Sediment transport in case of irregular non-breaking waves with a current

Part A: Text

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PREFACE

Without data, no theory can be verified.

Few experiments to investigate sediment transport rates, have been executed.
Two years ago, a joint effort of the Delft University of Technology and the Delft Hydraulics, started an experimental program. The objective was to improve experiments for investigation of sediment transport rates, and to get experimental data. The program was executed in a laboratory flume of the Laboratory of Fluid Mechanics, for which the facilities were present to generate irregular waves in combination with a current. The results were hopeful, and continuity seemed to be logical.
Last year, we participated in a second experimental program. A simular program was carried out, using sand bed material of 100 mu, instead of 200 mu of the first program.

The present report contains the description of the second program, the results of the experiments, and their comparisons with sediment transport prediction models. We were also able to compare the results of the first and the second program. This gave us insight in the influence of the particle sand diameter on the sediment transport rates.

For convenience this report is devided in two parts. Part A contains all text and illustrative figures, Part B contains all tables and figures of the experimental data.

We would like to thank:
- the employees of the Laboratory of Fluid Mechanics of the Delft University of Technology for their assistance and services at all times,
- Th. van der Kaay and M.W.C. Nieuwjaar for their advices for the setup of the experimental program.

We gratefully acknowledge the support of Dr.ir.L.C. van Rijn; his guidance during the execution of the experiments, and advices for interpretation of the experimental results.

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CONTENTS

1.INTRODUCTION

Many coastal engineering problems are related to transports of sediment. For prediction of coast-lines in the future, the prediction of the netto sediment transport is essential. Various models, such as that of Bijker, Nielsen, Engelund & Hansen, and Ackers & White are available to predict the sediment transport, by knowledge of wave height and current-strength. The reliability of these models are unknown, because data under field conditions are scarce. Only few relations between sediment transport, current velocity and wave height are known.
For these reasons a laboratory study was carried out to extend the knowledge of the basic phenomena in morphological processes. The study contains experiments in which sediment concentrations and fluid velocities have been measured in case of irregular non-breaking waves alone, in combination with following or opposing currents, and in case of current alone.

The present report contains a description of an experimental program, as a follow up of experiments by vd.Kaaij and Nieuwjaar in 1986. In this study a particle sand diameter of D50 = 100 mu was used for the experiments, v.d.Kaaij and Nieuwjaar used a D50 = 200 mu for their experiments. These latter experiments will be referred as the "200-mu-study" in this report. The "200-mu" results will be compared with the present "100-mu" results. Also results of Bosman (1982) have been compared with our measurements.

In chapter 3 the set up of the experiments will be described. In chapter 4 the methods for estimation the sediment transports and other parameters of importance will be described and the experimental results will be discussed. Chapter 5 discusses sand balance experiments, in which the sediment transport rates, as described in chapter 4, will be compared with the erosion rate of the sand bed, under the same wave and current conditions.
In chapter 6 the bed roughness will be discussed. Various models for predicting sediment transport will be described and discussed in chapter 7. The results of these models will be compared to experimental results of chapter 4. Eventually, in chapter 8, we will list a series of conclusions and recommendations.

To explain the objective of the experiments in this study, some basic theory of sediment transport processes will be described in the next chapter.

2. SEDIMENT TRANSPORT COMPUTATION

2.1. SEDIMENT TRANSPORT BASICS.

A simple method, to obtain sediment transport, is to multiply the sediment concentration distribution over the water depth with the sediment velocity. The sediment concentration over the depth is caused by stirring up of sediment particles from the sand bed. The stirring up proces is induced by wave and current movements in the near bed zone. This phenomena will be described in more detail in chapter 5 (sand balance computations).

By integration over the water depth, the local instantaneous sediment transport can be computed from:

$$Sx(x,t) = \int_{0}^{a(x)+\eta(x,t)} c(x,z,t) * U(x,z,t)\, dz \qquad (1.1)$$

with:

$Sx(x,t)$	=	Local instantaneous sediment transport rate per unit width	[kg/sm]
$c(x,z,t)$	=	Local instantaneous sediment concentration	[kg/m3]
$U(x,z,t)$	=	Local instantaneous x-component of the fluid velocity	[m/s]
x	=	Horizontal coordinate	[m]
z	=	Height above mean bed level	[m]
t	=	Time	[s]
η	=	Water surface elevation	[m]
a	=	Water depth	[m]

Measuring instantaneous fluid velocity and sediment concentration is quite difficult. Bosman (1986) investigated the concentration as a function of time. The concentration $c(z,t)$ was measured within a wave period, at a fixed point, about 3 [cm] above mean bed level. Fig.1b shows ensemble mean concentrations based on averaging over 99 periods and standard deviations. Based on the random scatter of the concentrations, Bosman concluded that it is not practical to relate instantaneous concentrations to instantaneous fluid velocities.
The experiments in this study were carried out measuring only time- and bed-averaged concentrations and velocities. This implies that a part of the total sediment transport is neglected, as will be shown below.

Defining : $c(x,z,t) = \bar{\bar{c}}(z) + c'(x,z,t) \qquad (1.2)$

$U(x,z,t) = \bar{\bar{U}}(z) + U'(x,z,t) \qquad (1.3)$

with:

$\bar{\bar{c}}(z)$ = Time- and bed-averaged component of the local instantaneous concentration.

$c'(x,z,t)$ = Fluctuating component of the local instantaneous concentration.

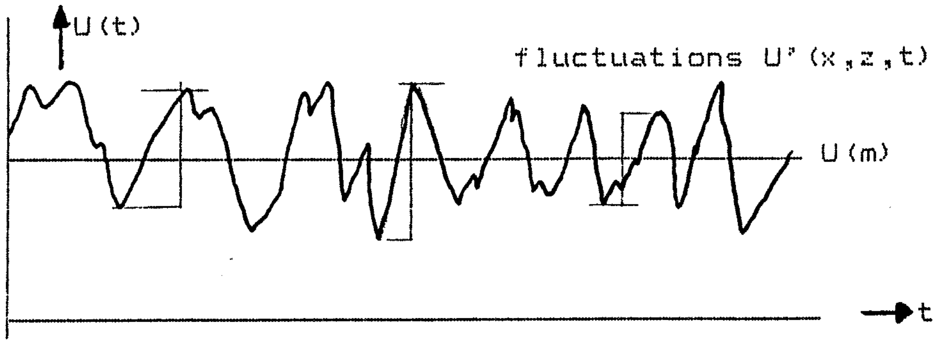


fig.1a. Time-and bed-averaged fluid velocity and fluctuations.

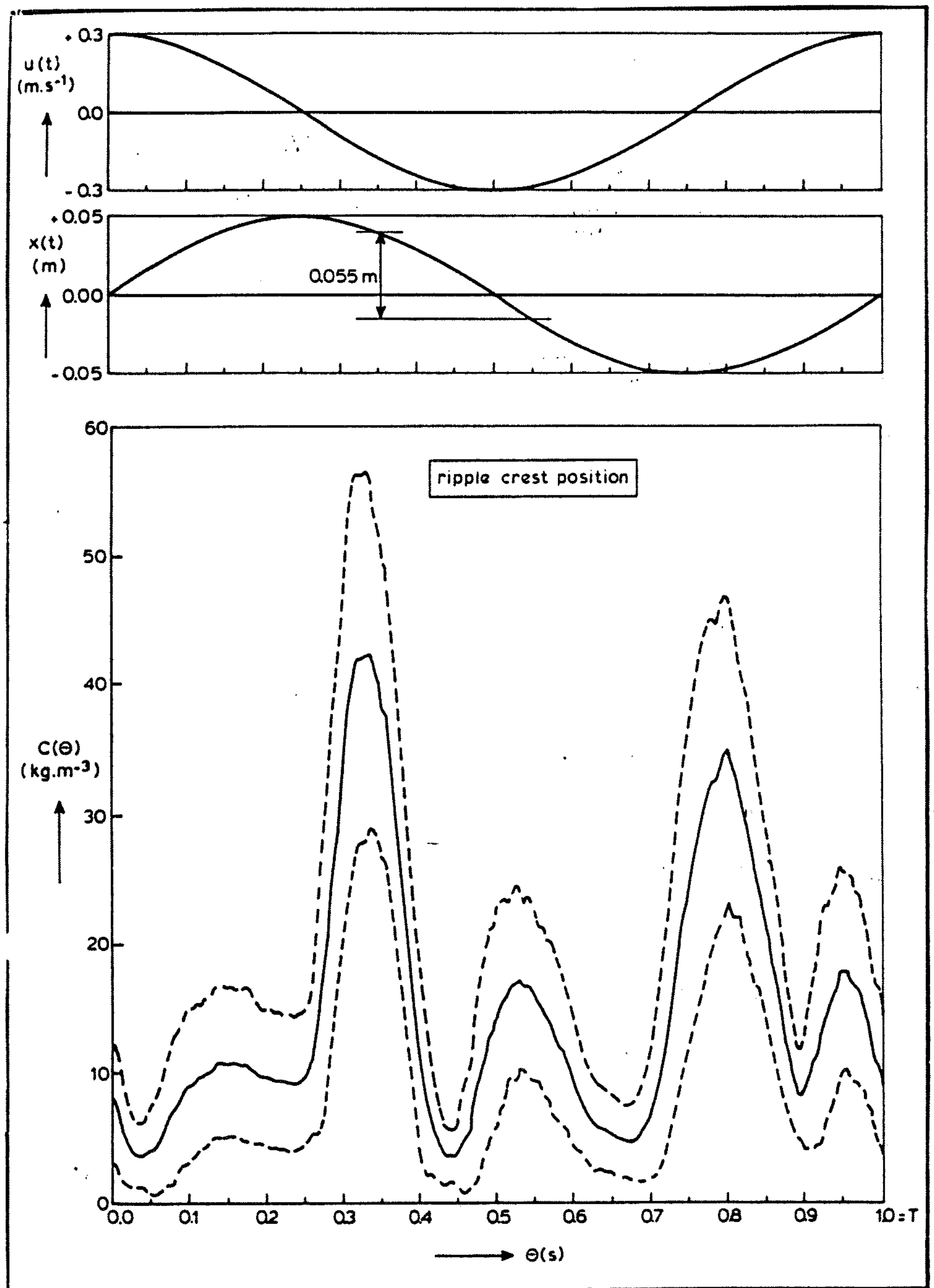


fig.1b

ENSEMBLE MEAN AND TOTAL STANDARD DEVIATION	T=1s	
OF CONCENTRATION IN SINGLE PERIOD T	$u_* = 0.30$ m/s	
DELFT HYDRAULICS LABORATORY	M 1695-II	

$\overline{\overline{U}}(z)$ = Time- and bed-averaged component of the local instantaneous fluid velocity.

$U'(x,z,t)$ = Fluctuating component of the local instantaneous fluid velocity.

The fluctuating components are caused by:
- orbital fluid movements, induced by the waves, and
- fluctuations in the main flow.

Turbulence and the irregularity of waves will increase this effect. See fig.1a-b.

Substituting eqs. (1.2) and (1.3) into eq. (1.1) leads, to eq. (1.4):

$$Sx(x,t) = \int_0^{a(x)+\eta(x,t)} c(x,z,t) \ast U(x,z,t)\, dz =$$

$$= \int_0^{a(x)+\eta(x,t)} \overline{\overline{c}}(z) \ast \overline{\overline{U}}(z)\, dz + \int_0^{a(x)+\eta(x,t)} c'(x,z,t) \ast \overline{\overline{U}}(z)\, dz +$$

$$\int_0^{a(x)+\eta(x,t)} \overline{\overline{c}}(z) \ast U'(x,z,t)\, dz + \int_0^{a(x)+\eta(x,t)} c'(x,z,t) \ast U'(x,z,t)\, dz \qquad (1.4)$$

Averaging over time and bed, the total sand transport now, is defined as:

$$Stot = \overline{\overline{Sx}}(x,t) \qquad (1.5)$$

And substitution of eq. (1.4) into eq. (1.5) yields:

$$Stot = \int_0^{a} \overline{\overline{\overline{\overline{c}}(z) \ast \overline{\overline{U}}(z)}}\, dz + \int_0^{a} \overline{\overline{c'(x,z,t) \ast \overline{\overline{U}}(z)}}\, dz +$$

$$\int_0^{a} \overline{\overline{\overline{\overline{c}}(z) \ast U'(x,z,t)}}\, dz + \int_0^{a} \overline{\overline{c'(x,z,t) \ast U'(x,z,t)}}\, dz$$

$$Stot = \int_0^{a} \overline{\overline{c}}(z) \ast \overline{\overline{U}}(z)\, dz + \int_0^{a} \overline{\overline{c'(x,z,t) \ast U'(x,z,t)}}\, dz \qquad (1.6)$$

The final result of eq. (1.6) shows that the total sediment transport is devided into two parts:
The first part is determined by time- and bed-averaging. It

represents the transport of sediment by U(z), as if there is a steady current. Therefore this part will be called the current-related sediment transport.
The second part is mainly caused by the orbital movements, U'(x,z,t), effected by the irregular waves. Thus, this part will be called the wave-related sediment transport.
(In the 200-mu-study the current- and wave-related parts were called respectively convective and diffusive part.)

Eq.(1.6) is a useful approximation of eq.(1.1). In practice, as will be described in chapters 3 and 4, only time- and bed-averaging concentrations and fluid velocities are determined. In both the 200-mu and this study this resulted in a proper estimation of the current-related sediment transport.
To investigate the relative importance of the wave-related sediment transport, sand balance experiments were executed, (see chapter 5).

2.2. LONG-SHORE AND CROSS-SHORE SEDIMENT TRANSPORT

Waves, approaching a coast, will reach the coast under a small angle , caused by refraction. The radiation stress, generated by the waves, under a small angle , and bottom friction stresses, result in a longshore current (see Bijker). Tides and waves can also induce a current perpendicular to the coast-line. Fig.2 shows two cross-sections, in which two different morphological processes are present.

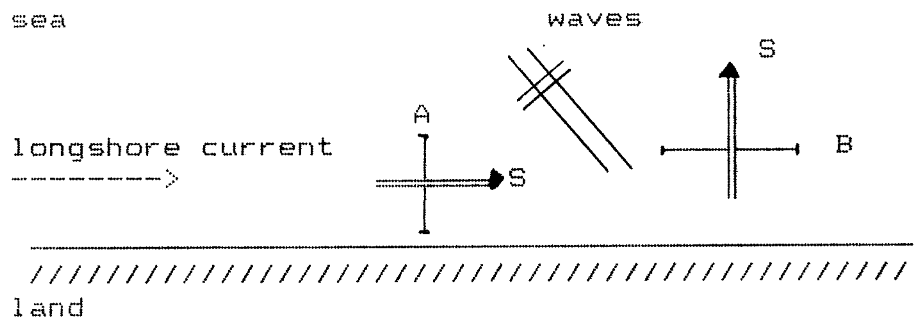


fig.2. Longshore and Cross-shore sediment transport.

The sediment transport in cross-section A represents a longshore sediment transport. This is stirring up of sediment, by waves and current, transported by a rather steady longshore current.
Trough cross-section B, a cross-shore sediment transport is present. In this case, the velocity oscillations U'(x,z,t), introduced by orbital movements, do strongly influence the transport of sediment, during a wave period.

The longshore sediment transport can be represented by the current-related part of the total sediment transport:

$$Scurr = \int_0^{a} \bar{\bar{c}}(z) * \bar{\bar{U}}(z) \, dz \qquad (1.7)$$

from eq.(1.6) rather well, because the fluid velocity does not depend on time (the longshore current is rather constant at each point above the mean bed level), and because the concentration c(z) is better known than the more precise c(z,t).

For cross-shore sediment transport, this simplification (eq.1.6) is not allowed. The parameter U(z,t) as the parameter c(z,t) do strongly depend on time. In this case, the wave-related sediment transport plays a much more important role than in the longshore transport computations.

This study is not carried out for special investigation of a longshore or cross-shore sediment transport. A more general purpose is chosen, to obtain basic sediment transport phenomena in a practical way. Therefore the experiments were carried out in a flume, in which current and waves have the same or opposite direction.
In chapter 7, in which several models for sediment transport prediction will be presented, the aspects of longshore and cross-shore transports will be discussed further.

2.3. OBJECTIVE OF THE EXPERIMENTS

1.
Identification of the relations between sediment transport, wave height and current velocity, and comparison with former experiments (200-mu-study and Bosman).

2.
Investigation of the relative importance of the current-related and wave-related sediment transport.

3.
Verification of a number of sediment transport models with the experimental results of this study, and those of the 200-mu-study.

4.
Investigation of the influence of the median sediment particle diameter (D50), on sediment transport parameters.

3. EXPERIMENTAL SET UP

3.1. THE FLUME

All experiments were conducted in the "Grote Speurwerk-goot", a flume of the *Laboratory of Fluid Mechanics of* the Faculty of *Civil Engineering of the Delft University of Technology*. This flume is sketched in fig.3.
Its total length of about 45 [m], a width of 0.8 [m] and a depth of 1.0 [m], makes it possible to perform experiments with a 30 [m] bed-length, a 0.12 [m] bed-height and a mean water depth of 0.5 [m] .
The sophisticated wave generator is able to generate irregular waves, in combination with a following or opposing current.

The flume consists of various sections:

A - Wave-generator section.
B - In- and outflow section.
C - Test section.
D - Section with wave damping slope structure.
E - In- and outflow section.

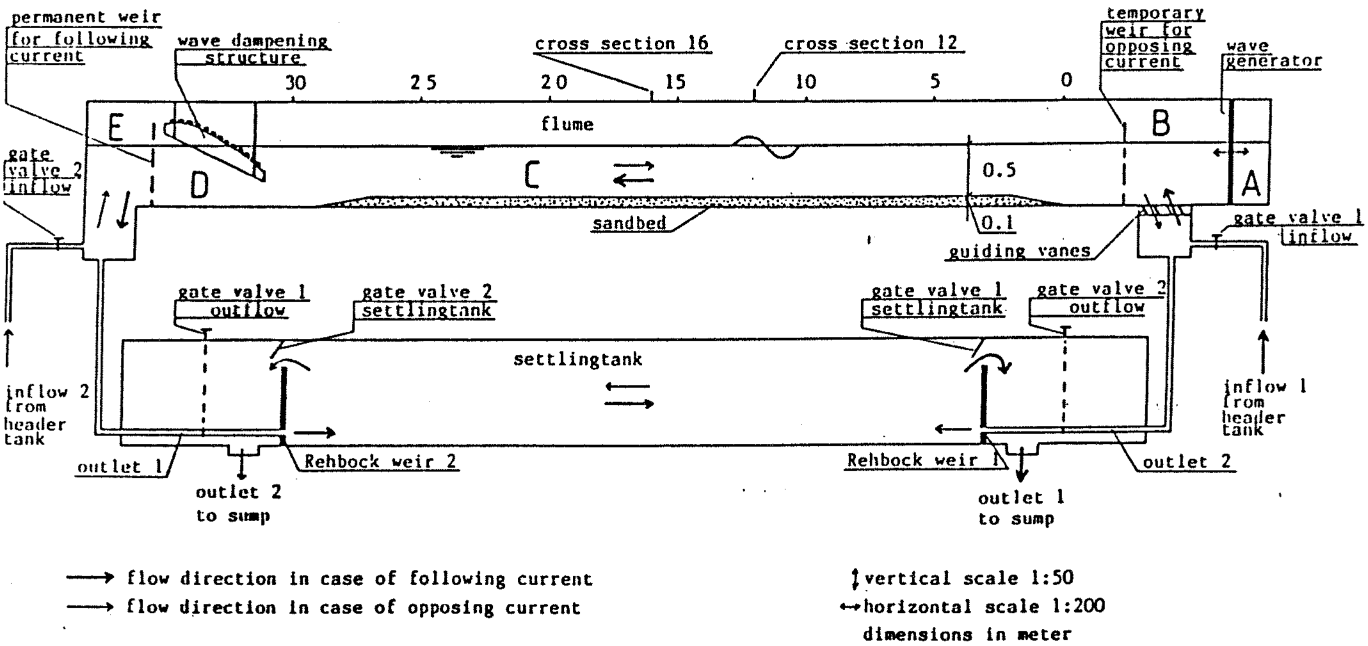


fig.3 Sketch of the flume.

A. WAVE GENERATION

The irregular waves are generated by the irregular movements of the wave paddle, driven by an electronical signal. The signal has come from a noise generator and a filter unit. The noise generator produces a white noise; by adjusting the filters it is possible to create a spectrum, which is sent to the electronic equipment of the wave paddle.
The filter unit consists of separated low and high frequency passage filters and an amplifier. By adjusting the period and damping factor of the filters, a desired single topped spectrum with a peak frequency of 0,4 [Hz] was achieved. These adjustments were kept constant during all the experiments. To obtain a certain significant wave height, the amplifier was manipulated.

B. and E. CURRENT GENERATION

The B and E sections are necessary for current generation. Following current is generated by opening both gate valves 1, while both gate valves 2 are closed. By manipulating gate valve 1 for inflow and measuring the Rehbock weir, the desired discharge can be obtained. A permanent overflow weir, situated just before section E is used to achieve the desired water depth of 0,5 [m], by adjusting the height of this weir. To generate an opposing current, gate valves 1 have to be closed and gate valves 2 have to be opened. After obtaining the desired discharge, a temporary weir, in front of the wave generator, can be used for adjusting the 0,5 [m] water depth. Manipulating valve 2 for outflow, equalization of the water depth before and behind the temporary weir is obtained, and the temporary weir will be removed. After a few experiments it appeared more practical to use no temporary weir and generate the opposing current just by manipulating the gate valves 2.
The inlet section B, used for inflow in case of following current, is equiped with guiding vanes. The inlet section E, used in case of opposing current, is not equiped with guiding vanes , because of the presence of the wave damping slope structure directly after the inlet.
When the water leaves the flume it will recirculate through the settling tank, where most of the sediment load will be trapped.

C. TEST SECTION

Water entering the flume had no initial sediment load; the concentration profiles had to build up completely in the section with the sand bed. The sand bed had a thickness of about 0.12 [m], with a slope of 1 : 15 on both ends of the sand bed. To provide enough length to reach equilibrium concentrations over the depth, <u>the measuring section</u> was situated at a distance of approximately thirty times the water depth from the beginning of the sand bed. In case of a following current, the measuring section was situated in cross section 16, in case of opposing current in cross section 12.

D. WAVE DAMPING SLOPE STRUCTURE

To reduce wave reflections as much as possible, the effect of the wave damping structure was examined in the 200- mu-study and re-examined in this study by measuring the wave reflection for different positions of the wave damper. Some tests with regular waves and no current were conducted. A few waves were generated. The generated and reflected waves were measured in the measuring section. The calculated reflection coefficient, defined as the ratio of the reflected wave height, Hr, and the incident wave height, Hi, was found to be less than about 0.1 :

$$\frac{Hr}{Hi} < 0.1$$

3.2.SEDIMENT

Because the sediments originated from nature (called "Asser sand), it had to be washed out, before it was brought in the flume. About 0.25 [m] sand was brought in a 1 [m2] reservoir. Water was added from the bottom of the reservoir, and by stirring the water and sand mixture, the silt and pollutions were washed out. After that, the sand was brought in the flume and leveled.
During the months the experiments took place, three bed material samples were taken; from the measuring section and the cross sections 5 and 25, before and after each experiment. By sieving the samples, the characteristics of the bed material have been determined: Dx is the sieve diameter passed by x % by weight. Values of D10, D50 and D90 are given in the following table, minimum and maximum values are presented over the experimental period.

Dx	D10	D50	D90
mean [mu]	75	107	149
minimum [mu]	67	95	124
maximum [mu]	82	113	173

min,max and mean Dx-values in the measuring section, during the study.

Fine material is easily stirred up, brought in suspension by wave movement, and deposited downstream. Since there is no supply of fine material at the beginning of the sand bed, the bed material became coarser there. Downstream, the stirring up of fine material and the supply were kept in equilibrium. At regular times, the sand bed was resupplied and remixed.

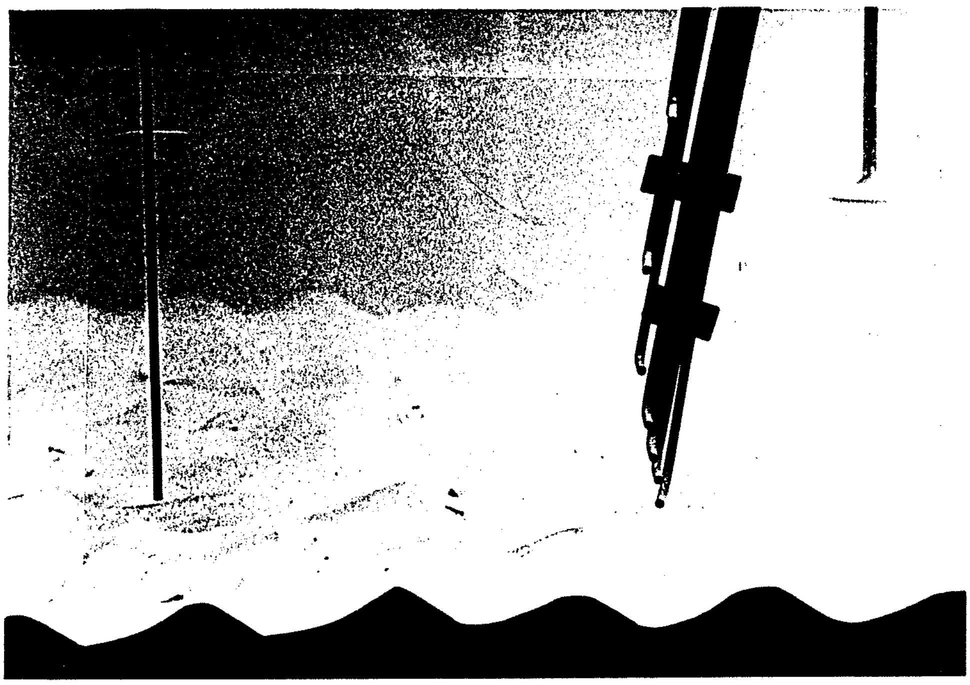
3.3. MEASURING INSTRUMENTS AND METHODS

The following instruments, with the parameters that were measured during the experiments, will be discussed:

- Discharge
- Mean bed level
- Water level
- Wave parameters and spectrum
- Time- and bed-averaging
- Sediment concentration measurements
- Water velocity measurements
- Ripple parameters
- Particle diameters of bed material
- Fall velocity
- Water surface slope measurement

3.3.1. Discharge

The discharge was measured using a Rehbock weir. Its accuracy in case of a small discharge is approximately 10 %, in case of a large discharge it is less than 3 %. The aim of measuring the discharge was to get an estimation of the desired current velocity.
For computation of the bedroughness parameter Ks, the discharge parameter Q will be used, via the Vanoni-Brooks method (see chapter 6).



picture 1. Concentration sampler, E.M.S. and provo.

The depth-averaged fluid velocity was calculated from the velocity distribution over the water depth.

3.3.2. Mean bed level

To determine the mean bed level δ in the measuring section, a profile follower (profo) and an integrator were used, like in the 200-mu-study. The electronical output signal of the profo is integrated by the integrator (during the integration time) which displays an integration number. The number is a measure for the height difference between the mean bed level and a chosen reference level, which is first determined and integrated. (see picture 1).

To average out variations in transverse direction, the mean bed level was determined in three longitudinal sections, and was carried out before and after each concentration and velocity measurements to get a time-averaged mean bed level for each test. see fig.4.

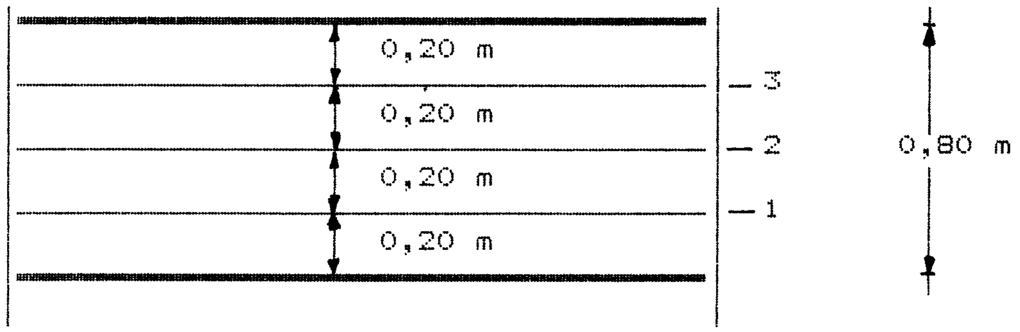


Fig.4. Distribution of longitudinal sections over the flume width.

3.3.3. Water level

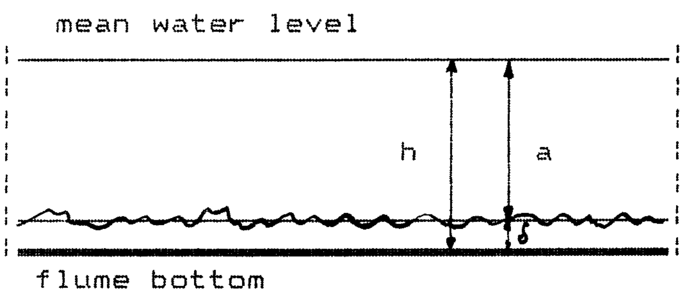


Fig.5 : Mean bed level and mean waterdepth.

A measuring scale was made on the flume window , to measure the water height. The measuring scale had its reference with the flume bottom and the mean bed level, so the water height relative to the mean bed level, a, can be determined as:

$a = h - \delta$

3.3.4 Wave parameters and spectrum

In each experiment, the wave spectrum was determined three times. The water level variations were measured with an electric resistance probe, situated just in front of the measuring section. (see fig.3).
The water surface elevation was sampled each 0.25 [s], during 30 minutes, and stored in a micro computer's memory. To prevent contributions of frequencies above 2 [Hz], an electronic filter was used before generating the wave paddle.

The wave spectrum was computed after sampling completion by a correlation and spectrum computer program.
The wave height distribution can be described by a Rayleigh distribution because the spectra were single topped (Battjes, 1982). The characteristic wave parameters were computed from the wave spectrum by a spectrum analyser program, as follows:

$$H_{sig} = 4\,(M0)^{0.5}$$
$$T_z = (M0/M2)^{0.5}$$
$$T_p = 1/f_p$$

with:
Hsig = Significant wave height
Tz = Zero-crossing period
Tp = Wave spectrum peak period
fp = Wave spectrum peak frequency
Mn = nth order moment of wave spectrum

Second, the waves during each test (approximately 900), were registrated with a pen recorder. This registration was used to determine the ratio H1%/Hsig (H1% is the wave height exceeded by 1% of the waves).

3.3.5 Time- and bed-averaging

Local and instantaneous concentration measurements show random variations of 50 to 100% (Bosman,1982,1985), because of their sensitivity for local conditions, especially in the near bed zone. A time- and bed-averaging method is necessary to reduce variations in the concentration measurements.
As in the 200-mu-study, the concentration and velocity measuring instruments were mounted on a moving carriage, to perform bed-averaging. The position of the instruments is given in fig.6. The carriage moved along the measuring section (length = 0,6 [m]) vice versa, with a speed of 0,02 [m/s].

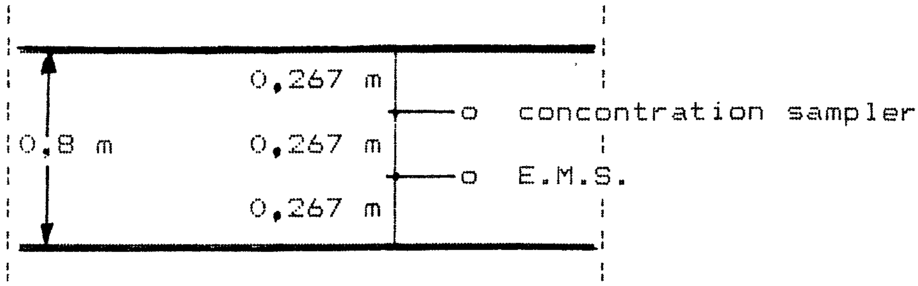


Fig.6. Measuring position of concentration sampler and velocity meter (E.M.S.).

Preliminary tests in the 200-mu- and this study, a non-moving carriage was used to examine the sensitivity of time-averaged concentrations. The relative standard deviations from concentrations above 4 ripple crests and 4 ripple troughs, is about 30%. Averaging the individual concentrations, show strong agreement with the concentrations measured with a moving carriage; about 10% accuracy.
The results are given below.

Exp T 15,0	average concentration * 10-3 kg/m3		
carriage :	moving	non-moving	d (%)
level			
1	4162	4254	2
2	2343	2268	3
3	1354	1247	8
4	630	552	12
5	179	154	14
6	13	9	31
7	2	2	0
8	1	1	0
9	0	0	-
10	0	0	-

Comparison concentration sampling by using a moving or non-moving carriage.

A special test was performed, to get information of the time period, needed to obtain an accurate value of the time-averaged concentrations. In the 200-mu-study a sampling period of 15 minutes, caused a 10% concentration variation. To reduce this variation, a sampling period of 30 minutes was chosen in this study.

3.3.6. Sediment concentration measurements

The sediment concentrations were carried out using an array of 10 brass intake tubes of 3 [mm] internal diameter. This concentration sampler instrument was attached to the moving

carriage; the openings of the intake tubes were placed in transverse direction (see Bosman et al,1984). Each tube was connected to a pump, bringing the sediment and water mixture with a 1,5 [m/s] intake velocity in a 10 [l] bucket.
Ten intake tubes were used to determine the concentration distribution over the water depth.

Tests showed that even tube distances of 10 [mm] do not disturb the concentration distribution (Streetzel,1984).
A prelimenary test has been carried out to verify this tests. A comparison has been made between the array of 10 intake tubes and a single intake tube. Therefore, the single tube was attached to the moving carriage instead of the E.M.S. (see fig.6). The height level of the intake of the single tube was the same as one of the 10 intake tubes from the array. For 15 minutes both the single tube and the array were sampling and concentrations were measured. This is done 10 times, at the level of each intake tube of the sampler instrument. The results are shown below.

