figure 2 and in Appendix II-c a reliable and an unreliable grain size distribution are shown. In total 203 samples are analyzed and 32% of the measurements (58 samples) have been removed due to the low obscuration. In the following chapters, the results of the grain size measurements are shown and described. When data points are removed it is described beneath the figures. The explanation for removing data can also be found in the file "GSA_results_outliers_removed.xlsx".

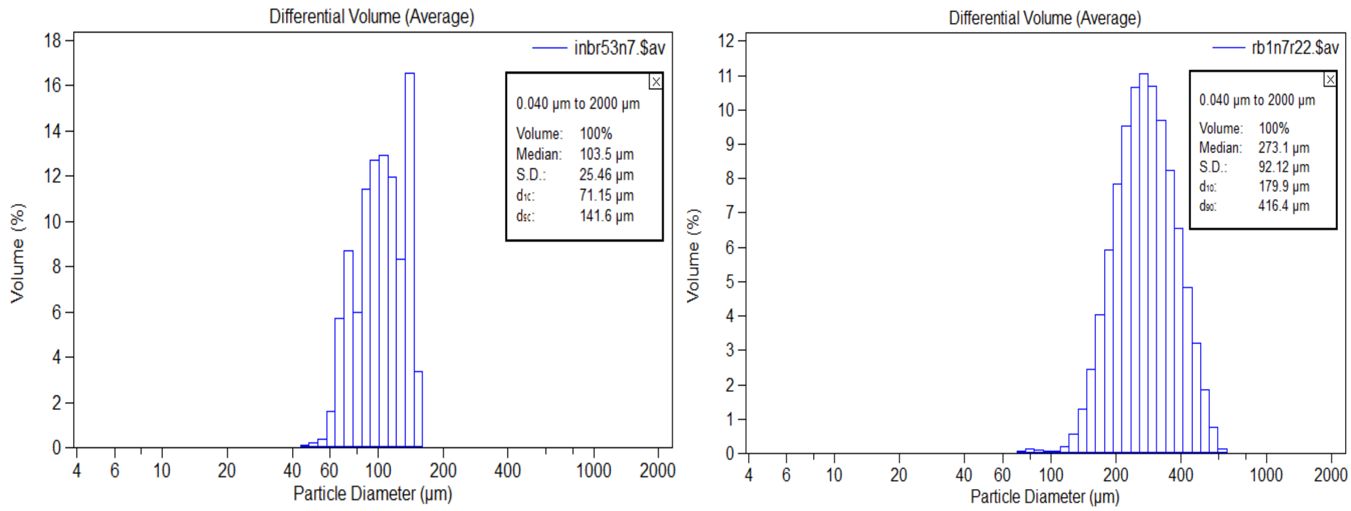


Figure 2: A measurement with a low obscuration and a measurement with a good obscuration

4. Results per condition

In this chapter, the results of the measurements are shown per condition. For every measuring condition the bed profile, the measuring locations and the course of the D_{50}-values per run are shown. By the use of the figures the findings and conclusions will be described and discussed. The figures in this chapter consist of the corrected measurements. Figures with the uncorrected data are shown in Appendix III.

4.1. Regular Breaking 1

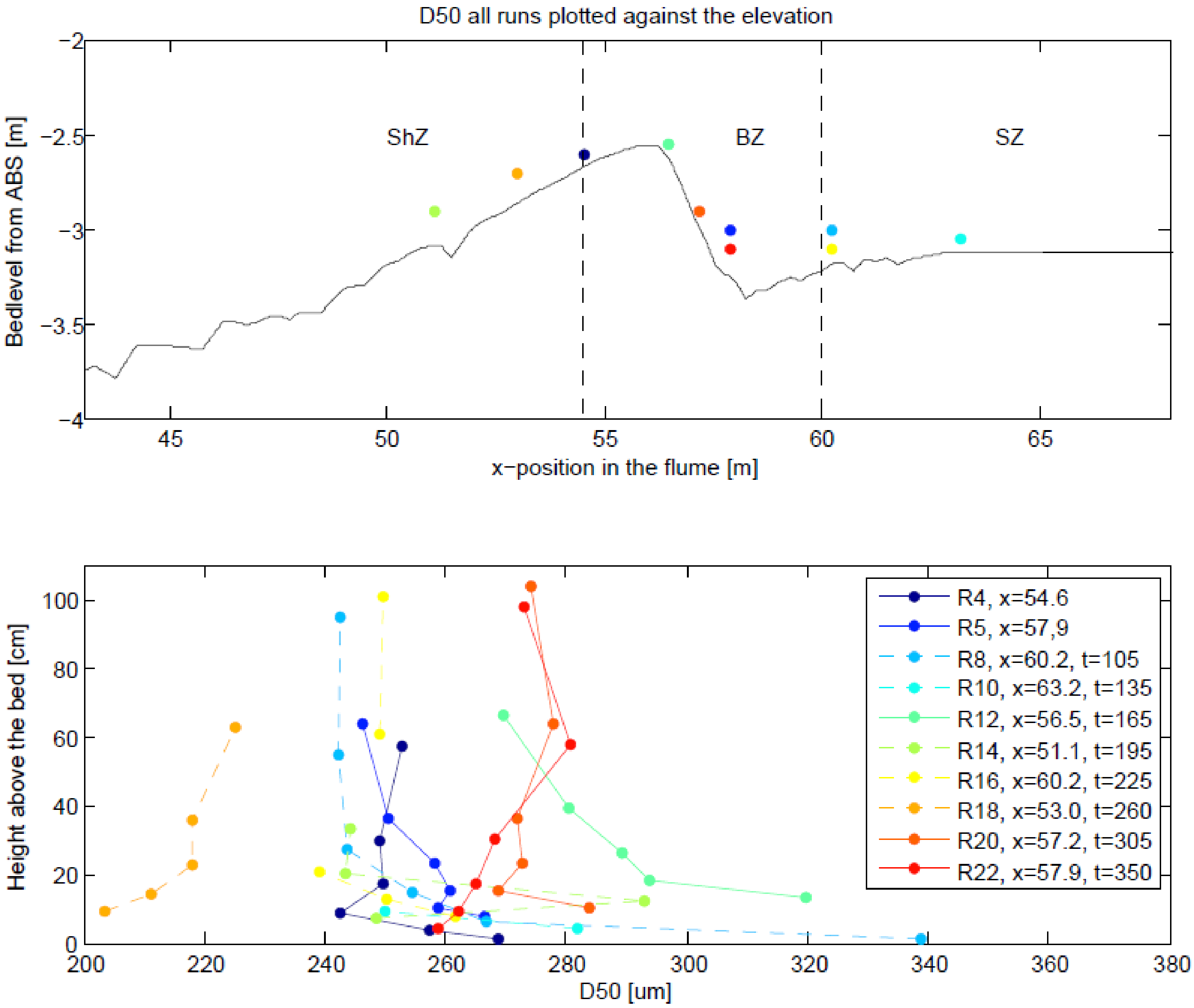


Figure 3: Grain size distribution for RB1-conditions (the dashed line represents the shoaling- and surf zone)

In Figure 3 the bed profile of measurement 22 is used to show the measuring locations. Because the concentration measurements showed a correlation with the bed evolution, notice that for the first measurements the breaker bar was still forming. The results of this measurement:

1. It can be noticed that the majority of the data varies between ±235 and 285 um.
2. The smallest grain sizes seem to occur in the shoaling zone. Because only two measurements were conducted in this zone, it is difficult to draw conclusions. The obscuration of measurement 18 deviated between 8,5% and 9,4%, and for measurement 14 that was between 4,5% and 9,9%.

3. In the surf zone the grain size is smaller than in the breaker zone, but the sand is vertically strongly sorted (see run 8 and 10), where in the breaker zone little vertical sorting takes place.
4. At the steep shoreward side of the breaker bar (the right-hand side in the figure) the grain size increases with the elevation above the bed. There, the size of the particles is more or less equally distributed over the height.
5. The larger grain sizes in the breaker zone can be explained by the breaking wave that picks up the smaller particles easier. These smaller particles can then be transported easier to other areas in the flume.
6. In the breaker zone the grain sizes seem to increase higher above the bed. It is possible that the sand is lifted in suspension near the bed and that higher in the water column the suspended sand originates from the breaker bar.
7. In run 4 and 5 the breaker bar was not formed and it can be seen that the grain size varies around 250 um. This is in line with the grain size (246 um) that was measured before the experiments.

To get a better overview on the processes in the breaker zone, the grain size distributions of this zone are shown in Figure 4.

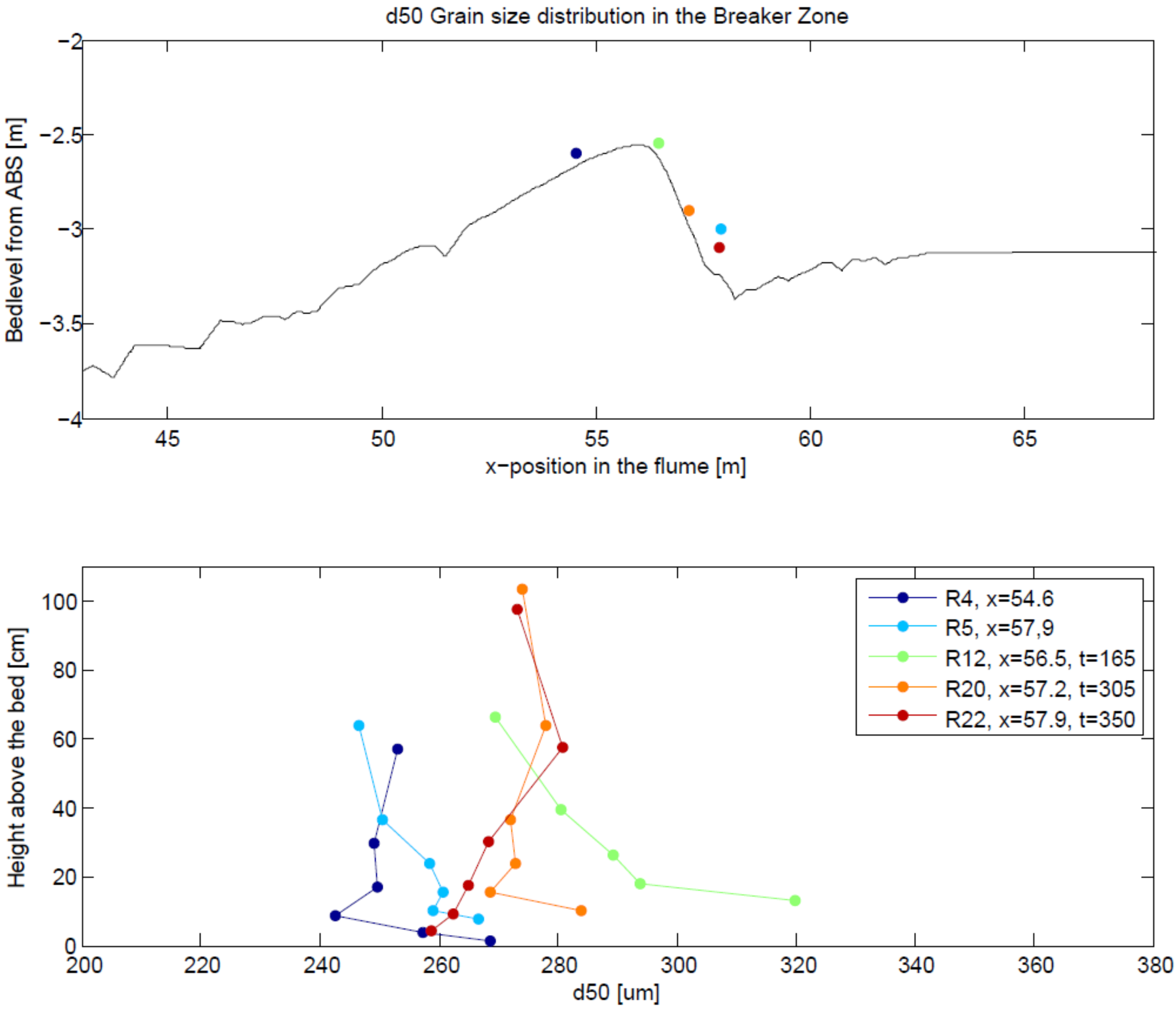


Figure 4: The grain size measurements in the breaker zone

4.2. Regular Breaking 2

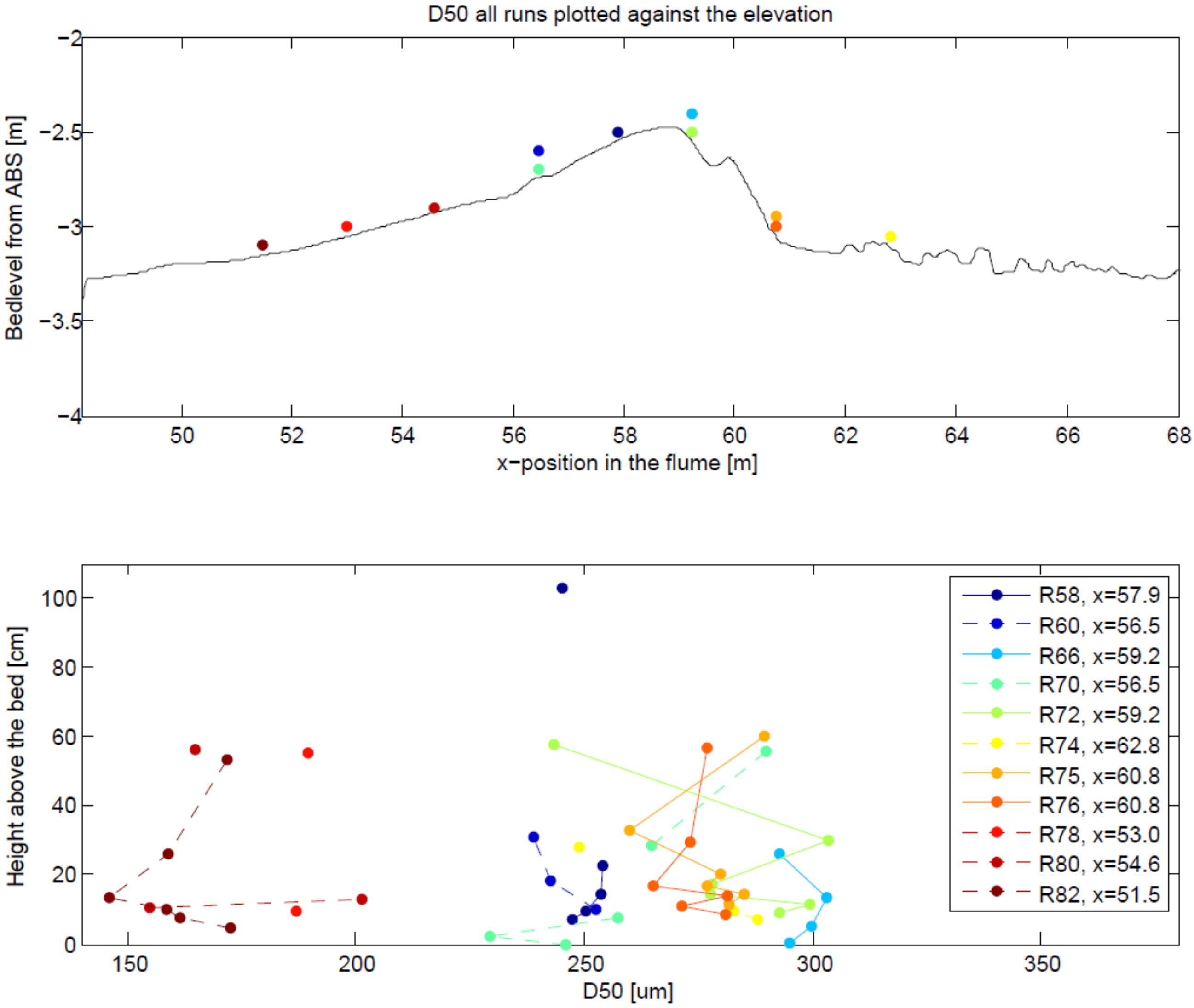


Figure 5: Grain size distribution for RB2-conditions (the dashed line represents the shoaling- and surf zone)

The main difference between the RB1 and the RB2-experiment is that the bed slope was changed from 1:10 to 1:20. Even though sand is added to create the different slope, it is possible that the horizontal sorting in the sand took place due to previous (test-) experiments. Findings and conclusions of the grain size analysis are listed below:

1. In this figure much more variation in the grain size distribution is found, but most of the measurements have a grain size between 240 and 310 um. In the second plot of Figure 5 it is difficult to see correlations regarding the vertical sorting. That is because many samples had a low obscuration for which the data was ignore. Still, the measurements near the top of the breaker bar show a well-mixed profile.
2. The distributions show a more random shape than with the RB1 conditions and more measurements were taken in the shoaling zone. Also the average D_{50} is higher than for the measurements with RB1-conditions.
3. In accordance to RB1 the grain sizes increase towards the breaker bar and shoreward (right-hand side of the plot) of the breaker bar the grain sizes decrease again. The largest grains are found in the area where the wave plunged.

4. The grain sizes in measurements 78, 80 and 82 are small. This can be explained by sediment sorting in previous runs, where the smaller sand particles could have been transported towards the shoaling zone. Also when looking at the grain size distributions of the RB1-conditions, the grains become smaller seawards of the breaker bar. It is possible that the smaller particles (140-200 um) were added when the bed slope was changed. Because of the (very) low grain sizes these measurements should be assumed to be unreliable.
5. Runs 66&72 were conducted at the same location and it can be seen that they have the same average grain size (an estimated error taken into account). They both show little sediment sorting and contain large particles (±290 um).

4.3. Irregular Non-Breaking

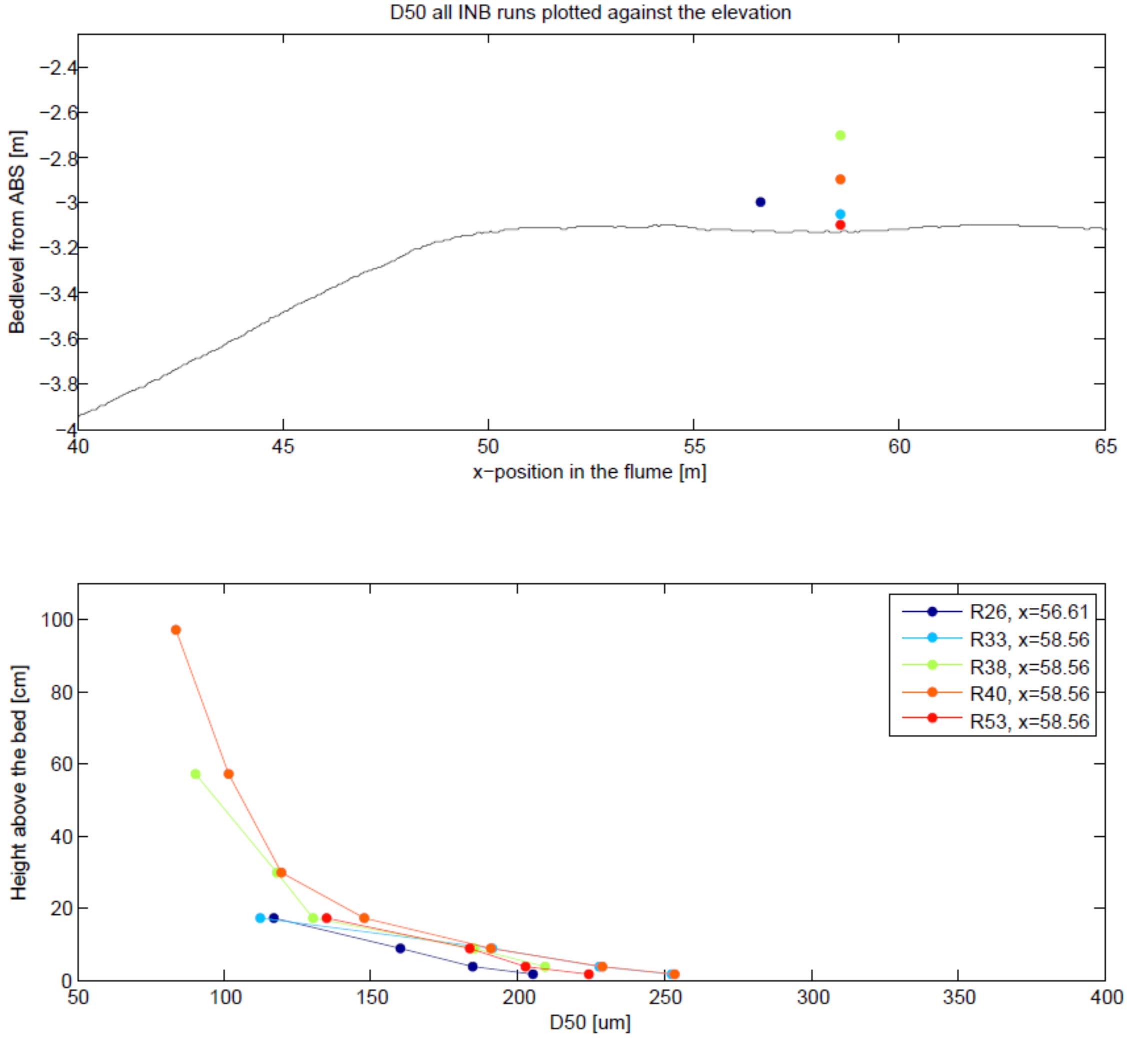


Figure 6: Grain size distribution for INB-conditions

Measurements with the INB-conditions are (except for one) conducted at the same location. Five different wave groups are created by the wave paddle and for every wave group one measurement is shown. The figure shows that the grain size becomes very small high in the water column and that the sand is well sorted near the bottom. The course of the D_{50} can be explained by the water velocities in under the non-breaking waves that were not strong enough to transport larger particles higher into the water column. In Appendix III-c the plot with the uncorrected data is shown, which shows that each measurement shows a curve like R40 in Figure 6. The obscuration of these measurements was very low, so most of the measurements are not reliable (see also Appendix “Data Overview”).

4.4. Bed samples after RB1

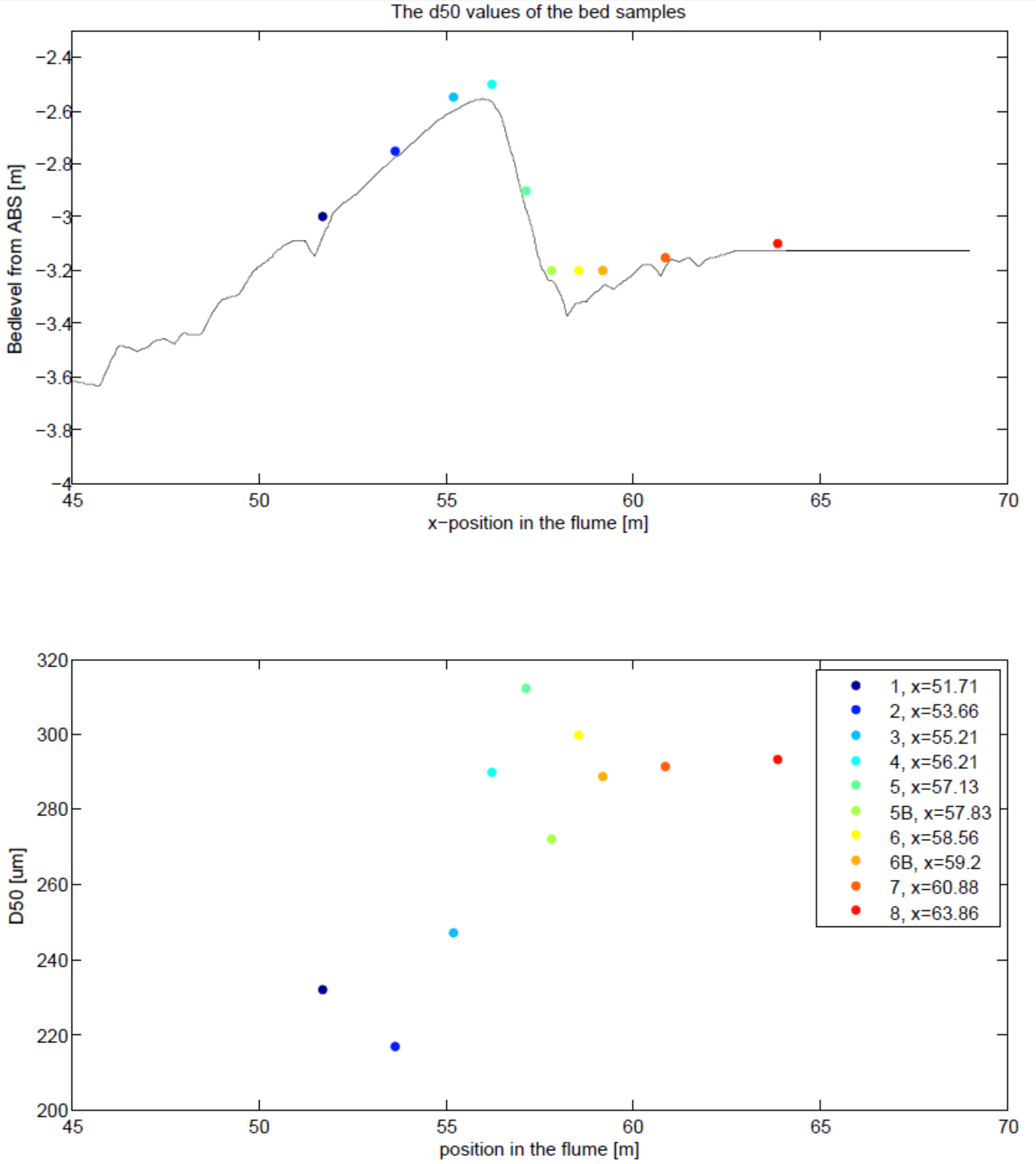


Figure 7: Grain size distribution of the bed samples after RB1

The bed samples in Figure 7 are collected after the measurements with RB1 conditions. The water was drained from the flume after the suspended particles was given time to sink. Wet samples were collected and they were dried before they were analyzed. From Figure 7 we can conclude that:

1. There is a clear correlation between the grain size and the position in the wave flume. Concentrations peak at the slope of the breaker bar and are lower in the shoaling zone.
2. Different from the results with RB-conditions is the grain size in the surf zone. In the RB-experiments the D_{50} was smaller in the shoaling and the surf zone. This is further explained in Chapter 5.

4.5. Bed samples after RB2

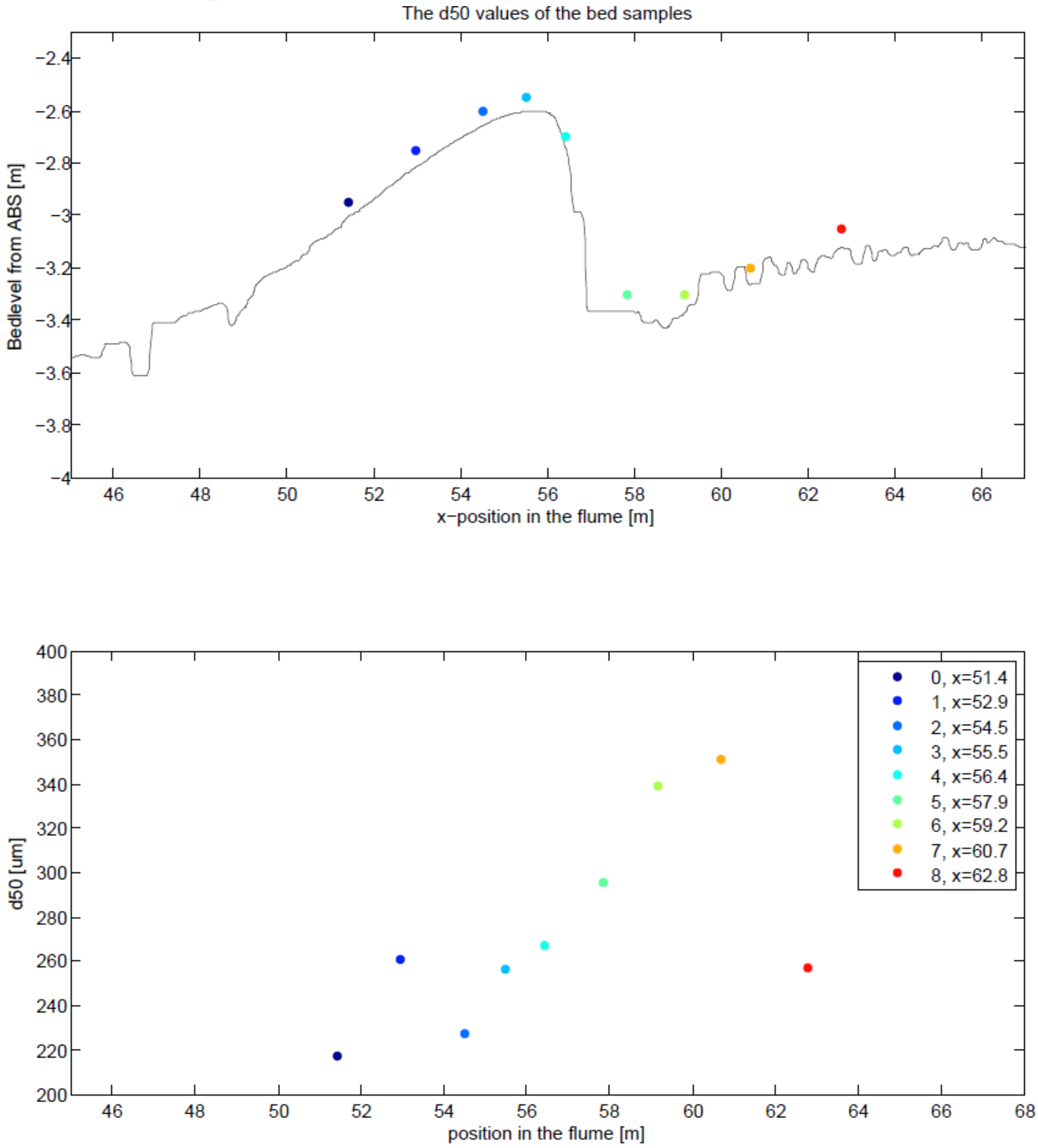


Figure 8: Grain size distribution of the bed samples after RB2

In Figure 8 the results of the bed sample grain sizes can be seen. Bed samples 1, 2, 3 and 4 have accidentally been mixed with bed samples that were taken after the INB experiments. For these bed samples 1/3 of the sample consisted of INB bed samples and 2/3 of the sample consisted of the bed sample of RB2. In the figure it is clear to see that the particles become larger towards the breaker zone and further in the surf zone the grain size is lower. This is in accordance with the results of the bed samples after RB1 in the previous paragraph. A difference with the other bed sample measurements is the average grain size at (or around) the top of the breaker bar, which is lower in Figure 7. Also there is more sorting in this measurement than with the bed sample measurements after RB1. Because the RB2-measurements took more time, the sand had more time to become sorted. The grain size distribution in Figure 7 may indicate a seaward transport of fine sediment from the breaker zone to the shoaling zone.

5. Comparison of the suction samples to the bed samples

In this chapter the bed samples are compared to the experiments with RB-conditions. First the bed samples are compared to the average values of the RB-experiments. To do that, only the samples are compared that were obtained at the same location in the flume. When plotting this same figure for the nozzles closest to the bed, it can be seen what the difference in grain size is between the bed and the bottom boundary layer. Because the values may deviate, the ratio of (all) the TSS- and the bed samples are calculated and shown in a figure with a bed profile. With this, explanations for the deviations in the results can be found. For the comparison of the suction samples and the bed samples, paragraph 5.1 explains how different factors are taken into account in the determination of the corrected D_{50}-values.

5.1. Calculation of the absolute D_{50} per sample

Every suction nozzle is positioned at a different elevation above the bed. From the samples, that are pumped up through these nozzles, the concentration and the grain size distribution can be calculated. The course of the concentration can be found in Appendix “Data Overview” where also the concentrations per nozzle are shown. The grain sizes and the sorting of sediment can be determined by looking at the course of the D_{50} at different elevations above the bed. The concentration and the elevation in the bed are of influence on the grain size distribution. Therefore, the range that every nozzle covers and the concentration per nozzle are taken into account and these factors are used in the following equation:

$$D = \frac{\sum(D_i \, C_i \, \Delta i)}{\sum C_i \, \Delta i} \qquad (1)$$

Where D_i is the D_{50} of nozzle *i*, C_i is the concentration of nozzle *i* and Δi is the range of nozzle *i*. The denominator in the equation consists of the total concentration times the range per nozzle. The new D_{50} is used in the comparison between the suction sample and the bed sample grain sizes.
The range (Δi) per nozzle is shown in Figure 9. The range is determined by the average height of two succeeding nozzles and for nozzle 1 the range is two times the upper limit and for nozzle 7 the range is two times the lower limit. Because the nozzles were attached to the mobile frame at a fixed position, the range of the nozzles is the same for every measurement. During the RB2 measurements the first 3 nozzles were repositioned after measurement 70, so for measurement 72-82 the range is slightly different. This different elevation is shown in Table 1 and in Figure 9 the elevation above the bed for all the other measurements is shown. In the calculation of the range, the water level and the bed level are not taken into account. Therefore it is possible that the range for nozzle 1 and 7 is overestimated.