Exp T 11,0 average concentration (single samples) * 10-3 kg/m3			
instrument: / level	array of 10 tubes	single tube	d (%)
1	1920	2170	-12
2	875	881	-1
3	718	740	-3
4	207	165	20
5	76	61	-20
6	9	5	44
7	2	2	0
8	-	-	-

Comparison of concentrations, by using 1 intake tube or an array of 10 intake tubes (single samples).

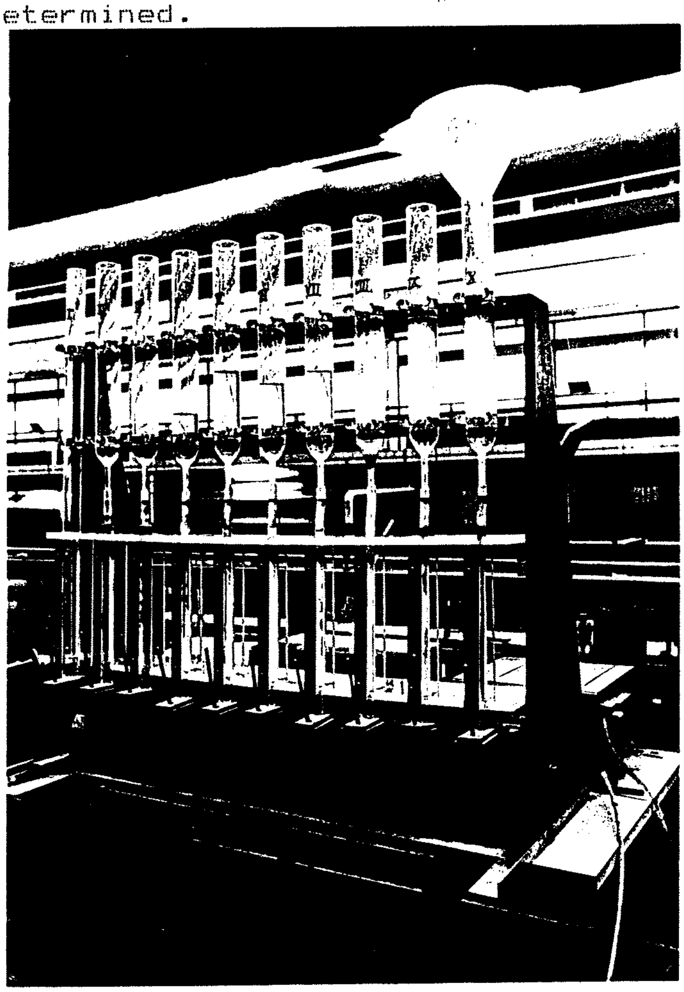
From these resulst one can conclude that:

. The array of 10 intake tubes gives good results, the differences with the single tube are within the standard deviation of the concentrations. The differences at higher levels might be caused by turbulence generated by the pole of the sample instrument. However, these latter differences hardly influence the sediment transport rates.

The trapping ratio T.R. (the sediment concentration in the sample divided by the undisturbed concentration in the flume) will be smaller than 1, because the sediment particles can not completely follow the curved water particles trajectories to the intake tubes (Bosman, v.d.Velden and Hulsbergen, 1987). The trapping ratio for the sediment used in this investigation is <u>1.28</u>, as given by Bosman et al (1987).

The sediment concentrations were measured by the following

procedure , which is somewhat different from the 200-mu-study. In that study the concentration sampler was adjusted at a desired height with the use of a gauging rod, and placed on a chosen ripple top. The rod was connected to the concentration sampler. It caused an extra inaccuracy of 2 [mm].
First the mean bed level δ was measured. The concentration sampler was adjusted at a height of about 2 [cm] above the mean bed level, using the reading scale of the sampler. This scale had a reference with the bottom of the flume, just like the mean bed level. Before starting the test, the carriage was moved along the measuring section, for checking that the sampler was moving freely over the ripples.
The test was now ready to start, the carriage moving and the pumps running for 30 minutes, in which every pump filled 2 standby buckets of 10 [l]. After filling, the water in the buckets was poured off and the remaining sediment was washed in a volume meter. See picture 2. The volume meter consists of 10 small calibrated glass cylinders with decreasing diameters. By reading the height of the sediment in the cylinder, the wet sediment volume was measured. Using a calibration table for each cylinder, the dry mass was determined for every bucket (including the T.R.ratio). The average of two buckets gave a sediment concentration value. The concentration measurements were repeated three times during each experiment. Based on this, a mean and standard deviation was determined.



picture 2. calibrated volume meters.

In the 200-mu-study a comparison has been carried out between the volume meter and an under water balance. Its result gave the volume meter an accuracy within 5%.

After the sediment volume measurement, the sediment samples were collected in sample bottles for further analysis (median fall velocity of the sediment). The samples of the 5 highest positioned intake tubes were collected together in one bottle because of the small volume of the individual samples.

<u>Accuracy of measuring elevation</u>

In this paragraph the depth parameters relations and errors will be described. see fig.7.

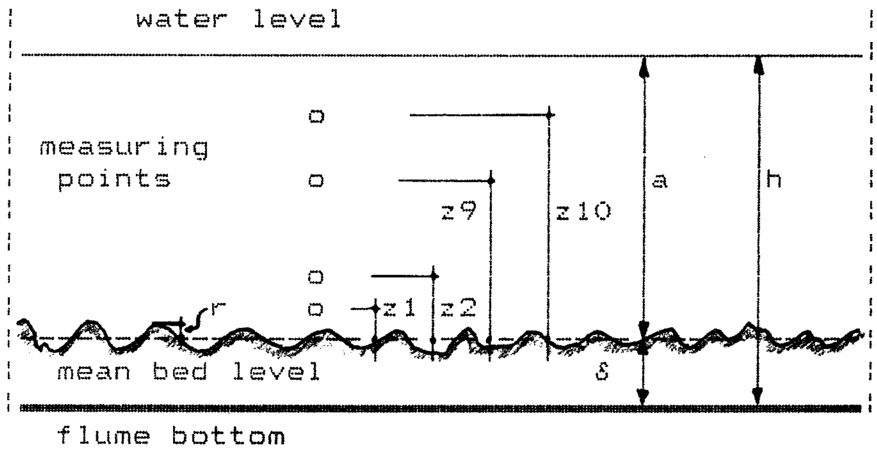


fig.7. Relation between depth parameters

In order to determine the distance z1 between the lowest intake tube of the concentration sampler and the mean bed level δ, a reference measurement was made at still water. The value z1 can be computed as:

$$z1 = h - s - \delta$$

with:

h = mean water level above bottom flume [m]

s = distance between lowest intake tube and still water level [m]

The error in z1 can be computed from the independent parameters h, s and δ,

$$d(z1) = \sqrt{d(h)^2 + d(s)^2 + d(\delta)^2} \quad [m] \qquad (3.1)$$

in which d(x) stands for error of parameter x.
The value d(h) is introduced by reading the measuring division on the flume window: $0.5 * 10^{-3}$ [m].

The value d(s) is caused :

a. by reading the measure scale on the concentration sampler, when the reference measurement was made with the lowest intake tube on water level: $0.5 * 10^{-3}$ [m], and by d(h), because the reference measurement was taken from the water level: $0.5 * 10^{-3}$ [m]. These were independent readings, so this part of d(s) becomes:

$$d(s) = \sqrt{0.5^2 + 0.5^2} = 0.71 * 10^{-3} \text{ [m]}$$

b. by reading the measuring scale in case the sampler was brought in measure position: $d(s) = 0.5 * 10^{-3}$ [m].

Thus d(s) can be computed as:

$$d(s) = \sqrt{0.5^2 + 0.71^2} = 0.87 * 10^{-3} \text{ [m]}.$$

The value of $d(\delta)$ is determined:

a. by determination of the reference measurement:
   - error in reading the distance between the flume bottom and the measuring point of the profo on the sand bed. This was done through the flume window, the error is approximately assumed to be $1 * 10^{-3}$ [m].
   - error by integrator and non-moving carriage, which is assumed to be $0.5 * 10^{-3}$ [m].

$$d(\delta) = \sqrt{1^2 + 0.5^2} = 1.12 * 10^{-3} \text{ [m]}.$$

b. by integration of each longitudinal section with a moving carriage, which is assumed to be $1 * 10^{-3}$ [m] (each section),
   which leads to a total integration error of:

$$d(\delta) = 1/3 * \sqrt{3 * 1^2} = 0.58 * 10^{-3} \text{ [m]}.$$

   This is done before and after each test, so the error may be reduced to:

$$d(\delta) = 1/2 * \sqrt{2 * 0.58^2} = 0.41 * 10^{-3} \text{ [m]}.$$

And the total error in the mean bed level becomes:

$$d(\delta) = \sqrt{1.12^2 + 0.41^2} = 1.19 * 10^{-3} \text{ [m]}.$$

Now the independent parameter errors will be substituted in eq.(3.1):

$$d(z1) = \sqrt{0.5^2 + 0.87^2 + 1.19^2} = 1.55 * 10^{-3} \text{ [m]}.$$

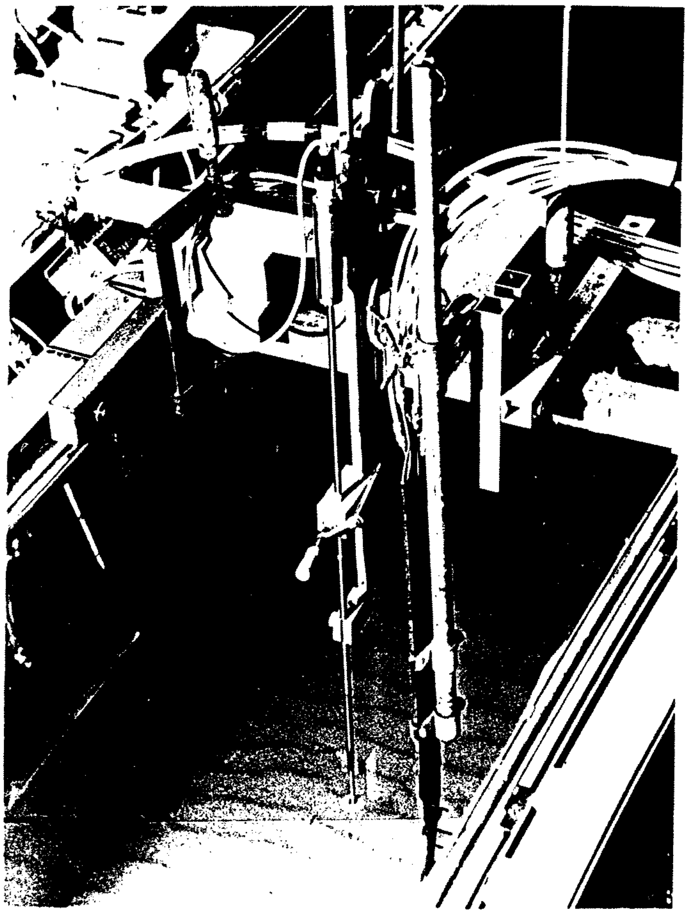
Because the parameters were determined every test, 3 times each experiment, d(z1) will be reduced:

$$d(z1) = 1/3 * \sqrt{3 * 1.55^2} = 0.90 * 10^{-3} \text{ [m]}.$$

This result is an improvement of the $1.9 * 10^{-3}$ [m] error in the 200-mu-study, because in this study no extra gauging rod was used (see paragraph 2.3.6.).

3.3.7. Water velocity measurements

The velocities were measured with an Electro-Magnetic Velocity meter (E.M.S.), see picture 3. The instrument generates an electro-magnetic field, the degree of disturbance of this field is a measure for the water velocity at the position of the measuring volume of the probe ,which is 3 [mm] below the probe. The time-averaged velocity was determined using a mean value meter (M.V.M.). It averages the electronical input signal over a certain time period. Time-averaging over 256 seconds (about 100 waves) gave reproducible results.
The E.M.S. was also attached to the moving carriage. The velocities were measured at the same height positions above mean bed level as the intake tubes of the concentration sampler. Therefore the reading of the E.M.S. was related with the reading of the concentration sampler at still water. Only one E.M.S. probe was used, therefore the velocity measurements at every height position were done one by one. During an experiment, consisting of three tests, a different order of measuring the height positions was chosen, to improve time-averaging.
Prelimenary tests applying the E.M.S. and a Laser Doppler (L.D) velocity meter showed differences within 3% in case of velocities higher than 0,1 [m/s]. At lower velocities the E.M.S. values were found to be higher than the L.D. values (maximum difference of 8%).



picture 3. Moving carriage with E.M.S. and concentration sampler

The movements of the carriage caused a small error in the time-averaged velocity. To reduce this error, the carriage moved the same amount of time to the right as to the left, yielding an error of 0.00125 [m/s]. (see the 200-mu-study). Like the sediment concentration results, a mean and standard deviation of the velocity measurements were computed, from 3 tests at each height level above the bed.

Current alone velocity measurements

In order to investigate the bottom friction of the sand bed on the water flowing above it, the following procedure was carried out:
After each experiment, the wave generator was stopped, the constant current over a sand bed, generated by the experiment's wave- and current characteristics, remains. The velocities over the depth were measured, which resulted in a velocity profile for current alone.

3.3.8. Ripple parameters

In each experiment ripple registrations were made using the profo (see pragragh 2.3.2) and a penrecorder. First a calibration was done: a. the height, using a calibration block with a height of 0,1 [m], and the pen recorder, b. the length, by the ratio of the velocities of the pen recorder and the moving carriage.
Ripple registrations were made in the three longitudinal sections before the first and after the last test (see fig.a.chapt.6). From these registrations the following ripple parameters were determined:

- mean ripple height η, and its standard deviation.
- mean ripple length λ, and its standard deviation.
- parameter $\lambda1/\lambda2$, to get impression of the bed regime.
  in which:
  $\lambda1$ = mean upstream length of the ripple.
  $\lambda2$ = mean downstream length of the ripple. see fig.8.

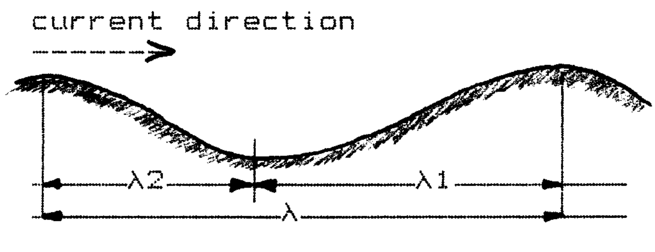


fig.8. Upstream and downstream ripple length.

In order to estimate the bed load transport, the ripple migration velocity of 10 ripples, at different positions on the sand bed, were measured. Along the flume window the distance covered by a ripple crest during a certain time period was measured. This was done twice for 10 ripples, from which a mean ripple velocity u_r and a standard deviation was computed.

3.3.9. Particle diameters of bed material

In each experiment a sample of the bed material at the measuring section was taken with the use of a small grab sampler. After drying the sample, a 30 [gr] representative part of it was sieved, and the particle size distribution was determined. From this the particle parameters D10, D50 and D90 were computed.

3.3.10. Fall velocity

The suspended sediment samples (see paragraph 2.3.6.), and the bed material samples were analysed in the sophisticated *Settling Tube of the Delft University (DUST)*, to determine the median fall velocity. The procedure for this is described in the 200-mu-study (ref. Slot).

3.3.11. Water surface slope measurement

In section 2.3.7. the current alone measurements were described, to determine bottom friction parameters. This will be described in chapter 6 in more detail.
Another procedure, to examine the bottom friction, is to determine the water surface slope during the current alone situation. Therefore two water level instruments (static pitot tubes) were situated at cross sections 6 and 26 (tubes 1 and 2), 10 meters before and after the measuring section (see fig.3). The instruments were related before the experiment, in still water conditions. During the current alone test, the water surface slope can be computed from:

$$i = \left| \frac{|a1(O) - a1(U)| - |a2(O) - a2(U)|}{L} \right| \qquad (3.2)$$

with:

i	= water surface slope	(-)
a1(O)	= water level in tube 1, in case of still water	(m)
a1(U)	= water level in tube 1, in case of current alone	(m)
a2(O)	= water level in tube 2, in case of still water	(m)
a2(U)	= water level in tube 2, in case of current alone	(m)
L	= distance between tube 1 and 2, (20 m)	

In the next chapter the results of bottom friction computation will be described. In chapter 6, a comparison will be made, between computation via the velocity profile in case of current alone, and via water surface slope computation.

3.3.12. Measuring procedure

A list of the actions, step by step, in the measuring procedure will be given here:

Preparation
1. Read the static pitot tubes.
2. Calibration of the velocity meter at still water.
3. Generation of the desired discharge and water depth.
4. Generation of the desired significant wave height.
5. Wait period (about half an hour) for generation of the characteristic ripple pattern.
6. Measure water temperature
7. Switch off the wave generator
8. Mark 10 ripple crest positions at flume window (for determination of ripple migration velocity).

Test measurements
9. Read the discharge
10. Make ripple registrations in the three longitudinal sections at the measuring section.
11. At the same time as 7., determine the mean bed level in the measuring section with the integrator.
12. Measure distance still water level to flume bottom.
13. Installation of the concentration sampler and velocity meter, about 2 [cm] above the mean bed level.
14. Start the moving carriage.
15. Check whether the concentration sampler and velocity meter do hit the bed ripples. (If so, return to 10.)
16. Start the wave generator.
17. Start spectrum computer program.
18. Start pumping out water-sediment samples at 10 heights above mean bed level. (Change buckets after about 15 minutes, for each pump).
19. Measure fluid velocities at 10 heights above mean bed level. (About 5 minutes per measurement)
20. Determine sediment concentrations with the volume meter. (Twice, for to series of buckets). Put the samples in sample bottles.
21. Read wave spectra, determine wave parameters by running the spectrum analyser program.
22. Switch off the wave generator.
23. Stop moving carriage.
24. Determine ripple migration velocity at 10 locations (see point 7, this is done only one time).

Points 9 to 23 have been carried out three times for each experiment.

25. Make ripple registrations, determine mean bed level. (see points 7 and 8).
26. Read discharge.

Current alone measurement

27. Measure fluid velocity at the measuring section at 10 heights above the bed, with moving carriage.
28. Read static pitot tubes every 10 minutes, determine the average water surface slope.

At last

29. Turn off flow.
30. Take three sediment samples from the sand bed, at cross sections 5, 27 and the measuring section.
31. Determine the sediment particle parameters (D10, D50 and D90) by sieving the samples after drying.
32. If necessary, resupply and remix the sand bed.
33. Determine the median fall velocity of the concentration samples in the settling tube (DUST). (This has been done in the period after all the experiments were already carried out.

3.3.13. Experimental program

The experiment program in this study was based upon the program in the 200-mu-study, to obtain a nice comparison of the results for different sediment diameters.
The following table gives the experiments carried out in this study.

Hsig [m] Um [m/s]	0	0.075	0.10	0.15	0.18
0		T 7.5,0	T 10,0	T 15,0	T'18,0
0.1		T 7.5,10	T 10,10	T 15,10	T'18,10
-0.1		T 7.5,-10	T 10,-10	T 15,-10	T'18,-10
0.2		T'7.5,20	T 10,20	T 15,20	T'18,20
-0.2		T 7.5,-20	T 10,-20	T 15,-20	T 18,-20
0.4	T 0,40	T'7.5,40	T 10,40	T'15,40	
-0.4	T'0,-40	T'7.5,-40	T 10,-40	T 15,-40	T 18,-40

The 29 experiments, given in the table, are identified by a test number. For example; T 10,-40 stands for an experiment with an approximate significant wave height of 10 [cm], (0.1 [m]), and a approximate mean current of 40 [cm/s], (0.4 [m/s]), opposing the waves. A positive sign means a following current. More precise values of these are given in the tables that give the data for each experiment (Part B).
The experiments with T' in stead of T, were <u>not</u> carried out in the 200-mu-study. The experiment program in the 200-mu-study contained five additional experiments with a wave height of 0.12 [m] and all currents from the table above.

After the experiments were carried out, three sand balance experiments were carried out, identified by:
S 15,10 , S 15,-10 and S 15,20.

4. EXPERIMENTAL RESULTS

4.1 GENERAL

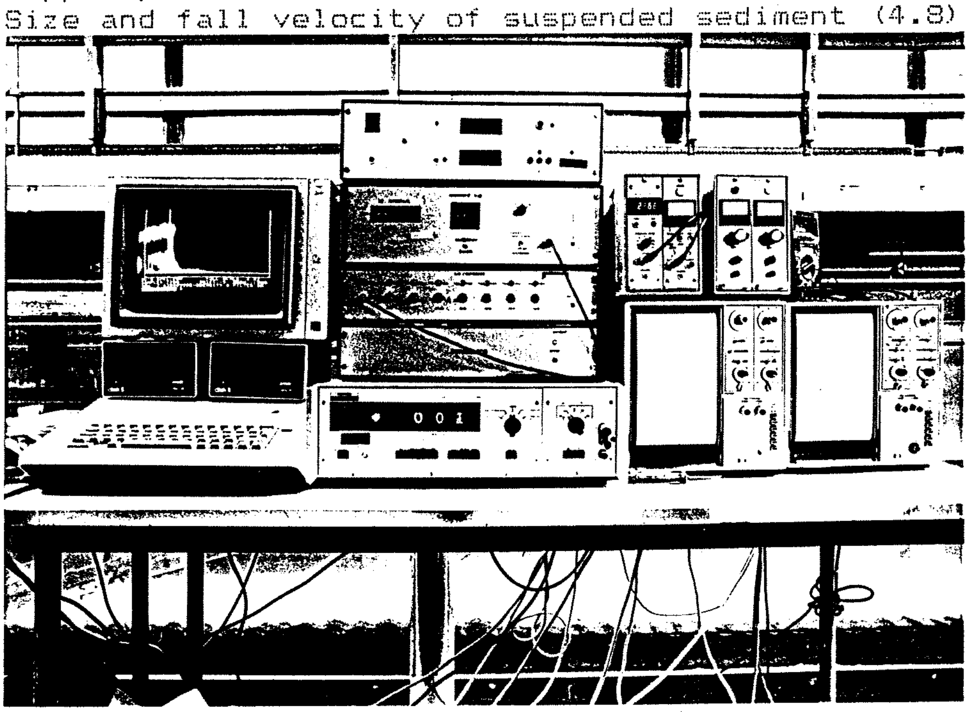
This chapter will present the experimental results, and the assumptions and computations for the parameters used in this study. Also a comparison of the results of this study with the 200-mu-study-results and other data will be made.
In part B of this report, the basic data are given in tables From these, the following data have been computed:

- Depth-averaged fluid velocity
- The mean and standard deviation of sediment loads
- The mean and standard deviation of transport rates
- The mean water surface slope, in case of current alone.

Although only three tests in each experiment were carried out, a mean and standard deviation presentation of the measurements was preferred, because of the stochastic character of sediment transport process. In the 200-mu-study, mean, maximum and minimum values were presented.

In the next sections, the following parameters will be described and discussed successively:

- Wave characteristics (4.2)
- Sediment concentration (4.3)
- Fluid velocities (4.4)
- Sediment loads (4.5)
- Sediment transport rates (4.6)
- Ripple parameters (4.7)
- Size and fall velocity of suspended sediment (4.8)



picture 4. Electronical equipment

4.2 WAVE CHARACTERISTICS

4.2.1. Wave spectra

The computed wave spectra are influenced by the current direction: Spectra, measured when waves travel with a current, are less narrow than spectra measured when waves travel against a current. For illustration, an example is given below, which shows the differences of the measured wave spectra of experiments T 15,10 and T 15,-10.

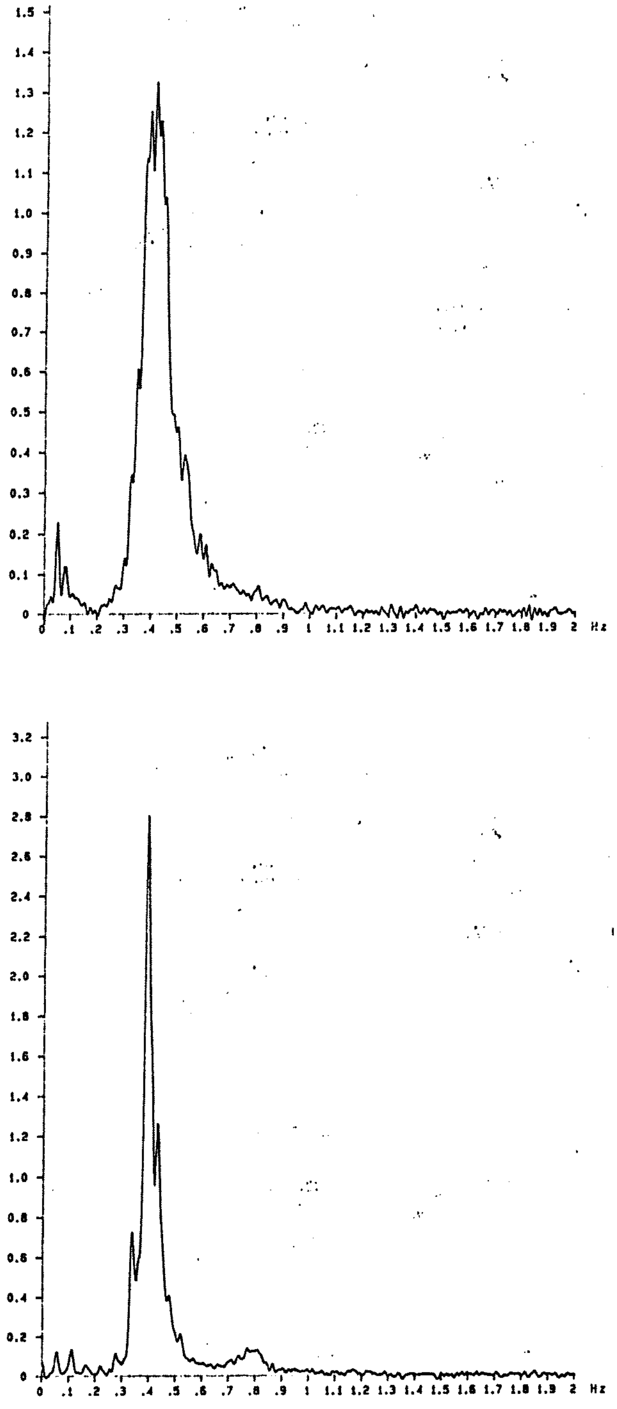


fig.9. Computer output of wave spectra.

The $H(1\%)/H_{ais}$-ratio from measurements was compared to the ratio according to the Rayleigh-distribution.
Generally the Rayleigh-distribution leads to an overestimation of large waves, because the $H(1\%)/H_{ais}$-ratio in the experiments are smaller (between 1.2 and 1.6) than the value of this ratio, that follows from Rayleigh-distribution ($H(1\%)/H_{ais} = 1.52$). This was also concluded in the 200-mu-study.
In the 200-mu-study it was found that the ratio was larger when waves opposed a current, then when waves followed the current. No such influence was found in this study. Here, the influence of H_{ais} is noticed: the $H(1\%)/H_{ais}$-ratio decreases with increasing H_{ais}.

4.2.2. Wave length and peak period

When a current is combined with the waves, the length of waves will be influenced. Waves travelling with the current have a larger wave length compared with the same waves, in case no current is superimposed. If waves travel against a current, a smaller wave length occurs then when no current is superimposed. These observations can also be declared from the characteristic wave parameters.

To compute the characteristic wave length, L, and the relative peak period, Tp,rel , the following equations are given (Jonsson et al,1970):

$$L = ca * Tp \qquad (4.1)$$

$$L = cr * Tp,rel \qquad (4.2)$$

$$ca = cr + Um \qquad (4.3)$$

$$cr = \sqrt{\frac{g * L}{2 * \pi} \tanh(2*\pi*a/L)} \qquad (4.4)$$

with:

L	= Characteristic wave length	[m]
Tp	= Absolute wave spectrum peak period	[s]
Tp,rel	= Wave spectrum peak relative to the current	[m/s]
Um	= Depth-averaged fluid velocity	[m/s]
ca	= Absolute wave celerity	[m/s]
cr	= Relative wave celerity	[m/s]
a	= Waterdepth	[m]

Now, the following implicite equation can be derived from the equations above (see 200-mu-study):

$$\sqrt{(a/L) * \tanh(2*\pi*a/L)} = \sqrt{\frac{2*\pi*a}{g*Tp}} * \left[1 - \frac{Um*Tp*(a/L)}{a} \right] \qquad (4.5)$$

The relative peak period, Tp,rel , and the wave length L, can be computed numerically from the waterdepth a, and the absolute wave spectrum peak period, Tp. This last parameter is computed by the spectrum analyser program (see 3.3.4).

The results of the above computations are given in table 4.1.

4.2.3. Orbital movement parameters

Two parameters, which characterize the wave action just above the bed, are introduced here:

- Ub = a characteristic orbital horizontal velocity amplitude [m]
- Ab = a characteristic orbital horizontal displacement amplitude [m]

These parameters are computed using the significant wave height H_{sig} as characteristic wave height.
The characteristic wave lenght, L, and the relative wave spectrum peak period, Tp,rel , as computed in the previous section, are used in the following formula, to account for the presence of the current:

$$Ub = \frac{\pi * H_{sig}}{Tp,rel * \sinh(2*\pi*a/L)} \qquad (4.6)$$

$$Ab = \frac{H_{sig}}{2 * \sinh(2*\pi*a/L)} \qquad (4.7)$$

The results of the above parameter computations are given in table 4.i.

4.3. SEDIMENT CONCENTRATIONS

4.3.1 General

The measured time- and bed-averaged concentration profiles for all experiments are shown in figs.4.1.A-G., in which the mean concentrations values at different heights above mean bed level and their standard deviation are stated. These values are also given in experimental data tables.
In the 200-mu-study, the time and bed averaged concentration profiles were determined in the following way :

1) For each intake tube, the heights above mean bed level were averaged over all three tests.
2) At the averaged heights, the concentrations for all three executed tests were determined by lineair interpolation.
3) At the averaged heights, the concentrations computed by lineair interpolation were averaged.

Via lineair interpolation the relevant variation in concentration is determined. This becomes more important when the measuring positions above the bed vary from test to test, as explained in paragraph 3.3.6.. Fig.10 shows the meaning of this (for convenience, only two tests are involved).

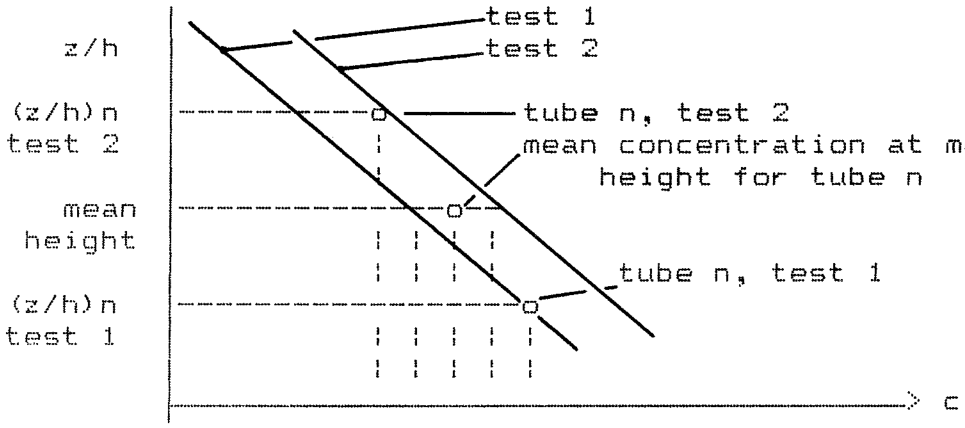


fig.10. Determination of mean concentration

In this study, the time and bed averaged concentration profiles for each experiment were determined as follows:

1) For each intake tube, the heights above mean bed level were averaged over all three tests.
2) In order to simplify the concentration profile computation, the measured concentrations for each intake tube were averaged over three tests.

This simplification is allowed, because in this study, the differences of the heights, in which the different tests were executed, are generally smaller than in the 200-mu-study. The better accuracy of the measuring elevations in this study (see paragraph 3.3.6) also justifies this assumption.
For a few experiments, in which the tests were executed with largest height variations above mean bed level, a comparison was made between the procedure in the 200-mu-study and the simplified procedure. The mean concentration differences ,at the mean heights above mean bed level, were small, and within the standard deviation.

4.3.2 Wave height influence

The significant wave height, H_{sig}, influences the concentration profile, as the figures 4.2.A-D. show:

- Increasing the significant wave height, H_{sig}, leads to an increase of concentrations.
  This becomes less with increasing current strength.

This tendency was also noticed in the 200-mu-study. In that study was also concluded that an increasing H_{sig} leads to a steeper concentration profile. In this study:

- Increasing the significant wave height, H_{sig}, does not lead to a steeper concentration profile.
  Although an increasing wave height causes an increase of mixing, it also causes a decrease of the ripple height and additional less vortices.

4.3.3 Current velocity influence

The concentrations are influenced by, the current strength, in the following ways (see fig.4.3.A-D.):

- A weak current (0.1 [m/s]) in combination with waves, leads to somewhat smaller concentration magnitudes in the near bed zone compared to the magnitudes in case of waves alone. On the other hand it does lead to an increase in concentrations in the upper layers.

- A stronger current (0,2-0,4 [m/s]) causes an increase in concentrations, especially in the upper layers. This increase becomes less with increasing current strenght. An increasing current strenght causes an increasing steepness of the concentration profile.

This indicates, that a stronger current leads to an **equilibrium in the upper layer concentrations, despite of the** H_{sig} influence. This equilibrium has not yet been reached in the 200-mu-experiments.
Bosman found very large magnitudes of concentrations in the upper layers. Probably this is caused by his closed water circuit system, that kept fine material in suspension; the sediment, brought in suspension, leaving the flume, will also re-enter the flume, because no settling basin was used. So, his results must be analysed with care.