Table 1: The representative range for measurements 72 to 82

Nozzle #	Elevation above the bed [cm]:
1	2.70
2	2.65
3	2.85
4	7.95
5	20.05
6	33.65
7	40.0

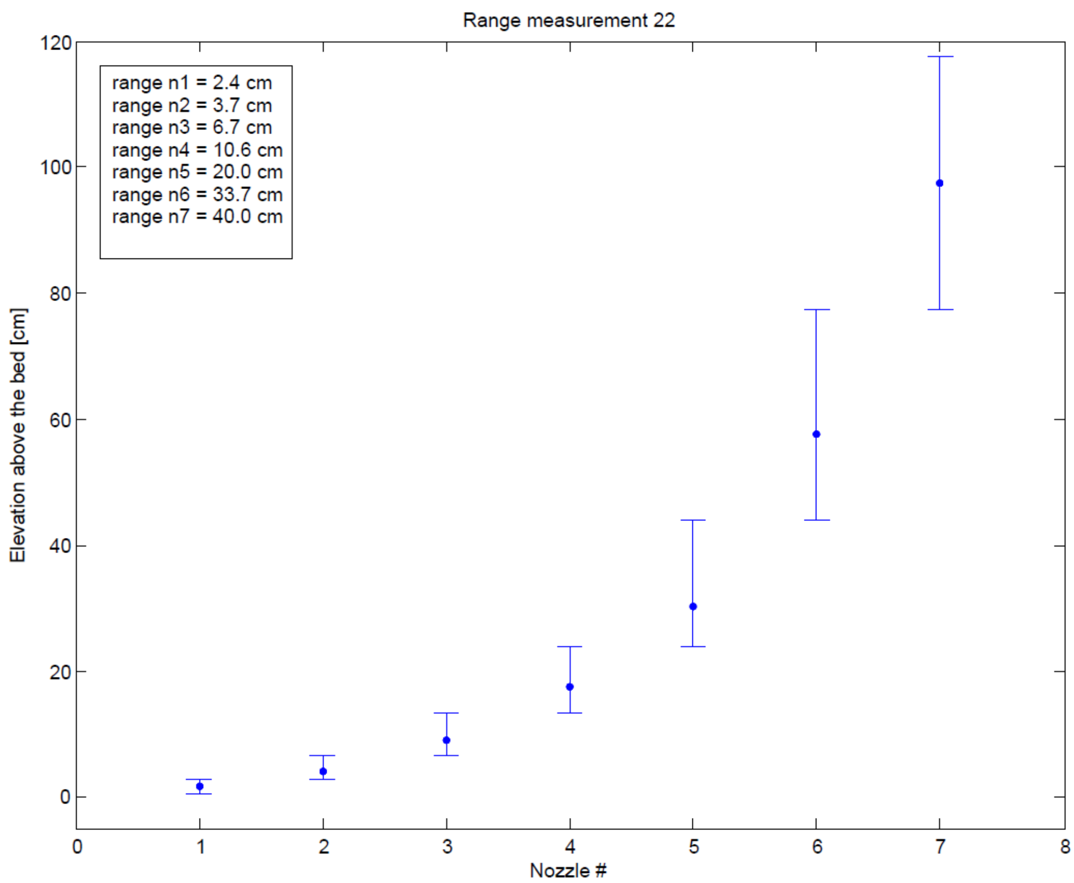


Figure 9: The area (range) that is covered by the nozzles

5.2. The weighted average D_{50} plotted on bed profile RB1

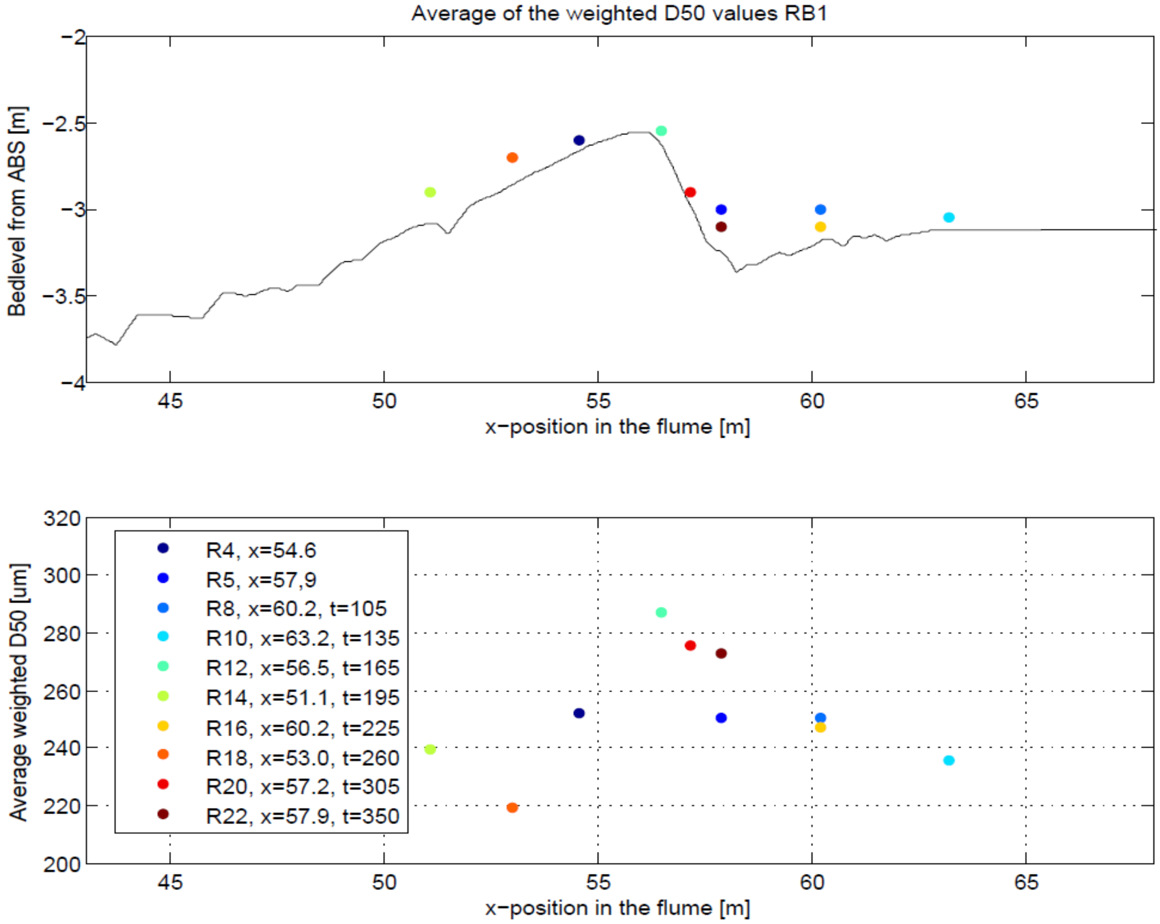


Figure 10: The weighted average D_{50} plotted against the measuring position in the flume

In Figure 10 it can be seen that the D_{50} is low in the shoaling- and surf zone and that it increases towards the top of the breaker bar. On average the results in the figure show that the grain sizes lie around the reference D_{50} of 246 um. The figure also shows that the D_{50} in the breaker zone increases over time (see R22 and R5) and that the D_{50} in the shoaling zone seems to decrease in later measurements (R18). Because measurement 18 shows an unexpected grain size distribution in Paragraph 4.1 the validity of this result is doubtable. When Figure 10 is compared to the bed samples after RB1 (Figure 7), it can be concluded that the suction sample grain sizes are smaller on average. In the surf zone the grain sizes decrease, while in Figure 7 the grain sizes stay at a D_{50} of ±290 um.

5.3. Bed samples 1 vs. regular breaking 1

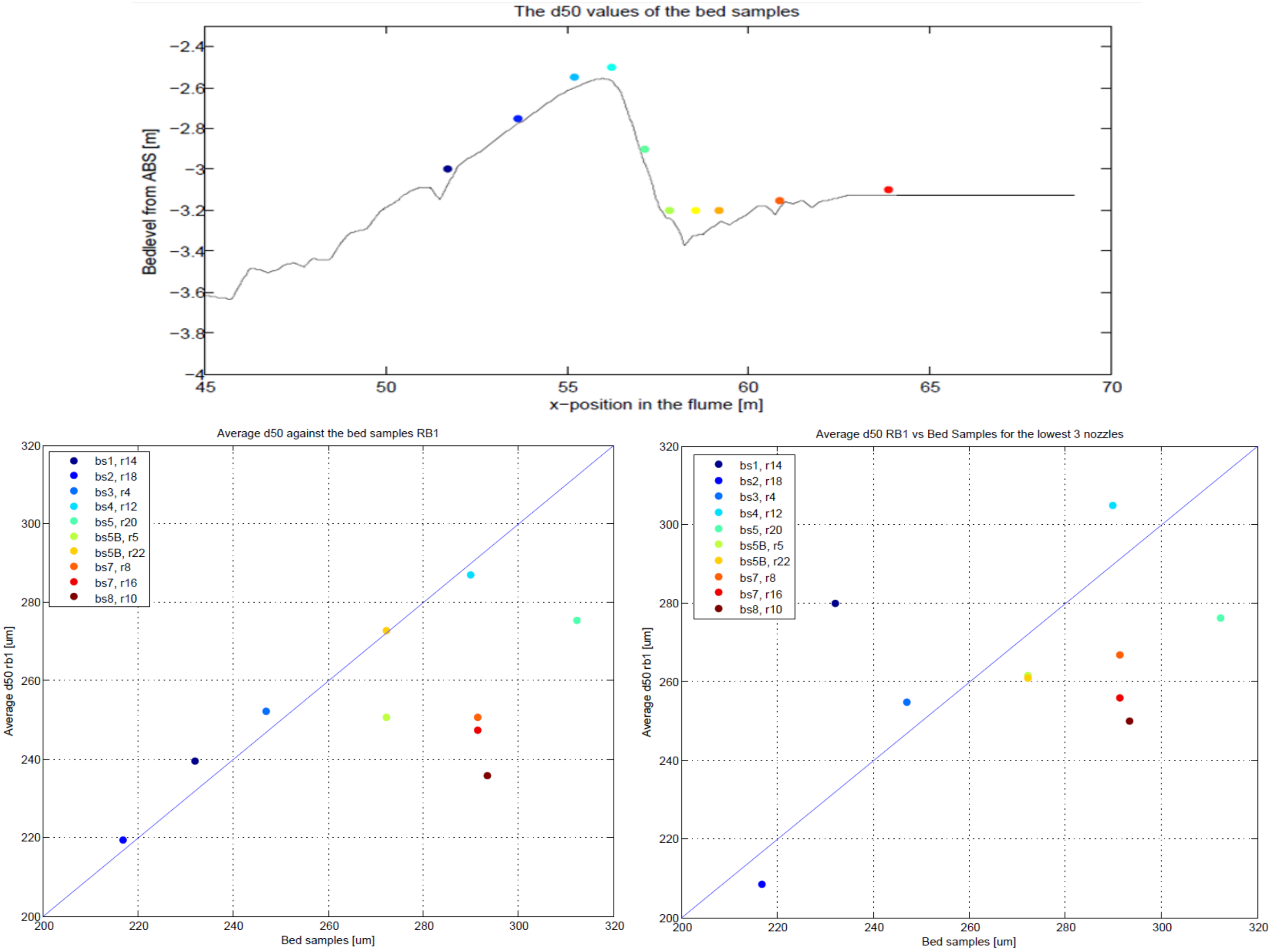


Figure 11: The average D_{50} per run compared to the bed samples at the same measuring location. The legend of the second and third plot also applies for the first plot.

In Figure 11 the suction sample results are plotted against the bed samples. The used values for the suction samples are the D_{50}-averages of all the nozzles per measurement (they are not corrected for the obscuration). In the plot on the right the D_{50}-average of the suction samples was taken for only the three lowest nozzles. This way the influence of the grain sizes in the upper section of the water column can be determined. For the left plot in Figure 11, the results are comparable for almost all the runs. For measurements under the plunging point and in the surf zone (bs5, bs7 and bs8), the bed samples have a larger grain size. From the right plot in Figure 11 we can conclude that the suction sample grain sizes are larger close to the bed. The influence of the fine sediment in the average D_{50} is the largest in the surf zone. In Paragraph 4.1 is shown that the majority of the suction samples have a grain size of 235-285 um. In Figure 11, however, can be seen that the grain sizes of the bed samples have a larger range (230-310 um). The difference in grain sizes can be explained by the fact that the suction samples were obtained over a period of time (±360 minutes of measuring) and the bed samples were all collected at once when the last measurement with the RB1-conditions was performed.

Table 2: D50 comparisons and the ratio TSS/BS. Outliers are not removed and the D_{50} TSS is the average grain size of all the nozzles.

Bed sample:	1	2	3	4	5	5B	5B	7	7	8
x-pos [m]	51,71	53,66	55,21	56,21	57,13	57,83	57,83	60,88	60,88	63,86
d50 TSS [um]	244	217	252	287	275	254	268	274	248	246
d50 bs [um]	232	217	247	290	312	272	272	291	291	293
ratio TSS/bs	1,05	1,00	1,02	0,99	0,88	0,93	0,98	0,94	0,85	0,84

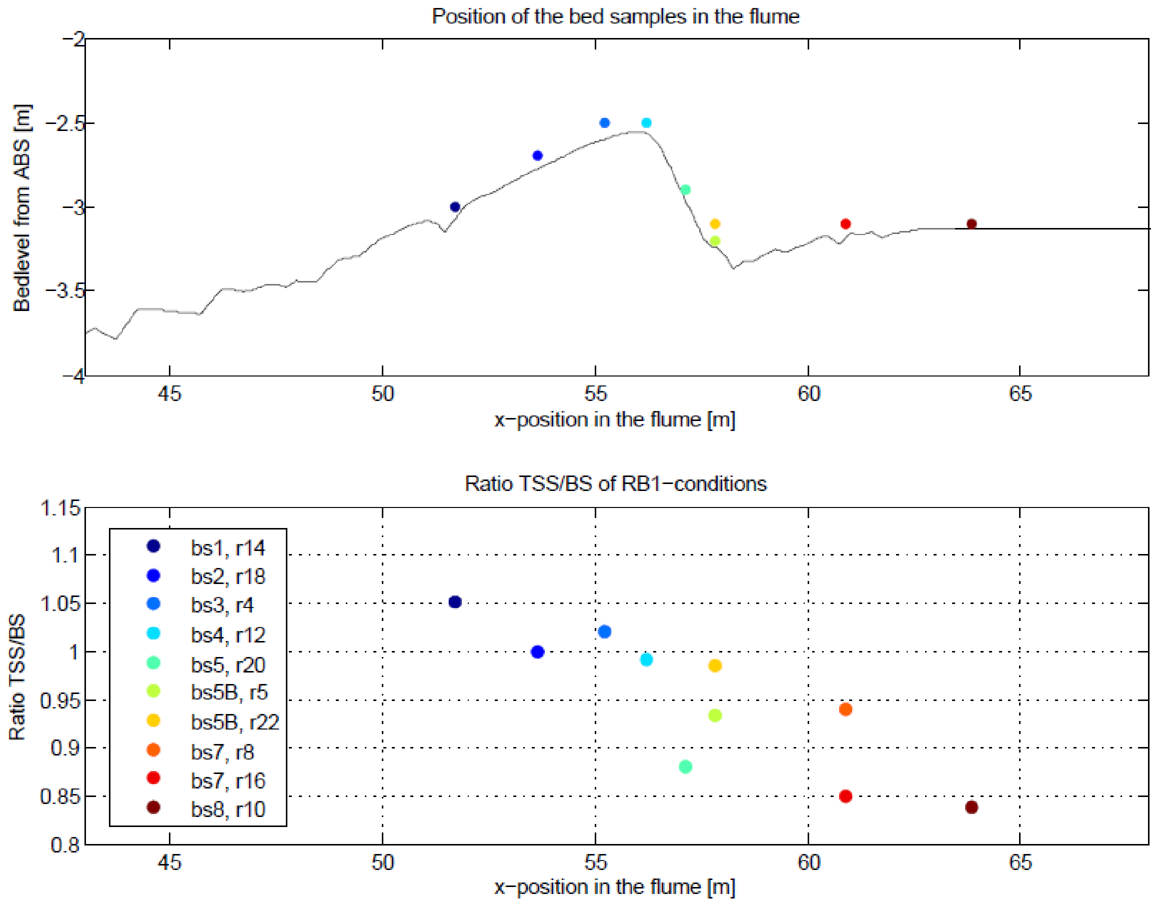


Figure 12: The TSS/BS-ratio plotted over the x-position in the flume

In Table 2 the ratio for Figure 12 is calculated. The bed samples at the shoreward slope of the breaker bar are smaller than the average suction samples. In the breaker zone the ratio decreases more and this continues towards the surf zone. This may suggest that the small particles are transported away from the breaker- and surf zone and they may have been transported towards the seaward side of the breaker bar.

5.4. The weighted average D_{50} plotted on bed profile RB2

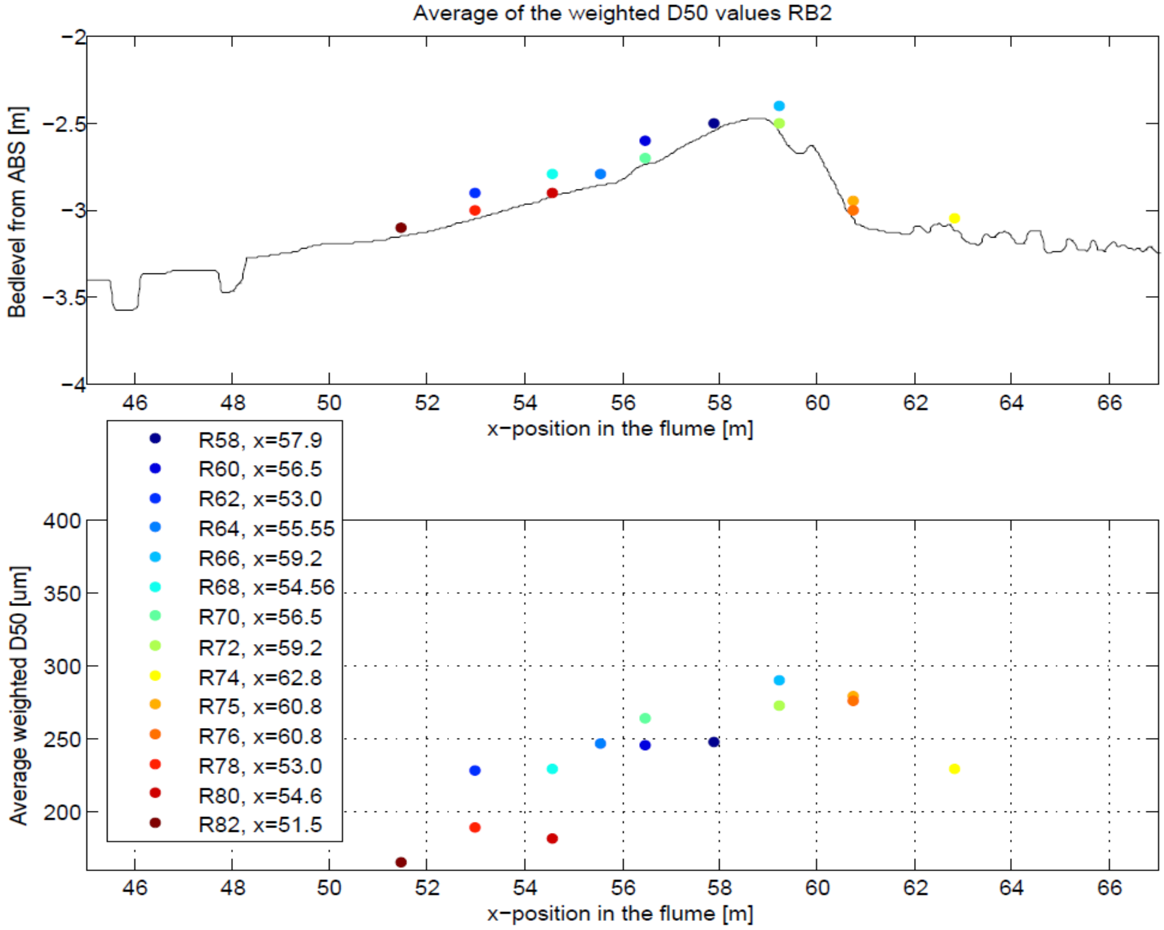
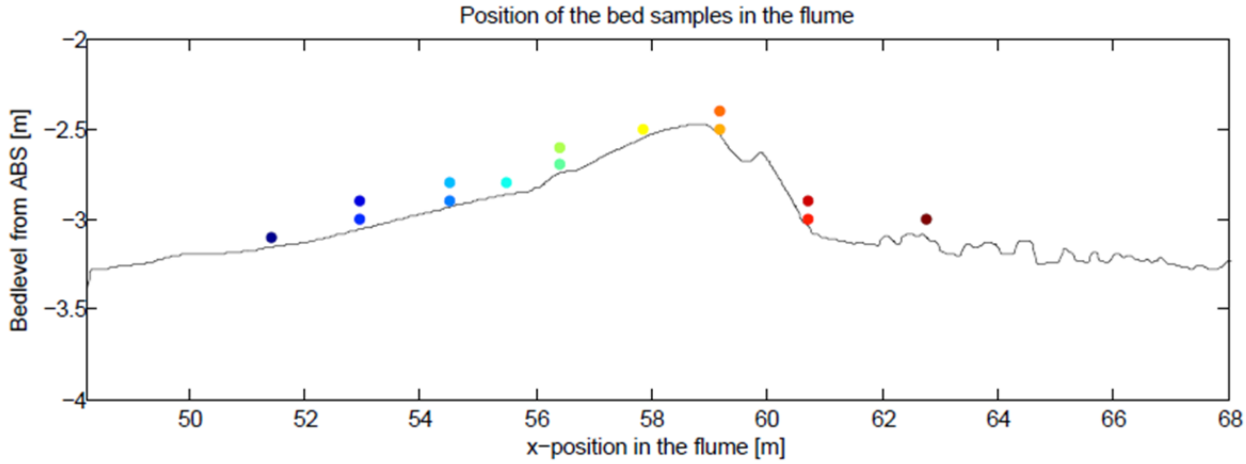


Figure 13: The weighted average D_{50} plotted against the measuring position in the flume

In Figure 13 it can be seen that the D_{50} is low in the surf- and shoaling zone and that it increases towards the top of the breaker bar. On average the results in the figure show that the grain sizes are higher than the reference D_{50} of 246 um. The figure also shows that the D_{50} in the shoaling zone the D_{50} seems to decrease in later measurements (see R68 and R80). Because measurements 78, 80 and 80 showed a strange grain size distribution in Paragraph 4.2, the validity of these results are doubtable. When Figure 10 is compared to the bed samples after RB2 (Figure 8), it can be concluded that the suction sample grain sizes are much smaller.

5.5. Bed samples 2 vs. regular breaking 2



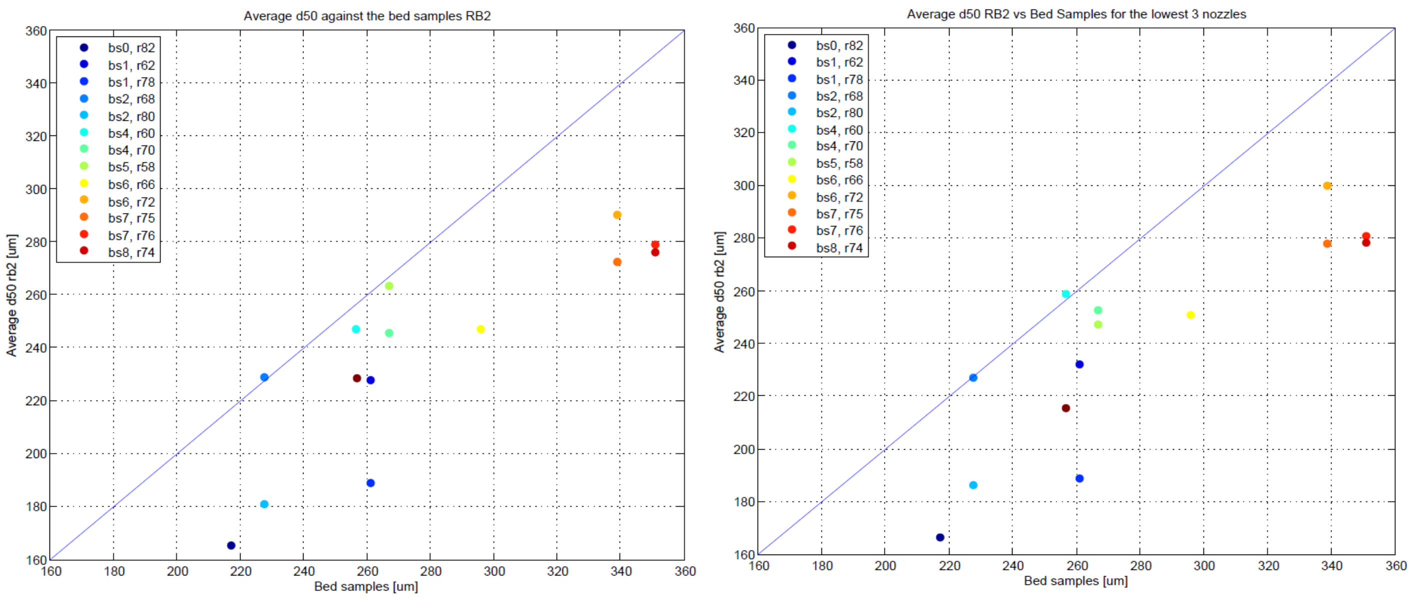


Figure 14: The average D_{50} per run compared to the bed samples at the same measuring location

All the suction samples turned out to have a smaller D_{50} than the bed samples in this measurement. An explanation for this is the added sand in the flume that consists of more fine sediment (dust). When looking at the nozzles closest to the bed, there is not a large difference in grain sizes.

Table 3: D50 comparisons and the ratio TSS/BS Outliers are not removed and the D_{50} TSS is the average grain size of all the nozzles.

Bed sample:	0	1	1	2	2	3	4	4	5	6	6	7	7	8
x-pos [m]	51,42	52,95	52,95	54,51	54,51	55,50	56,42	56,42	57,85	59,18	59,18	60,70	60,70	62,77
d50 TSS [um]	162	228	189	222	183	249	246	255	248	291	283	279	275	252
d50 bs [um]	217	261	261	228	228	257	267	267	296	339	339	351	351	257
ratio TSS/bs	0,74	0,87	0,72	0,98	0,80	0,97	0,92	0,96	0,84	0,86	0,83	0,79	0,78	0,98

In Table 3 the ratio per measurement is measured and in Figure 15 the ratio is plotted against the position in the flume.

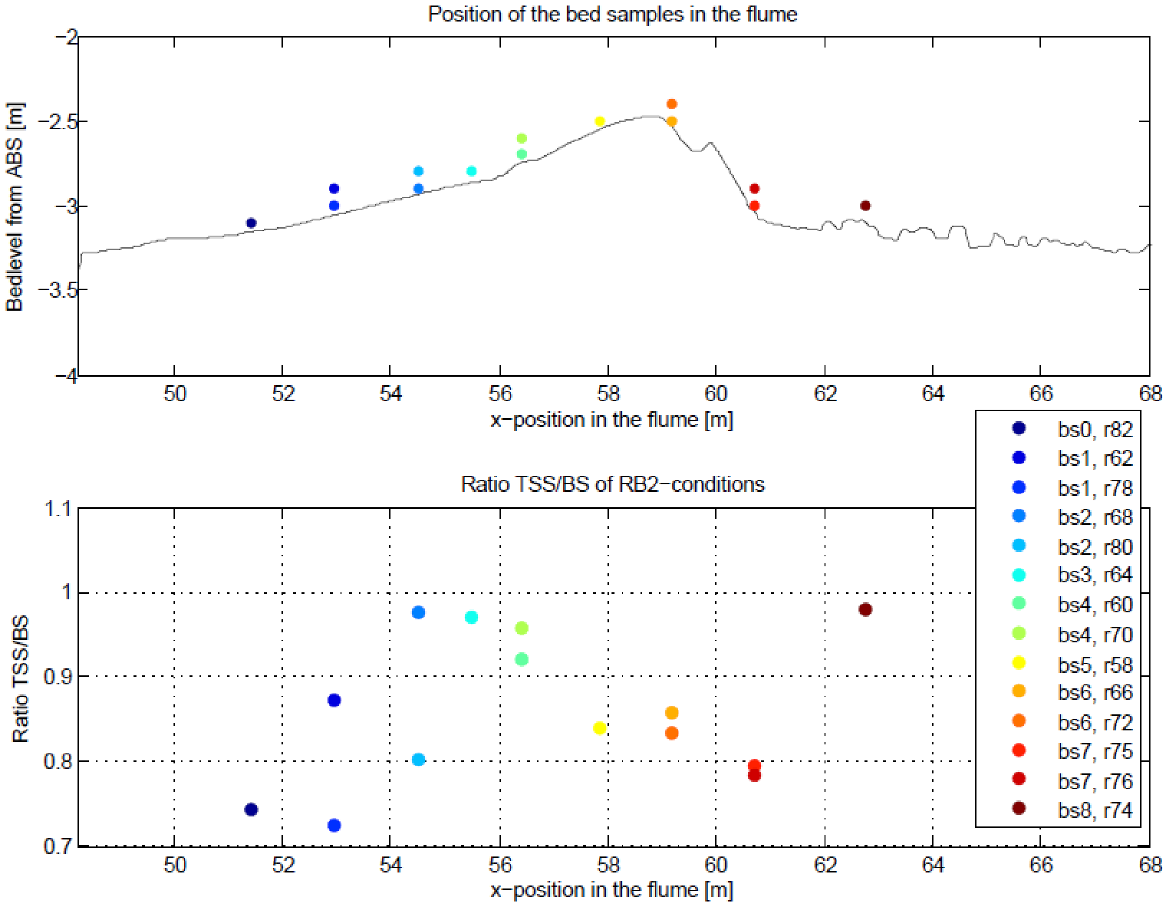


Figure 15: The TSS/BS-ratio plotted over the x-position in the flume

In this run all the bed samples have a larger average grain size than the suction samples. When bs0 and bs1 are disregarded, the ratio shows the same descending trend as was found with the results of the rb1/bs1-ratio. Measurements 78, 80 and 82 had a low obscuration and the grain sizes were very small. Also bs1, bs2, bs3 and bs4 were partially mixed (±1/3) with bed samples that were conducted after the INB-measurements. These two factors could explain the low ratios in the shoaling zone and the different results compared to Figure 12.

5.6. Bed samples after INB-conditions

After the measurements with the INB-conditions, 4 bed samples were collected at random positions from the bed. The samples were collected at a depth of ±30 cm and they are used as control measurements. It is assumed that the grain size distribution was undisturbed at this depth, what gives an idea of the total D_{50} of the sand that was used. The results of the grain size measurements are shown in Table 4:

Table 4: Measured results of the bed samples after INB

Results in [um]	D_{10}	D_{25}	D_{50}	D_{75}	D_{90}
Bedloc. 1	182	226	287	363	440
Bedloc. 2	184	226	285	358	432
Bedloc. 3	194	235	292	363	435
Bedloc. 4	184	232	297	374	450
Average:	186	230	290	364	439

Because there was enough sand (good obscurations), the results are considered to be reliable. Remarkable is that the grain size distribution shows little variation and that the D_{50} is 290 um, while the reference D_{50}-value was 246 um. It also shows that it is unlikely to measure grain sizes smaller than 180 um, which were measured in RB2- and the INB-conditions.

6. The β-calibration factor

Before measurements took place in the CIEM wave flume in Barcelona, the D_{50} was assumed to be 0.246 mm for every measurement. A β-calibration factor is used to calculate the true mass from the dry mass of the sample. Now the D_{50} is known for almost all the measurements, the new β-factor can be calculated. The deviation with the old value will give an indication of the error this caused in the calculated concentration. The initial β-calibration factor of Bosman et al. (1987) was calculated to be 1.4067 and is represented by the following equation:

$$\beta = 1 + \frac{1}{3}\tan^{-1}(D_{50}/D_r) \qquad (2)$$

Here the D_r = 0.090 mm (see Bosman et al., 1987) and is a fixed value and the D_{50} changes for every sample. The total deviation of the D_{50} is shown in Table 5 and Figure 16 and the effect of the D_{50} on the β-factor is shown in Table 6. In this paragraph the effect on the RB1-condition is shown and in Appendix V also the results of the RB2- and the INB-conditions are shown. In Appendix V also is explained how the absolute β-deviation was calculated.

Table 5: The deviation of the D_{50} from the initial D_{50} of 246 um

Condition:	% deviation compared to the highest D_{50}-value	% deviation compared to the lowest D_{50}-value
RB1	37.76	-17.28
RB2	23.42	-40.63
INB	-3.02	-66.04

Table 6: The new β-calibration and the deviation from the old value for RB1- measurements

Measurement #	Average β rb2	Absolute β-deviation of average β [%]	RMSE [%]
4	1,409	0,317	0,674
5	1,410	0,448	1,122
8	1,413	0,777	3,369
10	1,406	0,570	1,749
12	1,423	1,652	4,308
14	1,407	0,714	2,676
16	1,407	0,312	0,890
18	1,391	1,524	3,942
20	1,418	1,142	3,051
22	1,416	0,886	2,437

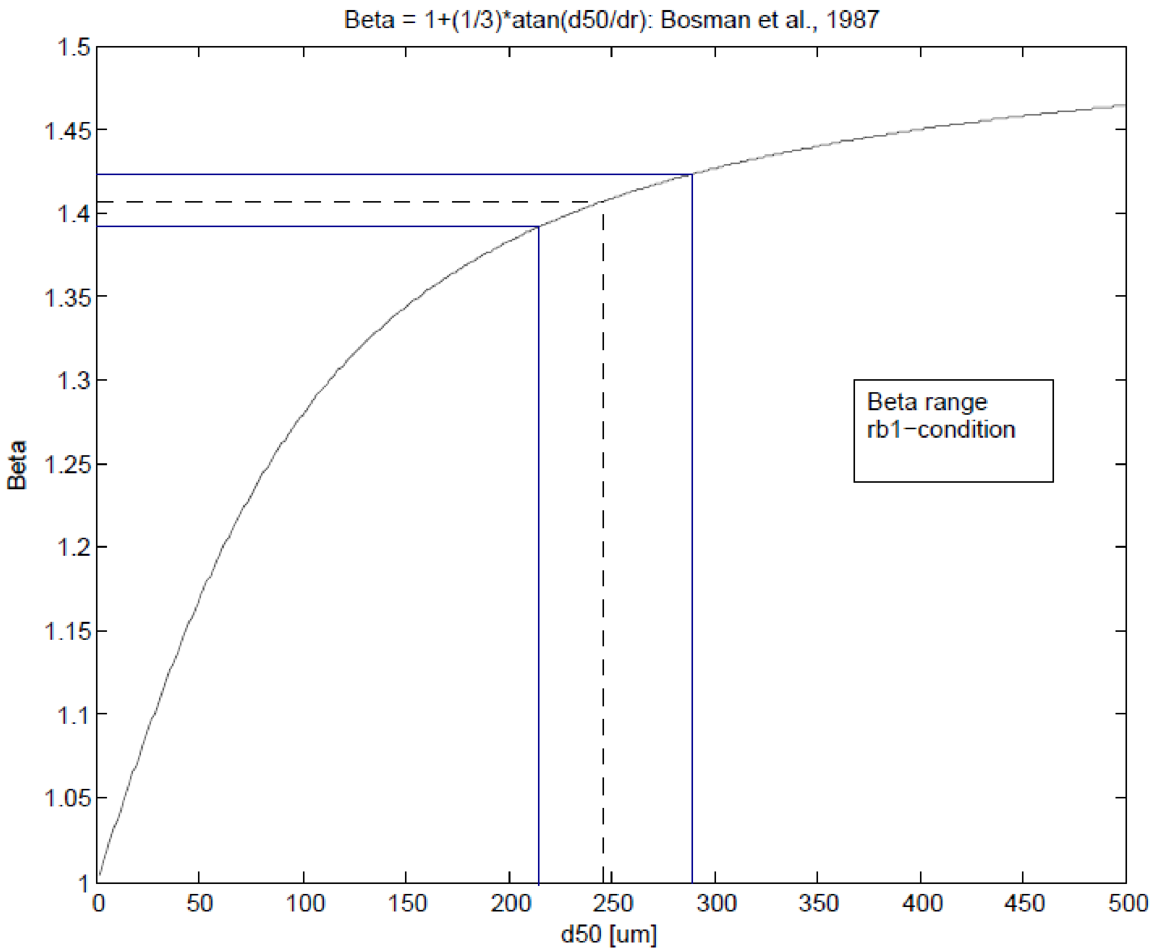


Figure 16: The β -variation for RB1-measurements

The average concentration of the measurements with the RB1-condition was 0.93 g/L. The maximal deviation of the β-factor was 1.65%, what results in an average deviation in the concentration of 0.015 g/L. This value is too small to have a large influence on the results of the measurements.

7. Discussion

As was described in Chapter 3, there were different sources that could produce errors. The cleaning of the data was done by looking at the obscuration of the samples. For the RB-measurements, obscurations lower than 4% are ignored and for the INB-measurements obscurations lower than 1% are removed. When looking at the figures where the D_{10} to D_{90} is plotted (see Appendix “Data Overview”), it can be noticed that with reliable obscurations the deviations per nozzle do not differ much. With some measurements the obscuration was said to be reliable, but the cumulative course of the distribution per nozzle was very different. Especially with INB-conditions this occurred and therefore a minimal obscuration should have been <2% or even <3.5%. With this approach, RB-measurements with low obscurations have been removed unnecessarily and therefore it may be better to reduce the minimal obscuration for RB-measurements to ±3%. Altogether, the cumulative D_{10} to D_{90} plots should have been used more with the cleaning of the data.

When the influences of the concentration and the range of the nozzles were added to the D_{50}-values, not all suction nozzles were taken into account. That is because sometimes a nozzle got buried in a ripple or because a suction sample got lost during the sampling. These values were set to NaN and therefore they were not taken into account in the calculation. This influenced the outcomes of the average D_{50}-values that are used in the comparison with the bed samples.