4.3.4 Current direction influence

- Waves following a current give somewhat steeper concentration profiles than waves opposing a current.

The 200-mu-study concluded the opposite; waves following a current gave somewhat less steeper concentration profiles than waves opposing a current. This was explained by the the relatively large velocity gradient and hence relatively large

mixing coefficient, in case of waves combined with an opposing current.
Given the fact the influence of the current direction on the concentration profile is relatively small, the underlying mechanism is difficult to identify. For example, it may easily be caused by small changes in the ripple shape or sediment diameter.

picture 5. Pumps and buckets.

4.4. FLUID VELOCITIES

4.4.1. General

The time- and bed-averaged velocities were measured as is described in paragraph 3.3.7.
These measurements were not carried out in case of waves alone. The velocities in this case are too small (0.02 [m/s]) to measure with the E.M.S.

The mean time- and bed-averaged velocities and their standard deviations are computed in the same way as the mean and standard deviated concentrations (see previous paragraph).
For comparison of velocity profiles, measured in different experiments, the measured velocities and the heights above mean bed level have been made dimensionless. This is done in figs.4.4.A-E., The time- and bed-averaged velocities, U(z), are divided by the depth-averaged velocity, Um, on the horizontal. The mean heights above the mean bed level, z, are divided by the mean waterdepth, a.

To compute the depth-averaged velocity, Um, from the measured velocities, two assumptions have been made (see fig.11.):

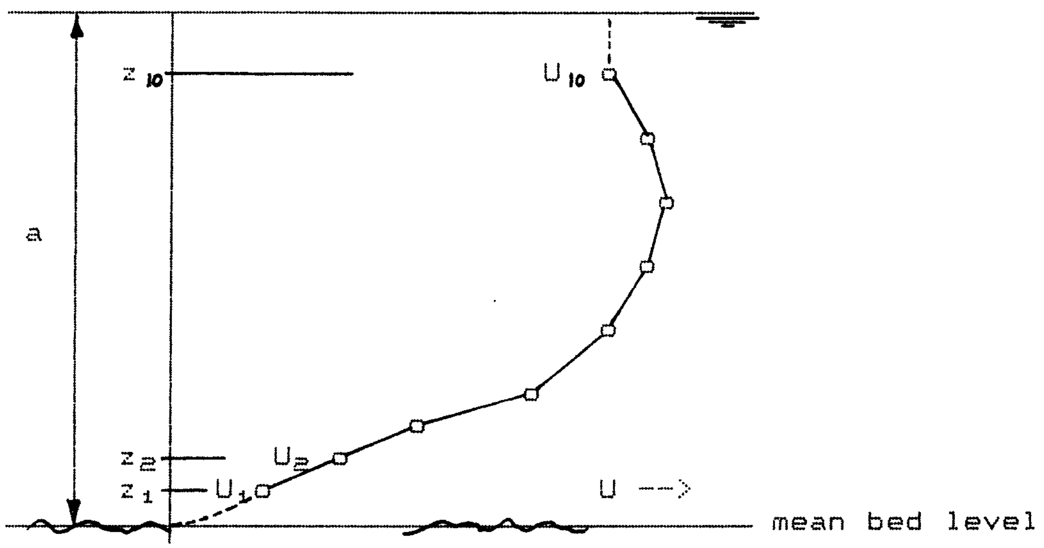


fig.11 Extrapolation of velocity profile.

1.
The velocities between mean bed level and the lowest measuring point are represented by a function, corresponding with a logarithmic velocity distribution in case of a rough bed (van Rijn, 1986):

$$U(z) = U1 * (z/z1)^n \quad ,\text{for} \quad 0 < z < z1 , \quad 0 < n < 1 \tag{4.8.}$$

with:
U(z) = Mean measured velocity at level z [m/s]
U1 = Mean measured velocity at lowest measuring point [m/s]
z = Height above mean bed level [m]

$z1$ = Mean height of lowest measuring point above mean bed level [m]
n = Power coefficient, as a result of the fitting of the mean measured velocities of the lowest three measuring points (z1, z2 and z3) [-]

2.
The mean velocity between the highest measuring point and the water surface are assumed to be equal to the measured velocity in the highest measuring point (U10).

Now, the depth-averaged velocity, Um, is computed as:

$$Um = 1/a \sum_{i=1}^{N} (U_i + U_{i-1}) * (z_i - z_{i-1}) /2 \qquad (4.9.)$$

with:
Um = Depth averaged fluid velocity [m/s]
U_i = Mean time- and bed-averaged velocity at height z_i above mean bed level [m/s]
N = Total number of points (including extrapolated points) [-]

Originally, the n-coefficient in eq.(4.8), had a value of $n = 0.25$. This value has been used in the 200-mu-study for all experiments.
The velocities in the near bed zone are important because of the transport of relative large sediment concentrations in this zone. Therefore the n-coefficient was analysed in this study. For each experiment, the n-coefficient was determined by linear regression of the mean measured velocities at the three lowest measuring points. This resulted in $n = 0.62$, as an average value of all experiments. In this report, the n-coefficient determined for each experiment was used.

4.4.2. Current alone

In each experiment current velocities were also measured in absence of waves. As described in paragraph 3.3.6, this was done for bed roughness determination, caused by the bed forms, generated by waves and a current.
Two current alone experiments (T 0, 40 and T 0,-40) were also carried out to measure sediment transport rates. In case of a weaker current (|Um| = 0,1 - 0,2 [m/s]) there was no movement of bed material particles.

In this section the velocity profile, in case of current alone will be analysed. This was done by comparison of the velocity profile from the measurements, with a logarithmic distribution from theory, presented as:

$$U(z) = (U*/k) * \ln(z/z0) \qquad (4.10)$$

with:
U(z) = Current velocity at level z [m/s]
U* = Bed-shear velocity [m/s]
z = Height above mean bed level [m]

$z0$ = Roughness length scale (zero-velocity level) [m]
k = The von Karman constant (=0,4) [-]

The bed roughness length of Nikuradse, Ks, is computed as:

$$Ks = 33 * z0 \qquad (4.11)$$

To eliminate side wall effects of the flume, only the lowest measuring points (average: z/a< 0,5) were used in the fitting procedure. The amount of measuring points depends on the regression coefficient. Chosen is for a regression coefficient between 0.98 and 1.00, which resulted in an average use of the lowest eight measuring points for the fitting procedure. Based on this, it is concluded that:

. A logarithmic velocity distribution is valid for z/a < 0.5.

The 200-mu-study gives the same conclusion.

The examination of bed roughness related to ripple parameters will be discussed in chapter 6.

4.4.3. Wave influence

As can be observed in figs.4.4.F-I., the velocity profiles in the wave-and-current experiments differ from the velocity profiles in case of current alone:

. Compared with current velocities when waves are absent, the velocities measured when waves follow a current are:
  - Relatively small in the near bed region (z/a < 0.1-0.2)
  - Relatively large in the middle layers (0.2 < z/a < 0.6)
  - Relatively small in the upper layers (z/a > 0.6-0.7)
  . Increasing the current strength, Um, leads to a decrease of the differences.
  . Increasing the significant wave height, H_{sig}, leads to an inrease of the differences.

. Compared with current velocities when waves are absent, the velocities measured when waves oppose a current are:
  - Relatively small in the near bed region (z/a < 0.1-0.2) (but even smaller than when waves follow a current)
  - Relatively small in the middle layers (0.2 < z/a < 0.6)
  - Relatively large in the upper layers (z/a > 0.6-0.7)
  . Increasing the current strength, Um, leads to a decrease of the differences.
  . Increasing the significant wave height, H_{sig}, leads to an inrease of the differences.

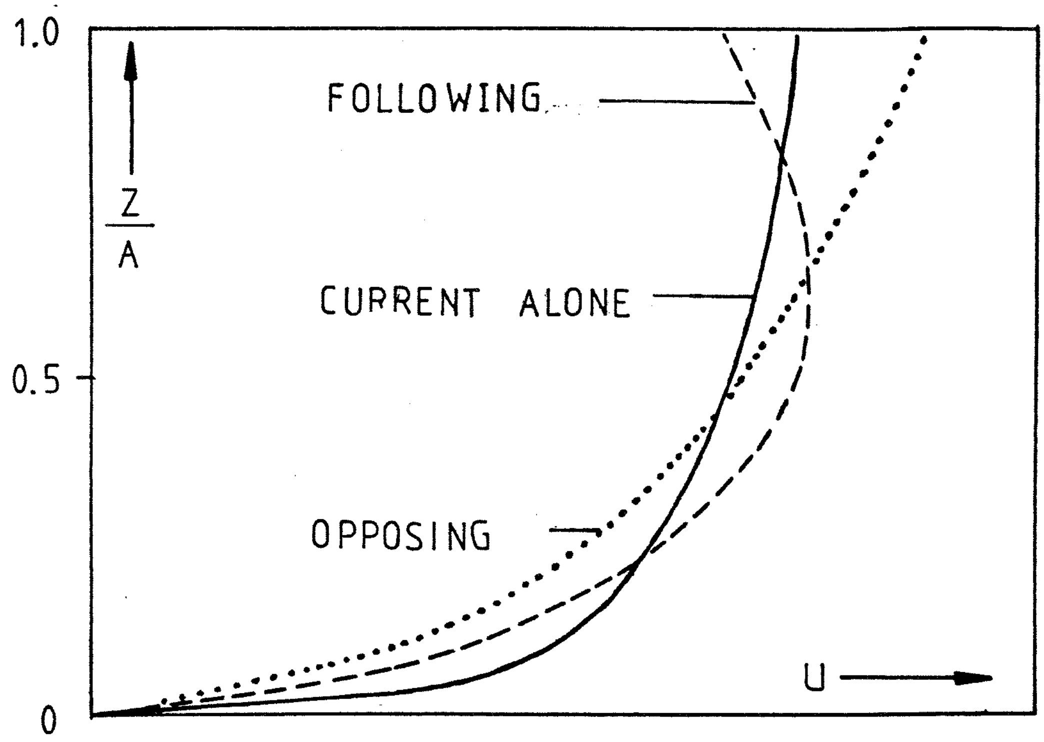


fig.12. Sketch of following and opposing current.

The most striking difference between the velocity profile in case of a following and opposing current is, that compared to current alone, the velocities are reduced in the near surface layer for a following current and enlarged for an opposing current (see fig.12).

These phenomena are also described in the 200-mu-study, and by Kemp and Simons (1983) and Bakker and van Doorn (1980) in case of regular waves.
The wave-induced changes in velocity distribution in the near bed zone can be explained by the extra turbulence of wave movement, which leads to an increase of shear stress.

4.5. SEDIMENT LOADS

4.5.1. General

The sediment load is defined as the total amount of moving sediment per unit bed surface area:

$$Lt = \int_{z=0}^{a} \overline{\overline{c}}(z)\ dz \qquad (4.12)$$

with:

Lt	= Total load	[kg/m2]
$\overline{\overline{c}}(z)$	= Time- and bed-averaged concentration at z	[kg/m3]
a	= Water depth	[m]

Here, the total load consists of two parts, the bed load and the suspended load:

$$Lb = \int_{z=0}^{r/2} \overline{\overline{c}}(z)\ dz \qquad (4.13)$$

$$Ls = \int_{z=r/2}^{a} \overline{\overline{c}}(z)\ dz \qquad (4.14)$$

$$Lt = Lb + Ls \qquad (4.15)$$

with:

Lb	= Bed load	[kg/m2]
Ls	= Suspended load	[kg/m2]
r	= Mean ripple height	[m]

In order to compute the measured concentrations in the mean bed region and near water surface region, two assumptions have been made (see fig.13):

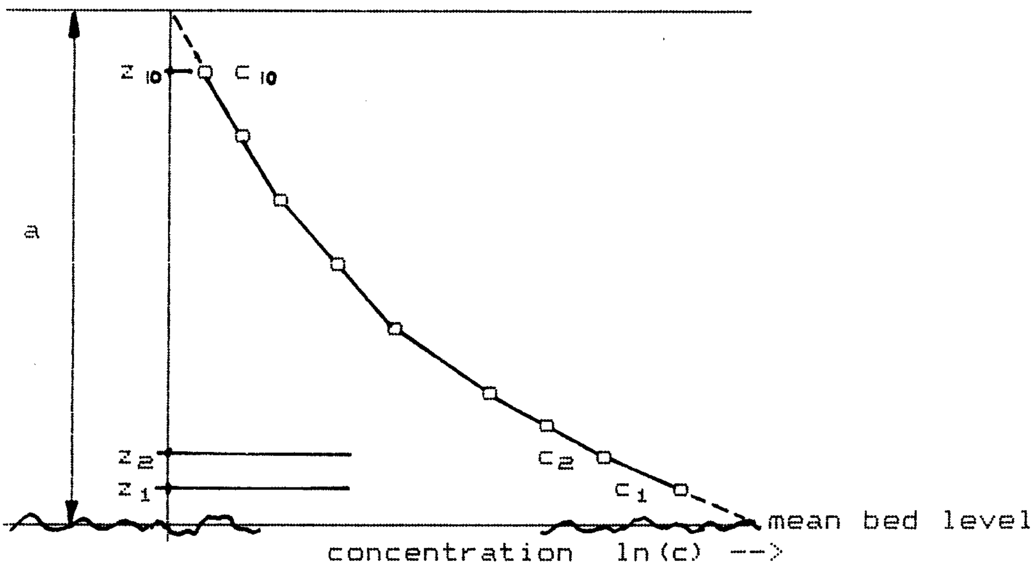


fig.13 Extrapolation of concentration profile

1.
The concentrations in the zone between the mean bed level and the lowest measuring point (z1) are approximated by:
(see also chapter 6)

$$c(z) = \exp(A*z + B) \quad ;\text{for } 0 < z < z1 \qquad (4.16)$$

The coefficients A and B are computed by linear regression using the lowest three measuring points. The concentrations in the near bed zone give a large contribution in the sediment transport, although the fluid velocities are small. To improve the approximation of the concentrations, for each of the three tests the A and B coefficients were computed, and averaged after, to be representive for the experiment. The same procedure has been carried out to compute the standard deviation.

2.
The concentrations in the area between the highest measuring point (z10) and the water surface are represented by a linear function, which leads to a zero concentration at the water surface, so:

$$c(z) = \left| \frac{a - z}{a - z10} \right| * c10 \quad ;\text{for } z1 < z < a \qquad (4.17)$$

with:
c10 = Mean measured concentration in the highest measuring point (z10) [kg/m3]
z10 = Mean height above mean bed level of the highest measuring point [m]

The same equation is used to determine the standard deviation.
Using these two assumptions, the bed load and suspended load are computed numerically, for mean and standard deviation values. These loads are given in tables 4.5.

4.5.2. Wave height influence

Increasing the significant wave height, H_{sig}, leads to a larger load. A table will be given here to show the wave height influence, for the particle sediment diameter of 100 and 200 mu.

Increase of Total Load by Increase of H_{sig} from 7.5 to 15 [cm]		
Um (m/s)	100 mu	200 mu
0	17	30
0.1	11	30
0.2	8	20
0.4	3	4

Table 1. Increase factors.

As was observed in paragraph 4.3., in which the concentration increase becomes less pronounced with increasing current strength, the table above shows that for loads this increase is even less for finer sediment.

4.5.3. Current strength influence

As can be seen in the next table, the same tendency is present. Now, total load increase factors are given for a wave height H_{sig} with increasing the depth-averaged fluid velocity from 0.2 to 0.4 [m/s]:

Increase of Total Load by Increase of Um from 0.2 to 0.4 [m/s]		
H_{sig} (cm)	100 mu	200mu
7.5	8	20
10	3	8
12	-	6
15	3	4
18	2	-

Table 2. Increase factors.

. A larger significant wave height causes a less pronounced increase of loads with increasing current strength.

From the figs.4.5.A-D. and table 4.2. one can observe that:

. A weak current (|Um|=0.1 [m/s]) superimposed on the waves leads to a decrease of the loads.

This phenomenon is related with the decrease of concentration in the near bed zone, influenced by a weak current, see

section 4.3.3. No reasonable explanation can be given for this yet.
This study (100 mu) and the 200-mu-study show that for |Um| < 0.1-0.2 [m/s], the wave influence on the total load becomes more important. From figs.4.5 can be observed that for different wave heights the loads will reach almost equal magnitudes in case of a strong current.

- The current direction does not influence the loads in this study, but the 200-mu-study measurements show somewhat larger loads in case the waves opposed the current. (This was explained by the relatively large $H1\%/H_{sig}$ ratio for waves opposing a current in that study).

- The increase of loads by increasing Hsig or Um, is relatively larger in case of 200 mu.
  The beginning of movement of sediment might play a role in this.

4.6. SEDIMENT TRANSPORT RATES

4.6.1 General

As is pointed out in chapter 2, the sediment transport rates are computed from the time- and bed-averaged concentrations and velocities. In this section only the time- and bed-averaged sediment transport will be discussed, so, the wave-related part of the total sediment transport will be neglected here. To be clear, the computed total sediment transport from time- and bed-averaged measurements will be called : Smeasured;

$$Stot = Smeas = \int_{z=0}^{a} \bar{\bar{c}}(z) * \bar{\bar{U}}(z)\, dz \qquad (4.18)$$

Like the sediment loads, the total sediment transport is devided in two parts:

-The bed load transport: $$Sb = \int_{z=0}^{r/2} \bar{\bar{c}}(z) * \bar{\bar{U}}(z)\, dz \qquad (4.19)$$

-The suspended load transport: $$Ss = \int_{z=r/2}^{a} \bar{\bar{c}}(z) * \bar{\bar{U}}(z)\, dz \qquad (4.20)$$

with:

Sb = Bed load transport [kg/ms]
Ss = Suspended load transport [kg/ms]
r = Mean ripple height [m]
$\bar{\bar{c}}(z)$ = Time- and bed-averaged concentration at height z [kg/m3]
$\bar{\bar{U}}(z)$ = Time- and bed-averaged fluid velocity at height z [kg/m3]

4.6.2. Bed load transport

Equation (4.19) defines the bed load transport as the total transport in the layer between z=0, the mean bed level, and z=r/2, half the mean ripple height above mean bed level. (see fig.14).

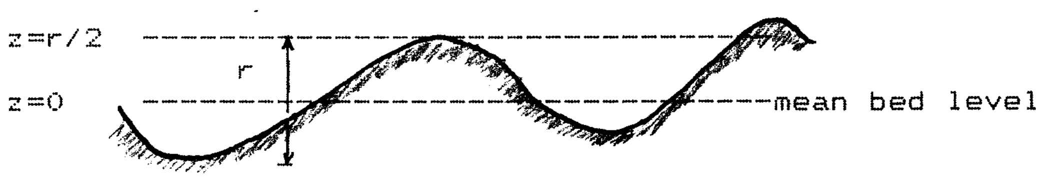


fig.14 Ripple height

Two fundementally different methods are used to compute the bed load transport:

1.
$$Sb1 = \int_{z=0}^{r/2} c(z) * U(z)\, dz \qquad (4.21)$$

with

$c(z) = \exp(A*z + B)$;for $0 < z < r/2$, from eq.4.16,

and

$U(z) = U1 * (z/z1)^{n}$;for $0 < z < r/2$, from eq.4.8.
$0 < n < 1$

These approximations have been discussed in paragraph 4.4. and 4.5. . The bed load transport, using this method, can be computed numerically. The mean values are computed as:

$$Sb1 = \int_{0}^{r/2} \bar{\bar{c}}(z) * \bar{\bar{U}}(z)\, dz \quad , 0 < z < r/2,$$

and the standard deviation of the bed load transport,d(Sb1);

$$d(Sb1) = \int_{0}^{r/2} d(c(z))*\bar{\bar{U}}(z) + \bar{\bar{c}}(z)*d(U(z)), \quad 0 < z < r/2$$

The results of these computations for all experiments are given in tables.

2. The bed load transport is computed from the emperical relation between the bed load transport and the mean migration velocity of the ripples, as:

$$Sb2 = \alpha * (1-p) * \rho_s * Ur * r \qquad (4.22)$$

with:

Sb2	= Bed load transport	[kg/ms]
α	= Shape factor (=0,6)	[-]
p	= Porosity (=0,4)	[-]
ρ_s	= Densiry of the sediment (=2650)	[kg/m3]
Ur	= Mean migration velocity of the ripples	[m/s]
r	= Mean ripple height	[m]

The mean and standard deviation of Sb2 can be computed from the mean and standard deviation of the migration velocity of the ripples.

The different methods lead to the same direction of bed load transport, but lead to very different values (see fig 4.6.).

The first method, the computation of Sb1, gives much larger magnitudes than the computation of Sb2. Also a more smoother tendency is observed, using the first method (see fig.4.6.). For this reason the first method is used for further computations of the total load transport.

So ,

$$Sb = Sb1$$

In the 200-mu-study the two different methods gave reasonable agreement (except for the experiments with a current strength of 0,1 [m/s]).
Although the differences between both methods are large, the influence of the bed load transport on the total transport is small, because the suspended load transport is dominating.

In the experiments with only wave action, the ripples were moving in the opposite direction of the wave celerity direction.

4.6.3. Suspended load transport

Equation (4.20) defines the suspended load transport as the total transport in the layer between z=r/2, half the mean ripple height above mean bed level, and the water surface. Between the lowest measuring point (z1) and z=r/2, the concentrations and velocities are computed by the approximations in eq.(4.16) and eq.(4.8). Between the highest measuring point and the water surface the concentrations and velocities are computed by eq.(4.17) and U10 (see 4.4.1). Now the suspended load transports can be computed numerically for a mean value, by:

$$Ss = \sum_{i=1}^{N} \left[(\bar{\bar{c}}*\bar{\bar{U}})_i + (\bar{\bar{c}}*\bar{\bar{U}})_{i-1} \right] * (z_i - z_{i-1})/2 \qquad (4.23)$$

with:

Ss	= Mean suspended load transport	[kg/ms]
$\bar{\bar{c}}*\bar{\bar{U}}_i$	= Mean time- and bed-averaged load transport at height z_i above mean bed level	[m/s]
N	= Total numbers of points (including extrapolated points)	[-]

and, the standard deviation by:

$$d(Ss) = \sum_{i=1}^{N} \{ [d(c)*\bar{\bar{U}}]_i + [d(c)*\bar{\bar{U}}]_{i-1} \} * (z_i - z_{i-1})/2 \quad +$$

$$\sum_{i=1}^{N} \{ [\bar{\bar{c}}*d(U)]_i + [\bar{\bar{c}}*d(U)]_{i-1} \} * (z_i - z_{i-1})/2 \qquad (4.24)$$

with:

d(Ss) = Standard deviation of the suspended load transport [kg/ms]

$d(c)_i$ = Standard deviation of the concentration at height z_i above mean bed level [m/s]
$d(U)_i$ = Standard deviation of the fluid velocity at height z_i above mean bed level [m/s]
N = Total numbers of points (including extrapolated points) [-]

The results of these computations are given in the experimental data tables.

4.6.4. Total sediment transport

The total transport is determined now as the sum of the bed and suspended load transports:

$$Stot = Sb + Ss \tag{4.25}$$

The results of Stot for all experiments are listed in table 4.2.
Most interesting now, is the dependence of total transports on the significant wave height, H_{sig}, and on the depth-averaged fluid velocity, Um. This dependence will estimate the accuracy needed for Hsig and Um to determine proper total sediment transport rates. From the figs. 4.7.A-F. some tendencies can be observed.

First the relation between the total transport and the significant wave height will be investigated. The relation can be described rather well by:

$$|St| \sim H_{sig}^{\;q} \tag{4.26}$$

in which q still depends on the depth-averaged velocity, Um. This parameter is computed, for constant Um, by linear regression of varying significant wave heights. This is also done for the 200-mu-study results, in the next table:

|Um|	100mu	200mu
[m/s]	q	q
0,1	3.2	4.5
0,2	2.1	2.9
0,4	1.3	1.8

The decrease in q leads to a less pronounced increase in total sediment transport, as can be seen from the table. In fig.4.7.E this is obvious. Noteworthy, is the constant relation between q for 100 mu and q for 200 mu for the same Um:

$$\frac{q(100mu)}{q(200mu)} = 0{,}71 - 0{,}72 = 0{,}5 * \sqrt{2} = 0.5 * \sqrt{\frac{200mu}{100mu}}$$

for 0.1 [m/s] < Um < 0.4 [m/s],
100 mu < D50 < 200 mu

The relation can also be observed in fig.4.7.B, the resulting curves in case of 100 mu and 200 mu are parallel for Um.
As can be seen from fig.4.7.A., Bosman's results are not consistent with the results from this and the 200-mu-study.

Second the relation between the total transport and the depth-averaged velocity will be investigated. The relation is presented by:

$$|St| \sim |Um|^{y} \tag{4.27}$$

in which the parameter y still depends on the significant wave height. Again by linear regression the next table gives an y for a significant wave height.

Hsig	100mu	200mu
[cm]	y	y
7.5	3.4	4.5
10	2.8	4.1
12	-	3.0
15	2.6	2.9
18	2.3	-

. The increase of H_{sig} leads to a decrease of y, meaning a less pronounced increase in total transport with increasing H_{sig}.

The results of the relations, listed above, are given in fig.4.7.**D**. The overall tendency from this figure is less explicit than in fig.4.7.B.

. By an increase of Hsig, y seemed to become constant, so the sediment transport will mainly depend upon the current-strength.

Probably the beginning of movement of sediment particles will play a role. For the finer sediment particles, 100 mu, relative larger transport rates are present in case of a small Hsig.

From the two tables above one can conclude that:
. the accuracy of Um and Hsig are relative more important in

case of an increasing D50.

. the accuracy of Um and Hsig becomes relatively more important in case of decreasing Um and Hsig values.

4.7. RIPPLE PARAMETERS

4.7.1. General

As can be observed in nature, on the beach, the wave and current movements generate bed forms. The size, shape and regularity of the bed forms depend on the intensity of water movement. On the other hand, the bed forms, have an important influence on the water movement in the near bed zone. See also chapter 6 about bed roughness.
Here, the bed forms and ripple parameters will be discussed. From ripple registrations, in the three longitudinal sections in the flume, ripple parameters were determined for each experiment. During these experiments, with increasing intensity of water movement, the following bed forms occured, defined as:

- 2-dimensional ripples (2-D)	: Regular ripple-shaped bed, with ripple crests parallel to wave crests. (perpendicular to flume window)
- 2.5-dimensional ripples (2.5-D)	: Semi-regular ripple-shaped bed, shape between 2- and 3-dimensional.
- 3-dimensional ripples (3-D)	: Irregular ripple-shaped bed, individual bumps.

Other forms, like "dunes" or a "flat bed", were not observed in this study. The bed form for each experiment is listed in the tables with experimental data under "Ripple shape".

. 2-D ripples were registrated in case of no current, or a small current (¦Um¦=0.1 [m/s]) combined with a wave height of 7.5-10 [cm].
. 3-D ripples were found in case of a strong current (¦Um¦= 0.4 [m/s]) combined with waves, or in case of Hsig= 18 [cm] combined with a current.
. 2.5-D ripples were generated in other combinations of wave height and current.

To describe these ripples the following parameters are used:

- Ripple height (r)
- Ripple length (λ)
- Ripple steepness (r/λ)
- Ripple shape ($\lambda 1/\lambda 2$)

A mean and standard deviation value of these parameters are determined. These parameters will be described briefly in the next paragraphs. Also 200-mu results will be presented in these.

4.7.2 Bed forms

Beside the distinction of ripples by shape (2-D to 3-D), also a distinction of ripples by symmetry can be made. As stated in paragraph 3.3.8., the parameters λ1 and λ2 determine the symmetry of ripples. The ratio λ1/λ2 determines whether the ripples are called wave-dominated (symmetrical) or current-dominated (a-symmetrical).
This is sketched in the figure below.

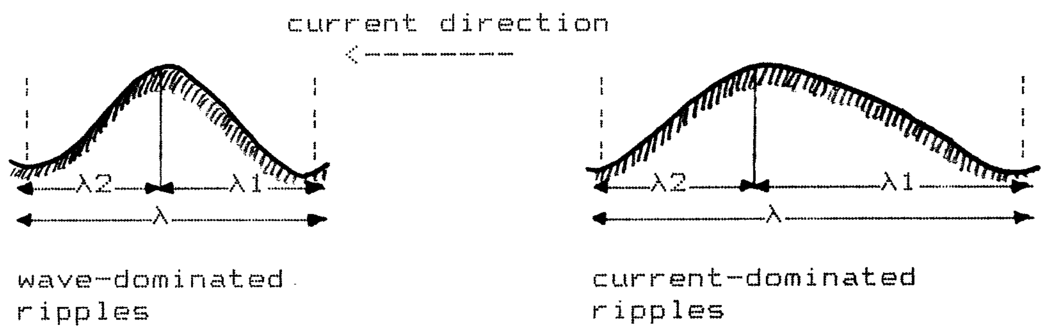


fig.15 Wave- and current-dominated ripples.

In this study, λ1/λ2-ratio values between 0.80 and 1.39 were found (see table 4.3).
Table 4.3 and fig.4.8.A show that there is no real tendency. Except for the experiments with |Um|= 0.4 [m/s], one can observe that λ1/λ2 > 1.0 .

To describe the influence of the water movement in the near bed zone on the ripple characteristics, the following dimensionless parameters are used:

- Ub^2/dgD50, to describe the wave influence, and
- Um/Ub, to indicate the importance of the current with regard to the waves.

Figure 4.8.A. shows the relation between Um/Ub and λ1/λ2. One can conclude from this figure:

. The overall λ1/λ2 ≅ 1.

. Ripples generated by a current opposing the waves, are somewhat more symmetrical than those generated by a following current.

The 200-mu-study verifies this. The relatively large reduction of the fluid velocities in the near bed zone, in case of waves opposing the current, is the explanation for this.

4.7.3 Ripple height

The experiments in this study showed ripple heights between

0.62 and 1.85 [cm]. These ripple heights are smaller than in the 200-mu-study: 1.0 to 3.0 [cm].

The irregularity of the 3-D ripples causes a relative larger standard deviation of the ripple height, compared to the 2-D ripples. In chapter 6, more details about this will be given. Figures 4.8.B-C. show several relations between the parameter r/Ab, the relative ripple height, and the water movement parameter, Ub^2/dgD50.

The experiments without a current show a tendency, given by waves:

. Increase of wave height leads to decrease of the mean ripple height.

This is explained by the increase of Ub, which leads to an increase of ripple crest erosion.
Fig.4.8.A shows the relation between r/r0 (r0= ripple height in case of the same wave height, but no current) and Um/Ub.
From this:

. In case of a strong current (|Um|=0.4 [m/s]), a somewhat larger r/r0 is observed, but the relation between r/r0 and Um/Ub show poor agreement.
. The current influence on the ripple height becomes more important than the wave influence, because one can observe a ripple height increase in case of increasing Um/Ub.

4.7.4 Ripple length

In the 200-mu-study ripple lengths of 8.0 to 20.0 [cm] were found. Decreasing the D50 of the bed material leads to a decrease in ripple length, as found in this study: 6.0 to 14.5 [cm].
As is done for the ripple heights, also the water movement parameters are related to the relative ripple length, λ/Ab, given in figures 4.8.A-C. , in which:

. the same conclusions for the ripple heights can be made for the ripple length.

4.7.5 Ripple steepness

The ripple steepness is defined as the ratio r/λ.

Despite of the 200-mu-results, in which an increase of current strength leaded to a decrease of the ripple steepness (0.16 - 0.11), no such influence was noticed in this study (see fig.4.8.). An average steepness of r/λ= 0.134 was found for 100 mu.

. Because the increase of λ and r are influenced equally by the water movements, the steepness is rather constant.

4.8 SIZE AND FALL VELOCITY OF SUSPENDED SEDIMENT

The tables with the experimental data gives the measured median fall velocity, w50, of the suspended sediment and bed material, from the lowest 5 intake tubes (about 0.15 [m] above the bed). Also an average value is given for the 5 highest intake tubes.
From these, the particle diameter, D50, can be computed (ref.Slot,1983).
The size and fall velocities show a somewhat finer sediment in the upper layers, but:

- The median fall velocity of the suspended material is equal to about 0.9 to 1.0 times the median fall velocity of the bed material. The influence of wave height and current strength is not clear.

5. SAND BALANCE COMPUTATIONS

5.1. GENERAL

The previous sediment transport experiments were aimed at measuring the time- and bed-averaged concentrations and velocities. Applying these values, the current-related part of the total sediment transport can be computed. The wave-related part of the sediment transport is totally neglected. The wave-related sediment transport can be determined as:

$$S_{wave} = S_{total} - S_{current} \quad (5.1)$$

To get insight into the importance of the wave-related part, three sand balance experiments were carried out:

- . S 15, 10 (following current)
- . S 15,-10 (opposing current)
- . S 15, 20 (following current)

The total sediment transport, in these experiments, can be determined, by measuring the decrease of the total sand bed volume, upstream of the measuring section. This has been done using two different methods:

1. by measuring the mean level of the sand bed using a profile follower (profo). This has been done in S 15,-10 and S 15,20
2. by weighing the sand volume, and is done in S 15,10.

Six experiments were carried out, using method 1. Only two of them were reliable. The electronic profo equipment caused lots of problems in the other four experiments; the integration values were not reproducable. After these, method 2, which was thought to be less practical at first sight, proved to be a workable and efficient. And even more accurate then method 1. Both methods will be described in more detail below.