In Chapter 5 the bed samples are compared to the suction samples. In this chapter all the suction samples were taken into account, what means that the measurements with low obscurations are also used in the calculation of the average (suction sample) grain size. When the measurements with low obscurations were ignored, the average suction sample grain size was often calculated over only one or two samples. This was the reason to take all measurements into account, but the samples with a low obscuration may have an influence on the results. Performing more grain size measurements is the only possibility of improving the reliability of the results.

A good way to reduce these points of discussion is do perform more measurements. This solution and some other recommended analysis is described more explicitly in Chapter 9, Recommendations.

8. Conclusions

The conclusions of the results will be described by giving answers to the research questions that were drafted in Chapter 2.

a. How is the grain size distributed over the height in the water column?

For the experiments with regular breaking waves the highest grain sizes were found in the breaker zone. For the RB1-conditions little sediment sorting occurred in the zone under the plunging wave, but on top of the breaker bar more sorting was found. There smaller sand particles were found higher in the water column, while closer to the bed the grain sizes increased. For the RB2-conditions in all zones very little sediment sorting occurred. Still, the grain sizes increased on top of the breaker bar and in the breaking zone. In the shoaling zone, the grain sizes were small for both the RB1- and the RB2-condition were smaller than in the breaker zone and little sediment sorting was found. In the surf zone however, larger grain sizes were found and the sand was well mixed.

For INB-measurements strong sorting was found in the region near the bottom. Higher in the water column, less sorting takes place and the grain sizes were very small. Five types of wave groups were measured with the INB-conditions and for each wave group one measurement was analyzed. The measurements were conducted at the same location and the values contained very little variation in D_{50}.

b. Does sorting take place in the horizontal plane?

Bed samples are taken after the RB1-, RB2- and INB-conditions. All the bed sample results show that the grain sizes increase towards the top of the breaker bar (shoreward). Also in the surf zone, a large D_{50} was measured. The grain size measurements show that the fine sand particles are transported from the breaker- and surf zone. Further, the grain sizes in the breaker zone showed a distribution that can be explained by sand transport from the breaker bar. Information of other measuring instruments is needed to prove that this actually occurred.

c. In what way do the D_{50} of the bed samples relate to the D_{50} of the suction samples?

The suction samples have been compared to the bed samples and to make this comparison more accurate, the range per suction nozzle and the sand concentration per measurement is taken into account. The results show that for the RB1-measurements the bed samples are in line with the suction samples. Only in the surf zone the suction samples become smaller than the bed samples and the influence of the fine material in the average of the suction samples shows an increase of ±10 um in the surf zone. These results may indicate that fine sediment is transported away from the surf zone towards the breaker zone. For RB2-conditions the suction samples grain sizes and the bed sample grain sizes are more different. Especially in the beginning of the shoaling part of the breaker bar the bed samples contain a larger grain size. For both RB1- and RB2-conditions the grain size of the bed samples show a larger range (e.g. rb1: ±230-310 um) than for the suction sample's grain size (e.g. rb1: ±235-285 um). The decrease in suction sample/bed sample-ratio towards the breaker zone is mostly determined by the suction samples that show a shoreward descending trend. Because all the bed samples had a reliable obscuration, it is assumed that the suction samples have the most influence on the trend that is shown in Figure 12 and Figure 15.

d. What is the influence on Bosman's β-calibration factor when the measured D_{50} per sample is used instead of a fixed D_{50}?

Before measurements took place in the CIEM wave flume in Barcelona, the D_{50} was assumed to be 0.246 mm for every measurement. The β-calibration factor is used to calculate the true mass from the dry mass of the sample. With the measured D_{50} per nozzle, the β-factor was calculated again. When the effect of the changed β-factor is computed for the concentrations, an approximation shows that the concentrations will deviate 0.015 g/L for rb1-, 0.019 g/L for rb2- and 0.073 g/L for INB-conditions. This little deviation lies within the measuring error.

9. Recommendations

This report shows how the grain sizes are distributed in the water column. To find more accurate answers to why some results were found, more information is needed and this information and recommended analysis will be described below.

First, the course of the grain size distributions in the shoaling- and surf zone can be explained better if water velocities and the flow directions are known. This can give an indication of where the fine sediment is transported to when it is not measured in the breaker- or surf zone. Altogether, it will give more information about the horizontal sediment sorting at different locations in the breaking process. Secondly, it would be good to have bed sample measurements that are obtained before the (test-) experiments. This will help to find out more about the grain sizes we expect to see, the reference D_{50}-value and the validation of the bed sample results. Thirdly, more measurements at the same location will give a better overview of the grain size distribution. Especially for the shoaling zone this is of importance, because very little reliable measurements were conducted there. Finally, with average water levels at measuring locations it is possible to make a better calculation of the nozzle-range, what can make the results more accurate. In this report the water level is not taken into account, what may give a deviating value for the ranges of nozzles 1 and 7.

With the data and the results that are shown in the previous chapters, more analysis can be done. To begin with, the TSS concentrations will not change much because of the recalculated β-factor, but they should be calculated in order to have a more accurate data set. This can be useful for the calibration of the ABS-data. The second recommendation for an extra analysis is to fit a line through the results of every grain size distribution. When this is done, the outliers become clearer and the comparison of the measurements becomes easier. With this line, the mixing length can be calculated. With the mixing length it is possible to quantify the amount of mixing per measurement. This is useful information when the sediment transport is evaluated.

Appendices

I. The Laser Diffraction System

Figure 17: The auto preparation system

Figure 18: A sand sample that is added to the water

Figure 19: The sample cells, the water in- and outlet (white hoses). This part of the instrument was taken out of the machine to take a photo

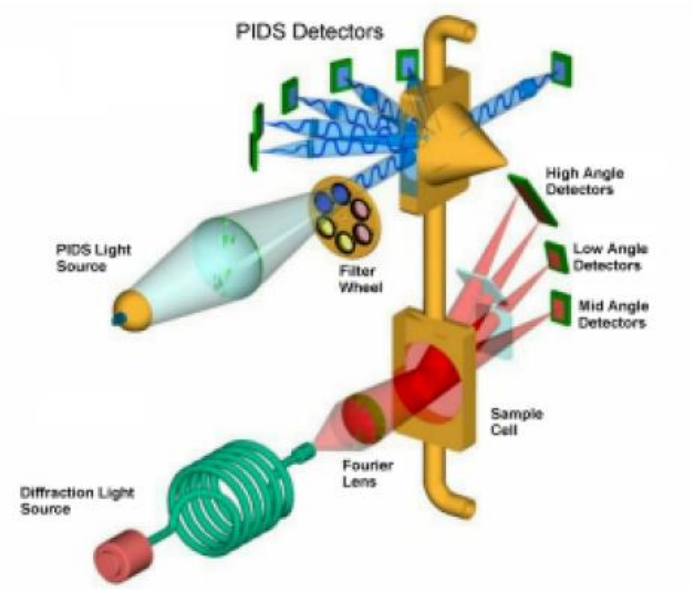


Figure 20: Schematic representation of the optical system of the LS 13 320

II. Overview of the raw data for a measurement

In this report an overview is given of the overall results of all the measurements. To show what information is available per measurement, an overview of all the data of one measurement is given in this chapter. The measurement that was chosen is the last measurement (run 22) and was performed with regular breaking wave conditions (RB1). The information that is available for each measurement is:

- The course of the sand concentration over the vertical in the water column
- The measuring position in the flume
- The area (range) that suction nozzles cover
- The course of the D_{50} over the vertical in the water column
- The course of the D_{10}, D_{25}, D_{50}, D_{75} and the D_{90}
- The obscuration, which gives information about the reliability of the grain size measurements

The area (range) that the suction nozzles cover is shown in Paragraph 5.1 and the rest of the information is shown in the next paragraphs. There an overview of the data of RB1-measurement 22 will be given followed by a cumulative grain size distribution. To give an idea of how the data was presented by the laser diffraction system, Paragraph II-c shows the grain size distribution of each nozzle of measurement 22, followed by three examples of measurements with a low obscuration.

a. The measured and calculated results of one measurement

Table 7: An overview of the measured and calculated results of measurement 22

Run:	location [m], zone:	Nozzle:	Concentration [g/L]:	Height above the bed [cm]:	D_{50} [um]:	Obscuration [%]:	Range nozzle [cm]:
22	57,89	1	NaN	1,7	NaN	NaN	2,4
		2	1,63	4,1	259	8,9	3,7
	Breaker	3	1,43	9,1	262	9,5	6,7
	Zone	4	1,30	17,4	265	8,7	10,6
		5	1,19	30,2	268	9,2	20,1
		6	1,37	57,5	281	9,0	33,7
		7	1,24	97,5	273	9,4	40,0

b. The cumulative grain size distribution

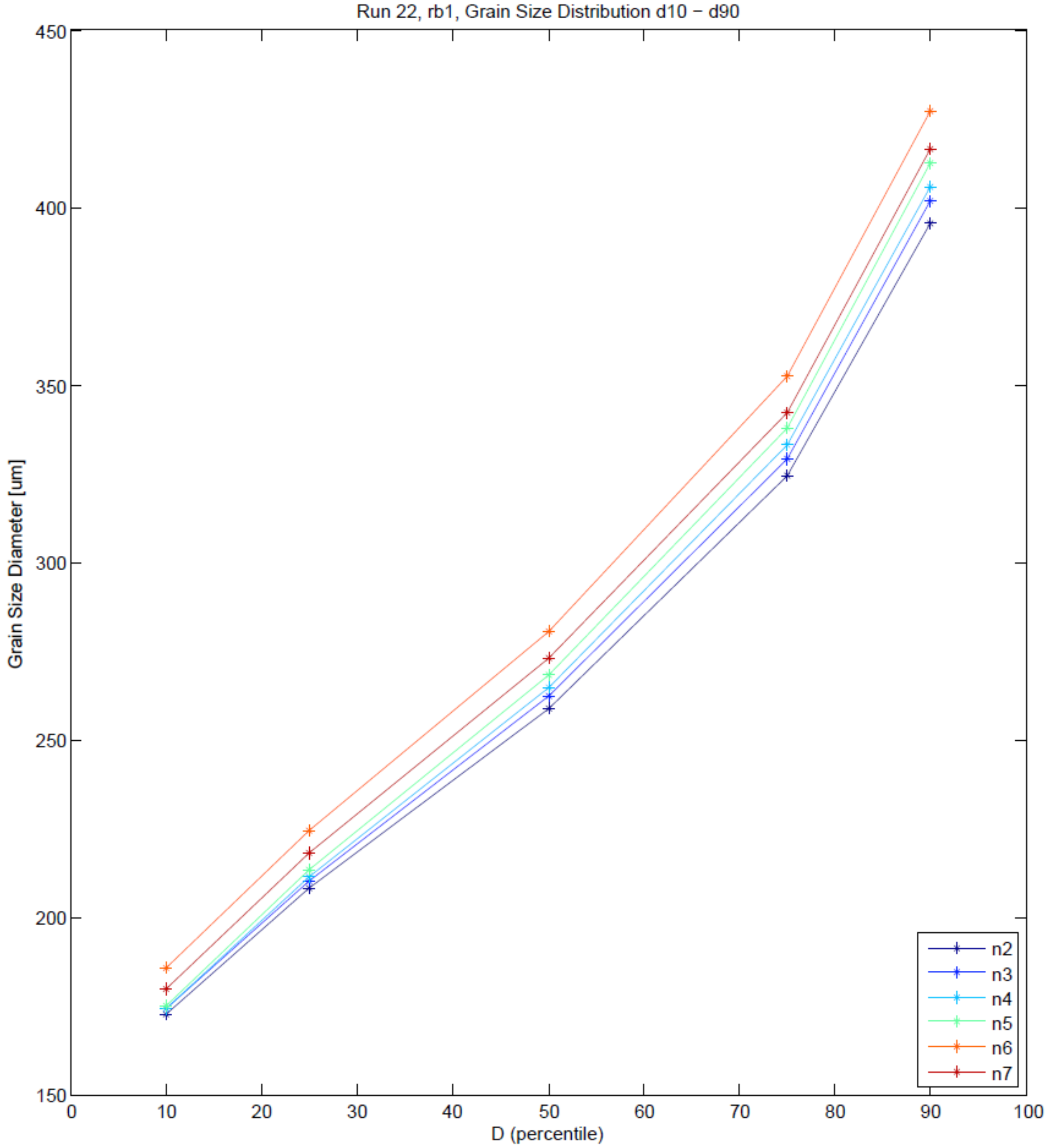


Figure 21: An example of the d10-d90 grain size distribution for one measurement.

Figure 21 shows the cumulative course of D_{10} to D_{90} of a measurement with a reliable obscuration. This measurement was conducted in the breaker zone while the breaker bar was fully developed. As can be seen in the Appendix “Data Overview”, the other measurements showed a distribution like Figure 21. With lower obscurations the lines (grain sizes) are more apart, what means that there is more sorting in grain size. A more exact grain size distribution can be seen in the figures in the next paragraph. Figures Figure 22 to Figure 27 show the grain size distribution per suction nozzle and have the shape of a normal distribution.

c. Grain size distributions per nozzle

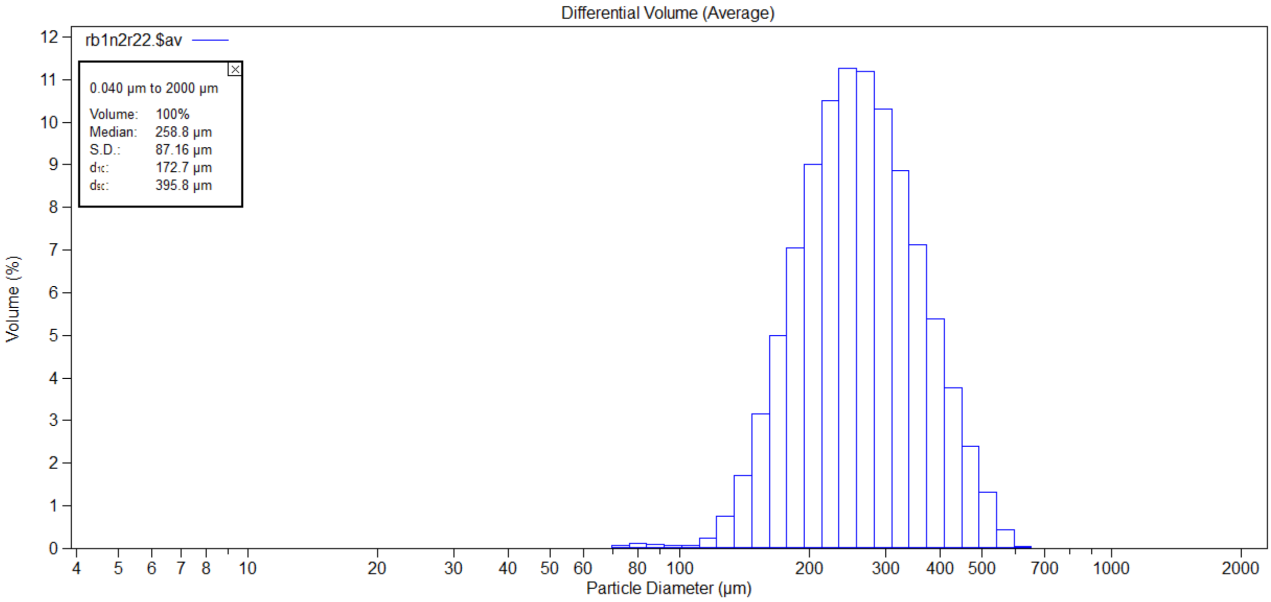


Figure 22: Grain size distribution measurement 22, nozzle 2

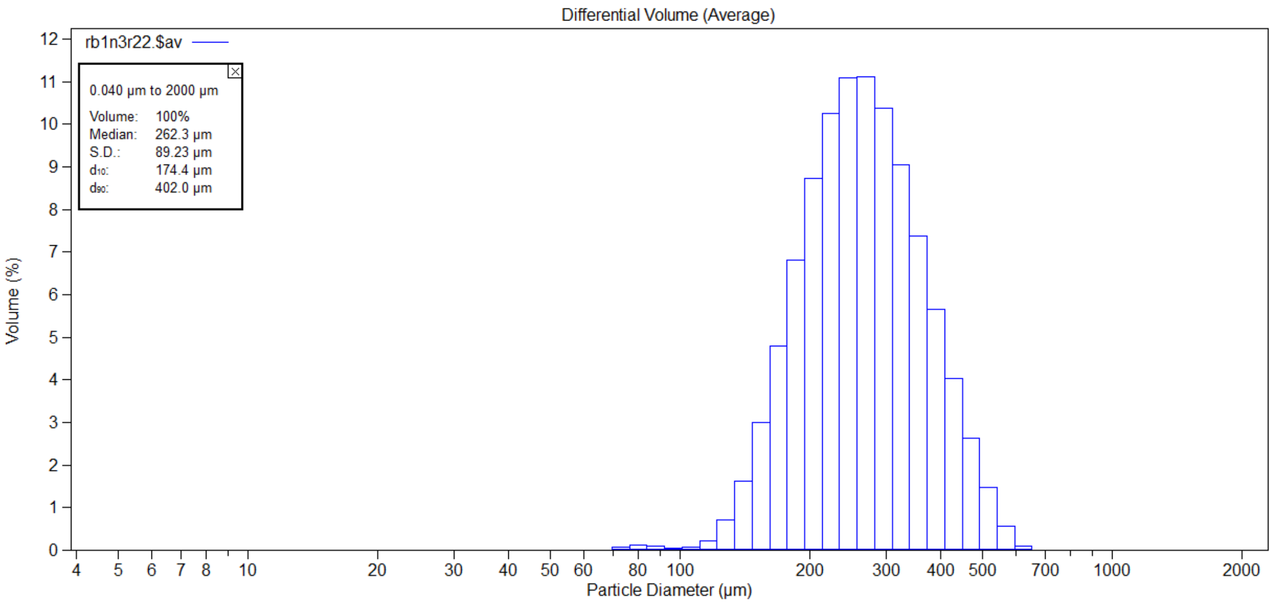


Figure 23: Grain size distribution measurement 22, nozzle 3

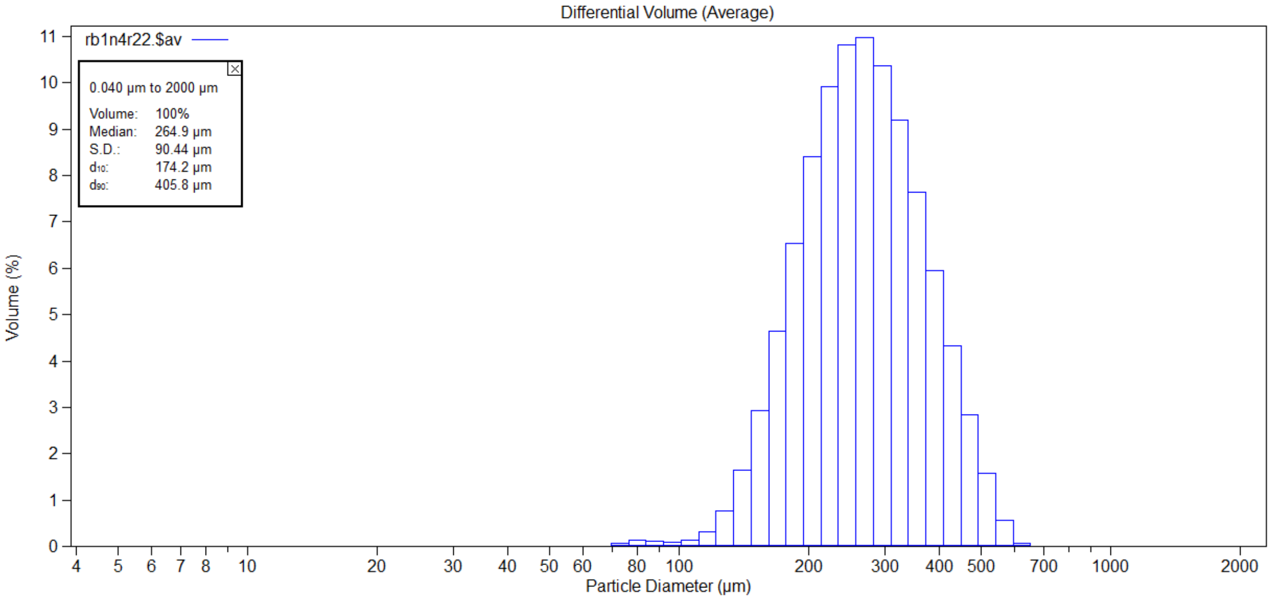


Figure 24: Grain size distribution measurement 22, nozzle 4

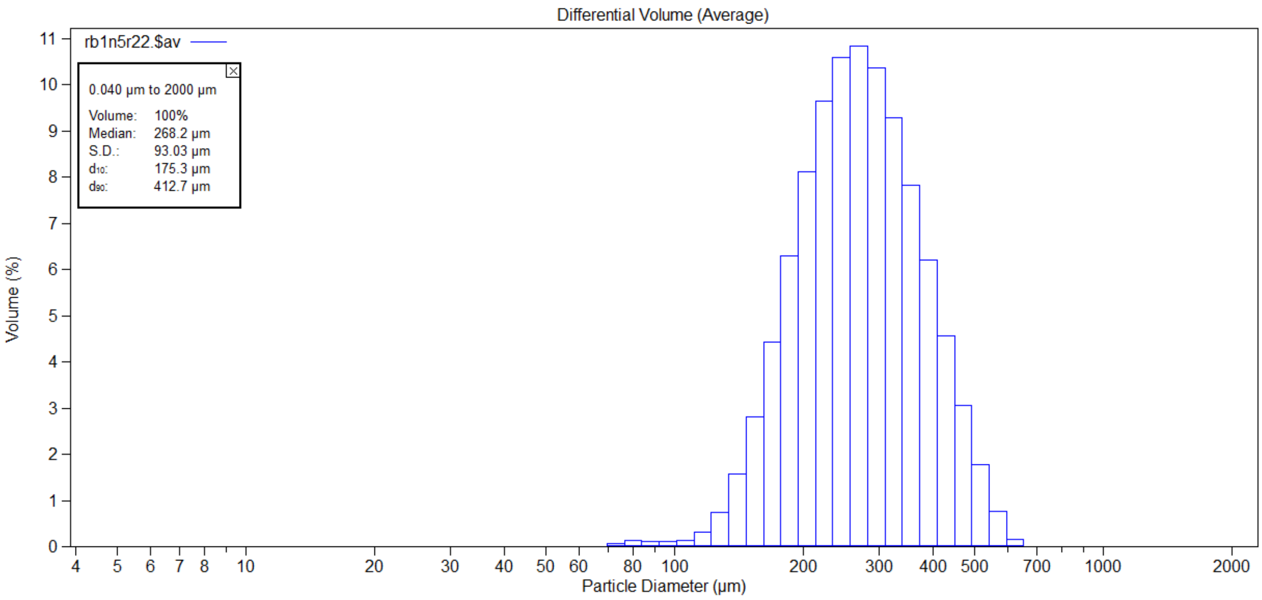


Figure 25: Grain size distribution measurement 22, nozzle 5

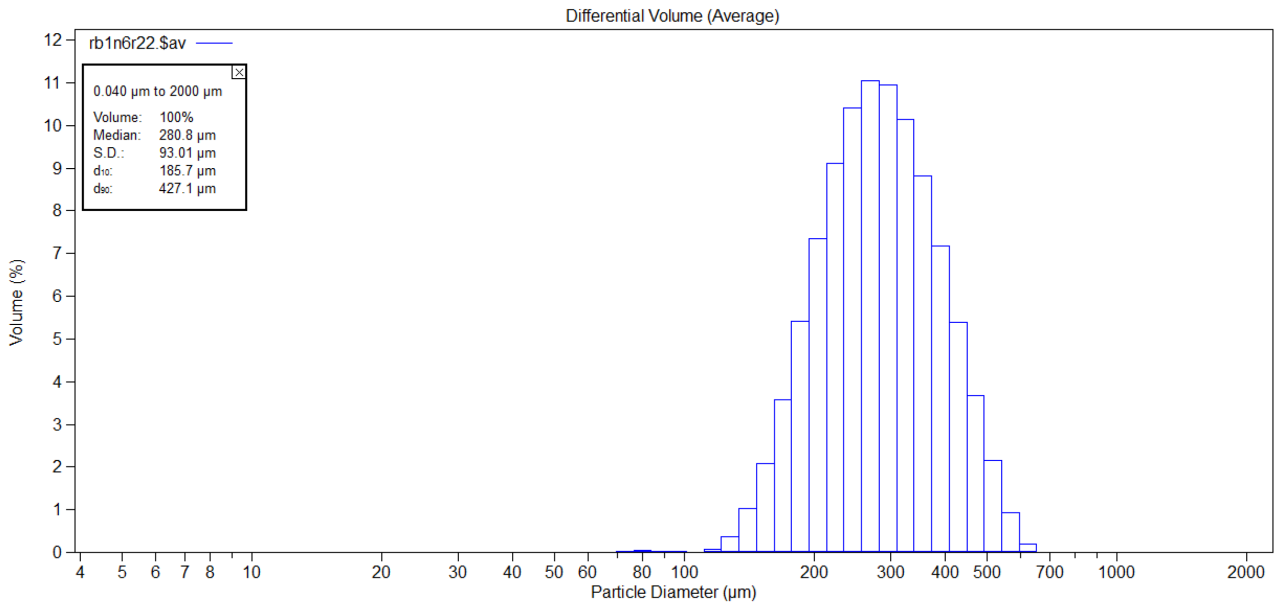


Figure 26: Grain size distribution measurement 22, nozzle 6

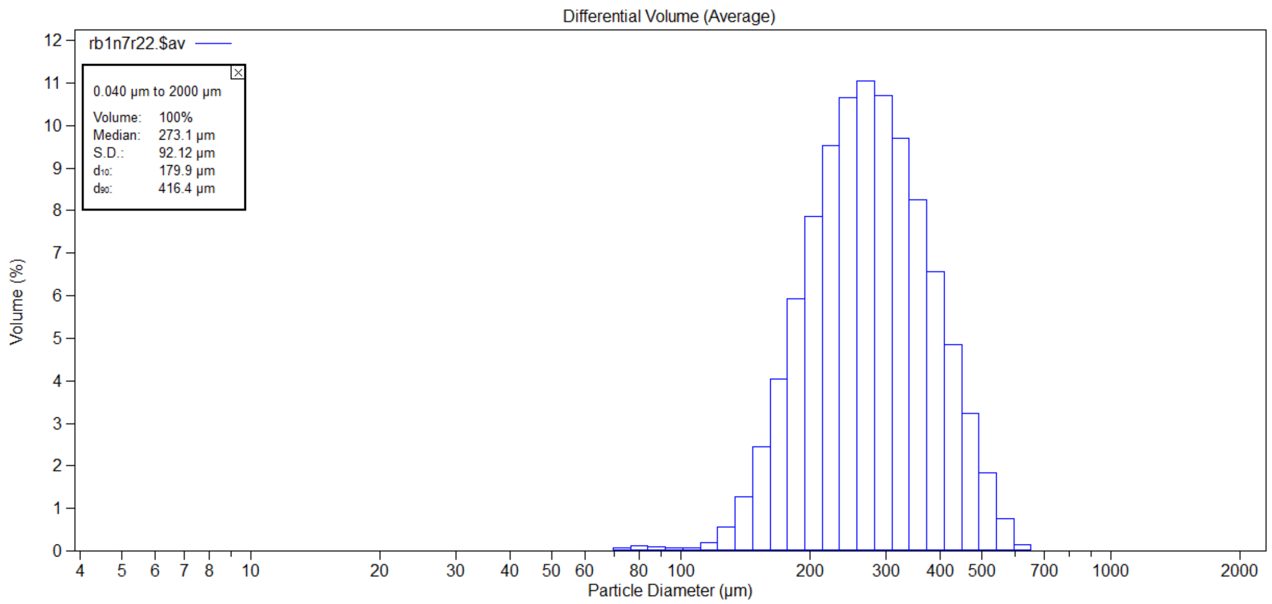


Figure 27: Grain size distribution measurement 22, nozzle 7

The bed sample that was taken at the same measuring location is shown below in Figure 28.

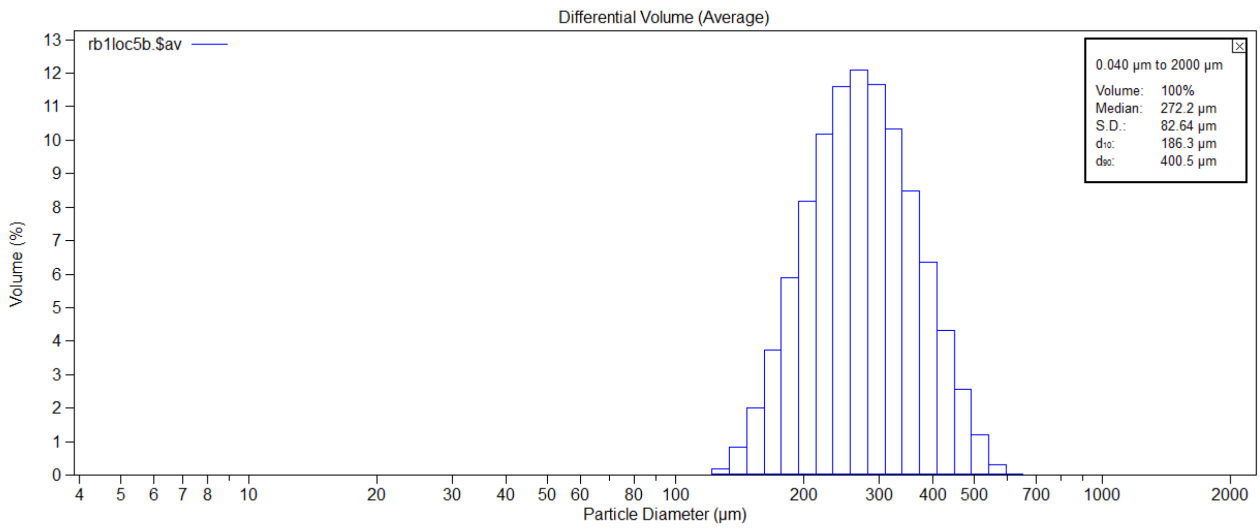


Figure 28: The bed sample that is taken at the same location as measurement 22

d. Three measurements with a low obscuration

Because measurement 22 contained enough sand, the grain size measurements were conducted with a good obscuration. For measurements with a lower obscuration, the bars of the histogram are wider and/or do not show a normal distribution. Examples of this are shown in Figure 29Figure 31 below.