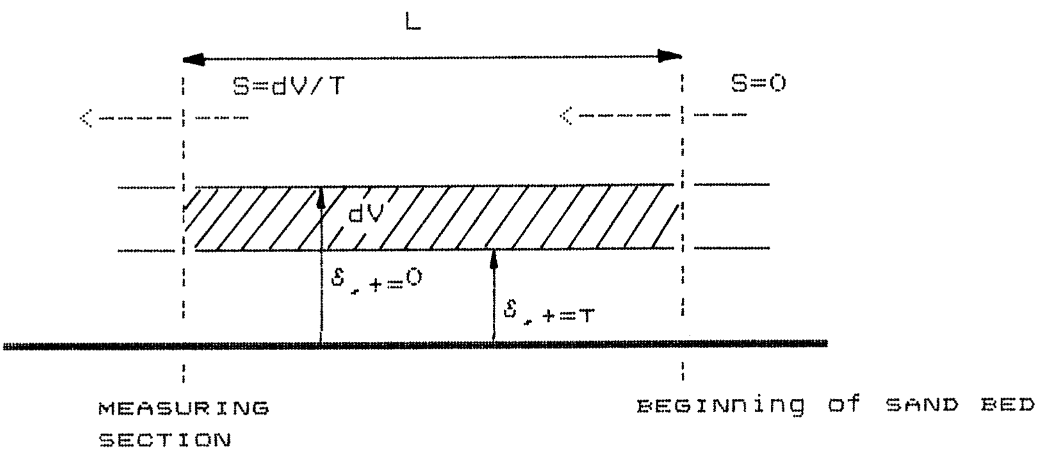


fig.16 Principle of the sand balance.

5.2 COMPUTATIONAL METHODS

The two methods for determining the total sediment transport will be described here. The principle of the sand balance computation is shown in the figure 16.

method 1.

The sand volume difference dV is computed from the measured mean bed levels as:

$$dV = \left(\overline{\delta_{z,t=0}} - \overline{\delta_{z,t=T}} \right) * L * b \qquad (5.2)$$

with:

dV	= Volume difference	[m3]
$\overline{\delta_{z,t=0}}$	= Averaged Mean bed level, before the test	[m]
$\overline{\delta_{z,t=T}}$	= Averaged Mean bed level, after the test	[m]
T	= Time period between two bed level measurements.	[s]
L	= Distance between the beginning of the sand bed and the measuring section.	[m]
b	= Flume width (0.8 m)	[m]

The mean bed level is measured with the profo. This is done in 8 longitudinal sections, to average out variations in transverse direction. The 200-mu-study was done using 3 longitudinal sections, but more accuracy appeared to be necessary.
Since there is no sediment load at the beginning of the sand bed, the total sediment transport can be computed as:

$$Stotal = dV * (1-p) * \rho_s / (T*b) \qquad (5.3)$$

with:

Stotal	= Total Sediment Transport	[kg/m.s]
p	= Porosity (p=0.4)	[-]
ρ_s	= Sediment Density (=2650)	[kg/m3]

method 2.

Before starting the sand balance experiment, the total weight of the sand bed between the beginning of the sand bed and the measuring section has been determined by an "under water balance" method. This weighing method is done because the sand stays wet and no difficult sand drying method is necesarry. The principle is shown in the figure below.

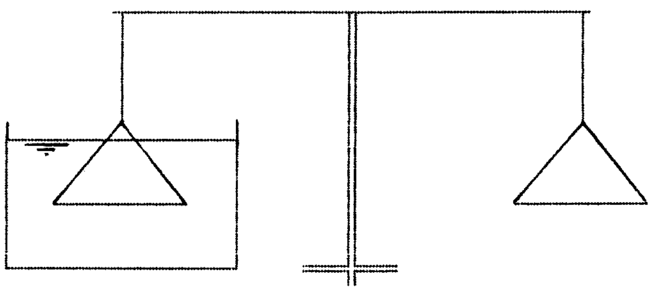


fig.17 the under water balance.

Buckets were filled with wet sand from the flume, and water was added. By stirring the mixture the remaining air will escape. Each bucket was submerged carefully in a water reservoir, and the under-water-weight was measured. About 20 buckets were necessary to obtain a sandlayer of approximately 0,05 [m] over length L. The dry weight W of the total sand bed can be computed as:

$$W = W(u.w) * (\rho_s - \rho_w) / \rho_w \qquad (5.4)$$

with :
W(u.w) = Total Weight of the sand volume under water. [kg]
ρ_w = Water Density [kg/m3]

After measuring period T the sand bed over length L was removed and the under-water-weighing was repeated. The weight difference dW now is computed as:

$$dW = W(t=0) - W(t=T), \qquad (5.5)$$

and the total sediment transport Stot as:

$$Stot = dW / (T*b) \qquad (5.6)$$

The first method has an estimated error of 0.001 m in mean bed level, which causes a 20% deviation in Total Sediment Transport. The second method gives a smaller error of about 8% caused by the weighing error. Therefore, the second method is preferred.

5.3.RESULTS OF SAND BALANCE TESTS

The mean sediment transport rates computed from the sand balance and from the concentration and velocity measurements are given in the following table (see also fig.5.1, page 9):

	Scurr	Swave	Stotal	Stotal/ Scurr
S 15,10	3.16 (0.67)	-1.45 (0.87)	1.71 (0.15)	0.54
S 15,20	15.03 (3.45)	-3.74 (6.01)	11.28 (2.56)	0.75
S 15,-10	-3.83 (0.90)	0.42 (1.44)	-3.40 (0.54)	0.89

mean sediment transports in kg/s.m * 10 -3,
(...) = standard deviation of the above value.
\+ = sediment transort in wave direction.
\- = sediment transport against wave direction.

table 3. Sand Balance Results

Although only three reliable sand balance experiments have been carried out, a few conclusions can be drawn based on the results of the sand balance tests:

- The wave-related sediment transport is opposite to the direction of wave propagation.
- Increasing the depth-averaged fluid velocity leads to a relative decrease of the wave-related part of the total sediment transport (see table 3).
- In case of a weak current, the total sediment transport in a following current is less than in a opposing current, because the wave-related transport is opposite to the direction of wave propagation.

5.4 SAND TRANSPORT MECHANISM

An attempt to give an explanation of the last conclusion will be made.

First, we will examine the sand transport mechanism:
This mechanism will called "the pick-up-and-transport" model, and can be devided in two steps:
1. Pick-up of sediment by eddies, generated behind the ripple crests.
2. Transport of sediment by fluid velocity in the opposite direction.
With the wave crest passing by (see figure), an eddy will be generated at the ripple front. If the fluid velocity near the bottom, generated by orbital wave motion is exceeding the critical value for initiation of sediment motion, bottom material will be eroded and the eddy will contain sediment particles. The concentration in the eddy will depend on fluid velocity. Increasing the wave height, the eddy concentration will increase.
When the wave trough starts passing, the eddy "explodes", and its sediment will be transported in:
a. the opposite direction (x-direction).
b. to higher regions (z-direction).
Also a part of the eddy sediment will fall back.
On the other hand also an eddy will arise at the ripple back and erode sediment. A part of that sediment concentration will now be transported by the wave crest fluid velocity in positive direction. So the proces will turn on and on, and sand grains will move back and forth; the bottom material, which is eroded during the presence of positive velocities, is moved in the negative direction and vica-versa.

For the explanation given here, the most important part of the sediment transport is the horizontal transport in x-direction.

Nielsen et al. developed different models for sediment transport by nonbreaking waves over rippled beds. Nielsen 's model: "grab and dump" model is most consistently in agreement with experimental evidence of wave-related sediment transport in the ripple regime. This model is based on displacements of sediment during half a wave period. The displacements are caused by orbital motion in the near bed zone, superimposed by the mean fluid velocity in this zone.

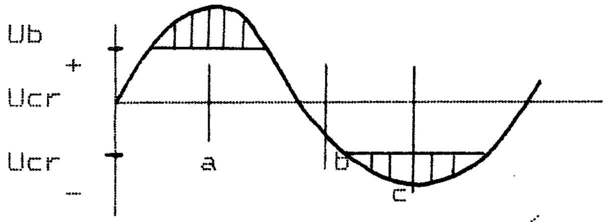
The entrainment coefficients A_f and A_b, which are determined by the size of the peak velocities U_{max} and U_{min}, are:

$$(A_f, A_b) = [\ 0.5*(U_{max}/U_b)^6\ ,\ 0.5*(U_{min}/U_b)^6\ ] \qquad (5.7)$$

with:

U_b	= the bottom fluid velocity amplitude	[m/s]
U_{max}	= $U_b + U(z_0)$	[m/s]
U_{min}	= $U_b - U(z_0)$	[m/s]
$U(z_0)$	= the mean fluid velocity in the near bed zone .	

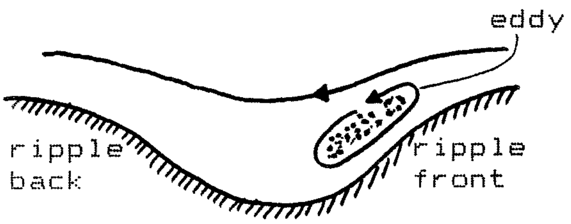
<u>SAND TRANSPORT MECHANISM SCHEME</u>



<----- direction of wave propagation

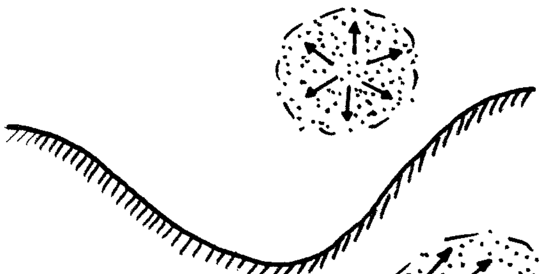
a. SAND ERODED BY EDDY.

- Ub positive.
- eddy picks up bottom material from ripple front.

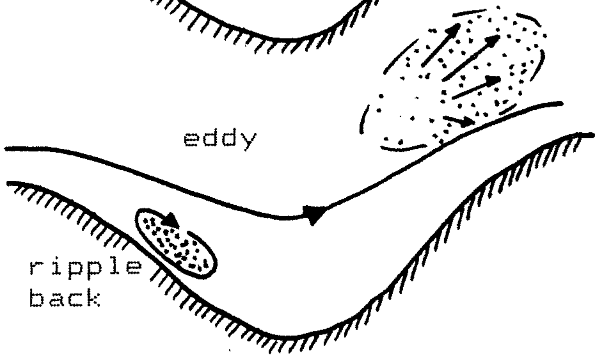


b. EDDY "EXPLODES".

- sediment disperses.



c. SEDIMENT TRANSPORT.



- Ub negative.
- eddy picks up bottom material from ripple back.
- sediment transport
  . in negative direction,
  . to higher regions (positive z-direction).
- sediment falls down.

This leads to an amount of Wave-related Sediment Transport:

$$Swave = Cos * w * (Ab - Af) * A \qquad (5.8)$$

with:
Cos = reference concentration ,see fig.
w = sediment settling velocity [m/s]
A = average transport distance during one wave period, in the direction opposite to the velocities that entrained it, and deposited ("dumped"). [m]
The bottom excursion amplitude is a measure for A.

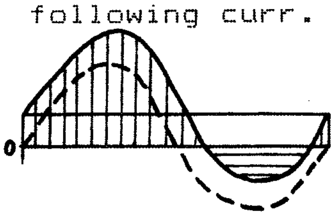
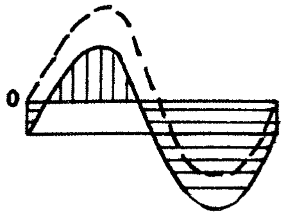
Because Af>Ab , the wave-related sediment transport will always be in opposite direction to the current.

To determine total sediment transport quantatively, a computation example will be given here for the S 15,10 and S 15,-10 experiments, using the entrainment coefficients, like in the "grab and dump" model.
The graphs for relative current-related sediment transppport, shows that the main convective sediment transports takes place between the mean bed level (z=0) and about 3 cm above this. In this area also the eddys and vortices are present, which indicates this area to be an important one. So the example-computations will be for the 0 to 3 cm zone, and its average fluid velocity is about 2 to 3 cm/s.

To investigate the importance of the average wave crest and trough distribution, two computation examples are given:
1. symmetrical sinusoidal wave
2. a-symmetrical sinusoidal wave

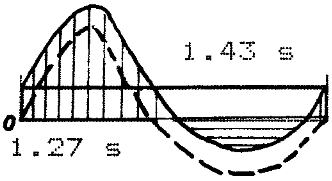
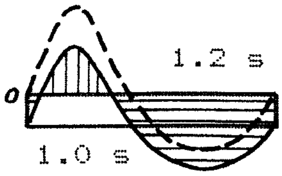
First, an example computation is made with a symmetric sinusoidal wave profile and wave-generated velocities, computed from a Hsig value.
The example shows the difference in sediment transport, influenced by the current and wave directions, while the convective sediment transports in both experiments are about the same in this zone. This indicates that the wave-related sediment transport for the following current experiments are larger than in the opposing current ones. This is consistent with the measured values (see table 3).

The values in this example are just only illustrative.

	S 15,10	S 15,-10
bottom fluid velocities (symmetric)	following curr. 	opposing curr. 
Tp,rel=	2,7 s	2,2 s
Ub =	0,301 m/s	0,286 m/s
u(z2)=	0,028 m/s	-0,024 m/s
Umax =	0,329 m/s	0,262 m/s
Umin =	-0,273 m/s	-0,310 m/s
Af =	0,85	0,30
Ab =	0,28	0,81
A =	0,130 m	0,100 m
Swave =	-0,0741 *Cos*w kg/m3.s	0,051 *Cos*w kg/m3.s

Second, the shape of the waves will be examined:
The waves in these experiments show an asymmetry in the average wave profile distribution, the crests are higher than the troughs, and the trough period is larger than the crest period.
Velocities caused by wave motion are not similar. The near-bed velocities under symmetric waves conditions are almost equal, when a wave-crest or a wave-trough is passing. Only a small magnitude of depth-averaged velocity in the near-bed zone, compared to the orbital wave velocity, will give a small deviation.
The asymmetric wave distribution produces a larger eddy concentration, while a wave-crest is passing, which is transported in current direction by the trough-related bottom velocity. And it produces a smaller eddy, containing sediment, while a wave-trough is passing, which is transported in the opposite direction. The result after an average wave has passed, is a netto sediment transport in a direction opposite to the wave celerity.
The Nielsen model does not take into account the shape of waves. Therefore a modification has been made for determination of Umax, Umin and A.
Thus, the example above will be carried out again for modified values, caused by the asymmetric average wave crest

and trough distribution. Measurements showed an average wave distribution with: Ucrest = 1.2 * Ub, and Utrough = 0.8 * Ub.

	S 15,10	S 15,-10
bottom fluid velocities (asymmetrical)	0.361 m/s 1.43 s  1.27 s 0.241 m/s	0.343 m/s 1.2 s  1.0 s 0.229 m/s
Tp,rel=	2.7 s	2.2 s
$\overline{Ub}$ =	0.301 m/s	0.286 m/s
u(z2)=	0.028 m/s	-0.024 m/s
Umax =	0.389 m/s	0.319 m/s
Umin =	-0.213 m/s	-0.253 m/s
Af =	2.33	0.96
Ab =	0.06	0.24
A =	0.130 m	0.100 m
Swave =	-0.295 *Cos*w kg/m3.s	-0.072 *Cos*w kg/m3.s

This example shows the effect of the asymmetric wave crest and trough distribution. In case of waves opposing the current, even a wave-related sediment transport in current direction results.

Both examples do not give the right solution. They are based on an average wave. This study is carried out, using irregular waves. This implies also irregular wave crest and trough distribution. More details should be known about this distribution during a test.

6. DETERMINATION OF THE BEDROUGHNESS

6.1. GENERAL

One of the problems that appears in studies concerning sediment tranportation is the determination of the bedroughness, especially in the ripple regime.
The concentration of moving sediment in the near bed zone is related to the bed shear stress. In case of waves alone, the relation between this stress and the water velocity near the bed is often given by a function which includes a friction factor (Johnson). This friction factor depends on the water displacement in the near bed zone and the bedroughness.
When waves are superimposed on a current, the current profile will change under influence of the waves (see section 4.4).
This inluence will especially be noticeable in the near bed zone, where the wave velocity is relatively large compared to the current velocity. The zone where the water motion is noticeably affected by the bed profile is called the boundery layer.

Rippled type bedforms can change the boundery layer structure in two ways :

- By introducing strong vortices.
  Because of this effect, the boundary layer can extend to a height far above the bed (several times the ripple height).

- The ripples will cause pressure forces which influence the water motion.

Considering the two effects mentioned above, one may conclude that the bedroughness in case of rippled bedforms will highly depend on the ripple geometry and their configuration.
Therefore ripple geometry and configuration will be described here first.

6.2 THE RIPPLE GEOMETRY

Because of their importance in this study, only vortex ripples are considered.The geometry of vortex ripples are closely connected with the water movement in the boundery layer (see section 4.7.2).
Note that, as ripples are formed, they start influencing the boundery layer and so the watermovement.
The connection between ripple geometry and the watermovement is not well understood in quantitative terms. Because in this study the ripple characteristics were obtained by measurement only qualitative aspests will be taken in consideration.

The most important ripple characteristics are :

r = ripple height
λ = ripple lenght
r/λ = ripple steepness

These characteristics can be described in mean values, but in case of waves and a current it can be useful to take the asymmetry of the ripples into account. Asymmetrycal ripples will be formed when the current influence on the ripple geometry is relatively large compared to the wave influence. The ripples were highly symmetrical troughout all experiments (see section 4.7.2) : in this study, the wave influence on the ripple geometry stayed noticeable ($\lambda 1/\lambda 2 = 1$).

Flow contraction near the ripple crest will cause a strongly increasing local shear stress. If the stress is strong enough it will cause the ripple crest to erode. If on the other hand a strong vortex is also present,a ripple can maintain much of its steepness because of the erosion in the trough.
The vortices are able to capture the sediment eroded from the ripple crest and ripple trough and keep it entrained. When the water velocity at the bottom changes its direction (waves), a vortex is ejected and the entrained sediment can go into suspension. The reversed velocity will generate a new vortex on the other side of the ripple and the process will repeat itself (see chapter 5).
If, in case of waves in combination with a current, the wave induced velocities at the bottom are relatively large compared to the current velocity at the bottom, the vortices account for the input of sediment into the main flow.
The strenght of a vortex is a function of the combined bottom velocity, the wave period T and the ripple characteristics (see Nielsen 1979).
As in the case of the ripple characteristics, the function is not well known.

More about this subject can be found in chapter 5.

6.3 THE RIPPLE CONFIGURATION

In this study ripple heights and the ripple lenghts were obtained from measurements (see chapter 2).
From these data the main ripple steepness can be computed as r/λ.
It may seem that the ripple geometry can be easily determined. This will indeed be the case if the ripple configuration of the bed is 2-dimensional (see section 4.7.2). In this study, a 2-dimensional configuration was only found in case of relatively small waves without a current. With increasing current velocity, the configuration becomes 3-dimensional.
Because of this effect, the configuration dimensionality of the ripples in each experiment was noted as : (see section 4.7.2) :

2-dimensional,
2.5-dimensional or
3-dimensional.

This was done by visual observation.

If the ripple configuration of the bed is 2-dimensional, the ripple heights and ripple lenghts can be determined rather accurately with the used measuring procedure.
Because in this study only three measuring sections have been used to determine the mean bed level, a 2.5-dimensional configuration will diminish the accuracy while a 3-dimensional configuration will diminsh the accuracy even more (see fig. 18).
As one can see from fig.18 , a 3-dimensional configuration will give a relatively large variation in the mean ripple height and mean ripple lenght compared to a 2-dimensional configuration.
To increase the accuracy there are two possibilities :

- increase the number of measuring sections (more ripples).

- measurement of individual ripples.

Especially in case of a 3-dimensional configuration, it can be that the larger ripples will have a relatively larger contribution in the bedroughness than the smaller ones.
To investigate this, the dominant ripple heights and ripple lenghts in case of 3-dimensionality, were calculated as:

$$H_{dom} = \frac{1}{L_{,tot.}} * \sum_{i=1}^{i=n} H(i) * L(i) \qquad (6.1)$$

$$L_{dom} = \frac{1}{L_{,tot.}} * \sum_{i=1}^{i=n} L(i)^2 \qquad (6.2)$$

In which :

$H(i)$ = the individual ripple height [m]

$L(i)$ = the individual ripple lenght [m]

$L_{tot} = \sum_{i=1}^{i=n} L(i)$ [m]

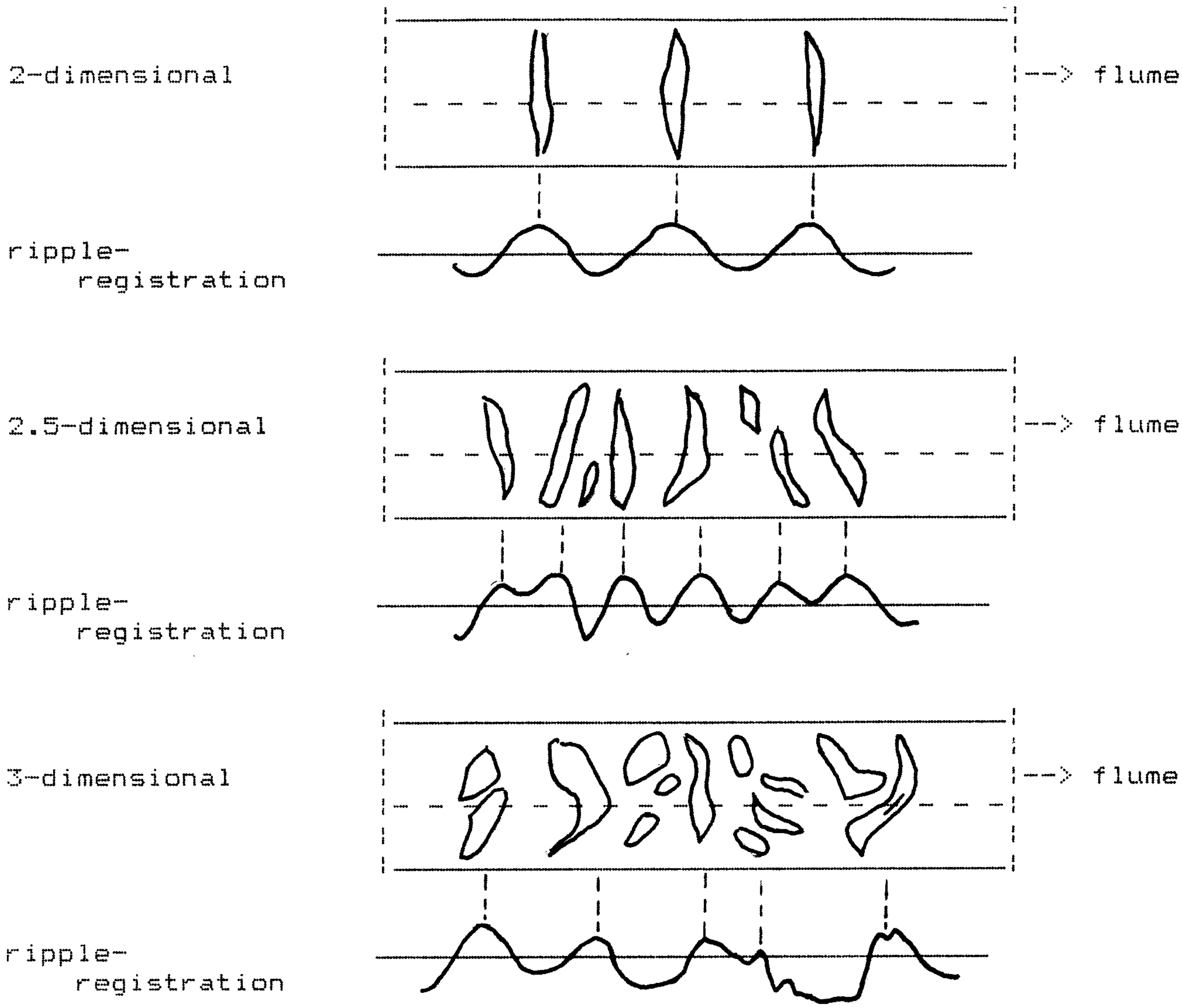


fig. 18   Effect of the ripple configuration upon
the determination of ripple characteristics.

By doing so, the individual ripple heights and ripple lenghts are weighted with the ripple lenghts.
Longer ripples will give a relatively larger contribution to Hdom and Ldom than the shorter ones.

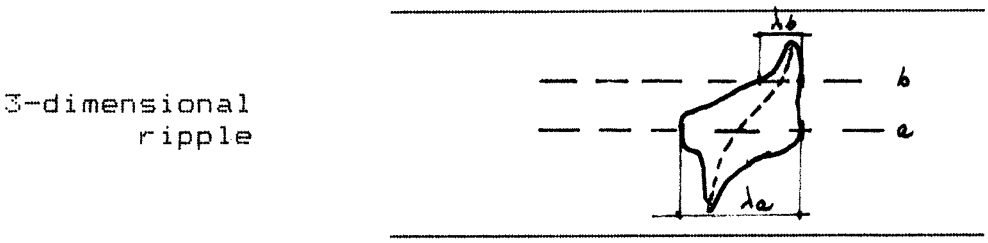


fig. 19   Ripple measurement.

Considering the steepness of an individual ripple, an argument for the followed procedure is that in case of a 3-dimensional configuration, the longer ripples are better measured over their full height (see fig. 19).

The calculations of Hdom and Ldom give values that are about 10% larger than the mean values of the ripple heights and ripple lenghts obtained from measurements.
First this means that the ripple steepness is rather well determined by the mean values of the measured ripple height and ripple lenght.
Second, it means that enough ripples were measured to estimate the mean ripple characteristics rather accurately.

One last note will be given in this paragraph :

The 3-dimensional configuration will be the effect of a three dimensional turbulence structure in the overall flow
In this study, a significant waveheight of 0.18 m in absence of a current showed a 3-dimensional ripple configuration.
Also a current of 0.4 m/s in absence of waves showed a 3-dimensional ripple configuration. It seems that high fluctuating bottom velocities (wave), as high more constant velocities (current), can result into a three dimensional turbulence. The effect will be a deformation of the ripples wich results in a 3-dimensional configuration.

. The ripple characteristics and the ripple configuration of the bed follow from hydraulic conditions in the near bed zone and the sediment characteristics. The bed roughness strongly depends upon the ripple characteristics,their configuration and their influence on the hydraulic conditions.

6.4 METHODS USED TO DETERMINE THE BED ROUGHNESS.

6.4.1 Determination via the logarithmic velocity profile.

Both in the 200-mu as in this study, in each experiment the current velocity profiles were measured in absence of waves (see chapter 3). These profiles have been investigated by fitting a logarithmic distribution of the form :

$$U(z) = (U_*/\kappa) * \ln(z/z_0) \quad \text{for } z > z_0 \qquad (6.3)$$

in which :

$U(z)$	= mean current velocity at height z	[m/s]
U_*	= bed-shear velocity	[m/s]
z	= height above mean bed level	[m]
z_0	= roughness lenght scale (zero-velocity level)	[m]
κ	= the Von Karman constant (= 0.4)	

The bedroughness can be computed from z0 as :

$$Ks = 33 * z0 \qquad (6.4)$$

Using this method, the values of u* and z0 were estimated for each individual test.
Ks can than be computed as given in 6.4.
Using this method :

- In the 200-mu-study, a roughness range of <u>2 to 8</u> times the mean ripple height was found.

- In this study, a roughness range of <u>3 to 10</u> times the mean ripple height was found.

In case of a 3-dimensional ripple configuration, the dominant ripple heights were computed (see 6.1). Using Hdom instead of the mean ripple height for these experiments did not influence the overall range of 3 to 10 times the mean ripple height.

Some notes concerning this method :

This method used to estimate the bedroughness Ks is based upon a logarithmic velocity distribution. This may not be fully valid close to the bed (two times the ripple height). To check the logarithmic distribution in that zone, the velocity values of the lowest 8 points were calculated using the logarithmic fit. This was done for all experiments. All the calculated velocities were within a 10% variation of the measured values. This indicates that the estimation of z0 is done correctly.
In case of a strong current (0.4 m/s), the ripples will undergo changes during the velocity measurement. This will reduce the accuracy.

<u>6.4.2 Determination via the Vanoni-Brooks method.</u>

An available method to determine the bedroughness is the Vanoni-Brooks method (see Appendix I).
Applying this method, an attempt is made to eliminate the influence of the flume walls in the estimation of the bedroughness.
The input of the method consists of :

Q = the water discharge [m3/s]
b = flume width [m]
h = water depth [m]
i = water surface slope

The Vanoni-Brooks method uses the relation :

$$U(m) = Cb * \sqrt{Rb * i} \qquad (6.5)$$

in which :

$$U(m) = \frac{Q}{b*h} \qquad [m/s]$$

Cb = the bottom Chezy coefficient according to Vanoni-Brooks [m^0.5/s]

Rb = the bed roughness (flume wall roughness eliminated) [m]

Q has been measured in all experiments, h and b are known (see chapter 3).The water surface slopes, i, were measured in the experiments of currents alone, over a bed with ripples generated during the experiments with waves and a following current. For these experiments, the Vanoni-Brooks bedroughness values have been computed (see tab. 6.1).

. Via the Vanoni-Brooks method, a roughness range of <u>2 to 6</u> times the mean ripple height was found.
  The use of Hdom did not effect this range.

A note concerning the Vanoni-Brooks method :

The water surface slope has been measured over 20 m of the flume. The bed roughness obtained from this method is the <u>overall</u> bed roughness of 20 m flume lenght. The "curve fitting" method from section 6.5.1 gives a <u>local</u> bed roughness because it follows from local velocity measurements. The Vanoni-Brooks method thus diminishes the influence of local velocity disturbances, but the accuracy is mainly determined by the accuracy of the water surface slope. The Vanoni-Brooks method has been developed for steady flow in flumes.

6.5 THE INFLUENCE OF THE RIPPLE STEEPNESS

If one defines the ripple steepness as mean ripple height devided by mean ripple length, in the 200-mu-study the following steepness range was found :

$0.11 < r/\lambda < 0.18$

In this study the range is (see fig. 6.1) :

$0.10 < r/\lambda < 0.17$

As one can see the steepness ranges are almost equal while the roughness ranges expressed in mean ripple heights do differ considerably (see table 6.1).
Measurements in steady flow over ripples (defined as bed forms with a length smaller than the flow depth), show the same effect (see fig. 6.1).
It seems that when a certain ripple steepness is exeeded (>0.1), the influence of the ripple steepness becomes less obvious.
Note that fig. 6.1 also concerns flume- and irrigation canal

measurements (ripples formed by a current). The bed roughness values are obtained from water slope and velocity measurements.

The following conclusions can be drawn :

- If the ripple steepness exeeds the value of 0.1, the influence of the ripple steepness upon the roughness range (expressed in ripple height), becomes less obvious.

- Within a steepness range of 0.1 to 0.2, a roughness range of 1 to 10 times the ripple height can be expected. Within this roughness range, a lower range for relatively courser sediment and a upper range for relatively finer sediment can be observed.

6.6 ROUGHNESS PREDICTION FOR RIPPLED BEDFORMS.

Many roughness predictors are available. Most of them are a function of the ripple and sediment characteristics :

Ks = F(r,l,r/l,D90,D50)

They can be used if the ripple characteristics have been determined.
In some of these functions (Swart, van Rijn), the configuration and hydraulic conditions are not taken into consideration. If no measurements are available one can use predictors for the ripple characteristics or use empirical relations (Nielsen, 1985).
In the 200-mu-study, the following roughness predictors have been used to test existing sediment transport formula :

Van Rijn : $Ks = 3*D90 + 1.1*r*(1-\exp(-25*r/\lambda))$ (6.6)

Swart : $Ks = 25*((r^2)/\lambda)$ (6.7)

Grant-Madsen : $Ks = 8*r*(r/\lambda) + 190*D50*\sqrt{t'-0.05}$ (6.8)

in which :

d = ripple height [m]
l = ripple lenght [m]
d/l = ripple steepness
D50 = grain diameter exeeded by 50% of the bed material [m]
D90 = grain diameter exeeded by 10% of the bed material [m]
t' = Shields skin friction parameter (see appendix IV)

In both the 100- and 200-mu-study, the predictors have been computed for all experiments. In the next section a comparison will be made.

6.7 THE BEDROUGHNESS RANGE

Various bedroughness ranges can be derived from the present and other measurements. The following resumption is made :

The 200-mu-study

. A roughness range of 1 to 5 times the mean ripple height was found with the use of roughness predictors.

. A roughness range of 1 to 8 times the mean ripple height was found by curve fitting of a logarithmic velocity distribution.

The 100-mu-study

. A roughness range of 1 to 5 times the mean ripple height was found with the use of roughness predictors.

. A roughness range of 3 to 10 times the mean ripple height was found by curve fitting of a logarithmic velocity distribution.

. A roughness range of 2 to 6 times the mean ripple height was found with the Vanoni-Brooks method.

If a comparison is made between the predictors and the applied methods from section 6.5, one can see that the roughness predictors give relatively small roughness values. As noticed before, the reason for this may be that the predictors exclude the ripple configuration.

D50	PREDICTORS	VANONI-BROOKS	CURVE FITTING
200 MU	1-5	-	2-8
100 MU	1-5	2-6	3-10

Two conclusions concerning the 100-mu-study can be made :

. The values of Ks found by curve fitting and the Vanoni-Brooks method do not show a clear relation with the significant waveheight (see table 6.1).

. An increasing current strenght causes a slight increase of Ks but also causes an increase of the mean ripple height. Therefore, the relation of Ks (expressed in mean ripple height) and the current strenght is also not very clear (see fig. 6.1.A).

For these reasons, the values of Ks expressed in mean ripple

heights have been averaged over all experiments.
This has been done for the values found by curve fitting and with those found via the Vanoni-Brooks method as well.

. The curve fitting averaged Ks value is approximately 6.6 times the mean ripple height.

. The Vanoni-Brooks averaged Ks value is approximately 3.8 times the mean ripple height.

The two methods used thus give the following roughness range for the 100-mu-study :

. Ks = 3 TIMES THE MEAN RIPPLE HEIGHT, A LOWER LIMIT

. Ks = 7 TIMES THE MEAN RIPPLE HEIGHT, AN UPPER LIMIT

This roughness range will be used in chapter 7 to test the Bijker, the Nielsen, the (modified) Englund-Hansen and the Bagnold-Bailard transport formulae !