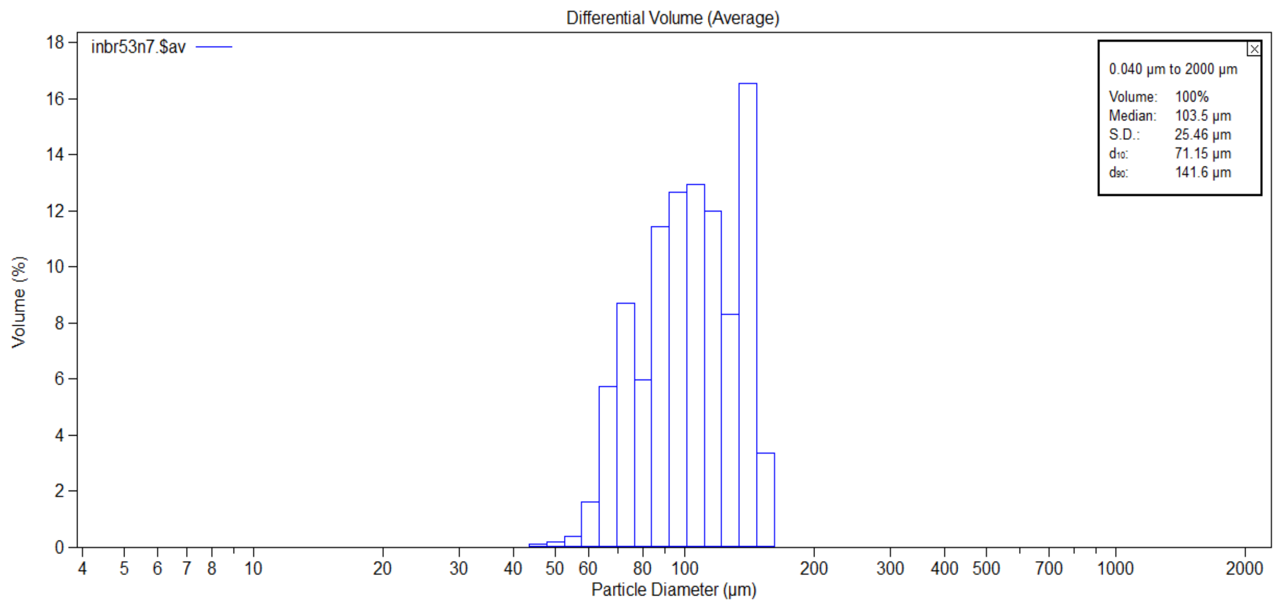


Figure 29: Example measurement (INB-condition) with an obscuration of 0.1%

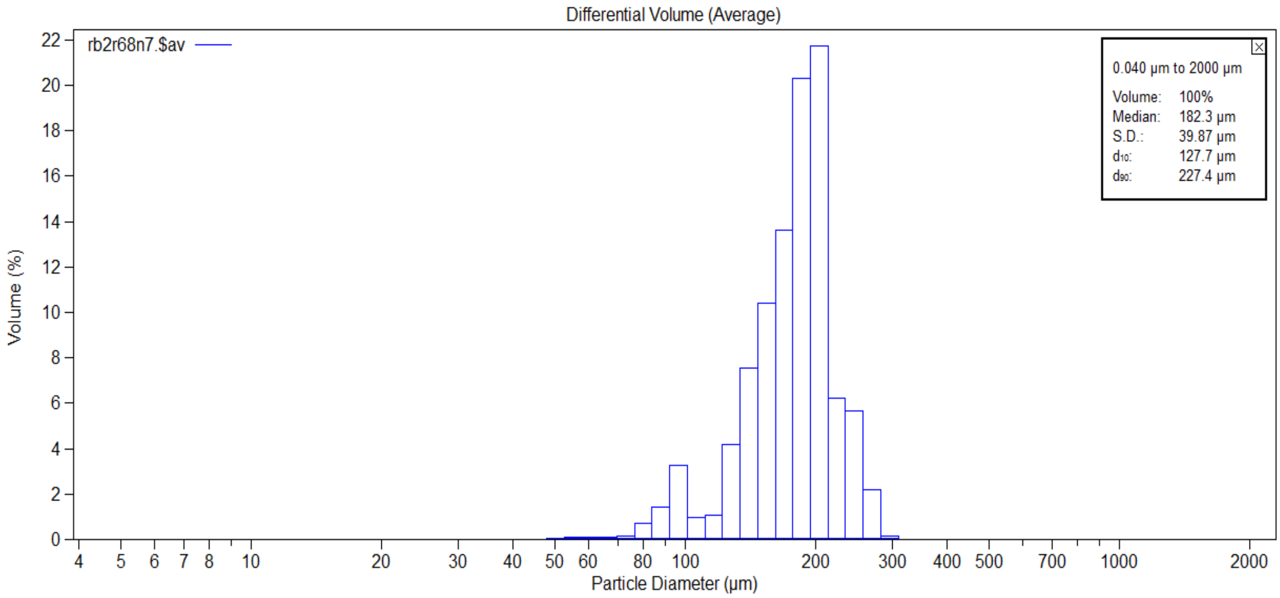


Figure 30: Example measurement (RB2-condition) with an obscuration of 0.05%

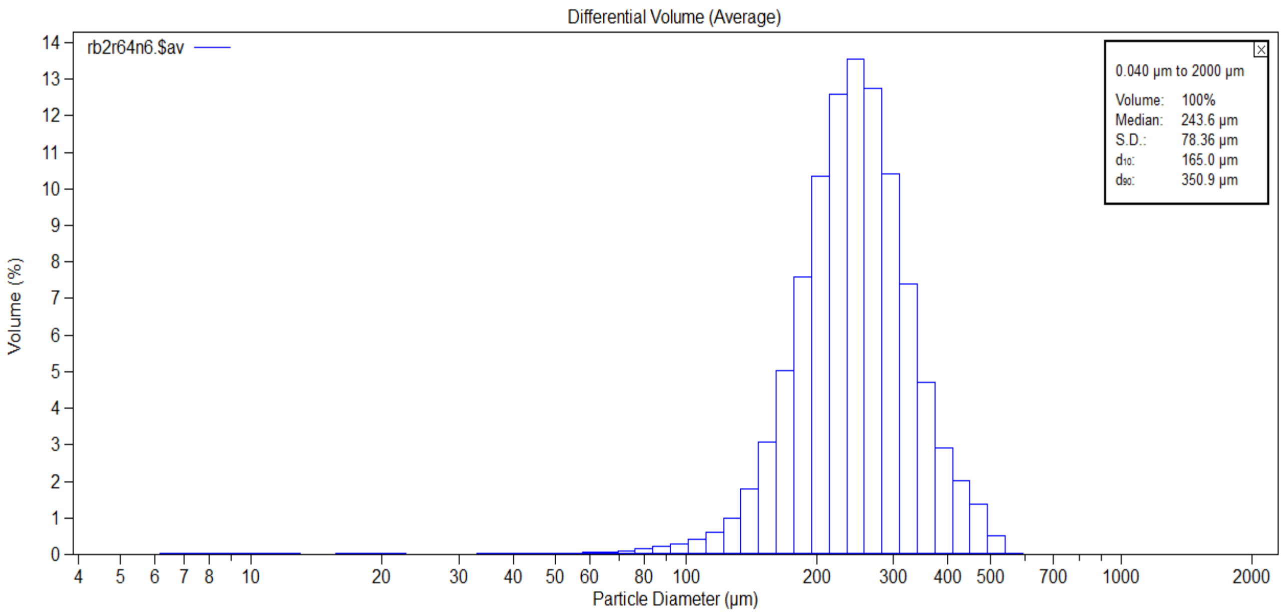
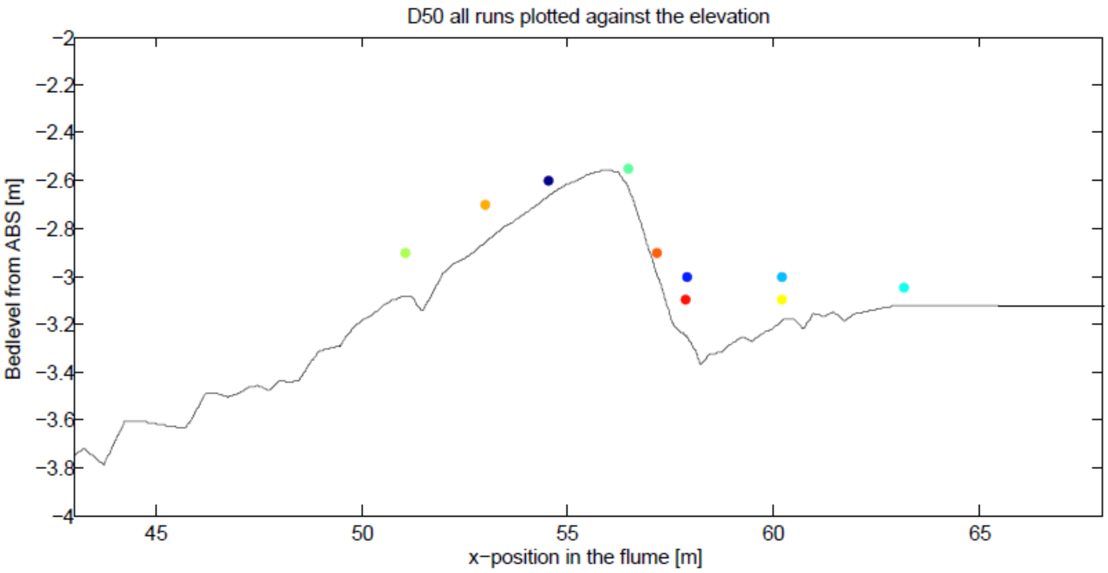


Figure 31: Example measurement (INB-condition) with an obscuration of 1.0%

III. Figures with uncorrected data

a. Regular breaking 1



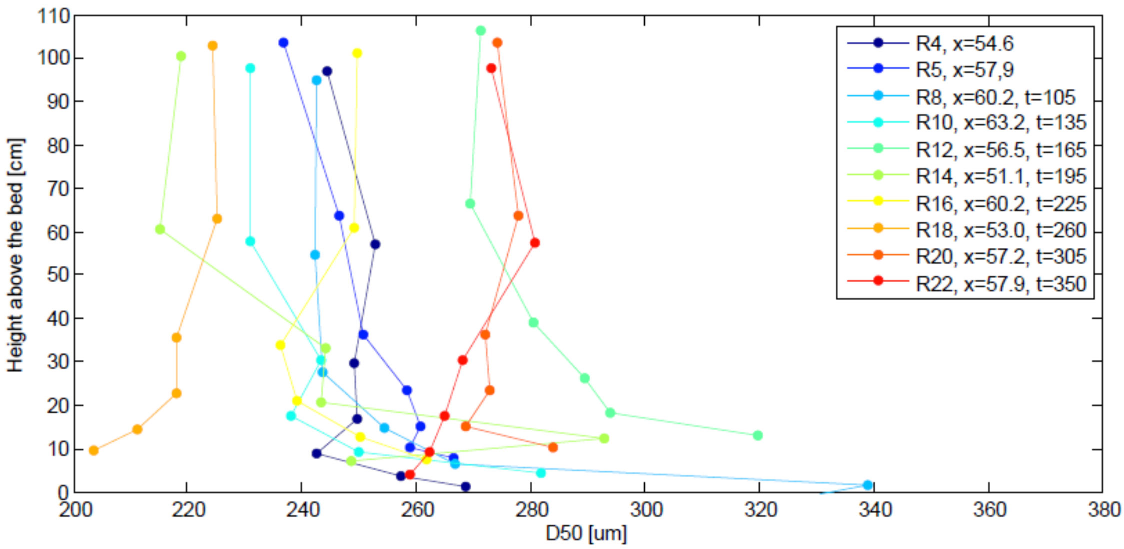
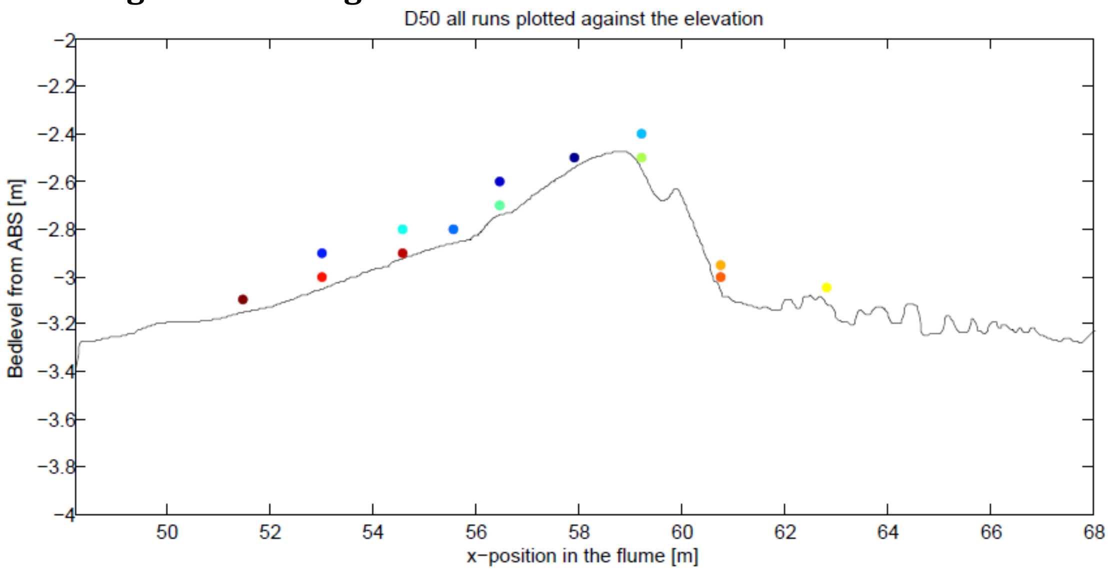


Figure 32: All the D50 grain size distributions of the RB1 condition

b. Regular breaking 2



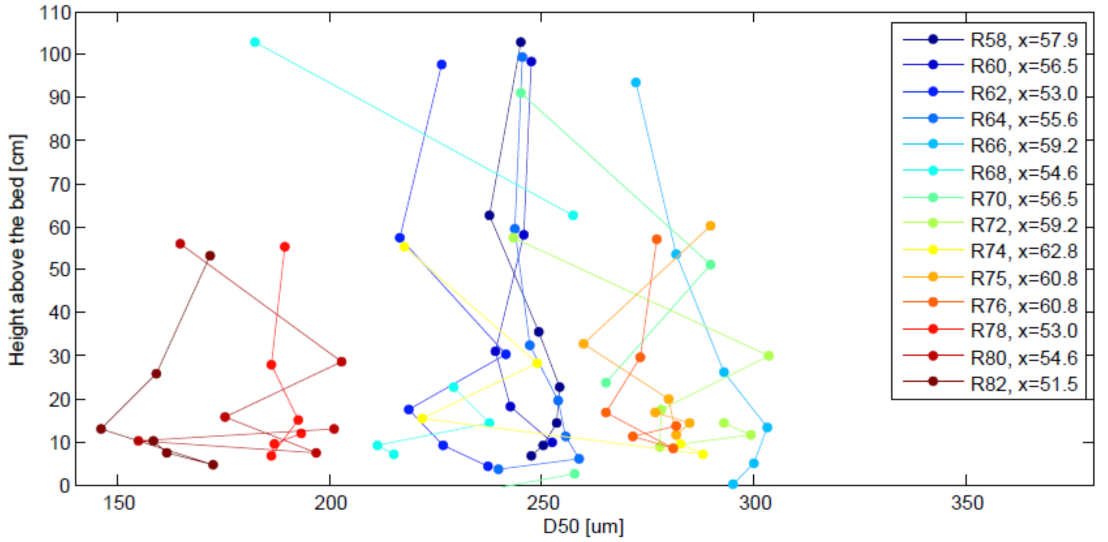


Figure 33: All the D50 grain size distributions of the RB2 condition

c. Irregular Non-Breaking

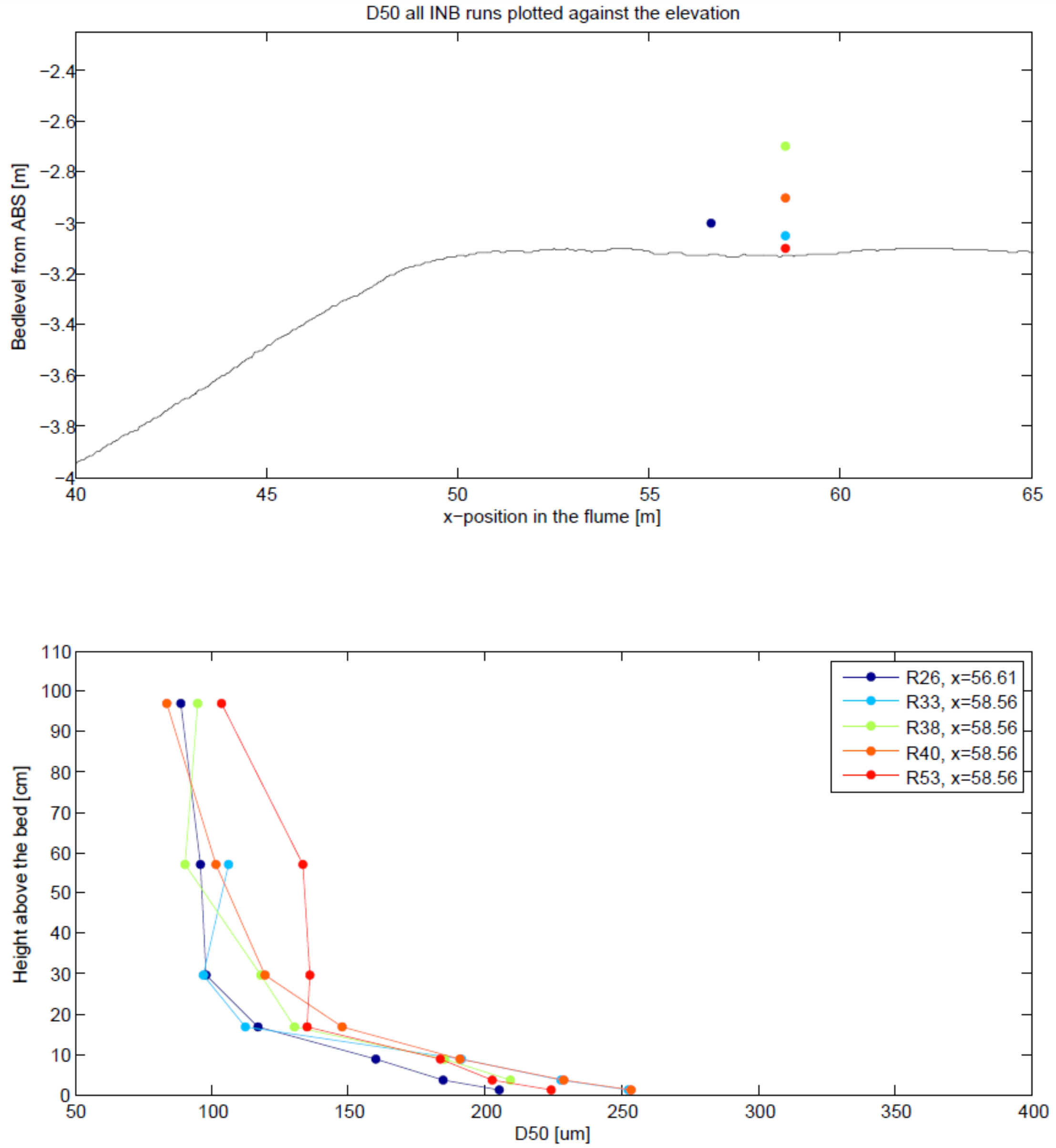


Figure 34: All the D50 grain size distributions of the INB condition

IV. Comparison of bed samples with RB experiments

a. Bed samples 1 vs. Regular Breaking 1

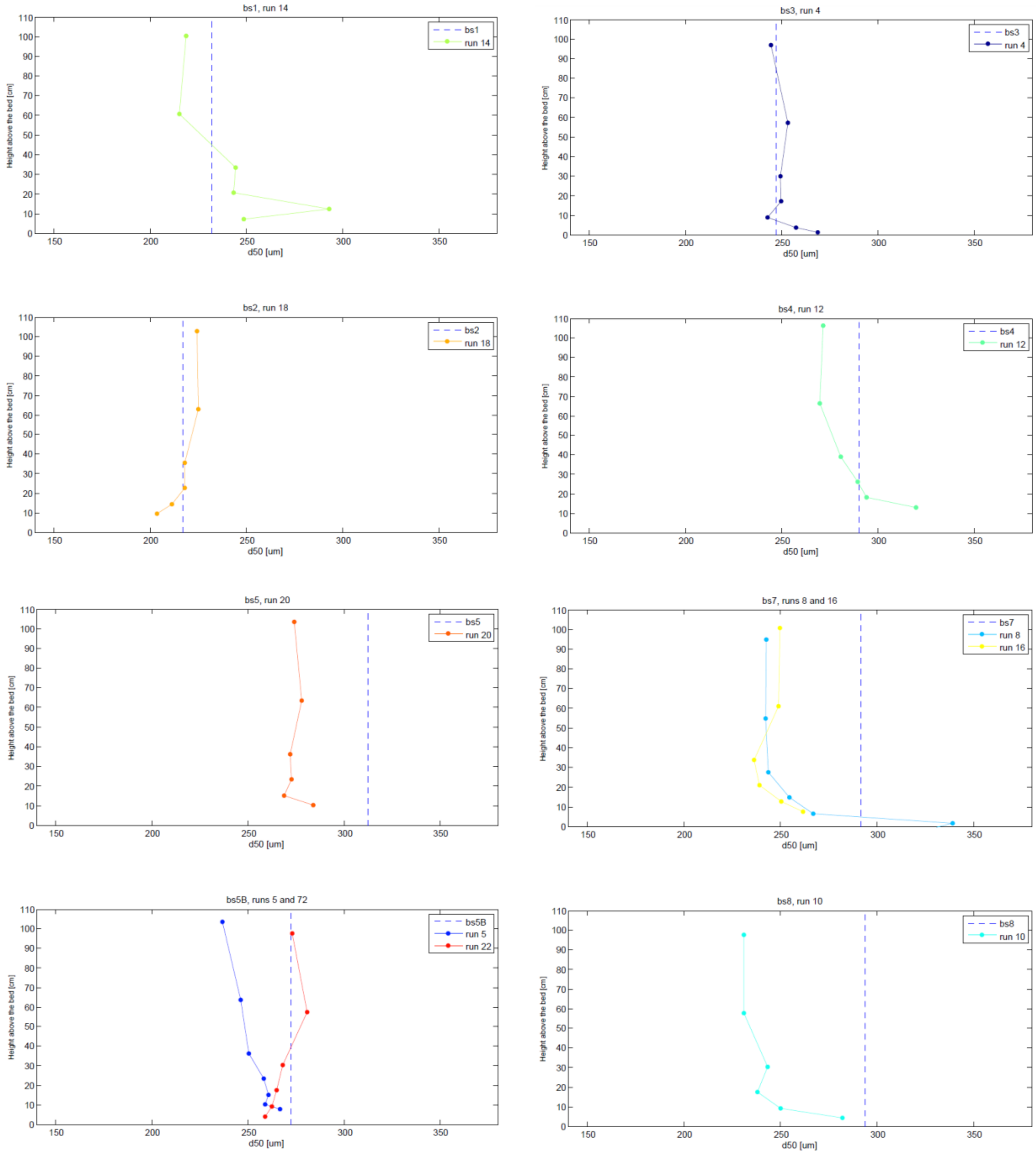


Figure 35: Comparison between the RB1 measurements and the bed samples that were collected at the same position in the flume (the uncorrected suction samples are used)