6.8 THE WAVE INFLUENCE ON THE BED ROUGHNESS

The bed roughness range from section 6.6 has been obtained from measurements concerning currents in absence of waves. Waves will influence the current velocity profile by introducing extra roughness near the bed due to pressure forces. Because of this effect the outer current profile is shifted (see fig. 20).
Figure 6.2.A shows that waves superimposed upon a current introduce an apparent roughness increase by the factor z1/z0. Outside a relatively thin layer, the current velocity profile has the usual logarithmic form (Lundgren, 1972) :

$$U(z) = (U*/k)*\ln(z/z1) \qquad \text{for } z > z1 \qquad (6.9)$$

Compared to the logarithmic profile from section 6.5.1, the only change is that the zero intercept z0 (=Ks/33) has been replaced by the larger z1.
The effect will be an apparent roughness increase from 33*z0 to 33*z1.

In this study it has been investigated whether the velocity profile in presence of (irregular) waves is still of a logarithmic form for z > z1. If this is thrue, the value of z1 can be obtained from measurements in the same way as has been done for the value of z0 (see section 6.5.1).
First the correlations between the measured velocities at different heights above the bed have been determined. Just as described in section 4.4, only those points that give a correlation of 0.98 and higher were taken into consideration. This was the case for the lowest eight measuring points (z/h < 0.5). The profiles thus appear to have a logarithmic form.

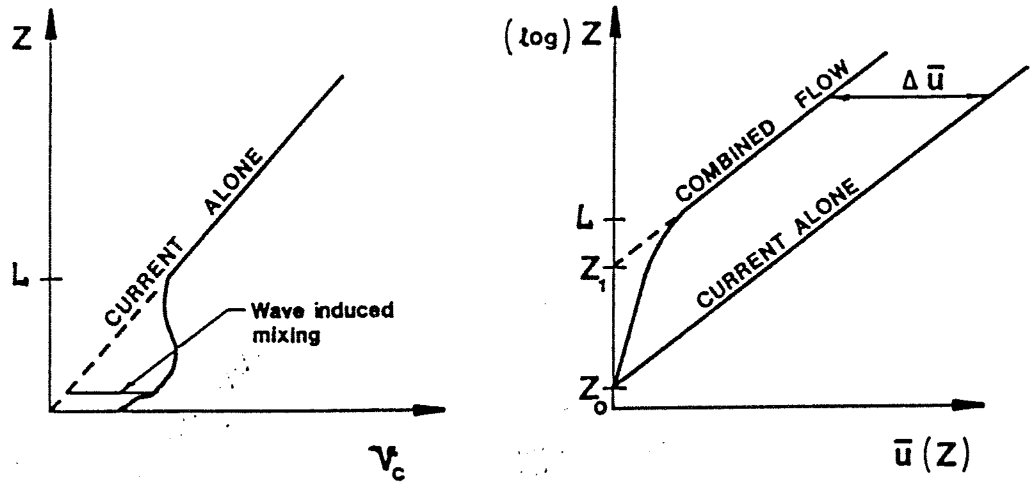


fig.20 Apparent roughness increase by wave influence.

As described in section 6.5.1, u* and z1 can be determined by curve fitting, which has been done for all experiments. For each experiment the apparent roughness increase z1/z0 has been determined.
An apparent roughness increase z1/z0 of 1 to 10 is found. The value 1 is found in case of a small significant wave height and a strong current, the value 10 in case of a large significant wave height and a weak current (see fig 6.2.A).
Figure 6.2-A shows z1/z0 against the ratio Ub/Um in which :

Ub = bottom orbital velocity amplitude that follows from Hsig. (m/s)

Um = mean velocity in case of current and waves (m/s)

From figure 6.2.A can be seen that z1/z0 = 1 for Ub/Um = 0. This can be expected.

Ub/Um seems to be a correct parameter to describe the apparent roughness increase, but a closer investigation is necessarry.

The apparent roughness increase has also been determined with data from the 200-mu-study. For 200-mu, an apparent roughness increase z1/z0 of 1 to 7 is found (see fig. 6.2.C). Compared to
the 100-mu roughness increase, the 200-mu roughness increase does not show such a clear trend.

In the theory concerning the apparent roughness increase, U* is considered to be only current related. From fig. 6.2.B and fig. 6.2.D can be observed that this is not true : waves also

contribute into a friction velocity increase.
Values of the apparent roughness increase are given in table 6.2 A-B
If the apparent roughness increase has a value > 7, and one considers the upper limit of the bed roughness range of section 6.6 which follows from current measurements, one can see that the roughness can become as large as the mean water depth. Just as decribed in section 6.5, velocities have been computed with the use of U* and z1 in case of apparent roughness increases > 7.

For the 100-mu-study only the velocities of the lowest measuring points gave values that are 20%-40% lower than the measured values. The velocities of the higher measuring points were within a 15% variation of the measured values. Sensitivity tests showed that an improvement of the lowest velocity lead to worse values in the higher region.

For the 200-mu-study, all computed velocity values in case of an apparent roughness increase > 6 , were within a 15% variation of the measured velocities.

- The (mean) velocity profile in case of irregular waves in combination with a current, can be of a logarithmic form with a zero intercept z1 > z0

- In case of irregular waves in combination with a current, an apparent roughness increase (z1/z0) of <u>1 to 10</u> can be expected for 100mu :
  1, in case of small waves and a strong current,
  10, in case of large waves and a weak current.

  An apparent roughness increase (z1/z0) of <u>1 to 7</u> can be expected for 200mu.

- The <u>bed</u>roughness from section 6.7 should be used in computations concerning the current related bed shear stress.
  The <u>apparent roughness increase</u> should be used in computations concerning the wave related bed shear stress, fluid velocities and flow resistance.

One note :

In case of large waves in combination with a current, the induced vortices (see section 6.1), will be sediment filled. This also contributes in the apparent roughness increase z1/z0 (ejected sediment filled vortices), especially in case of relatively fine sediment (large bottom concentrations).

7. MODELS FOR SEDIMENT TRANSPORT

7.1 GENERAL

In this chapter four existing models for sediment transport prediction will be discussed. The models are used to compare the predicted results with the experimental results in this study and the 200-mu-study. The experimental results are called Smeas, as explained in chapter 4.

As explained in chapter 2, the sediment transport has been devided in longshore and cross-shore sediment transport. For longshore sediment transport four models, that are often used in practice, will be described here:

1. Bijker model (1967,1971)
2. Nielsen model (1985)
3. Modified Engelund & Hansen formula (by van der Graaff and van Overeem, 1979)
4. Bagnold-Bailard formula (1981)

The Bijker and Nielsen models have the advantage of more physical background. Both give an explicit estimation of the concentration and fluid velocity profiles. The modified Engelund & Hansen formula is more simple, but it gives no insight in the sediment transport parameters.
The Bijker model and the modified Engelund-Hansen formula (E-H) are usually applied to calculate the longshore sediment transport in the breaker zone.
Nielsen has based his model on the results of flume experiments. His formula gives both parts, an estimation of the current-related and wave-related sediment transport.
The Bailard- concept is based on dissipation of energy from fluid velocities. Instantaneous bed load and suspended load transport is related to instantaneous fluid velocity, which should be known or assumed to be known. No distinction can be made between the wave-related and current-related parts of sediment transport.

All models will be discussed separately. The precise description of the formulae are given in the Appendix II-V. Their results will be compared to the experimental results. Note, that the figures for concentration and transport rates have a logarithmic scale. For comparison of the results, there will be spoken about small transport rates (<0.001 kg/m.s) and about large transport rates (>0.03 kg/m.s).

The parameters for calculation of the transport rates will be given in the next paragraph. A precise comparison of formula results and experimental results is not always possible, because the use of the input parameters are subjective. So assumptions have to be made to accomplish a reasonable comparison.

7.2 PARAMETERS FOR TRANSPORT MODELS

7.2.1 General

The parameters, needed for the calculations of transport rates, will be discussed in this paragraph. These parameters are: wave period, wave height and bedroughness. Other parameters, as mean fluid velocity, ripple height and median fall velocity of the sediment, can easily be read from the experimental result tables.
In all computations the following parameters were kept constant:

- mass density of water : ρ = 1000 [kg/m3]
- mass density of sediment : ρs = 2650 [kg/m3]
- porosity : p = 0.4 [-]
- acceleration of gravity : g = 9.81 [m/s2]

7.2.2 Wave period

The available parameters for the wave period are:

- The (relative) zero crossing period Tz
- The (relative) wave spectrum peak period Tp,rel (see 4.2.2)

Preliminary calculations showed small influence of the wave period parameter on sediment transport results. It was decided to use the relative peak period, Tp,rel, as the characteristic parameter. In case of irregular waves, the energy wave spectrum shows that most energy is concentrated around this period. To account for the presence of the current, the relative peak period, Tp,rel, and corresponding wave length, L, were used in all computations (see paragraph 4.2).

7.2.3 Wave height

Because of the irregularity of the waves, a characteristic wave height must be chosen for computations. From preliminary calculations was concluded that the influence of wave height is significant. In order to investigate the wave height influence on the model results, three different wave height parameters were chosen:

1. The significant wave height, Hsig
2. The root mean square wave height, Hrms
3. The probability-weighted wave height, Hprob

The last one needs more explanation. Because the measured wave spectra were single topped, it was decided to assume a Rayleigh wave height distribution. Assuming Rayleigh distribution, the probability that a wave height H is exceeded is:

$$P(H) = Pr\{ \underline{H} > H \mid Hsig\} = \exp(-2 * (H/Hsig)^2) \qquad (7.1)$$

The probability of occurence of a wave height H is approximately equal to:

$$p(H) = P(H-dH) - P(H+dH) \qquad (7.2)$$

in which p(H) is the probabilty that H falls in the interval $(H-dH) < H < (H+dH)$.

The sediment loads and transport rates are computed step by step, starting with H = dH, continuing with H = 3dH, 5dH, until p(H) is smaller than 10-4. The results of the computation in each step are weighted with the probability of occurence of the wave height in that step. Now, all weighted results will be summarized, to get the probability-weighted value of a parameter:

$$Pa = \frac{\sum_{H=dH}^{N*dH} Pa(H) * p(H)}{\sum_{H=dH}^{N*dH} p(H)} \qquad (7.3)$$

with:

Pa = Probability-weighted value of a parameter
Pa(H) = Parameter value calculated with wave height H
p(H) = Chance of occurence of wave height H
N = Number of steps

Applying all models the loads and sediment transport rates were calculated as probability-weighted parameters. In the models, according to Bijker and Nielsen, other parameters were also calculated like this.

From earlier computations it appeared that the probability-weighted parameters did not change noticeably, when the steps were smaller than dH = Hsig/20. So, this interval was chosen for the probabilty-weighted parameters.

7.2.4. Bedroughness

As mentioned in chapter 6, the bedroughness parameter, Ks, is of great importance for sediment transport computation. A bottom limit and an upper limit were chosen for computations:

- lower limit: $K_{s,min} = K_s = 3 * r$ (Vanoni-Brooks method)
- upper limit: $K_{s,max} = K_s = 7 * r$ (velocity profile fitting)

in which r is the mean ripple height.

7.3. BAGNOLD-BAILARD FORMULA

The Bagnold-Bailard-concept is based on the Bagnold approach for steady current. Bagnold (1966) related the sediment transport to the dissipated energy from the current. The dissipated energy will partly be used for stirring up of sediment, and for transport of the sediment. Bailard modified Bagnold's concept for sediment transport for coastal areas. He introduced oscillating fluid velocity components, assuming that the instantaneous transport rates are related to the instantaneous fluid velocities. He also brought a bottom slope component in his model. Therefore this model can also be used for cross-shore sediment transport.
Although the formula is only valid for "sheetflow" conditions, a comparison with the experimental results has been made. The formula gives no insight in concentration or velocity distribution.

When the orbital fluid velocity above the bed, U(t) and the depth-averaged fluid velocity, Um, are known, the sediment transport can be computed. The total transport is devided in a bed and suspended sediment transport. By using a third order Stokes equation, it is possible to describe the fluid velocity U(t) under asymmetrical waves (see also chapter 5). See figure 21. Therefore, a representive wave was chosen. This wave form was also measured from the experiments in this study. From this wave , one can easily determine the orbital fluid velocity.
It is not quite clear how to combine the orbital and the mean current velocity. Bailard is not precise about this.

Therfore two approaches have been used.
In this study, the sediment transport is related with Ut defined as:

$$Ut = Uc + U(t) \qquad (7.4)$$

with:

Uc = a representive fluid velocity to represent the current effect [m/s]
U(t) = orbital fluid velocity above bed at time t [m/s]

In the <u>first approach</u> the representive fluid velocity is taken:

$$Uc = Um$$

The total sediment transport, Stot, is devided in:

- Bed load transport : $Sb \sim |Ut|^2 * Ut$ (7.5)
- Suspended load transport : $Ss \sim |Ut|^3 * Ut$ (7.6)

($\sim$ means: related to)
The sediment transport has been calculated numerically from

Ut, at every dt = T/20 (twenty steps). More steps (a smaller time interval) did not improve the results noticeable.
A more precise description of the Bagnold-Bailard formula is given in Appendix I. For further information on the Bagnold-Bailard concept, see J.C.M.de Waal (report D.U.T).

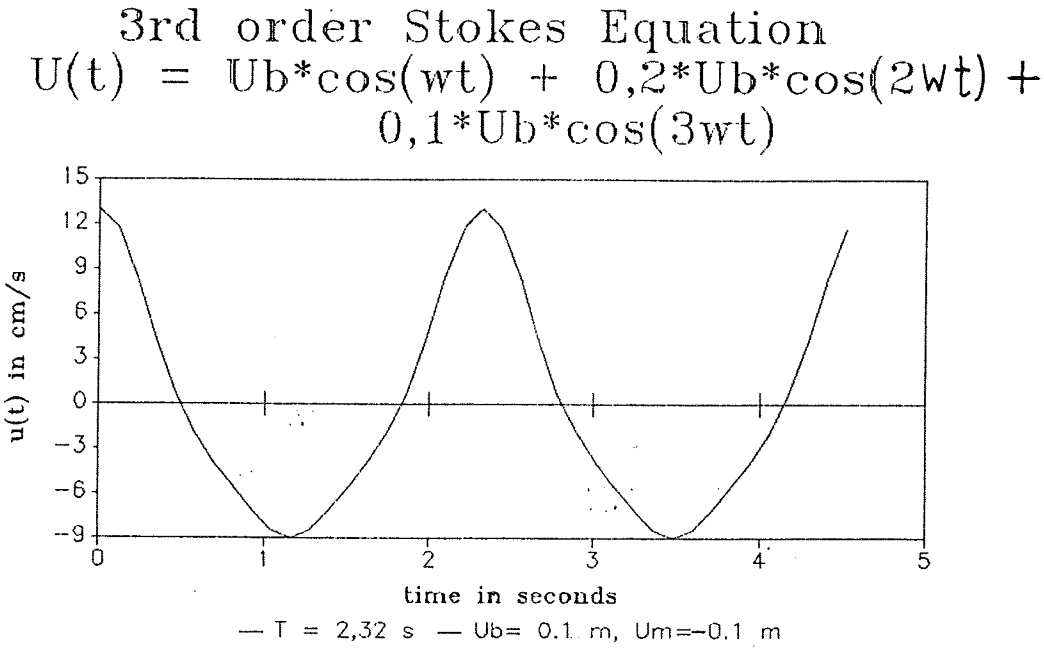


fig.21 Third order Stokes equation in Bagnold-Bailard computations.

The Bailard computations are carried out, using :
- the bedroughness parameter Ks= 3*r and Ks= 7*r
- the wave height parameter Hrms (to compute Ub).

The Bagnold-Bailard formula gives poor results, in case of Uc=Um is used to represent the current effect.
One can conclude that:

- the formula overestimates the experiments with a factor of about <u>100</u>.
- the bed load transport, according to the βailard formula, gives a relative larger (about 20%) contribution to the total sediment transport than follows from the experiments.

The last fact might be caused by the "sheetflow" conditions of the Bailard formula. The definition for bed load transport is not equal.

- the Bailard results do have a same tendency as the experimental results, increasing the wave height Hrms, leads to a same increase factor of the total sediment transport.
- the Bailard results for waves following a current, give consequently larger sediment transports, than for waves opposing a current. This is inconsistent with the experimental results.

The results for the first approach are not listed in this

report.
The definition of Ut, seemed to be very strange, because the orbital fluid velocity near the bottom (z=0) is compared with a depth-averaged velocity.
Therefore a second approach was used with:

$$Uc = 0.2\ Um,$$

an assumption based upon the approximately average velocity in the region of about 0.1 [cm] above the sand bed. So, now the sediment transport will be related with:

$$Ut = 0.2 * Um + U(t) \tag{7.7}$$

The results for the total transport rates are given in table 7.1. and figure 7.1.
The change for Ut did not lead to improvement of the tendency. Compared to the measured transport rates, the computed rates according to the changed Ut, leads to:

- relative good results for transport rates when waves were opposing a current. The computed transport rates differed a factor 0.33 to 3 from the measured results.
  In case of a large wave height combined with an opposite weak current (experiments T 15,-10 and T 18,-10) the computations gave a transport opposing the current.
- different transport rates for transport rates when waves were following a current:
  a factor 30 too large, for small transport rates, and good results, for large transport rates (factor 0.5 to 3).
- larger magnitudes for Ks=7*r, in case of large transport rates, and
  smaller magnitudes for Ks=3*r, in case of small transport rates.

The different results for waves opposing or following a current can be explained by the superimposed current and orbital velocities. The Stokes equation causes asymmetrical orbital velocities, U(t), which, in case of waves following a current, leads to larger values of Ut. Although the smaller and negative Ut is longer present during one wave period, in case of waves opposing a current, the sediment transport rates according to eq.(7.5) and eq.(7.6) will be much smaller. So, the sediment transport rates, according to the Bagnold-Bailard formula are very sensitive for Ut.
One can conclude that:

- The representation of Ut in the Bagnold-Bailard formula, to compute sediment transport rates, is incorrect.
  The power 4 in Ut^4, related to the suspended sediment transport is not correct.

7.4 THE MODIFIED ENGELUND-HANSEN FORMULA

The Engelund-Hansen (E-H) formula is popular because of its simplicity. The original E-H formula was developed for predicting the total load transport in rivers. Van de Graaff and van Overeem (1979) modified the formula, by increasing the bed shear stress when waves are present, applying the Bijker method. Details are given in Appendix II.
Only five parameters are required for sediment transport computation with the E-H formula:

- the wave height, H
- the depth-averaged fluid velocity, Um
- the bedroughness parameter, Ks
- the median grain diameter of the sediment, D50
- the waterdepth, a

The computations were carried out on a computer spread-sheet program. The computations and comparison with the experimental results are given in table 7.2. and figs. 7.2.A-B.

First, the calculations with the E-H formula were carried out with H = Hrms and Ks= 7*r and Ks= 3*r. Second, the wave height parameter was substituted by H = Hprob. This resulted in similar results, which are not given. Third, the computations were carried using H= Hsig and also both Ks values.
From the figures 7.2.A-B. one can conclude that:

. The results show poor tendency for all Ks= 7*r and rather good tendency for Ks= 3r, for both H= Hrms and H= Hsig.

. Too large sediment transport rates were computed with the E-H formula compared to the experimental results, especially in case of Ks= 7*r.
  Average factors S(E-H)/S(meas):

		transport rates	
		small	large
Hrms	Ks= 3*r	9	3
	Ks= 7*r	16	3
Hsig	Ks= 3*r	20	6
	Ks= 7*r	40	9

Overestimeted factors, using the E-H formula for $0.1 < U_m < 0.4$ [m/s] and D50=100mu.

In the 200-mu-study the overestimated factor was about 100 for small transport rates and about 5 for large tranport rates, in case of probability-weighted wave height. Because the use of this wave height gives computed transport rates between the rates for H= Hrms and H= Hsig, one can conclude that:

- The E-H formula does not give a fair sediment particle diameter influence.

7.5 NIELSEN MODEL

The Nielsen model (1985) is a very complex method. On the other hand, the method gives insight in the parameters that are involved in sediment transport prediction. Nielsen predicts a concentration and velocity pofile. Also, the metod distinguishes current-related and wave-related sediment transport.
Some parameters are predicted from other parameters (see Appendix IV), which might lead to inconsistency. In regard to the bedroughness and ripple height, the Nielsen prediction has been replaced by ripple characteristics, derived from the experimental results of this study. Nevertheless, as can be seen in the final results, inconsistency is still present.

Six different computations to compare with all 23 experimental results were carried out: for H = Hrms, Hsig and Hprob, two values for the bedroughness parameter, Ks=3*r and Ks=7*r were used.
Because Nielsen distinguishes current- and wave-related sediment transport, a comparison has been made between the current-related part, Scurr, and the experimental results, Smeas. For comparison with the sand balance experiments both the current- and wave-related parts are computed.

The computations are carried out, as given in the Nielsen's computer program (Appendix I, Nielsen report, 1985).
All Nielsen model results and comparisons with the experimental results are given in tables 7.3.A-B. and figures 7.3.A-D.

Sediment transport

Comparing the Nielsen model results with the experimental results, one can observe from the figures and tables, that:

- The Nielsen formula gives good results for small sediment transport rates (S(Nielsen)<0.01 kg/m.s), and
- Much to large sediment transport magnitudes in case of larger transports (Scurr > 0,01 kg/m.s), and
- Incorrect tendency.

Varying the parameters H and Ks and with D50 = 100 mu, does not lead to improvement of the overall results but the following conclusions can be drawn:

- The order H = Hrms, H(prob), Hsig gives larger sediment transports in the same order.
- The use of Ks(max) gives larger sediment transports than Ks(min).

		transport rates	
		small	large
Hprob	Ks= 3*r	0.3 - 2	40 - 100
	Ks= 7*r	0.4 - 3	20 - 200
Hrms	Ks= 3*r	0.2 - 1	4 - 30
	Ks= 7*r	0.3 - 1	10 - 70
Hsig	Ks= 3*r	0.6 - 6	8 - 100
	Ks= 7*r	0.2 - 8	6 - 300

enlargement factors by Nielsen model computations.

The main problem, to compare the Nielsen model transport results with the experimental results, is that Nielsen computes the sediment transport different from the method in this study. In this study Scurr is defined as:

$$Scurr(meas) = \sum_{z=0}^{a} \bar{\bar{c}}(z) \quad \bar{\bar{U}}(z) \quad , \qquad (7.9)$$

while Nielsen uses another method, related to the shear current velocity, U*c, and the median fall velocity of the sediment paricles, W:

$$Scurr(Nielsen) = exp(\; 1.1 \; U{*}c/W) \; * \sum_{z=0}^{a} cw(z) \quad U(z) \quad , \qquad (7.10)$$

in which cw is the wave-related concentration.

Increase of Um leads to increase of U*c and increase of the exponential factor. The sediment transport according to the Nielsen method leads to too large values, especially in case of strong current strengts.

For the 200 mu computations can be observed that:
. The formula gives an overall overestimation, compared to the experimental results (a factor <u>4 to 14</u>), but
. Good tendency.
. Compared to the results, in case of 100 mu, the tendency is

different, mainly caused by the less pronounced influence of the exponential factor.

concentration profile

The concentration profiles are based on a modified method, applying a modified length scale parameter Ls= Ls + kU*z/Ws (see Appendix IV). The computed profiles show reasonable agreement with the measured values. Some of the results are shown by figures 7.3.E-G.
From these can be concluded that the results of Nielsen's modified concentration model gives compared to the experimental results:

. too steep concentration profiles in all computations
. too large concentrations in case of small transport rates (a factor 3)
. too small concentrations in case of large transport rates (a factor 10)
. rather consistent concentrations in case of Um= 0.2 [m/s].

To compute the transport rates, Nielsen uses another method by introducing a correction factor f=exp(1.1U*/W).
These two approaches are not consistent.

Velocity profile

In the Nielsen method, a modified logarithmic velocity distribution is used (see Appendix IV). The velocity profiles are determined with the parameters z0, z1, F and U*. The calculated and measured velocity profiles are shown in tables 7.3.C-?. and some of them in figures 7.3.E-G.
As can be observed from these, compared to the measured velocities, the velocities according to the Nielsen model are:

. rather consistent velocity profiles,

more precise:
. rather consistent (within a factor 2) for velocities between the mean bed level and 0.1 [m] above this.
. too large velocities (within a factor 1.3) between 0.1 and 0.2 [m] above the mean bed level.
. too small velocities (within a factor 1.3) at the water surface
. hardly not influenced by the use of Hrms, Hprob or Hsig.

The use of Ks(min) or Ks(max) in the model causes

. smaller velocities in the bottom zones with Ks(max), and
. larger velocities in the upper zones with Ks(min).

These differences are rather small, within 20%.

Resuming

In case of small transport rates (< 0.01 kg/m.s) the Nielsen model gives rather consistent results.
The overall velocity profiles give good results, compared to the measured velocities.
The total sediment transport rates, computed by the Nielsen model are mainly influenced by a too steep concentration profile and by the exponential factor.

Because of the model's complex structure, it is hard to investigate the model to improve the tendency and final results, compared to the measurements.

7.6 BIJKER FORMULA

The Bijker formula is a typical longshore transport formula, based on bed friction forces. As pointed out in the introduction of this chapter, the formula estimates the current-related sediment transport, and gives no estimation of the wave-related part.

The Bijker model computes a total sediment transport, devided in a bed load transport and a suspended load transport. First, the bed load transport is computed with the modified Kalinske-Frijlink formula. This formula is originally used for sediment transport for currents. Bijker modified the bottom shear stress term in the stirring parameter of the Kalinske-Frijlink formula, because the waves contribute primarly to the stirring up of material from the sand bed. Knowing the bed load transport, the concentration in the bed load layer is computed. The thickness of this layer is assuming to be equal to the bed roughness.
Second, the suspended load transport follows from the bed load in the following way:
The concentration profile is approximated by an Einstein-Rouse concentration distribution, in which the bed layer concentration is used as reference concentration. The velocity profile is assumed to be logarithmic. By multiplication of the concentration profile and velocity profile follows the suspended load transport.
Now, the total load transport is the sum of the bed load and suspended load transport.For further details see Appendix V.

Some parameters in the Bijker formula need attention.
The Kalinske-Frijlink formula, used to compute the bed load transport, contains a dimensionless emprical parameter B. Values between 1 and 5 have been suggested. For computation of longshore transport in the breaker-zone this parameter is usually taken equal to 5. In this study, non-breaking waves are involved, for which B is chosen equal to 1 (also to be consistent with the 200-mu-study).
Bijker assumed the bedroughness parameter, Ks, to be equal to half the average ripple height. This study and the 200-mu-study indicate that Ks may have a value of 3 to 7 times the average ripple height. As mentioned in the introduction of this chapter, these values were used in the computations.

Varying the wave height parameter by using Hrms, Hsig and Hprob, and the use of two bedroughness values, Ks(min) and Ks(max), leads to six different Bijker computations for 23 experiments. Computations have been made for:
- the bed, suspended and total load transport,
- the concentration distribution, and
- the fluid velocity distribution.

The results of the total load transport, and the comparison with the experimental data are given in tables 7.4.A-B and some of them in figures 7.4.A-H.

The comparisons of computed and measured concentration and velocity profiles will be made in case of H= Hrms.

The results from Bijker computations will now be compared to the results from the experiments.

Sediment transport

Generally spoken, one can conclude from the figures 7.4.A-D. and tables 7.4.A-B., that, compared to the experimental data:

- the Bijker formula gives rather consistent values of the total sediment transport rates,
- good tendency does not, but not confirm with the experimental data (Smeas) ,
- the Bijker formula gives larger transport rates (about a factor 4), in case of a weak current (Um = 0.1 [m/s]), than Smeas,
  about the same results, in case of a current of Um = 0.2 [m/s] , and
  smaller transport rates (about a factor 4), in case of a stronger current of Um = 0.4 [m/s].

For more precise comparison of the measured and computed transport rates, see table below:

		transport rates	
		small	large
Hprob	Ks= 3*r	1 - 5	0.3- 0.4
	Ks= 7*r	1 - 4	0.2- 0.8
Hrms	Ks= 3*r	1 - 5	0.3- 0.9
	Ks= 7*r	1 - 3	0.2- 1
Hsig	Ks= 3*r	1 - 13	0.5- 1
	Ks= 7*r	1 - 10	0.2- 1

Enlargement factors S(Bijker)/S(meas)

In the 200-mu-study about the same conclusions were made.

By comparison of the use of different wave height and bedroughness parameters one can conclude that the Bijker formula gives relatively:

- larger values of transports with the use of Hsig,
- about the same magnitudes for Hrms and Hprob,
- larger transport rates with the use of Ks(max) than the use of Ks(min).

. The best overall results are obtained for Hrms and Ks(min).
and more precise, dependent of Um:

. Um = 0,1 [m/s] , H = Hrms , Ks = Ks(max) ,
. Um = 0,2 [m/s] , H = Hprob, Ks = Ks(min) ,
. Um = 0,4 [m/s] , H = Hsig , Ks = Ks(min) ,

A view of these last results can be seen in fig.7.4.D.
Because the Bijker formula gives similar results for the 200-mu-study, it can be said that:

. the Bijker model represents the influence of the median grain diameter, D50, rather well in the range 100 mu to 200 mu.

Concentration profile

The concentration profile is strongly influenced by the value of the bedroughness parameter, Ks(min) or Ks(max). The constant concentration between the mean bed level (z=0) and the z=Ks is the result of this. This makes it not possible to obtain a reasonable comparison of the concentration profiles, according to Bijker with the measured concentration profiles. Some profiles are shown in figures 7.4.E- H.
The Bijker model computes the bed load transport first. The bed layer concentration follows from this, by deviding the bed load transport to the fluid velocity in the bed layer zone. Bijker assumed the bed layer thickness to be equal to half the ripple height. Because in this study the computations were carried out using 3 or 7 times the ripple height, the computed (with H= Hrms) bed layer concentration is, compared to the measured concentrations in the near bed zone:

. about a factor 7 too small, using Ks= 3*r, and
. about a factor 12 too small, using Ks= 7*r

Overall can be said that:

. the concentration profiles according to Bijker are steeper than the measured ones.

This is also concluded in the 200-mu-study.
In the next section, 7.7, the concentration profile will be discussed.

Velocity profile

The Bijker formula computes logarithmic velocity profiles. This leads to a different shape of the velocity profiles, compared to the measured velocity profiles (see figs. 7.4.E-H). The logarithmic profile gives larger values in the near bed zone, and smaller values at the water surface. More precise, compared to the measured velocities, this leads to:

. less steep velocity profiles in case of Um= 0.1 and 0.2

[m/s], and

. rather consistent velocity profiles in case of Um= 0.4 [m/s].
. less steeper velocity profiles with the use of Ks= 3*r than with the use of Ks= 7*r.

The 200-mu-study gives the same conclusions.

Resuming

The near bed zone (about 0.1 [m] above the sand bed) needs most attention. About 80 to 95 % of the total sediment transport is measured in this area, in which the Bijker model's concentrations and velocities differ most from the measurements.
So, a resuming conclusion can be drawn that:

. the Bijker formula gives too small concentrations and too large fluid velocities in the near bed zone, resulting in reasonable sediment transport rates (within a factor 4).

The figures 7.4.E- H. show the sediment transport distributions.

In order to improve the Bijker model results, an systematic investigation has been carried out. This will be described in the next section.

7.7 INVESTIGATION OF THE BIJKER MODEL

7.7.1 A review

In section 7.6, the Bijker tranport formula has been used to compute the total load transports for all experiments. This has been done using various waveheights and bedroughness estimations (see section 7.6).
The trend of the computed transports is not in agreement with the trend of transports that follow from measurements. Altough this difference, the computed transports are consistent (little scatter). This was also found in the 200-mu-study. In both studies, the transports computed via the Bijker formula show the same difference with the transports that follow from measurements : The Bijker formula seems to be consistent for different sediment properties.

The Bijker formula computes the total load transport by multiplying the concentration profile with the velocity profile. In section 7.6 was concluded that the computed velocities were relatively large in the near bed zone and that, especially in the near bed zone, the concentrations were much to small.
The difference between the computed and measured transports is mainly caused by the difference between the concentration profiles. A better result can be achieved if this difference can be reduced.
In the following, an attempt is made to modify the Bijker formula to reduce the difference between the measured and the computed concentration profiles. This will be done without changing the main principle of Bijkers modification of the bed shear stress in the Kalinske-Frijlink formula in case of waves in combination with a current.
First the velocity profile will be treated shortly. Second, the concentration magnitude and distribution will be treated.

7.7.2 The velocity profile

The Bijker formula uses a logarithmic velocity profile to compute the fluid velocities. The computed velocities were relatively large in the near bed zone. For this reason, Ks is taken 7*r ; the upper limit of the bedroughness range from section 6.6.
The bed shear velocity is computed as :

$$U* = \frac{Um}{\ln(h/(e*z0))} \qquad (7.8)$$

in which :

Um = depth averaged velocity [m/s]
h = water depth [m]
z0 = roughness length scale [m]

7.7.3 The objective of modification

The objective of the modification of the Bijker model is to compute a concentration profile, that will be consistent with the measurements. See figure below.

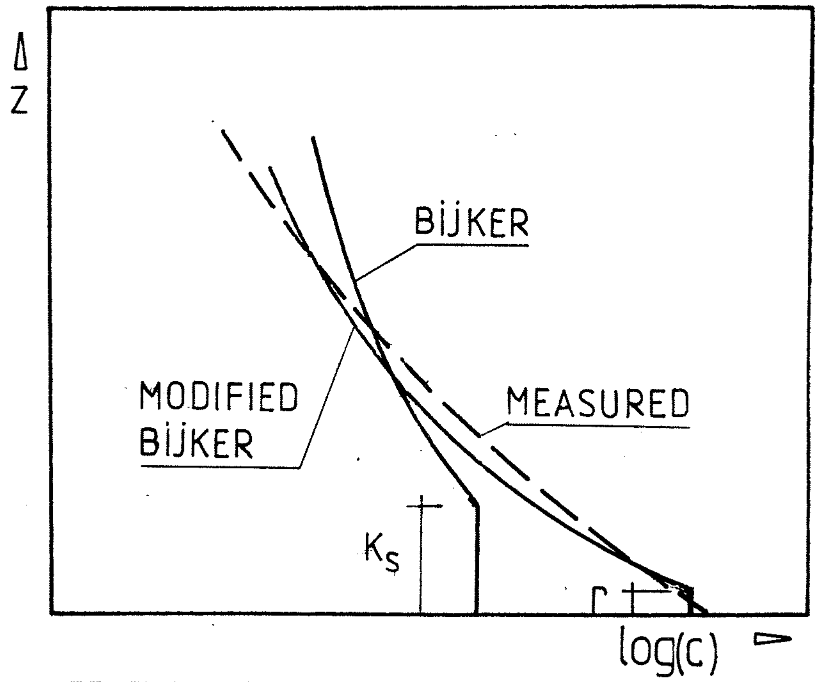


fig.22 Objective of modification.

The time- and bed-averaged concentration profiles are characterized by two properties, namely:

1. magnitude
2. distribution.

Both will be discussed in the following paragraphs.

7.7.4. The concentration magnitude

The magnitude of the concentrations computed via the Bijker formula, is mainly determined by the bed load transport Sb that follows from the modified Kalinske-Frijlink formula :

$$Sb = \frac{B*D50*\sqrt{g}}{C} * \exp\left[\frac{-\beta*d*D50*\rho*g}{\mu*Tc[1+0.5(\xi*Ub/Um)^2]}\right] \qquad (7.9)$$

see Appendix V.

The value of B is not very clear. β is a calibration coefficient.
The computations from section 7.6 have been done with :
B = 1 , because the waves were non-breaking, and
β = 0.27

Bijker assumed the bottom concentration to be constant over a height equal to the bedroughness Ks. He suggested using a bedroughness equal to 0.5 times the ripple height r : Very large fluid velocities would be the result !
Here, the bottom concentration Cb, is assumed to be constant over a height equal to the ripple height r.
Cb will now be computed from 7.9 as :

$$Cb = \frac{Sb}{\int_{z0}^{r} U(z)\ dz} \qquad (7.10)$$

The original Kalinske-Frijlink formula is a river transport formula.
To check this formula, Sb is computed for the experiments T 0,40 and T 0,-40 with B=1 and β=0.27.
Cb is now computed from 7.10.
The computations of Cb gave values that are about a factor 5 to large compared to the measured concentrations in the near bed zone.

From this was concluded that the value of 0.27 (β) in the exponential part of 7.9 is to small.
If β is taken 0.5 instead 0.27, the Cb values become rather well.
With the value 0.5 in the exponential part, the modified Kalinske-Frijlink formula will be checked in case of waves in combination with a current.
The characteristic parameters :

- the bedroughness , Ks, follows from section 7.7.2, and is taken : Ks=7*r.
- the wave height is taken Hrms, because the computations from section 7.6 gave best results for the combination of Ks=7*r and H=Hrms.

From several computations with B=1 and β=0.5, it was found that, especially in case of large wave heights in combination with an opposing current, Cb values were to low.
This can be explained by the fact that the values of Ub are smaller in case of an opposing current. Because an overall modification is prefered, no distinction has been made between following and opposing current experiments. After many sensitivity computations concerning the coefficients B and β, the following values were found to obtain Cb values that are in agreement with the measured concentrations in the near bed zone :

$0.6 < \beta < 0.8$

$3 < B < 4$

In the following, B is taken the value 3.5 and β is taken the value 0.7. With these values for B and β, Cb values were computed for all experiments.

Note that all values Ks/Ab used to compute the Johnson friction parameter Fw, are smaller or just a little higher than 1.47. This means that Fw has a rather constant value of 0.32.

Next the concentration distribution will be treated.

7.7.5 The concentration distribution

First the concentration distribution will be treated more general.
Several models have been developed to describe averige concentration profiles in case of an oscillating water movement (Rouse, Einstein, Coleman and Bhattacharya).
In general, they are diffussion models in which the description of the eddy viscosity (diffusion coefficient) plays an important role.
In general, the existing models are derived from the next equation :

$$dC(z)/dz = -W/E(z) * C(z) \qquad (7.11A)$$

in which :

z	= Height above mean bed level	[m]
C(z)	= Averige sediment concentration at level z	[kg/m3]
W	= Fall velocity of the sediment	[m/s]
E(z)	= Eddy vicosity for sediment movement	[m2/s]

E(z) will depend upon the hydraulic conditions. Because it is not exactly known how, E(z) is derived from the viscosity distribution for the water movement. Also it is not very clear if W is the fall velocity of the bed material ; Just as E(z), W can be related to the height above the bed (W(z)).

Both in this study as in the 200-mu-study, three types of concentration profiles were found (see fig. 22).
Profile 1 was found in case of waves alone. Profile 3 was found in case of waves in combination with a strong current.
Profile 2 was found in case of waves with a relatively weak current which, on its own, was not able to bring sediment into suspension.
It seems that in case of waves in combination with a current an increasing current strenght will cause the concentration profile to change from Profile 1 to Profile 3.

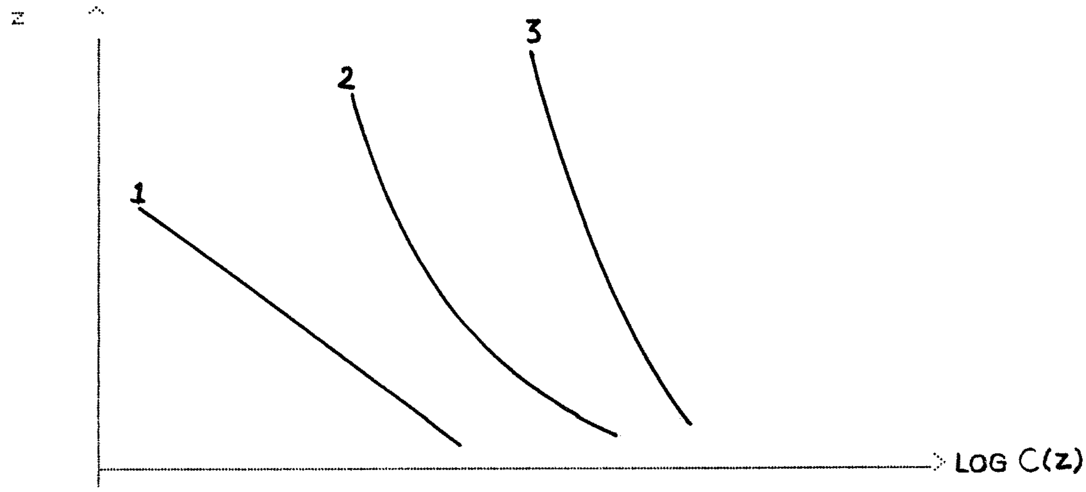


fig. 23 Occuring concentration profiles (log. scale)

Profile 1 from figure 22 can be described with a diffusion model in which E(z) has a constant value (adapted Coleman model). The solution of equation 7.11A then becomes :

$$C(Z) = C(0) * \exp((-W/E)*Z) \qquad (7.11B)$$

In which :

C(0) = Concentration at z=0
W = Fall velocity of the bed material
E = Constant eddy viscosity for the sediment movement

Profile 2 and 3 can be decribed with a diffusion model in which the eddy viscosity is a function of the height above the bed : E(z). Such a model is the Rouse/Einstein model :

$$E(z) = 4 * Em * (1-z/h) * z/h \qquad (7.12)$$

In which :

Em = The eddy viscosity at z/h = 0.5 (see fig. 24)
h = The water depth

The solution of equation 7.12 then becomes :

$$C(z) = C(x) * \left[\frac{h-z}{z} * \frac{x}{h-x} \right]^{Z*} \qquad (7.13)$$

In which :

z0 = A referance level : C(z)=C(x) for z < x
Z* = W*h/4*Em

The concentration becomes infinite for z=0. Because of this, the profile is defined for z > x.
With this model, Profile 1 and 3 can be reasonably well decribed if Em is well chosen. Em can be related to the

parameters used in the logarithmic velocity distribution. The result is that Em becomes :

$$Em = 0.25 * k * (U*) * h \tag{7.14}$$

$$Z* = W/k*U* \tag{7.15}$$

In which :

k = The von Karman constant (=0.4)
U* = The current stress velocity
h = The water depth

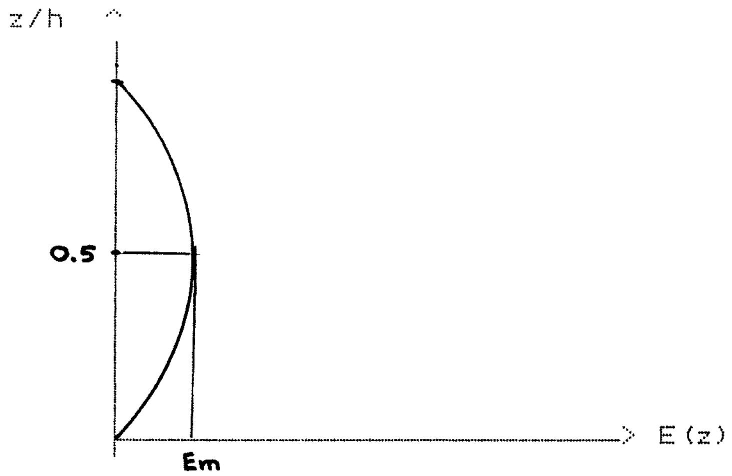


Fig. 24 The eddy viscosity distribution.

Bijker uses the Einstein model by taking C(x)=Cb and modifying Z* to account for the influence of waves. (see appendix V).
Bijker's modification of Z* lead to concentration profiles that are to steep compared to the measured ones.

Both in the 100-and 200-mu-study is found that the concentration distribution is strongly current related. Therefore it was decided, first to use current parameters to compute Z* for the concentration distribution.
With the use of 7.15 and the computed Cb values from section 7.7.3, concentration profiles have been computed with the Rousse/Einstein model.

After sensitivity tests, distributions that are in agreement with measured distribution were found if Z* is taken :

$$Z* = (W/k*U*)^{n} \tag{7.16}$$

with $0.4 < n < 0.6$

U* is the current shear velocity.

In the following, n is taken 0.5.
For the calculated conentration profiles, see table 7.6 A-F

7.7.6 Transport computation with the modified Bijker formula

The total load transport computations are made with :

$B = 3.5$
$\beta = 0.7$
$n = 0.5$

Sb is computed with the modified Kalinske-Frijlink formula using the new values for B and β.

Ss is computed as :

$$Ss = \int_r^h Cb * \left(\frac{h-z}{z} * \frac{r}{h-r} \right)^{Z*} * U(z)\, dz$$

with:

$$Z* = (W/k*U*)^{0.5}$$

U(z) = the logarithmic velocity profile

The computed transports, now show a good trend compared with the transports that follow from measurements.
To check the modification for a different sediment size, also transports for 200 mu have been computed using the same values for B, b and n. Altough the 200-mu-study results have not been used in the calibration to determine B, β and n, the trend stayed good .See fig.7.5.A and table 7.6 G-L

In figures 7.5.B-G. the concentration-, velocity- and total load transport profiles for some experiments are shown.

- The new values of β and B in the modified Kalinske-Frijlink formula in combination with a bed load layer thickness of r yields a much better trend for the predicted bed concentration.

- The mixing parameter Z* is not good represented by taking U*,cw as proposed by Bijker. The present results show that Z* is strongly current related :
  more research is neceserry.

- The difference between the newly computed transports and the measured transports will be mainly caused by the difference between the velocity profiles.

8. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

From the measurements:

1. An increase of the significant wave height or an increase of the depth-averaged fluid velocity leads to an increase of the concentration magnitudes. (see 4.3)

2. Current in combination with following or opposing waves give smaller velocities in the near bed zone than current alone.
Waves that follow a current causes larger time-averaged fluid velocities in the near bed zone and smaller time-averaged velocities in the upper zone, compared to those in case waves oppose a current. (4.4)

3. The bedroughness parameter, Ks, in case of waves in combination with a current, is about 3 to 7 times the average ripple height. (6.7)

4. In case of irregular waves in combination with a current, an apparent roughness increase (z1/z0) of 1 to 10 can be expected:
1, in case of small waves and a strong current,
10, in case of large waves and a weak current. (6.8)

5. Waves in combination with a current produces larger total load amounts by an increase of the significant wave height or the depth-averaged fluid velocity.
However, given a constant significant wave height, the total load amounts for waves alone will be somewhat larger than for waves in combination with a weak current (0.1 [m/s]). (4.5.2)

6. The median fall velocity of the suspended material is equal to about 0.9 to 1.0 times the median fall velocity of the bed material. The influence of wave height and current strength is not clear. (4.8)

7. The influence of the significant wave height, Hsig, on the total load transport, St, can be reflected rather well by the relationship

$$St \sim Hsig^{q}$$

in which q is a parameter that is related to the median size of the bed material, D50, and the depth-averaged fluid velocity.
The influence of the depth-averaged velocity, Um, on the total load transport, St, can be reflected by

$$|St| \sim |Um|^{y}$$

in which y is a parameter that is related to the median size of the bed material, D50, and the significant wave height. (4.6.4)

8. Waves that follow or oppose a current give no significant differences in sediment transport rates. (4.6)

From the results of model computations:

9. The Bagnold-Bailard concept as described in this study predicts current-related sediment transport rates that are much too large (factor 10 to 50) in case of waves following a current. In case of waves oppose a current the concept predicts these rates within a factor 3. (7.3)

10. The modified Engelund-Hansen formula computes current-related sediment transport rates that are much too large in all cases, and inconsistent for the median size of the bed material. (7.4)

11. The Nielsen model reflects the velocity profile rather well. Compared to the experimental data, the current-related transport rates, computed by the Nielsen model, gives results within a factor 2 for small transport rates (<0.001 kg/m.s). Much too large (a factor 100) rates are computed for large transport rates (>0.03 kg/m.s), mostly influenced by Nielsen's exponential enlargement factor. (7.5)

12. The Bijker model predicts too small concentration magnitudes and too large fluid velocities in the near bed zone. This results in current-related sediment transport rates that are a factor 4 too large for small transports (< 0.001 kg/m.s) and a factor 4 too small for large transports (> 0.03 kg/m.s). (7.6)

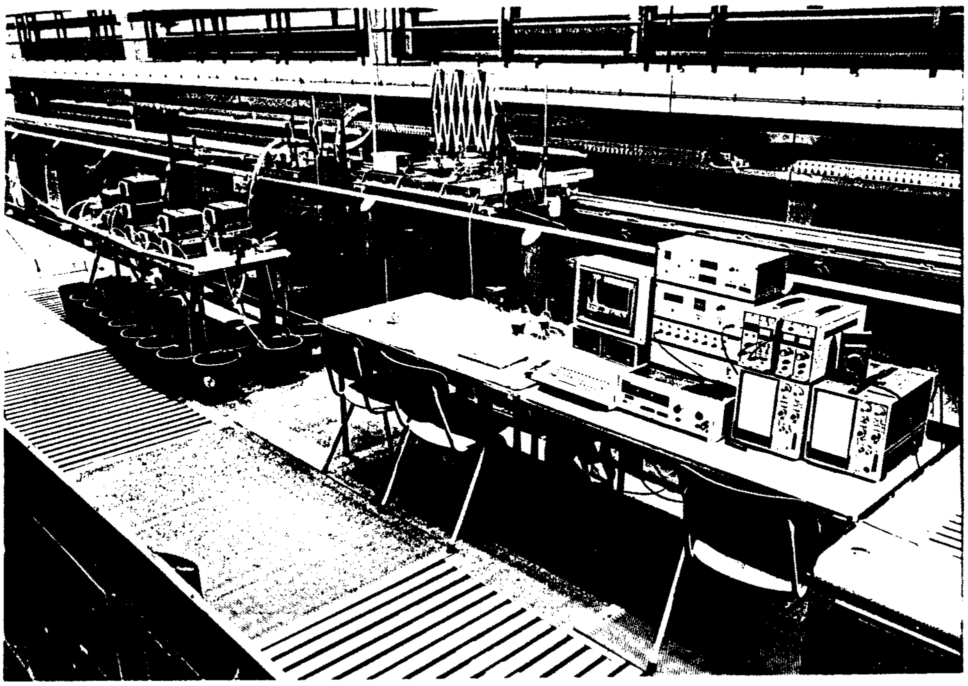
13. By modification of the Kalinske-Frijlink-Bijker formula with parameters B and β, and by assumption that the bottom concentration, Cb, is constant over the mean ripple height, the concentration in the near bed zone can be predicted rather well.
If this is combined with a modification of the Rouse-Einstein integral, by changing the dimensionless coefficient $Z*$, the concentration profile is well predicted
For the velocity profile the assumption $Ks = 7*r$ fits best.
These modifications lead to improvement of the computed current-related sediment transport rates. Magnitudes within a factor 3 compared to the experimental results. The differences now, are mostly influenced by the computed logarithmic velocity profile. (7.7)

RECOMMONDATIONS

1. More data of sand balance experiments are required for determination of the wave-related sediment transport rates. These can easily be carried out within an accuracy of 10%, using the method of the "under water balance". (5.2)

2. For better understanding of the sediment transport mechanism, the knowledge of the instantaneous fluid velocity in the near ripple zone is required. This might be done by registration of the amplitudes of the velocities in this zone. (5.3)

3. More investigation and experimental data are necessary to verify the B, β and Z* parameters of the Bijker method. (7.7)



LIST OF SYMBOLS

a	- water depth	[m]
A	- dimensionless roughness	[-]
Ab	- dimensionless enhancement factor in the Nielsen model	[-]
	- horizontal orbital displacement amplitude	[m]
A1	- coefficient in the Nielsen model	
Af	- dimensionless enhancement factor in the Nielsen model	[-]
b	- width of the flume	[m]
B	- coefficient in the Kalinske-Frijlink-Bijker formula	[-]
c	- concentration	[kg/m3]
$\bar{\bar{c}}$	- time- and bed-averaged concentration	[kg/m3]
c'	- concentration fluctuation	[kg/m3]
ca	- absolute wave celerity	[m/s]
cr	- relative wave celerity	[m/s]
C	- Chezy friction coefficient	[m^0.5/s]
C'	- Chezy friction coefficient	[m^0.5/s]
Cb	- bed concentration	[kg/m3]
d(.)	- standard deviation of (.)	[.]
	- error in (.)	[.]
Dx	- grain diameter exceeded by x%	[m]
f	- frequency	[1/s]
fp	- peak frequency	[1/s]
fw	- friction factor	[-]
f'w	- skin friction factor	[-]
F	- coefficient in Niesen model	[-]
g	- acceleration of gravity	[m/s2]
h	- water depth relative to the flume bottom	[m]
H	- wave height	[m]
Hsig	- significant wave height	[m]
Hrms	- root-mean-square wave height	[m]
Hprob	- probabilistic-weighted wave height	[m]
H1%	- wave height with 1% probability of being exceeded	[m]
i	- water surface slope	[-]
I1	- Einstein integral	[-]
I2	- Einstein integral	[-]
L	- wave length	[m]
Lb	- bed load	[kg/m2]
Lc	- vertical concentration length scale	[m]
Lcb	- concentration length scale (Nielsen model)	[m]
Lcf	- concentration length scale (Nielsen model)	[m]
Ls	- suspended load	[kg/m2]
Lt	- total load	[kg/m2]
Ks	- bedroughness parameter	[m]
n	- power coefficient	[-]
P(.)	- probability of exceedence (.)	[-]
p(.)	- probability of occurance of (.)	[-]
p	- porosity	[-]
q	- power coefficient	[-]
r	- mean ripple height	[-]
Sb	- bed load transport	[kg/m.s]
Scurr	- current-related sediment transport	[kg/m.s]
Ss	- suspended load transport	[kg/m.s]

St ,

Stot	- total load transport	[kg/m.s]
Swave	- wave-related sediment transport	[kg/m.s]
t	- coordinate of time	[s]
T	- wave period	[s]
Tc	- bed shear stress	[N/m2]
Tp	- wave spectrum peak period	[s]
Tp,rel	- wave spectrum peak period relative to the current	[s]
Tz	- zero-crossing period	[s]
ur	- velocity of ripple migration	[m/s]
U	- fluid velocity	[m/s]
U	- time- and bed-averaged fluid velocity	[m/s]
U'	- fluid velocity fluctuation	[m/s]
Ub	- horizontal orbital velocity amplitude	[m/s]
Uc	- representive velocity for current effect	[m/s]
Um	- depth-averaged fluid velocity	[m/s]
U*	- shear velocity	[m/s]
U*,c	- shear velocity by current	[m/s]
U*,w	- shear velocity by waves	[m/s]
v	- velocity	[m/s]
V	- sand bed volume in flume	[m3]
W	- mass of sand bed in flume	[kg]
w50	- median fall velocity of sediment	[m/s]
x	- coordinate of wave propagation	[m]
X	- length of bed for sand balance	[m]
y	- power coefficient	[-]
z	- vertical coordinate	[m]
z0	- zero velocity level	[m]
zi	- level of intake tube i	[m]
z1	- adapted zero velocity level	[m]
Z*	- dimensionless parameter in Bijker model	[-]
α	- shape factor	[-]
β	- coefficient in Kalinske-Frijlink-Bijker formula	[-]
δ	- mean bed level	[m]
θ'	- Shields skin friction parameter	[-]
θr	- Shields parameter corrected for flow contraction near the ripple crests.	[-]
η	- ripple height	[m]
κ	- constant of von Karman	[-]
λ	- ripple length	[m]
$\bar{\lambda}$	- mean ripple length	[m]
$\lambda 0$	- ripple length in case of waves alone	[m]
$\lambda 1$	- upstream ripple length	[m]
$\lambda 2$	- downstream ripple length	[m]
μ	- ripple factor	[-]
ρ	- density of fluid	[kg/m3]
ρs	- density of sediment	[kg/m3]
ν	- kinematic viscosity	[m2/s]
ξ	- parameter	[-]

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APPENDIX I. THE VANONI-BROOKS METHOD

This method determines the bedroughness with side-wall correction.
To determine the shear-stress related to the bed in case of unequal bed and side-wall roughness, a correction metod must be used, when the depth/width ratio of the flow is less than about 5.
A method which is frequently used, is that of Vanoni-Brooks (1957).

The input parameters to determine the bedroughness are:

- h = water depth [m]
- Q = discharge [m3/s]
- b = flume width [m]
- i = water surface slope [-]

Constant parameters in these computations are:

- ν = kinematic viscosity coefficient = 10^-6 [m2/s]
- g = acceleration of gravity = 9.81 [m/s2]

The series of computations that have to be carried out to determine the bedroughness parameter Ks, according to the Vanoni-Brooks method, are given here in the following order:

1. $R = \dfrac{b\ h}{b + 2h}$ = hydraulic radius [m]

2. $U_* = (g\ R\ i)^{0.5}$ = shear velocity [m/s]

3. $U_m = Q / b\ h$ = depth-averaged velocity [m/s]

4. $f = 8\ (U_*/U_m)^2$ = friction coefficient [-]

5. $Re = 4\ U_m\ R / \nu$ = Reynolds' number [-]

6. $f_w = 0.0026\ [\log(Re/f)]^2 - 0.0428\ \log(Re/f) + 0.1884$

   = friction coefficient related to smooth side-walls according to V-B ($10^5 < Re/f < 10^8$) [-]

7. $f_b = f + 2h(f - f_w)/b$ = friction coefficient related to the bed [-]

8. $R_b = R\ f_b / f$ = hydraulic radius related to the bed [m]

9. $U_{*,b} = (g\ R_b\ i)^{0.5}$ = shear stress related to the bed [m/s]

10. $C_b = U_m / (R_b\ i)^{0.5}$ = Chezy coefficient related to the bed [m^0.5/s]

11. $K_s = 12R_b\ 10^{(-C_b/18)}$ = effective bedroughness [m]

APPENDIX II. THE BAGNOLD-BAILARD CONCEPT

(WITHOUT BED SLOPE INFLUENCE)

Bailard used the Bagnold-approach for sediment transport. Bailard devides the totalload transport into two parts:

1. The bed load transport is computed from:

$$Sb(t) = \rho s \frac{\epsilon b \quad Cf}{d \; g \; tan} \; |Ut|^2 \; Ut \qquad [kg/m.s]$$

2. The suspended load transport is computed from:

$$Ss(t) = \rho s \frac{\epsilon s \quad Cf}{d \; g \; w50} \; |Ut|^3 \; Ut \qquad [kg/m.s]$$

with:
- Bagnold proposes values for the coefficients ϵb and ϵs:

ϵb = 0.11 - 0.15
ϵs = 0.016 - 0.024

In this study the values, proposed by the Delft Hydraulics Laboratory, are used:

ϵb = 0.10
ϵs = 0.02

- Cf is the friction coefficient according to Jonsson:

Cf = exp{-6 + 5.2(Ab/Ks)^-0.19}

- tan = 0.63
- d = 1.65
- g = 9.81 [m/s2]
- w50 = the median fall velocity of the bed material [m/s]
- Ut = Uc + U(t)

with:
Ut = the combined fluid velocity at time t [m/s]
Uc = a representive velocity for the current effect [m/s]
U(t) = the horizontal orbital velocity at time t, according to a third order Stokes equation:
U(t) = Ub cos(wt) + a Ub cos(2wt) + b Ub cos(3wt).
with subjective a and b values.
Uc is related to Um.

The total sediment transport can be computed numerically from:

$$Stot = \sum_{t=0}^{N} Sb(t) + Ss(t) \qquad [kg/m.s]$$

with N is the number of steps within 1 wave period.

APPENDIX III. THE MODIFIED ENGELUND-HANSEN FORMULA

The Engelund-Hansen formula was originally developed for rivers. Applying the Bijker concept of modifying the bed shear stress for the combined action of waves and current, leads to:

$$St = Um*\frac{0.05*C*T_c^2*(1 + 0.5*(\xi*\hat{U}b/Um)^2)^2}{\rho^2*g^{5/2}*\Delta^2*D50} \qquad (III-1)$$

in which:

St = Total load transport per unit width (not including the voids) expressed in [m3/ms]. In order to be able to compare the measured total load transports with the calculated total load transports, the outcome of Eq. (V-1) was multiplied by ρ_s, after which the transport is expressed in [Kg/ms].

Um = Depth-averaged velocity [m/s]

C = Chezy coefficient; see Eq. (V-2) [m /s]

Tc = Bed shear stress due to the current; see Eq. (V-8) [N/m2]

ξ = Parameter; see Eq. (V-9) [-]

$\hat{U}b$ = Amplitude of orbital velocity at the bed according to lineair wave theory; see Eq. (V-12) [m/s]

ρ = Mass density of water (= 1000) [Kg/m3]

g = Acceleratiom of gravity (= 9.81) [m/s2]

Δ = Relative sediment density (= 1.65) [-]

D50 = Grain diameter exceeded by 50% (by weight) of the bed material [m]

When applied to rivers, the Engelund-Hansen formula also provides a predictor for the Chezy coefficient. Because this predictor is only valid in case of dunes and anti-dunes, the Chezy coefficient was calculated with Eq. (VI-2). For the roughness Ks again a minimum and a maximum approximation was used, the van Rijn bed roughness and the Swart bed roughness.

APPENDIX IV. THE NIELSEN MODEL

Note that other names are used in this Appendix for:
CURRENT-RELATED TRANSPORT is called CONVECTIVE TRANSPORT,
WAVE-RELATED TRANSPORT is called DIFFUSIVE TRANSPORT, here.

The Nielsen method (Nielsen, 1985) distinguishes convective and diffusive sediment transport.

Convective sediment transport

The convective sediment transport is computed as:

$$Scon = \int_{z=0}^{h} \overline{C}(z)*\overline{U}(z)\, dz \qquad (IV-1)$$

in which:

Scon	=	Convective sediment transport per unit width	[m3/ms]
$\overline{C}(z)$	=	Time-averaged concentration at height z	[m3/m3]
$\overline{U}(z)$	=	Time-averaged velocity at height z	[m/s]
h	=	Water depth	[m]

To calculate the convective sediment transports, the velocities are approximated by a modified logarithmic velocity distribution:

$$\overline{U}(z) = \begin{cases} \dfrac{\overline{U*}}{\kappa * F} * \left[\dfrac{z}{z0} - 1\right] & ; z < A1 \\ \dfrac{\overline{U*}}{\kappa} * Ln\left[\dfrac{z}{z1}\right] & ; z > A1 \end{cases} \qquad (IV-2)$$

in which:

$\overline{U*}$	=	Current shear velocity	[m/s]
κ	=	Von Karman constant (= 0.4)	[-]

$z0$ = Zero-velocity level [m]

$$z0 = Ks/30 \qquad (IV\text{-}3)$$

$z1$ = Adapted zero-velocity level [m]

F = Dimensionless factor [-]

$A1$ = Thickness of the wave influenced layer [m]

$$A1 = z0 * F \qquad (IV\text{-}4)$$

The zero velocity level z1 can be found by matching the two expressions of Eq. (V-2) at height $z = z0*F$:

$$z1/z0 = F*\exp(1/F - 1) \qquad (IV\text{-}5)$$

To predict the factor F, Nielsen derived the following empirical relation:

$$F = 1 + (\tilde{U}*/|\overline{U*}|)^3/6 \qquad (IV\text{-}6)$$

where: $\tilde{U}*$ = Wave shear velocity [m/s]

$$\tilde{U}* = \sqrt{0.5*fw}*\hat{U}b \qquad (IV\text{-}7)$$

with: fw = Bed friction coefficient (see appendix II) [-]

$\hat{U}b$ = Amplitude of orbital velocity at the bed (see appendix II) [m/s]

Until now, the current shear velocity $\overline{U*}$ is unknown. Nielsen gives a method of determining U* when the velocity is measured at one single elevation above the bed. However, in the present investigation the velocity was measured at 10 heights above the bed. Therefore, the current shear velocity was determined from the depth-averaged velocity Um, see appendix VI.

Nielsen uses the Grant and Madsen (1982) fomula to estimate the bed roughness:

$$Ks = 8*\Delta r*RS + 190*D50*\sqrt{\theta' - 0.05} \qquad (IV-8)$$

in which:

Δr = Ripple height [m]

RS = Ripple steepness [-]

D50 = Grain diameter exceeded by 50% (by weight) of the bed material [m]

θ' = Skin friction shields parameter [-]

$$\theta' = 0.5*f'_w*(\hat{U}b^2/\Delta g D50) \qquad (IV-9)$$

where: f'_w = Skin friction coefficient [-]

$$f'_w = \exp(5.213*(2.5*D50/\hat{A}b)^{0,194}-5.977) \qquad (IV-10)$$

$\hat{A}b$ = Amlitude of orbital displacement at the bed (see appendix II) [m]

Δ = Relative sediment density (= 1.65) [-]

g = Acceleration of gravity (= 9.81) [m/s2]

For the ripple parameters, needed to compute the bed roughness (Eq. (V-8)), Nielsen gives the following relations:

- Ripple height : $\Delta r = \hat{A}b*(0.275 - 0.022*(\hat{U}b^2/\Delta g D50)^{1/2})$ (IV-11)
- Ripple length : $\lambda r = \hat{A}b*(2.2 - 0.345*(\hat{U}b^2/\Delta g D50)^{0,34})$ (IV-12)
- Ripple steepnes: $RS = 0.182 - 0.24*(\theta')^{3/2}$ (IV-13)

As suggested by Nielsen (1985), the ripple calculations were based on the significant wave height. The ripple dimensions calculated with the significant wave height were also used to determine the probability-weighted parameters. This is assumed to be justified because the characteristic ripple pattern does not adjust immediately to each individual wave.

To calculate the convective transport, Nielsen uses an exponential concentration distribution:

$$\overline{C}(z) = Cb*\exp(-z/Lc) \qquad (IV-14)$$

in which:

$\overline{C}(z)$ = Time-averaged concentration at height z [m3/m3]

Cb = Reference concentration at z = 0 [m3/m3]

Lc = Mixing length scale for waves alone [m]

The reference concentration Cb Nielsen computes from:

$$Cb = 0.005*\theta r^3 \qquad (IV-15)$$

in which:

θr = Shields parameter corrected for flow contraction near ripple crests [-]

$$\theta r = \theta'/(1 - \pi *RS) \qquad (IV-16)$$

The reference concentration Cb is expressed in [m3/m3] and does not include the voids. To express the reference concentration in [Kg/ms] it needs to be multiplied by ρ_s.