In Figure 25 only the measurements are shown that were taken at the same location as the bed samples. For most of the runs, the bed samples are in accordance with the results from the TSS measurements.

b. Bed samples 2 vs. Regular Breaking 2

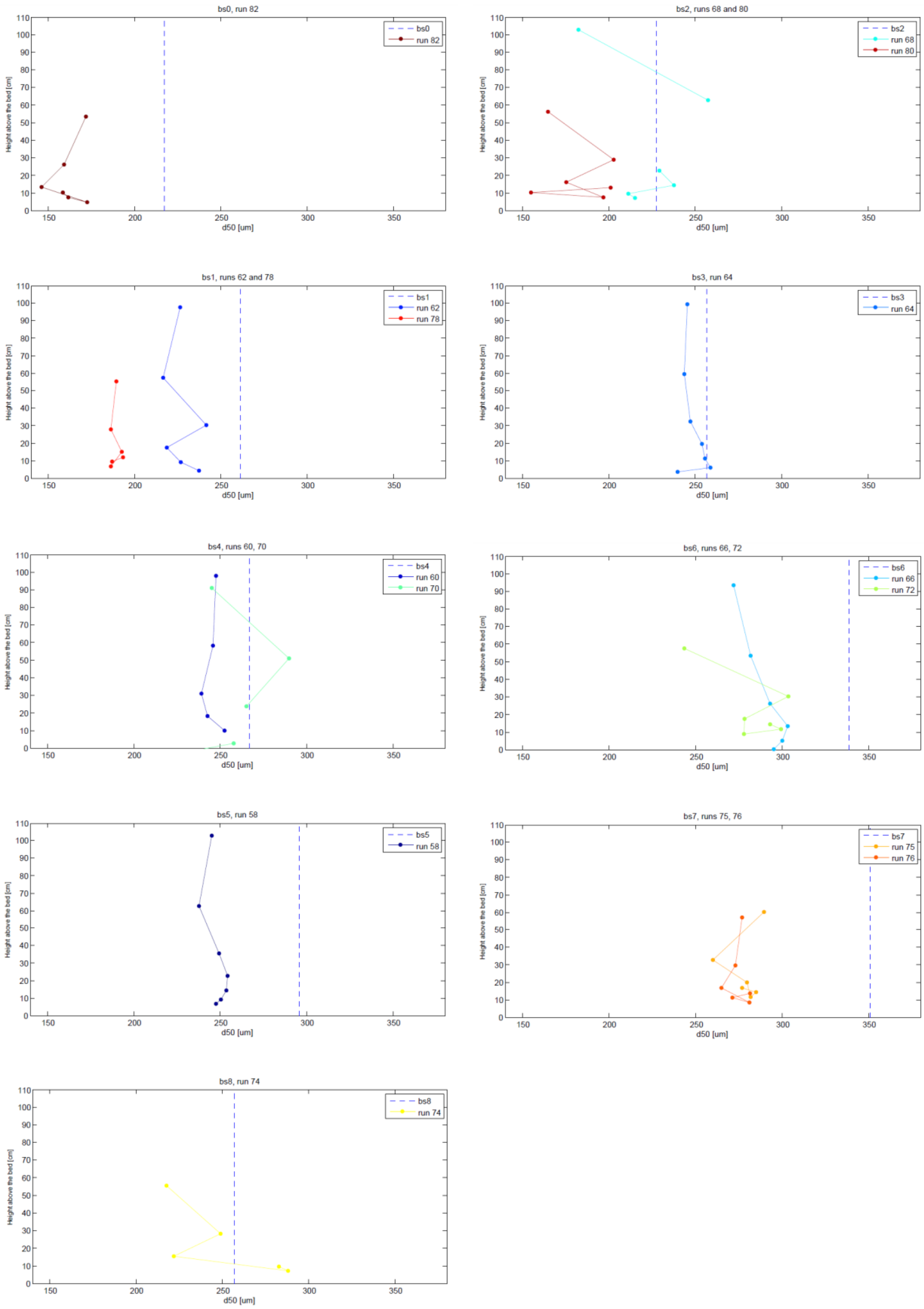


Figure 36: Comparison between the RB2 measurements and the bed samples that were collected at the same position in the flume.

In Figure 36 it can be seen that the TSS measurements have different results than the bed samples. As is described earlier, the smaller (lighter) particles can be moved while draining the flume. This can explain the higher D_{50} of the bed samples.

V. The β-factor with the calculated D_{50} for RB1-, RB2- and INB-conditions

To find out what the influence of the changing β-value is, the absolute β-deviation was calculated for each measurement with equation 3:

$$\Delta\beta = \frac{1}{7}\left(\sum_{i=1}^{7} |\beta_{nozzle\ i} - \beta_{old}|\right) \tag{3}$$

where β_{old} is the β that was measured with the initial D_{50} of 246 um. To clarify this formula, the values are shown in Table 8:

Table 8: example calculation of rb1, measurement 12

Nozzle:	$\beta_{nozzle\ i}$	β_{old}	Absolute deviation [%]:
1	1,4321	1,4067	2,54
2	1,4245	1,4067	1,78
3	1,4231	1,4067	1,64
4	1,4201	1,4067	1,34
5	1,4162	1,4067	0,95
6	1,4168	1,4067	1,01
7	1,4224	1,4067	1,57
Average:	1,4323	Average β-deviation [%]	**1,6518**

RB1-conditions:
The average concentration of the measurements with the rb1-condition was 0.93 g/L. The maximal deviation of the β-factor was 1.65%, what results in an average deviation in the concentration of 0.015 g/L. This approximation is made to estimate the effect of the new β-factor.

Table 9: The new β-calibration and the deviation from the old value for RB1- measurements

Measurement #	Average β rb1	Absolute β-deviation of average β [%]	RMSE [%]
4	1,409	0,317	0,674
5	1,410	0,448	1,122
8	1,413	0,777	3,369
10	1,406	0,570	1,749
12	1,423	1,652	4,308
14	1,407	0,714	2,676
16	1,407	0,312	0,890
18	1,391	1,524	3,942
20	1,418	1,142	3,051
22	1,416	0,886	2,437

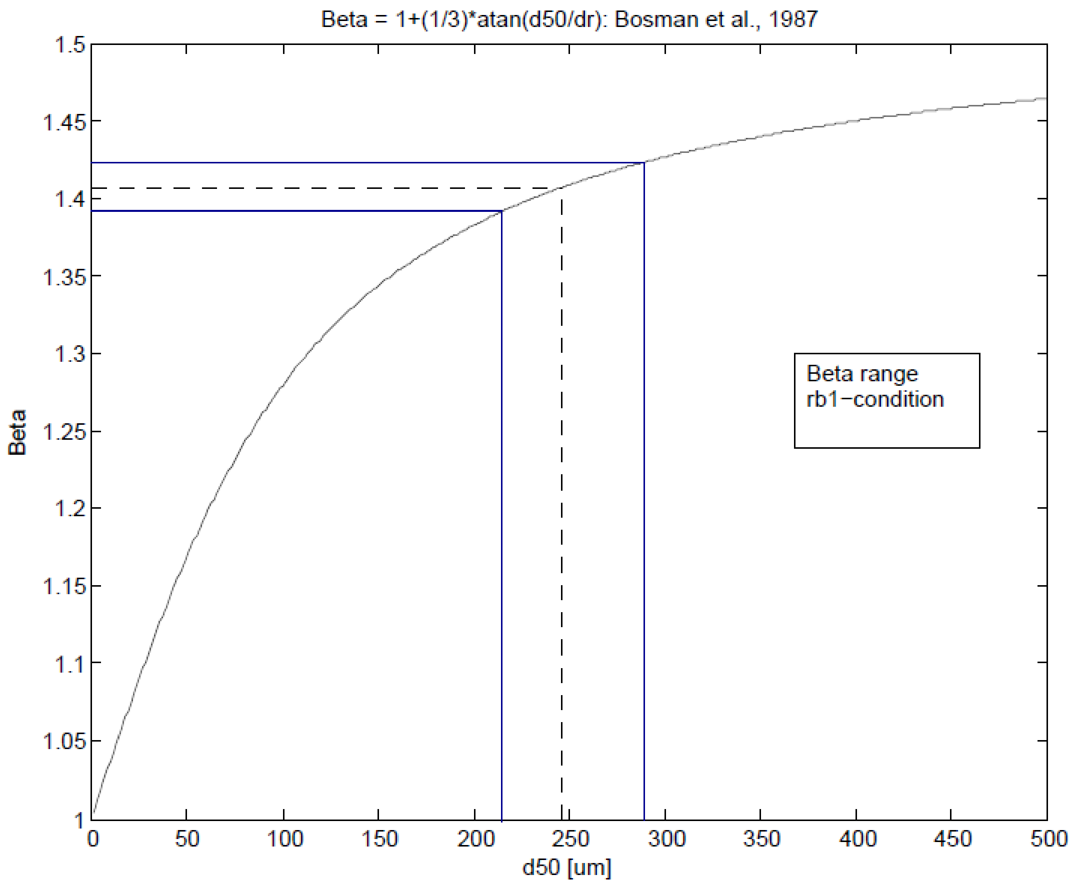


Figure 37: The β -variation for RB1-measurements

RB2-conditions:

The average concentration of the measurements with the rb2-condition was 0.36 g/L. The maximal deviation of the β-factor was 5.28%, what results in an average deviation in the concentration of 0.019 g/L. This approximation is made to estimate the effect of the new β-factor.

Table 10: The new β-calibration and the deviation from the old value for RB2-measurements

Measurement #	Average β rb2	Absolute β-deviation of average β [%]	RMSE [%]
58	1,408	0,183	0,657
60	1,406	0,165	0,453
64	1,408	0,248	0,772
66	1,423	1,676	4,523
70	1,410	0,622	2,084
72	1,420	1,403	3,651
74	1,417	1,047	2,807
75	1,419	1,272	3,251
76	1,418	1,138	2,727
78	1,376	3,114	7,752
80	1,370	3,688	10,033
82	1,354	5,280	12,966

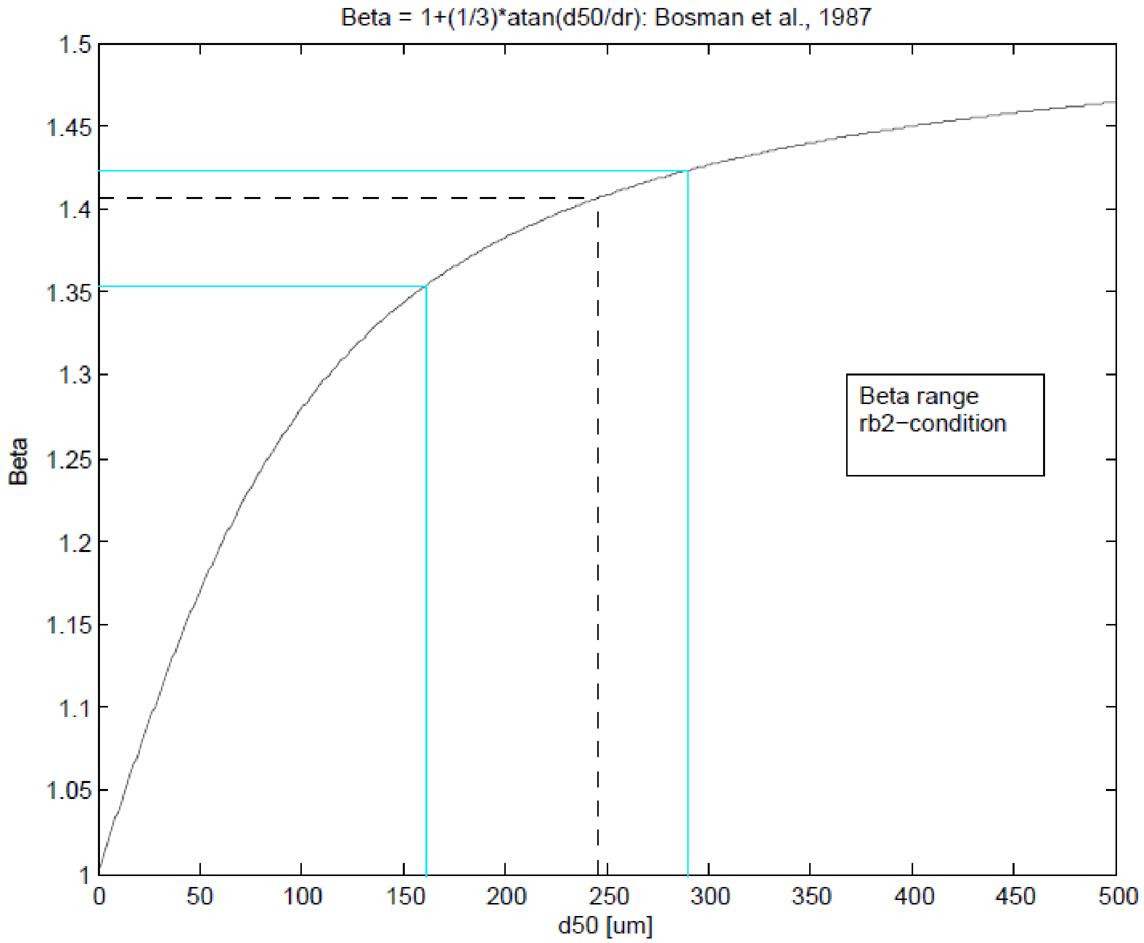


Figure 38: The β -variation for RB2-measurements

INB-conditions:
The average concentration of the measurements with the rb2-condition was 0.75 g/L. The maximal deviation of the β-factor was 9.72%, what results in an average deviation in the concentration of 0.073 g/L. This approximation is made to estimate the effect of the new β-factor.

Table 11: The new β-calibration and the deviation from the old value for INB-measurements

Measurement #	Average β inb	Absolute β-deviation of average β [%]	RMSE [%]
26	1,310	9,719	27,81
33	1,332	7,432	21,55
38	1,322	8,482	25,26
40	1,330	7,672	24,11
53	1,340	6,737	19,59

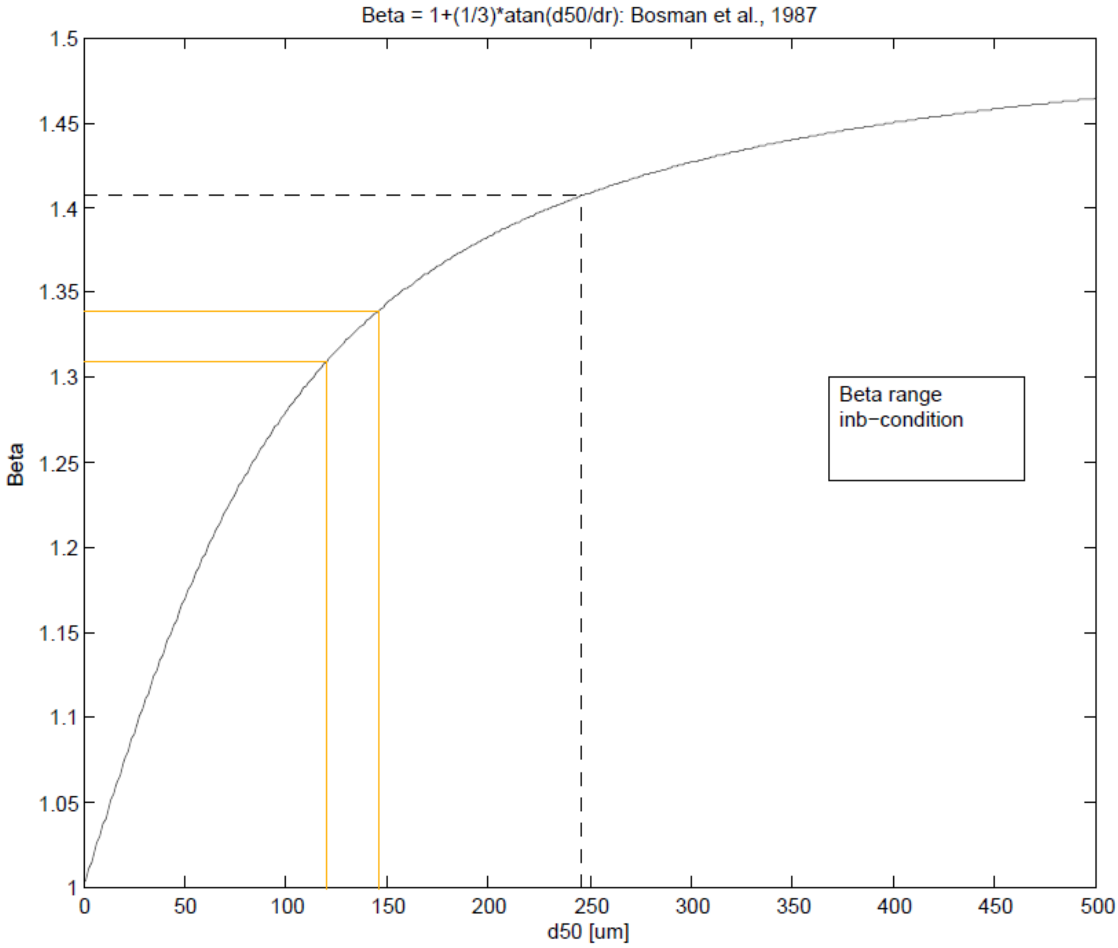


Figure 39: The β -variation for INB-measurements