Nielsen calculates the mixing length scale Lc with the use of a maximum (forward) and a minimum (backward) combined velocity. These velocities are calculated from the measured first and second order harmonic component (the method is based on regular waves experiments) and the phase between them. In case of irregular waves there is no characteristic phase difference. Therefore, only the first harmonic component was used to calculate the maximum and minimum combined velocity.

$$Umax = \overline{U*}/\sqrt{0.5*fw} + \hat{U}b \tag{V-17}$$

$$Umin = \overline{U*}/\sqrt{0.5*fw} - \hat{U}b \tag{V-18}$$

Using these combined velocities, the mixing length scale Lc can be calculated from the following set of equations:

$$Lcf = \Delta r*\left\{0.2 + 1.24*exp\left[\frac{-40}{(Umax/W50)^2}\right]\right\} \tag{V-19}$$

$$Lcb = \Delta r*\left\{0.2 + 1.24*exp\left[\frac{-40}{(Umin/W50)^2}\right]\right\} \tag{V-20}$$

$$Lc = (Lcf + Lcb)/2 \tag{V-21}$$

where: W50 = Median fall velocity of the bed material [m/s]

Nielsen states that Eq. (V-14) takes no account for extra mixing and resulting upward stretching of the concentration profile due to the steady current. He suggests that a reasonable approach is to apply in stead of Eq. (V-14):

$$\overline{C}(z) = Cb*exp\left\{-\int_{z'=0}^{z}\frac{dz'}{Lc(z')}\right\} \tag{V-22}$$

in which:

$Lc(z')$ = Mixing length scale for waves and currents

$$Lc(z') = Lc + \frac{\kappa * |\overline{U*}| * z'}{W50} = Lc + X * z' \qquad (V-23)$$

with $X = \kappa * |\overline{U*}| / W50$ [-]

Nielsen gives no further information, but working out (see appendix VII) leads to:

$$\overline{C}(z) = Cb * \left[\frac{Lc}{Lc + z * X}\right]^{1/X} \qquad (V-24)$$

Substitution of the velocity profile Eq. (V-2) and the concentration profile Eq. (V-14) in the sediment transport Eq. (V-1) leads to:

$$Scon = \frac{Cb * Lc^{2} * \overline{U*}}{Al} * (1 - \exp(-1.9 * (Al/Lc)^{0,79})) \qquad (V-25)$$

Because Eq. (V-14) and hence Eq. (V-25) takes no account for the presence of the current and sustitution of Eq. (V-24) causes a non-solvable integral, Nielsen modifies the sediment transport Eq. (V-25), resulting in:

$$Scon = \left\{ \frac{Lcf^{2} * Cb * Af * \overline{U*}}{\kappa * Al} * (1 - \exp(-1.9 * (Al/Lcf)^{0,79})) + \frac{Lcb^{2} * Cb * Ab * \overline{U*}}{\kappa * Al} * (1 - \exp(-1.9 * (Al/Lcb)^{0,79})) \right\} * \exp\left[1.1 * \frac{|\overline{U*}|}{W50}\right]$$

(V-26)

in which Af and Ab are dimensionless enhancement factors used by Nielsen to represent the current influence on the bed concentration Cb.

$$Af = 0.5*(Umax/\hat{U}b)^6 \qquad (V-27)$$

$$Ab = 0.5*(Umin/\hat{U}b)^6 \qquad (V-28)$$

The last term in Eq. (V-26) was added by Nielsen to account for the current-induced mixing.

<u>Diffusive sediment transport</u>

The diffusive transport Nielsen computes from:

$$Sdiff = \frac{1}{T}\int_{t'=t}^{t+T}\int_{z=0}^{h} C(z,t')*\tilde{U}(z,t')\ dz\ dt' \qquad (V-29)$$

in which:

Sdiff = Diffusive sediment transport per unit width (not including the voids) [Kg/ms]

C(z,t') = Instantaneous concentration at height z [Kg/m3]

$\tilde{U}(z,t')$ = Instantaneous wave velocity at height z [m/s]

Using the fact that the entrainment of sediment from rippled beds occurs close to the moment that the velocity changes direction, Nielsen derived expressions for the instantaneous load. By substituting a simple harmonic velocity in Eq. (V-29), Nielsen derived the following equations to calculate the diffusive transport:

$$Sf = -Af*Cb*\hat{U}b*Lcf*\frac{2*\pi*Lcf/(T*W50)}{(1 + (2*\pi*Lcf/(T*W50))^2)} \qquad (IV-30)$$

$$Sb = Ab*Cb*\hat{U}b*Lcb*\frac{2*\pi*Lcb/(T*W50)}{(1 + (2*\pi*Lcb/(T*W50))^2)} \qquad (IV-31)$$

$$Sdiff = Sf + Sb \qquad (IV-32)$$

with: T = Wave period [s]

Knowing the convective and diffusive transport, the total transport can be calculated from:

$$Stot = Scon + Sdiff \qquad (IV-33)$$

APPENDIX V. THE BIJKER MODEL

Bijker devided the total load transport into two parts, the bed load transport and the suspended load transport. The bed load transport is calculated with the Kalinske-Frijlink formula, in which the combined action of waves and current is accounted for by a modification of the bed shear stress:

$$Sb = \frac{B*D50*Um*\sqrt{g}}{C}*\exp\left[\frac{-0.27*\Delta*D50*\rho*g}{\mu*Tc*(1 + 0.5*(\xi*\hat{U}b/Um)^2)}\right] \qquad (V-1)$$

in which:

Sb = Bed load transport per unit width [m3/ms]

The bed load transport according to Eq.(II-1) is expressed in [m3/ms] and includes the voids. In order to be able to compare the measured with the calculated transports, it is necessary to convert the units of the bed load transport. After multiplying the bed load transport according to Eq.(V-1) with a factor $(1 - p)*\rho_s$ (with p = porosity [-]; ρ_s = sediment density [Kg/m3]), the bed load transport is expressed in [Kg/ms] and no longer includes the voids.

B = Coefficient [-]

This coefficient might reflect the influence of the breaking of the waves. In the breaker zone, B is usually taken equal to 5 and outside the breaker zone equal to 1. Because we are dealing with non-breaking waves, B was taken equal to 1.

C = Chezy coeffient [$m^{1/2}/s$]

C = 18 log(12h/Ks) (II-2)

where: h = waterdepth [m]

Ks = Bed roughness [m]

Two roughness predictors are used in combination with the Bijker formula:

- The van Rijn (1982) roughness (a minimum approximation):

$$Ks = 3*D90 + 1.1*\Delta r*(1 - \exp(-25*\Delta r/\lambda r)) \qquad (V-3)$$

where: D90 = Grain diameter exceeded by 10% (by weight) of the bed material [m]

Δr = Ripple height [m]

λr = Ripple length [m]

- The Swart (1976) roughness (a maximum approximation):

$$Ks = 25*(\Delta r^2/\lambda r) \qquad (V-4)$$

D50 = Grain diameter exceeded by 50% (by weight) of the bed material [m]

Um = Depth-averaged velocity [m/s]

g = Acceleration of gravity (= 9.81) [m/s2]

Δ = Relative sediment density [-]

$$\Delta = (\rho_s - \rho)/\rho = 1.65 \qquad (V-5)$$

μ = Ripple factor [-]

$$\mu = (C/C90)^{3/2} \qquad (V-6)$$

where: C90 = Chezy coefficient based upon D90 [m /s]

$$C90 = 18 \log(12h/D90) \qquad (V-7)$$

Tc = Bed shear stress due to the current [N/m2]

$$Tc = \rho*g*Um^2/C^2 \qquad (V-8)$$

ξ = Dimensionless parameter [-]

$$\xi = C*\sqrt{fw/2g} \qquad (V-9)$$

where: fw = Dimensionless coefficient (Jonsson, 1966) [-]

$$fw = \begin{cases} \exp(-5.977 + 5.213*(\hat{A}b/Ks)^{-0,194}); & 1.47 < \hat{A}b/Ks < 3000 \\ 0.32; & \hat{A}b/Ks < 1.47 \end{cases} \qquad (V-10)$$

$\hat{A}b$ = Amplitude of the orbital displacements at the bed [m]

$$\hat{A}b = \frac{H}{2} * \frac{1}{\sinh(2*\pi*h/L)} \qquad (V-11)$$

where: H = Wave height [m]

L = Wave length [m]

$\hat{U}b$ = Amplitude of orbital velocity at the bed [m/s]

$$\hat{U}b = \hat{A}b*(2*\pi/T) \qquad (V-12)$$

where: T = Wave period [s]

Bijker assumes that the bed load transport takes place in a bed load layer having a thickness of the bed roughness Ks. The concentration in this layer is assumed to be constant over the entire thickness of this layer:

$$Cb = C(Ks) = \frac{Sb}{6.34*\sqrt{Tc/\rho}*Ks} \qquad (V-13)$$

where: Cb = Concentration in the bed load layer [Kg/m3]

The suspended load transport is calculated as:

$$Ss = \int_{z=Ks}^{h} C(z)*U(z)\, dz \qquad (V-14)$$

in which:

C(z) = Concentration at height z [Kg/m3]

U(z) = Velocity at height z [m/s]

To compute the suspended load transport, the velocities are approximated by the Prandtl-Von Karman logarithmic velocity distribution:

$$U(z) = (U*/\kappa)*Ln(z/z0) \qquad (V-15)$$

in which:

U(z) = Fluid velocity at height z [m/s]

U* = Shear velocity [m/s]

κ = Von Karman coefficient (= 0.4) [-]

z0 = Elevation at which the velocity is zero [m]

$$z0 = Ks/33 \qquad (V-16)$$

The concentrations are approximated by an Einstein (1950) concentration distribution:

$$C(z) = Cb*\left[\frac{h - z}{z}*\frac{Ks}{h - Ks}\right]^{Z*} \qquad (V-17)$$

in which:

C(z) = Concentration at height z above mean bed level [Kg/m3]

Z* = Dimensionless parameter [-]

$$Z* = \frac{W50*\sqrt{\rho}}{\kappa*\sqrt{Tc*(1 + 0.5*(\xi*\hat{U}b/Um)^2)}} \qquad (V-18)$$

where: W50 = Median fall velocity of the bed material [m/s]

Substitution of Eqs.(V-15) and (V-17) into Eq.(V-14) leads to:

$$Ss = 1.83*(I1*Ln(33h/Ks) + I2)*Sb \qquad (V-19)$$

in which I1 and I2 are Einstein's integrals.

$$I1 = 0.216*\frac{A^{Z*-1}}{(1-A)^{Z*}}*\int_{x=A}^{1}\left[\frac{1-x}{x}\right]^{Z*} dx \qquad (V\text{-}20)$$

$$I2 = 0.216*\frac{A^{Z*-1}}{(1-A)^{Z*}}*\int_{x=A}^{1}\left[\frac{1-x}{x}\right]^{Z*}*Ln(x)\ dx \qquad (V\text{-}21)$$

with: A = Dimensionless roughness [-]: A = Ks/h

x = Dimensionless height [-]: x = z/h

These integrals were solved using the binomium of Newton (Bogaard, 1977).

Knowing the bed load transport, the suspended load transport can be computed from Eq.(V-19) after which the total load transport can be computed as:

$$St = Sb + Ss \qquad (V\text{-}22)$$

The loads are determined in the following way. Bijker assumes the concentration to be constant over the entire thickness Ks of the bed load layer, the bed load can therefore be computed as:

$$Lb = Cb*Ks \qquad (V\text{-}23)$$

The suspended load is calculated as:

$$Ls = \int_{z=Ks}^{h} C(z)\ dz \qquad (V\text{-}24)$$

Substituting (V-17) and solving:

$$Ls = 4.63*Lb*I1 \quad (V\text{-}25)$$

Knowing the bed load and the suspended load, the total load can be computed as:

$$Lt = Lb + Ls \quad (V\text{-}26)$$

TABLES WITH EXPERIMENTAL DATA

including:

- DATA from 30 SEDIMENT TRANSPORT EXPERIMENTS
  (see chapter 4)

- DATA from 3 SAND BALANCE EXPERIMENTS
  (see chapter 5)

Test	:T 0 ,40	Date	:27-07-'87
Experimentno.	: 20	Watertemperature:	19,6 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	0,00	0,00
Zero-cross Period Tz	(*10 -2 m)	0,00	0,00
Peak Period Tp	(*10 -2 m)	0,00	0,00
Ratio H(1%)/Hsig	(-)	0,00	-
Waterdepth to mean bed a	(*10 -2 m)	50,30	0,17
Depth averaged Velocity v	(*10-2 m/s)	38,12	0,70

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,22	0,70
Ripple Length λ	(*10 -2 m)	10,48	2,11
Ripple Velocity ur	(*10 -6 m/s)	15,25	4,26
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN	STAND.DEV. *10 -3	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	4,04	2,03	208	27	19,42	2,28
2	6,02	3,03	164	7	22,73	0,07
3	8,01	4,03	133	11	26,00	0,99
4	10,99	5,53	109	2	27,52	1,09
5	15,57	7,83	70	5	31,10	0,52
6	23,72	11,93	46	4	36,56	1,18
7	35,45	17,83	24	1	40,17	0,63
8	47,77	24,03	14	2	41,92	0,74
9	60,10	30,23	8	1	43,89	0,79
10	74,02	37,23	5	1	42,18	0,88

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	3,72	0,51
Suspended Load Ls	(")	17,80	1,54
Total Load Lt	(")	21,52	2,05
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,15	0,12
Suspended Load Transport Ss	(")	5,03	0,65
Total Load Transport St	(")	5,18	0,76

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	4,04	2,03	19,42
2	6,02	3,03	22,73
3	8,01	4,03	26,00
4	10,99	5,53	27,52
5	15,57	7,83	31,10
6	23,72	11,93	36,56
7	35,45	17,83	40,17
8	47,77	24,03	41,92
9	60,10	30,23	43,89
10	74,02	37,23	42,18

WATER SURFACE SLOPE : i= - *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	9,77	114
1	7,88	101
2	7,58	100
3	7,88	101
4	2,22	51
5	7,74	102
6 to 10	2,47	54
mixture	8,30	104

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	76
D50	:	108
D90	:	150

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 0, -40	Date	:24-08-'87
Experimentno.	: 36	Watertemperature:	22,6 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	0,00	0,00
Zero-cross Period Tz	(*10 -2 m)	0,00	0,00
Peak Period Tp	(*10 -2 m)	0,00	0,00
Ratio H(1%)/Hsig	(-)	0,00	-
Waterdepth to mean bed a	(*10 -2 m)	50,63	0,45
Depth averaged Velocity v	(*10-2 m/s)	-38,11	0,71

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,16	0,66
Ripple Length λ	(*10 -2 m)	9,82	3,36
Ripple Velocity ur	(*10 -6 m/s)	-42,75	11,67
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	5,04	2,55	282	42	-21,33	2,06
2	7,01	3,55	233	71	-24,11	1,70
3	8,99	4,55	159	25	-26,50	0,44
4	11,95	6,05	123	12	-28,36	0,69
5	16,49	8,35	83	20	-30,36	0,81
6	24,59	12,45	55	16	-34,22	0,24
7	36,24	18,35	32	13	-38,18	1,12
8	48,49	24,55	26	13	-41,25	0,51
9	60,73	30,75	22	11	-43,27	1,11
10	74,56	37,75	17	10	-44,62	1,05

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	6,48	1,13
Suspended Load Ls	(")	27,98	7,53
Total Load Lt	(")	34,46	8,66
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,56	0,32
Suspended Load Transport Ss	(")	-8,12	2,85
Total Load Transport St	(")	-8,67	3,16

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	5,04	2,55	-21,33
2	7,01	3,55	-24,11
3	8,99	4,55	-26,50
4	11,95	6,05	-28,36
5	16,49	8,35	-30,36
6	24,59	12,45	-34,22
7	36,24	18,35	-38,18
8	48,49	24,55	-41,25
9	60,73	30,75	-43,27
10	74,56	37,75	-44,62

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	-	-
1	-	-
2	-	-
3	-	-
4	-	-
5	-	-
6 to 10	-	-
mixture	-	-

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	82
D50	:	113
D90	:	165

WATER SURFACE SLOPE : i= 2,45 *10 -4

Test	: T 7.5,0	Date	: 6-07-'87
Experimentno.	: 10	Watertemperature:	21,0 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,38	0,06
Zero-cross Period Tz	(*10 -2 m)	2,15	0,05
Peak Period Tp	(*10 -2 m)	2,32	0,00
Ratio H(1%)/Hsig	(-)	1,57	-
Waterdepth to mean bed a	(*10 -2 m)	49,30	0,00
Depth averaged Velocity v	(*10-2 m/s)	0,00	0,00

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,04	0,25
Ripple Length λ	(*10 -2 m)	6,37	3,30
Ripple Velocity ur	(*10 -6 m/s)	-0,14	0,04
Ripple Shape		2-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	2,58	1,27	270	21	0,00	0,00
2	4,60	2,27	178	13	0,00	0,00
3	6,63	3,27	116	5	0,00	0,00
4	9,68	4,77	69	21	0,00	0,00
5	14,34	7,07	24	3	0,00	0,00
6	22,66	11,17	4	0	0,00	0,00
7	34,62	17,07	0	0	0,00	0,00
8	47,20	23,27	0	0	0,00	0,00
9	59,78	29,47	0	0	0,00	0,00
10	73,98	36,47	0	0	0,00	0,00

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	4,34	0,50
Suspended Load Ls	(")	9,26	1,02
Total Load Lt	(")	13,60	1,51
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,00	0,00
Suspended Load Transport Ss	(")	0,00	0,00
Total Load Transport St	(")	0,00	0,00

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	0,00	0,00	0,00
2	2,03	1,00	0,00
3	4,06	2,00	0,00
4	7,10	3,50	0,00
5	11,76	5,80	0,00
6	20,08	9,90	0,00
7	32,05	15,80	0,00
8	44,62	22,00	0,00
9	57,20	28,20	0,00
10	71,40	35,20	0,00

WATER SURFACE SLOPE : i= 0,00 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	8,44	105
1	8,57	106
2	7,88	101
3	7,45	97
4	3,12	60
5	6,55	90
6 to 10	-	-
mixture	8,30	104

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	70
D50	:	100
D90	:	128

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 7.5,10	Date	:09-10-'87
Experimentno.	: 46	Watertemperature:	20,8 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,31	0,12
Zero-cross Period Tz	(*10 -2 m)	2,12	0,04
Peak Period Tp	(*10 -2 m)	2,32	0,00
Ratio H(1%)/Hsig	(-)	1,60	-
Waterdepth to mean bed a	(*10 -2 m)	51,00	0,00
Depth averaged Velocity v	(*10-2 m/s)	9,96	0,20

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,99	0,26
Ripple Length λ	(*10 -2 m)	6,62	1,23
Ripple Velocity ur	(*10 -6 m/s)	2,72	0,70
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN	STAND.DEV. *10 -3	VELOCITY V (M/S) MEAN	STAND.DEV. *10 -2
1	2,94	1,50	221	52	2,40	0,40
2	4,90	2,50	97	5	3,30	0,10
3	6,86	3,50	63	6	4,40	0,10
4	9,80	5,00	40	2	5,90	0,30
5	14,31	7,30	17	1	7,10	0,40
6	22,35	11,40	5	1	8,60	0,50
7	33,92	17,30	2	0	10,40	0,20
8	46,08	23,50	0	0	11,20	0,20
9	58,24	29,70	0	0	11,00	0,20
10	71,96	36,70	0	0	12,00	0,10

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	4,56	1,36
Suspended Load Ls	(")	7,61	1,28
Total Load Lt	(")	12,16	2,64
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,01	0,01
Suspended Load Transport Ss	(")	0,26	0,06
Total Load Transport St	(")	0,27	0,07

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	2,94	1,50	4,50
2	4,90	2,50	5,50
3	6,86	3,50	6,40
4	9,80	5,00	6,60
5	14,31	7,30	7,90
6	22,35	11,40	10,60
7	33,92	17,30	11,00
8	46,08	23,50	11,30
9	58,24	29,70	11,60
10	71,96	36,70	12,00

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,20	115
1	10,20	115
2	9,55	112
3	3,71	66
4	8,81	108
5	-	-
6 to 10	-	-
mixture	9,77	114

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	73
D50	:	108
D90	:	148

WATER SURFACE SLOPE : i= 0,25 *10 -4

Test	:T 7.5, -10	Date	:06-08-'87
Experimentno.	: 25	Watertemperature:	20,3 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,10	0,69
Zero-cross Period Tz	(*10 -2 m)	1,91	0,08
Peak Period Tp	(*10 -2 m)	2,31	0,12
Ratio H(1%)/Hsig	(-)	1,48	-
Waterdepth to mean bed a	(*10 -2 m)	48,07	0,15
Depth averaged Velocity v	(*10-2 m/s)	-9,37	0,29

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,95	0,30
Ripple Length λ	(*10 -2 m)	6,28	1,29
Ripple Velocity ur	(*10 -6 m/s)	-1,72	0,77
Ripple Shape		2-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	2,29	1,10	267	42	-1,24	0,13
2	4,37	2,10	208	10	-2,18	0,30
3	6,45	3,10	147	6	-3,01	0,06
4	9,57	4,60	92	6	-3,97	0,32
5	14,35	6,90	40	1	-5,63	0,08
6	22,88	11,00	13	1	-6,58	0,97
7	35,16	16,90	5	0	-8,83	0,19
8	48,05	23,10	2	0	-10,48	0,11
9	60,95	29,30	0	0	-11,55	0,49
10	75,51	36,30	0	0	-12,42	0,35

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	3,34	0,82
Suspended Load Ls	(")	11,21	0,90
Total Load Lt	(")	14,56	1,72
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,01	0,00
Suspended Load Transport Ss	(")	-0,36	0,04
Total Load Transport St	(")	-0,36	0,05

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	2,29	1,10	-4,41
2	4,37	2,10	-5,01
3	6,45	3,10	-6,12
4	9,57	4,60	-6,42
5	14,35	6,90	-7,55
6	22,88	11,00	-8,28
7	35,16	16,90	-10,01
8	48,05	23,10	-10,26
9	60,95	29,30	-10,33
10	75,51	36,30	-10,05

WATER SURFACE SLOPE : i= 0,25 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	9,37	111
1	3,40	64
2	3,21	63
3	7,12	97
4	7,12	97
5	6,51	92
6 to 10	-	-
mixture	7,74	102

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	60
D50	:	100
D90	:	140

from: Delft University of Technology / Delft Hydraulics.
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 7.5,20	Date	:15-10-'87
Experimentno.	: 50	Watertemperature:	20,9 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,51	0,15
Zero-cross Period Tz	(*10 -2 m)	2,07	0,06
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,58	-
Waterdepth to mean bed a	(*10 -2 m)	50,67	0,06
Depth averaged Velocity v	(*10-2 m/s)	19,06	0,57

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,27	0,25
Ripple Length λ	(*10 -2 m)	8,44	1,21
Ripple Velocity ur	(*10 -6 m/s)	9,67	2,75
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,45	1,75	259	9	6,60	0,40
2	5,43	2,75	172	10	9,00	0,50
3	7,40	3,75	142	8	9,60	0,70
4	10,36	5,25	103	9	11,70	1,30
5	14,90	7,55	60	0	13,80	0,50
6	22,99	11,65	31	3	16,70	0,70
7	34,64	17,55	21	0	19,20	1,00
8	46,87	23,75	10	0	21,10	0,70
9	59,11	29,95	3	2	22,40	0,80
10	72,92	36,95	2	1	22,60	0,30

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	4,90	0,13
Suspended Load Ls	(")	15,95	0,83
Total Load Lt	(")	20,86	0,97
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,04	0,02
Suspended Load Transport Ss	(")	1,81	0,21
Total Load Transport St	(")	1,85	0,23

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,36	1,70	9,40
2	5,33	2,70	11,80
3	7,30	3,70	12,04
4	10,26	5,20	13,95
5	14,80	7,50	16,00
6	22,89	11,60	17,31
7	34,54	17,50	19,34
8	46,77	23,70	21,36
9	59,01	29,90	22,98
10	72,82	36,90	22,55

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	W50 (M/S) *10 -3	D50 (M) *10 -6
bed	9,37	111
1	3,75	67
2	10,20	115
3	9,55	112
4	9,77	114
5	-	-
6 to 10	8,99	109
mixture	9,26	110

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*	
D10 :	76
D50 :	106
D90 :	143

WATER SURFACE SLOPE : i= 0,65 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	: T 7.5, -20	Date	: 12-08-'87
Experimentno.	: 29	Watertemperature:	20,0 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,05	0,67
Zero-cross Period Tz	(*10 -2 m)	2,03	0,07
Peak Period Tp	(*10 -2 m)	2,24	0,00
Ratio H(1%)/Hsig	(-)	1,47	-
Waterdepth to mean bed a	(*10 -2 m)	49,17	0,21
Depth averaged Velocity v	(*10-2 m/s)	-18,43	0,38

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,83	0,46
Ripple Length λ	(*10 -2 m)	6,83	1,86
Ripple Velocity ur	(*10 -6 m/s)	-8,46	1,94
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	3,60	1,77	352	-	-4,98	0,23
2	5,63	2,77	276	-	-7,86	0,01
3	7,67	3,77	192	-	-9,40	0,33
4	10,72	5,27	135	-	-10,47	0,53
5	15,40	7,57	101	-	-13,56	0,64
6	23,73	11,67	62	-	-15,56	0,37
7	35,73	17,57	36	-	-17,81	0,50
8	48,34	23,77	22	-	-19,86	0,53
9	60,95	29,97	14	-	-21,75	0,55
10	75,19	36,97	9	-	-23,10	0,33

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	4,80	0,01
Suspended Load Ls	(")	27,20	0,01
Total Load Lt	(")	32,00	0,02
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,02	0,02
Suspended Load Transport Ss	(")	-2,95	0,09
Total Load Transport St	(")	-2,97	0,11

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	3,66	1,80	-9,88
2	5,69	2,80	-10,26
3	7,73	3,80	-12,10
4	10,78	5,30	-12,94
5	15,46	7,60	-15,19
6	23,79	11,70	-16,33
7	35,79	17,60	-18,62
8	48,40	23,80	-18,93
9	61,01	30,00	-19,46
10	75,25	37,00	-20,28

WATER SURFACE SLOPE : i= 0,43 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	10,22	116
1	8,21	103
2	8,21	103
3	7,58	100
4	7,58	100
5	7,58	100
6 to 10	6,86	94
mixture	8,44	105

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	77
D50	:	111
D90	:	156

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 7.5,40	Date	:28-07-'87
Experimentno.	: 21	Watertemperature:	19,8 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,67	0,00
Zero-cross Period Tz	(*10 -2 m)	1,95	0,05
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,51	-
Waterdepth to mean bed a	(*10 -2 m)	51,63	0,31
Depth averaged Velocity v	(*10-2 m/s)	36,40	0,98

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,15	0,58
Ripple Length λ	(*10 -2 m)	9,40	3,06
Ripple Velocity ur	(*10 -6 m/s)	16,45	5,87
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV. *10 -3	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV. *10 -2
1	3,68	1,90	1437	75	17,83	1,61
2	5,62	2,90	1056	92	17,93	1,82
3	7,55	3,90	768	161	22,14	0,45
4	10,46	5,40	666	82	24,02	0,74
5	14,91	7,70	541	61	27,75	0,94
6	22,85	11,80	335	42	31,95	2,00
7	34,28	17,70	194	29	37,86	0,43
8	46,29	23,90	98	22	40,49	1,02
9	58,30	30,10	60	10	42,47	1,25
10	71,86	37,10	44	17	41,46	2,62

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	27,55	0,44
Suspended Load Ls	(")	124,54	15,24
Total Load Lt	(")	152,09	15,69
Bed Load Transport Sb	(*10 -3 kg/s.m)	1,49	0,84
Suspended Load Transport Ss	(")	32,68	6,23
Total Load Transport St	(")	34,16	7,07

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	0,00	-	-
2	1,94	1,00	-
3	3,87	2,00	-
4	6,78	3,50	-
5	11,23	5,80	-
6	19,17	9,90	-
7	30,60	15,80	-
8	42,61	22,00	-
9	54,62	28,20	-
10	68,18	35,20	-

WATER SURFACE SLOPE : i= 0,26 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	9,77	114
1	8,81	108
2	8,74	107
3	8,74	107
4	8,44	105
5	2,54	55
6 to 10	2,42	54
mixture	9,37	111

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	74
D50	:	108
D90	:	156

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 7.5, -40	Date	:17-08-'87
Experimentno.	: 32	Watertemperature:	21,1 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	7,23	0,37
Zero-cross Period Tz	(*10 -2 m)	2,17	0,05
Peak Period Tp	(*10 -2 m)	2,36	0,04
Ratio H(1%)/Hsig	(-)	1,31	-
Waterdepth to mean bed a	(*10 -2 m)	49,13	0,06
Depth averaged Velocity v	(*10-2 m/s)	-38,84	0,49

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,48	0,89
Ripple Length λ	(*10 -2 m)	11,65	1,76
Ripple Velocity ur	(*10 -6 m/s)	-44,59	6,73
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,66	1,80	1270	184	-16,19	1,04
2	5,70	2,80	1045	150	-18,72	1,31
3	7,73	3,80	861	114	-20,83	0,60
4	10,79	5,30	684	88	-22,54	0,57
5	15,47	7,60	527	81	-27,01	0,31
6	23,81	11,70	335	31	-32,34	0,22
7	35,82	17,60	215	24	-37,81	0,71
8	48,44	23,80	107	12	-42,64	0,52
9	61,06	30,00	74	6	-45,59	0,71
10	75,31	37,00	43	5	-48,05	0,72

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	24,88	3,90
Suspended Load Ls	(")	117,81	14,98
Total Load Lt	(")	142,69	18,87
Bed Load Transport Sb	(*10 -3 kg/s.m)	-1,10	0,82
Suspended Load Transport Ss	(")	-32,16	4,71
Total Load Transport St	(")	-33,26	5,53

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,66	1,80	-15,95
2	5,70	2,80	-19,58
3	7,73	3,80	-23,97
4	10,79	5,30	-26,27
5	15,47	7,60	-30,62
6	23,81	11,70	-34,99
7	35,82	17,60	-39,35
8	48,44	23,80	-42,34
9	61,06	30,00	-45,40
10	75,31	37,00	-47,11

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,40	117
1	10,20	115
2	8,99	109
3	8,81	108
4	10,22	116
5	9,77	113
6 to 10	8,44	105
mixture	9,37	111

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	80
D50	:	112
D90	:	152

WATER SURFACE SLOPE : i= 1,28 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 10,0	Date	:03-07-'87
Experimentno.	: 9	Watertemperature:	18,6 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	10,33	0,07
Zero-cross Period Tz	(*10 -2 m)	2,04	0,06
Peak Period Tp	(*10 -2 m)	2,32	0,00
Ratio H(1%)/Hsig	(-)	1,53	-
Waterdepth to mean bed a	(*10 -2 m)	49,80	0,10
Depth averaged Velocity v	(*10-2 m/s)	0,00	0,00

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,90	0,28
Ripple Length λ	(*10 -2 m)	6,34	2,97
Ripple Velocity ur	(*10 -6 m/s)	-2,90	0,93
Ripple Shape		2-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION c (KG/M3) MEAN	STAND.DEV. *10 -3	VELOCITY v (M/S) MEAN	STAND.DEV. *10 -2
1	2,95	1,47	1263	91	0,00	0,00
2	4,96	2,47	802	81	0,00	0,00
3	6,97	3,47	512	47	0,00	0,00
4	9,98	4,97	308	37	0,00	0,00
5	14,60	7,27	111	10	0,00	0,00
6	22,83	11,37	11	1	0,00	0,00
7	34,68	17,27	2	0	0,00	0,00
8	47,13	23,47	0	0	0,00	0,00
9	59,58	29,67	0	0	0,00	0,00
10	73,63	36,67	0	0	0,00	0,00

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	20,04	1,33
Suspended Load Ls	(")	47,46	4,10
Total Load Lt	(")	67,50	5,43
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,00	0,00
Suspended Load Transport Ss	(")	0,00	0,00
Total Load Transport St	(")	0,00	0,00

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY v (M/S) *10 -2
1	0,00	0,00	0,00
2	2,01	1,00	0,00
3	4,02	2,00	0,00
4	7,03	3,50	0,00
5	11,65	5,80	0,00
6	19,88	9,90	0,00
7	31,73	15,80	0,00
8	44,18	22,00	0,00
9	56,63	28,20	0,00
10	70,68	35,20	0,00

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	7,58	100
1	3,29	62
2	7,43	96
3	2,99	59
4	3,06	60
5	2,92	58
6 to 10	-	-
mixture	7,88	101

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	67
D50	:	95
D90	:	124

WATER SURFACE SLOPE : i= 0,00 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 10 ,10	Date	:08-10-'87
Experimentno.	: 45	Watertemperature:	20,0 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	10,39	0,30
Zero-cross Period Tz	(*10 -2 m)	2,09	0,04
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,56	-
Waterdepth to mean bed a	(*10 -2 m)	50,17	0,06
Depth averaged Velocity v	(*10-2 m/s)	9,85	0,22

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,95	0,28
Ripple Length λ	(*10 -2 m)	6,63	1,39
Ripple Velocity ur	(*10 -6 m/s)	6,08	1,96
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV. *10 -3	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV. *10 -2
1	2,93	1,47	822	57	2,30	0,10
2	4,92	2,47	489	7	3,30	0,20
3	6,92	3,47	319	14	4,00	0,40
4	9,91	4,97	185	0	5,20	0,60
5	14,49	7,27	80	6	6,60	0,20
6	22,66	11,37	22	2	9,00	0,50
7	34,42	17,27	5	3	10,40	0,40
8	46,78	23,47	3	2	11,60	0,00
9	59,14	29,67	2	0	11,80	0,30
10	73,09	36,67	1	1	11,40	0,10

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	13,88	0,82
Suspended Load Ls	(")	31,46	1,87
Total Load Lt	(")	45,34	2,69
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,05	0,02
Suspended Load Transport Ss	(")	1,12	0,17
Total Load Transport St	(")	1,16	0,19

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	2,99	1,50	4,80
2	4,98	2,50	6,20
3	6,98	3,50	6,40
4	9,97	5,00	8,00
5	14,55	7,30	8,80
6	22,72	11,40	9,40
7	34,48	17,30	10,30
8	46,84	23,50	10,60
9	59,20	29,70	11,00
10	73,15	36,70	10,70

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	9,77	113
1	10,20	115
2	9,77	113
3	8,99	109
4	8,57	106
5	7,74	102
6 to 10	2,92	58
mixture	9,37	111

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	73
D50	:	107
D90	:	147

WATER SURFACE SLOPE : i= 0,20 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 10, -10	Date	:05-08-'87
Experimentno.	: 24	Watertemperature:	20,3 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	10,17	0,55
Zero-cross Period Tz	(*10 -2 m)	1,93	0,07
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	-	-
Waterdepth to mean bed a	(*10 -2 m)	49,40	0,10
Depth averaged Velocity v	(*10-2 m/s)	-10,60	0,21

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,80	0,30
Ripple Length λ	(*10 -2 m)	5,95	0,00
Ripple Velocity ur	(*10 -6 m/s)	-5,07	1,24
Ripple Shape		2-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION c (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY v (M/S) MEAN *10 -2	STAND.DEV.
1	2,37	1,17	1363	197	-1,89	0,19
2	4,39	2,17	861	125	-2,56	0,47
3	6,42	3,17	586	90	-3,62	0,43
4	9,45	4,67	359	57	-4,52	0,24
5	14,11	6,97	147	26	-6,09	0,30
6	22,41	11,07	38	6	-7,97	0,27
7	34,35	16,97	11	2	-10,34	0,15
8	46,90	23,17	4	1	-11,60	0,27
9	59,45	29,37	0	0	-12,56	0,31
10	73,62	36,37	0	0	-13,85	0,22

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	16,29	2,27
Suspended Load Ls	(")	49,51	7,46
Total Load Lt	(")	65,80	9,72
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,01	0,01
Suspended Load Transport Ss	(")	-1,63	0,40
Total Load Transport St	(")	-1,64	0,41

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY v (M/S) *10 -2
1	2,43	1,20	-5,57
2	4,45	2,20	-6,36
3	6,48	3,20	-7,20
4	9,51	4,70	-7,38
5	14,17	7,00	-8,59
6	22,47	11,10	-9,86
7	34,41	17,00	-10,44
8	46,96	23,20	-10,87
9	59,51	29,40	-10,94
10	73,68	36,40	-10,67

WATER SURFACE SLOPE : i= 0,25 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,20	115
1	-	-
2	-	-
3	-	-
4	-	-
5	6,48	92
6 to 10	-	-
mixture	-	-

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	73
D50	:	110
D90	:	162

Test :T 10 ,20
Experimentno. : 53

Date :21-10-'87
Watertemperature: - C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	10,10	0,10
Zero-cross Period Tz	(*10 -2 m)	2,00	0,03
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,60	-
Waterdepth to mean bed a	(*10 -2 m)	48,97	0,06
Depth averaged Velocity v	(*10-2 m/s)	20,27	0,36

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,19	0,40
Ripple Length λ	(*10 -2 m)	8,14	2,06
Ripple Velocity ur	(*10 -6 m/s)	12,81	3,77
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN	STAND.DEV. *10 -3	VELOCITY v (m/s) MEAN	STAND.DEV. *10 -2
1	4,08	2,00	896	139	7,30	0,20
2	6,13	3,00	655	61	9,50	0,90
3	8,17	4,00	503	39	11,40	1,40
4	11,23	5,50	388	24	12,60	0,60
5	15,93	7,80	247	13	16,30	0,80
6	24,30	11,90	118	13	19,00	0,30
7	36,35	17,80	59	4	22,30	0,60
8	49,01	24,00	30	5	23,40	0,20
9	61,67	30,20	17	2	23,70	0,20
10	75,96	37,20	11	2	22,80	0,50

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	17,36	4,67
Suspended Load Ls	(")	61,74	7,41
Total Load Lt	(")	79,10	12,08
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,17	0,09
Suspended Load Transport Ss	(")	7,51	1,19
Total Load Transport St	(")	7,69	1,28

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	4,08	2,00	11,09
2	6,13	3,00	12,55
3	8,17	4,00	13,30
4	11,23	5,50	15,40
5	15,93	7,80	16,60
6	24,30	11,90	20,12
7	36,35	17,80	20,46
8	49,01	24,00	23,24
9	61,67	30,20	24,03
10	75,96	37,20	22,52

WATER SURFACE SLOPE : i= 0,80 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	8,44	105
1	8,44	105
2	8,21	103
3	7,29	98
4	2,38	52
5	3,12	60
6 to 10	2,27	50
mixture	7,74	102

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	70
D50	:	100
D90	:	133

Test	:T 10,-20	Date	:11-08-'87
Experimentno.	: 28	Watertemperature:	20,0 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	10,46	0,06
Zero-cross Period Tz	(*10 -2 m)	1,93	0,03
Peak Period Tp	(*10 -2 m)	2,34	0,00
Ratio H(1%)/Hsig	(-)	1,44	-
Waterdepth to mean bed a	(*10 -2 m)	48,50	0,17
Depth averaged Velocity v	(*10-2 m/s)	-19,81	0,23

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,85	0,40
Ripple Length λ	(*10 -2 m)	6,34	1,37
Ripple Velocity ur	(*10 -6 m/s)	-16,24	4,36
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	3,03	1,47	1250	110	-5,36	0,21
2	5,09	2,47	812	37	-7,61	0,36
3	7,15	3,47	577	21	-9,52	0,67
4	10,25	4,97	400	28	-10,94	0,07
5	14,99	7,27	233	9	-12,93	0,28
6	23,44	11,37	129	8	-15,69	0,24
7	35,61	17,27	61	4	-18,62	0,25
8	48,39	23,47	38	4	-21,66	0,45
9	61,18	29,67	23	2	-23,91	0,09
10	75,61	36,67	11	1	-25,32	0,44

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	17,08	2,47
Suspended Load Ls	(")	67,86	4,97
Total Load Lt	(")	84,95	7,44
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,12	0,09
Suspended Load Transport Ss	(")	-6,85	0,68
Total Load Transport St	(")	-6,97	0,77

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	3,09	1,50	-9,70
2	5,15	2,50	-12,09
3	7,22	3,50	-12,67
4	10,31	5,00	-14,30
5	15,05	7,30	-16,53
6	23,51	11,40	-16,92
7	35,67	17,30	-18,80
8	48,45	23,50	-19,88
9	61,24	29,70	-21,16
10	75,67	36,70	-21,58

WATER SURFACE SLOPE : i= 0,42 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	10,22	116
1	8,21	103
2	7,50	99
3	7,58	100
4	7,58	100
5	7,22	98
6 to 10	6,75	94
mixture	8,21	105

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	77
D50	:	111
D90	:	157

Test	:T 10 ,40	Date	:29-07-'87
Experimentno.	: 22	Watertemperature:	20,1 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	9,46	0,01
Zero-cross Period Tz	(*10 -2 m)	1,90	0,01
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,29	-
Waterdepth to mean bed a	(*10 -2 m)	49,70	0,28
Depth averaged Velocity v	(*10-2 m/s)	34,72	1,05

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,44	0,51
Ripple Length λ	(*10 -2 m)	11,08	3,11
Ripple Velocity ur	(*10 -6 m/s)	25,14	8,33
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (KG/M3) MEAN *10 -3	STAND.DEV. *10 -3	VELOCITY v (M/S) MEAN *10 -2	STAND.DEV. *10 -2
1	4,63	2,30	1950	10	15,56	0,46
2	6,64	3,30	1525	78	17,28	0,21
3	8,65	4,30	1270	156	20,04	0,39
4	11,67	5,80	1082	137	22,68	1,85
5	16,30	8,10	856	126	26,46	0,84
6	24,55	12,20	547	77	30,95	0,07
7	36,42	18,10	322	54	35,56	0,48
8	48,89	24,30	153	41	37,81	1,59
9	61,37	30,50	88	16	40,83	2,82
10	75,45	37,50	59	9	41,42	2,27

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	42,25	0,01
Suspended Load Ls	(")	193,41	21,06
Total Load Lt	(")	235,67	21,07
Bed Load Transport Sb	(*10 -3 kg/s.m)	1,52	0,69
Suspended Load Transport Ss	(")	47,48	7,76
Total Load Transport St	(")	48,99	8,45

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (M/S) *10 -2
1	5,03	2,50	18,03
2	7,04	3,50	21,52
3	9,05	4,50	23,99
4	12,07	6,00	25,67
5	16,70	8,30	29,92
6	24,95	12,40	33,55
7	36,82	18,30	38,45
8	49,30	24,50	38,64
9	61,77	30,70	41,47
10	75,86	37,70	40,01

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	W50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,20	115
1	-	-
2	-	-
3	7,83	101
4	8,32	105
5	8,26	104
6 to 10	-	-
mixture	8,24	106

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	73
D50	:	109
D90	:	162

WATER SURFACE SLOPE : i= 2,45 *10 -4

Test	:T 10,-40	Date	:18-08-'87
Experimentno.	: 33	Watertemperature:	21,4 C

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	10,30	0,45
Zero-cross Period Tz	(*10 -2 m)	2,30	0,17
Peak Period Tp	(*10 -2 m)	2,53	0,28
Ratio H(1%)/Hsig	(-)	1,34	-
Waterdepth to mean bed a	(*10 -2 m)	49,27	0,38
Depth averaged Velocity v	(*10-2 m/s)	-38,85	0,80

RIPPLE PARAMETERS

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,39	0,63
Ripple Length λ	(*10 -2 m)	11,03	3,02
Ripple Velocity ur	(*10 -6 m/s)	-54,29	10,37
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION c (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY v (M/S) MEAN *10 -2	STAND.DEV.
1	3,45	1,70	2787	481	-15,24	1,02
2	5,48	2,70	1880	203	-17,53	0,52
3	7,51	3,70	1547	176	-20,12	1,27
4	10,55	5,20	1231	141	-21,71	1,28
5	15,22	7,50	918	101	-26,84	0,65
6	23,54	11,60	548	76	-32,17	1,02
7	35,52	17,50	270	65	-38,12	1,13
8	48,10	23,70	141	31	-42,81	0,91
9	60,69	29,90	81	15	-45,46	0,89
10	74,89	36,90	45	5	-48,06	1,22

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	56,11	11,89
Suspended Load Ls	(")	199,24	29,65
Total Load Lt	(")	255,35	41,54
Bed Load Transport Sb	(*10 -3 kg/s.m)	-2,28	1,25
Suspended Load Transport Ss	(")	-49,75	9,68
Total Load Transport St	(")	-52,03	10,93

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY v (M/S) *10 -2
1	3,45	1,70	-18,47
2	5,48	2,70	-21,45
3	7,51	3,70	-25,21
4	10,55	5,20	-27,19
5	15,22	7,50	-30,98
6	23,54	11,60	-34,65
7	35,52	17,50	-40,25
8	48,10	23,70	-43,40
9	60,69	29,90	-46,55
10	74,89	36,90	-47,53

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,49	118
1	11,60	123
2	9,77	113
3	9,55	112
4	9,77	113
5	9,55	112
6 to 10	9,37	111
mixture	9,77	113

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	81
D50	:	113
D90	:	151

WATER SURFACE SLOPE : i= 1,69 *10 -4

Test	:T 12,0	Date	:30-06-'87
Experimentno.	: 06	Watertemperature:	20,2 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	12,09	0,00
Zero-cross Period Tz	(*10 -2 m)	2,04	0,00
Peak Period Tp	(*10 -2 m)	2,32	0,01
Ratio H(1%)/Hsig	(-)	1,45	-
Waterdepth to mean bed a	(*10 -2 m)	48,40	0,00
Depth averaged Velocity v	(*10-2 m/s)	0,00	0,00

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,82	0,31
Ripple Length λ	(*10 -2 m)	6,73	2,50
Ripple Velocity ur	(*10 -6 m/s)	-5,10	3,40
Ripple Shape		2-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN	STAND.DEV. *10 -3	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	2,33	1,13	2220	165	0,00	0,00
2	4,40	2,13	1343	155	0,00	0,00
3	6,47	3,13	872	101	0,00	0,00
4	9,57	4,63	454	94	0,00	0,00
5	14,32	6,93	190	43	0,00	0,00
6	22,79	11,03	25	13	0,00	0,00
7	34,98	16,93	3	2	0,00	0,00
8	47,79	23,13	0	0	0,00	0,00
9	60,60	29,33	0	0	0,00	0,00
10	75,06	36,33	0	0	0,00	0,00

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	27,86	1,81
Suspended Load Ls	(")	70,62	8,89
Total Load Lt	(")	98,49	10,70
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,00	0,00
Suspended Load Transport Ss	(")	0,00	0,00
Total Load Transport St	(")	0,00	0,00

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	0,00	0,00	0,00
2	2,07	1,00	0,00
3	4,13	2,00	0,00
4	7,23	3,50	0,00
5	11,98	5,80	0,00
6	20,45	9,90	0,00
7	32,64	15,80	0,00
8	45,45	22,00	0,00
9	58,26	28,20	0,00
10	72,73	35,20	0,00

WATER SURFACE SLOPE : i= 0,00 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	-	-
1	-	-
2	-	-
3	-	-
4	-	-
5	-	-
6 to 10	-	-
mixture	-	-

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	69
D50	:	97
D90	:	127

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 15,0	Date	:01-07-'87
Experimentno.	: 07	Watertemperature:	20,7 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	15,38	0,22
Zero-cross Period Tz	(*10 -2 m)	1,85	0,05
Peak Period Tp	(*10 -2 m)	2,32	0,00
Ratio H(1%)/Hsig	(-)	1,23	-
Waterdepth to mean bed a	(*10 -2 m)	47,77	0,21
Depth averaged Velocity v	(*10-2 m/s)	0,00	0,00

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,75	0,35
Ripple Length λ	(*10 -2 m)	6,58	2,03
Ripple Velocity ur	(*10 -6 m/s)	-3,31	2,36
Ripple Shape		2-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	3,41	1,63	4137	350	0,00	0,00
2	5,51	2,63	2208	203	0,00	0,00
3	7,60	3,63	1260	94	0,00	0,00
4	10,74	5,13	603	56	0,00	0,00
5	15,55	7,43	209	17	0,00	0,00
6	24,14	11,53	15	2	0,00	0,00
7	36,49	17,43	3	3	0,00	0,00
8	49,47	23,63	2	2	0,00	0,00
9	62,45	29,83	0	0	0,00	0,00
10	77,10	36,83	0	0	0,00	0,00

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	72,86	7,08
Suspended Load Ls	(")	157,87	14,36
Total Load Lt	(")	230,73	21,44
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,00	0,00
Suspended Load Transport Ss	(")	0,00	0,00
Total Load Transport St	(")	0,00	0,00

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	0,00	0,00	0,00
2	2,09	1,00	0,00
3	4,19	2,00	0,00
4	7,33	3,50	0,00
5	12,14	5,80	0,00
6	20,72	9,90	0,00
7	33,08	15,80	0,00
8	46,05	22,00	0,00
9	59,03	28,20	0,00
10	73,69	35,20	0,00

WATER SURFACE SLOPE : i= 0,00 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	7,88	101
1	7,41	95
2	7,19	93
3	6,83	90
4	2,89	57
5	6,57	89
6 to 10	-	-
mixture	7,88	101

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	67
D50	:	96
D90	:	124

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 15 ,10	Date	:12-10-'87
Experimentno.	: 47	Watertemperature:	18,0 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	14,74	0,27
Zero-cross Period Tz	(*10 -2 m)	1,97	0,05
Peak Period Tp	(*10 -2 m)	2,60	0,00
Ratio H(1%)/Hsig	(-)	1,37	-
Waterdepth to mean bed a	(*10 -2 m)	49,40	0,00
Depth averaged Velocity v	(*10-2 m/s)	9,18	0,28

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,86	0,32
Ripple Length λ	(*10 -2 m)	6,47	0,00
Ripple Velocity ur	(*10 -6 m/s)	15,21	5,42
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	Height to mean bed z *10 -2 m	Concentration c (kg/m3) mean	Concentration stand.dev. *10 -3	Velocity v (m/s) mean *10 -2	Velocity stand.dev. *10 -2
1	3,44	1,70	2190	495	1,90	0,28
2	5,47	2,70	1115	290	2,95	0,21
3	7,49	3,70	649	175	3,90	0,57
4	10,53	5,20	339	92	5,05	0,50
5	15,18	7,50	130	22	6,90	0,10
6	23,48	11,60	36	1	9,85	0,35
7	35,43	17,50	14	2	11,00	0,14
8	47,98	23,70	7	0	11,20	0,28
9	60,53	29,90	3	0	10,55	0,50
10	74,70	36,90	3	1	9,75	0,64

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	45,89	9,23
Suspended Load Ls	(")	87,77	19,51
Total Load Lt	(")	133,65	28,74
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,06	0,04
Suspended Load Transport Ss	(")	2,25	0,77
Total Load Transport St	(")	2,31	0,81

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	Height to mean bed z *10 -2 m	Velocity v (m/s) *10 -2
1	3,04	1,50	5,13
2	5,06	2,50	6,08
3	7,09	3,50	6,50
4	10,12	5,00	6,64
5	14,78	7,30	7,28
6	23,08	11,40	9,01
7	35,02	17,30	9,42
8	47,57	23,50	10,47
9	60,12	29,70	10,68
10	74,29	36,70	10,84

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	9,77	113
1	8,74	107
2	7,88	101
3	8,21	103
4	7,77	98
5	3,02	59
6 to 10	2,86	57
mixture	3,48	64

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	74
D50	:	107
D90	:	151

WATER SURFACE SLOPE : i= 0,23 *10 -4

Test	: T 15,-10	Date	: 07-08-'87
Experimentno.	: 26	Watertemperature:	20,5 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	14,87	0,21
Zero-cross Period Tz	(*10 -2 m)	1,81	0,02
Peak Period Tp	(*10 -2 m)	2,33	0,12
Ratio H(1%)/Hsig	(-)	1,36	-
Waterdepth to mean bed a	(*10 -2 m)	48,97	0,42
Depth averaged Velocity v	(*10-2 m/s)	-12,12	0,25

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,75	0,31
Ripple Length λ	(*10 -2 m)	6,17	1,65
Ripple Velocity ur	(*10 -6 m/s)	-12,13	4,92
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	3,27	1,60	3673	482	-2,35	0,40
2	5,31	2,60	2703	46	-3,12	0,36
3	7,35	3,60	1773	118	-3,94	0,21
4	10,41	5,10	948	19	-5,16	0,68
5	15,11	7,40	377	25	-6,84	0,28
6	23,48	11,50	73	1	-9,09	0,35
7	35,53	17,40	18	4	-11,38	0,22
8	48,19	23,60	6	1	-13,39	0,13
9	60,85	29,80	3	1	-14,88	0,30
10	75,15	36,80	0	0	-16,25	0,50

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	47,10	5,70
Suspended Load Ls	(")	161,28	12,89
Total Load Lt	(")	208,38	18,59
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,14	0,09
Suspended Load Transport Ss	(")	-5,31	0,97
Total Load Transport St	(")	-5,45	1,06

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	3,27	1,60	-5,93
2	5,31	2,60	-6,33
3	7,35	3,60	-7,26
4	10,41	5,10	-7,86
5	15,11	7,40	-8,80
6	23,48	11,50	-9,96
7	35,53	17,40	-10,89
8	48,19	23,60	-11,43
9	60,85	29,80	-11,21
10	75,15	36,80	-11,41

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	10,20	115
1	7,01	95
2	6,56	92
3	7,20	97
4	6,72	93
5	6,56	92
6 to 10	6,26	89
mixture	7,58	110

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	75
D50	:	110
D90	:	160

WATER SURFACE SLOPE : i= 0,16 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 15 ,20	Date	:19-10-'87
Experimentno.	: 51	Watertemperature:	20,2 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	14,92	0,19
Zero-cross Period Tz	(*10 -2 m)	1,92	0,06
Peak Period Tp	(*10 -2 m)	2,61	0,00
Ratio H(1%)/Hsig	(-)	1,39	-
Waterdepth to mean bed a	(*10 -2 m)	50,40	0,10
Depth averaged Velocity v	(*10-2 m/s)	19,29	0,35

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,10	0,62
Ripple Length λ	(*10 -2 m)	7,79	3,23
Ripple Velocity ur	(*10 -6 m/s)	25,77	10,10
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,63	1,83	2160	259	6,20	0,40
2	5,62	2,83	1400	70	7,50	0,40
3	7,60	3,83	986	41	9,90	0,10
4	10,58	5,33	645	32	11,70	1,00
5	15,14	7,63	372	17	14,70	0,20
6	23,27	11,73	156	9	17,60	1,00
7	34,98	17,63	58	6	21,10	0,40
8	47,28	23,83	29	2	22,80	0,20
9	59,58	30,03	20	4	22,40	0,20
10	73,47	37,03	16	1	21,80	0,60

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	43,39	10,87
Suspended Load Ls	(")	113,70	11,29
Total Load Lt	(")	157,09	22,16
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,40	0,32
Suspended Load Transport Ss	(")	10,83	1,46
Total Load Transport St	(")	11,23	1,78

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,57	1,80	10,16
2	5,56	2,80	11,42
3	7,54	3,80	12,90
4	10,52	5,30	14,01
5	15,08	7,60	16,10
6	23,21	11,70	17,97
7	34,92	17,60	20,33
8	47,22	23,80	22,46
9	59,52	30,00	22,58
10	73,41	37,00	22,81

WATER SURFACE SLOPE : i= 0,74 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	W50 (M/S) *10 -3	D50 (M) *10 -6
bed	9,77	114
1	9,77	111
2	2,78	57
3	9,55	112
4	8,81	108
5	9,77	111
6 to 10	8,44	105
mixture	9,77	114

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	77
D50	:	109
D90	:	153

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 15,-20	Date	:14-08-'87
Experimentno.	: 31	Watertemperature:	20,7 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	14,81	0,12
Zero-cross Period Tz	(*10 -2 m)	1,97	0,02
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,37	-
Waterdepth to mean bed a	(*10 -2 m)	49,43	0,06
Depth averaged Velocity v	(*10-2 m/s)	-20,84	0,22

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,62	0,37
Ripple Length λ	(*10 -2 m)	6,34	1,74
Ripple Velocity ur	(*10 -6 m/s)	-20,36	5,35
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN	STAND.DEV. *10 -3	VELOCITY v (m/s) MEAN	STAND.DEV. *10 -2
1	3,50	1,73	3693	200	-4,80	0,47
2	5,52	2,73	2503	35	-6,46	0,66
3	7,55	3,73	1603	40	-8,76	0,14
4	10,58	5,23	951	21	-10,70	0,20
5	15,23	7,53	475	34	-13,06	0,27
6	23,53	11,63	195	20	-15,97	0,67
7	35,46	17,53	91	9	-19,94	0,19
8	48,01	23,73	43	4	-22,81	0,08
9	60,55	29,93	29	5	-24,85	0,24
10	74,71	36,93	16	4	-27,30	0,19

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	44,72	3,25
Suspended Load Ls	(")	192,32	10,53
Total Load Lt	(")	237,03	13,79
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,16	0,16
Suspended Load Transport Ss	(")	-14,22	1,69
Total Load Transport St	(")	-14,38	1,85

CURRENT ALONE

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	VELOCITY v (m/s) *10 -2
1	3,44	1,70	-9,61
2	5,46	2,70	-10,78
3	7,49	3,70	-12,52
4	10,52	5,20	-13,25
5	15,17	7,50	-15,21
6	23,47	11,60	-17,44
7	35,40	17,50	-18,33
8	47,95	23,70	-20,36
9	60,49	29,90	-21,72
10	74,65	36,90	-22,37

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (m/s) *10 -3	D50 (m) *10 -6
bed	10,22	116
1	9,55	112
2	7,58	100
3	7,41	99
4	7,30	97
5	7,30	97
6 to 10	7,35	98
mixture	7,58	100

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	79
D50	:	112
D90	:	153

WATER SURFACE SLOPE : i= 0,39 *10 -4

Test	:T 15 ,40	Date	:22-10-'87
Experimentno.	: 54	Watertemperature:	- C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	13,99	0,64
Zero-cross Period Tz	(*10 -2 m)	1,79	0,03
Peak Period Tp	(*10 -2 m)	2,33	0,01
Ratio H(1%)/Hsig	(-)	1,31	-
Waterdepth to mean bed a	(*10 -2 m)	50,50	0,56
Depth averaged Velocity v	(*10-2 m/s)	38,63	0,67

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,51	0,63
Ripple Length λ	(*10 -2 m)	11,84	3,88
Ripple Velocity ur	(*10 -6 m/s)	84,15	12,18
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	4,61	2,33	3880	394	16,90	2,40
2	6,59	3,33	3180	341	20,20	2,80
3	8,57	4,33	2837	335	21,90	1,80
4	11,54	5,83	2503	362	24,50	1,50
5	16,10	8,13	1688	234	28,60	0,00
6	24,22	12,23	995	128	33,60	0,90
7	35,90	18,13	545	9	39,50	0,30
8	48,18	24,33	225	47	44,40	0,80
9	60,46	30,53	111	24	46,00	0,50
10	74,32	37,53	79	19	45,20	0,90

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	78,56	6,83
Suspended Load Ls	(")	369,23	43,83
Total Load Lt	(")	447,79	50,66
Bed Load Transport Sb	(*10 -3 kg/s.m)	2,78	1,58
Suspended Load Transport Ss	(")	96,57	17,07
Total Load Transport St	(")	99,35	18,65

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	5,54	2,80	17,97
2	7,52	3,80	19,06
3	9,50	4,80	21,50
4	12,48	6,30	25,20
5	17,03	8,60	28,88
6	25,15	12,70	36,26
7	36,83	18,60	40,92
8	49,11	24,80	45,48
9	61,39	31,00	46,47
10	75,25	38,00	46,49

WATER SURFACE SLOPE : i= 3,28 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	9,26	110
1	8,99	109
2	8,81	108
3	8,57	106
4	8,99	109
5	8,57	106
6 to 10	2,45	54
mixture	8,79	108

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	73
D50	:	105
D90	:	153

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 15,-40	Date	:19-08-'87
Experimentno.	: 34	Watertemperature:	21,3 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	14,19	0,34
Zero-cross Period Tz	(*10 -2 m)	2,17	0,14
Peak Period Tp	(*10 -2 m)	2,68	0,00
Ratio H(1%)/Hsig	(-)	1,35	-
Waterdepth to mean bed a	(*10 -2 m)	50,40	0,42
Depth averaged Velocity v	(*10-2 m/s)	-38,02	0,32

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,85	-
Ripple Length λ	(*10 -2 m)	14,50	-
Ripple Velocity ur	(*10 -6 m/s)	-57,59	9,82
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION c (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY v (M/S) MEAN *10 -2	STAND.DEV.
1	4,96	2,50	4085	983	-16,84	0,71
2	6,94	3,50	2870	156	-18,19	1,37
3	8,93	4,50	2560	127	-19,43	0,98
4	11,90	6,00	2115	78	-22,55	0,42
5	16,47	8,30	1460	99	-26,04	0,20
6	24,60	12,40	870	33	-31,32	0,29
7	36,31	18,30	432	39	-37,60	0,32
8	48,61	24,50	197	30	-42,15	0,53
9	60,91	30,70	90	16	-45,44	0,05
10	74,80	37,70	43	6	-47,26	0,58

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	117,61	124,51
Suspended Load Ls	(")	336,90	57,61
Total Load Lt	(")	454,51	182,12
Bed Load Transport Sb	(*10 -3 kg/s.m)	-6,22	-
Suspended Load Transport Ss	(")	-80,75	13,75
Total Load Transport St	(")	-86,97	13,75

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY v (M/S) *10 -2
1	5,16	2,60	-19,33
2	7,14	3,60	-21,86
3	9,13	4,60	-23,92
4	12,10	6,10	-28,54
5	16,67	8,40	-31,82
6	24,80	12,50	-34,58
7	36,51	18,40	-38,32
8	48,81	24,60	-41,54
9	61,11	30,80	-42,95
10	75,00	37,80	-42,46

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,49	118
1	11,50	122
2	10,40	117
3	10,20	115
4	10,22	116
5	9,77	113
6 to 10	9,26	110
mixture	10,49	118

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	82
D50	:	113
D90	:	150

WATER SURFACE SLOPE : i= 2,08 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 18,0	Date	:07-07-'87
Experimentno.	: 11	Watertemperature:	21,5 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	18,08	0,24
Zero-cross Period Tz	(*10 -2 m)	1,85	0,02
Peak Period Tp	(*10 -2 m)	2,57	0,00
Ratio H(1%)/Hsig	(-)	1,25	-
Waterdepth to mean bed a	(*10 -2 m)	49,67	0,06
Depth averaged Velocity v	(*10-2 m/s)	0,00	0,00

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,70	0,28
Ripple Length λ	(*10 -2 m)	5,99	2,19
Ripple Velocity ur	(*10 -6 m/s)	-3,07	4,94
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,76	1,87	6403	449	0,00	0,00
2	5,78	2,87	3290	165	0,00	0,00
3	7,79	3,87	1811	135	0,00	0,00
4	10,81	5,37	803	22	0,00	0,00
5	15,44	7,67	224	29	0,00	0,00
6	23,70	11,77	21	5	0,00	0,00
7	35,57	17,67	4	0	0,00	0,00
8	48,06	23,87	1	1	0,00	0,00
9	60,54	30,07	1	1	0,00	0,00
10	74,63	37,07	0	0	0,00	0,00

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	130,18	7,67
Suspended Load Ls	(")	285,84	18,17
Total Load Lt	(")	416,02	25,84
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,00	0,00
Suspended Load Transport Ss	(")	0,00	0,00
Total Load Transport St	(")	0,00	0,00

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	0,00	0,00	0,00
2	2,01	1,00	0,00
3	4,03	2,00	0,00
4	7,05	3,50	0,00
5	11,68	5,80	0,00
6	19,93	9,90	0,00
7	31,81	15,80	0,00
8	44,29	22,00	0,00
9	56,77	28,20	0,00
10	70,87	35,20	0,00

WATER SURFACE SLOPE : i= 0,00 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	8,30	104
1	6,67	92
2	6,67	92
3	-	-
4	6,09	87
5	5,51	82
6 to 10	-	-
mixture	6,07	89

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	70
D50	:	99
D90	:	127

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 18 ,10	Date	:13-10-'87
Experimentno.	: 48	Watertemperature:	20,1 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	17,97	0,55
Zero-cross Period Tz	(*10 -2 m)	1,90	0,04
Peak Period Tp	(*10 -2 m)	2,60	0,00
Ratio H(1%)/Hsig	(-)	1,30	-
Waterdepth to mean bed a	(*10 -2 m)	49,60	0,00
Depth averaged Velocity v	(*10-2 m/s)	8,60	0,23

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,88	0,33
Ripple Length λ	(*10 -2 m)	6,72	2,29
Ripple Velocity ur	(*10 -6 m/s)	22,83	13,11
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,23	1,60	4151	318	2,00	0,40
2	5,24	2,60	2170	220	3,50	0,10
3	7,26	3,60	1130	156	4,50	0,20
4	10,28	5,10	488	64	5,80	0,60
5	14,92	7,40	176	11	7,80	0,10
6	23,19	11,50	47	6	9,50	0,50
7	35,08	17,40	16	2	10,30	0,00
8	47,58	23,60	6	1	10,40	0,60
9	60,08	29,80	6	1	9,90	0,20
10	74,19	36,80	6	2	8,50	0,10

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	90,75	4,57
Suspended Load Ls	(")	151,52	12,62
Total Load Lt	(")	242,27	17,19
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,11	0,08
Suspended Load Transport Ss	(")	3,99	0,81
Total Load Transport St	(")	4,11	0,89

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,23	1,60	5,57
2	5,24	2,60	6,51
3	7,26	3,60	7,31
4	10,28	5,10	7,52
5	14,92	7,40	8,48
6	23,19	11,50	9,51
7	35,08	17,40	11,21
8	47,58	23,60	10,75
9	60,08	29,80	10,63
10	74,19	36,80	11,26

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	W50 (M/S) *10 -3	D50 (M) *10 -6
bed	9,26	110
1	8,99	109
2	8,57	106
3	7,57	102
4	7,88	101
5	7,32	97
6 to 10	6,36	89
mixture	8,74	107

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*		
D10	:	74
D50	:	105
D90	:	150

WATER SURFACE SLOPE : i= 0,18 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test :T 18,-10 Date :06-08-'87
Experimentno. : 27 Watertemperature: 19,4 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	17,92	0,55
Zero-cross Period Tz	(*10 -2 m)	1,78	0,01
Peak Period Tp	(*10 -2 m)	2,33	0,00
Ratio H(1%)/Hsig	(-)	1,23	-
Waterdepth to mean bed a	(*10 -2 m)	49,40	0,27
Depth averaged Velocity v	(*10-2 m/s)	-13,10	0,30

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,70	0,38
Ripple Length λ	(*10 -2 m)	6,77	2,20
Ripple Velocity ur	(*10 -6 m/s)	-15,87	4,72
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV. *10 -3	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV. *10 -2
1	2,98	1,47	6823	448	-2,00	0,35
2	5,00	2,47	3980	381	-2,95	0,28
3	7,02	3,47	2369	219	-4,10	0,47
4	10,06	4,97	1237	159	-5,53	0,54
5	14,72	7,27	434	29	-7,38	0,36
6	23,02	11,37	74	6	-9,71	0,37
7	34,96	17,27	17	2	-12,37	0,33
8	47,51	23,47	8	1	-14,67	0,22
9	60,06	29,67	2	1	-16,17	0,56
10	74,23	36,67	0	0	-17,32	0,34

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	94,92	5,33
Suspended Load Ls	(")	253,41	19,82
Total Load Lt	(")	348,33	25,15
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,16	0,14
Suspended Load Transport Ss	(")	-7,16	1,49
Total Load Transport St	(")	-7,32	1,63

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,04	1,50	-6,41
2	5,06	2,50	-7,11
3	7,09	3,50	-7,64
4	10,12	5,00	-8,57
5	14,78	7,30	-9,13
6	23,08	11,40	-10,64
7	35,02	17,30	-11,19
8	47,57	23,50	-11,90
9	60,12	29,70	-11,24
10	74,29	36,70	-11,28

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,22	116
1	6,96	96
2	6,63	93
3	6,75	94
4	6,50	92
5	6,25	90
6 to 10	5,40	83
mixture	7,58	100

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	76
D50	:	111
D90	:	158

WATER SURFACE SLOPE : i= 0,35 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:T 18 ,20	Date	:20-10-'87
Experimentno.	: 52	Watertemperature:	19,3 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	18,00	1,04
Zero-cross Period Tz	(*10 -2 m)	1,86	0,05
Peak Period Tp	(*10 -2 m)	2,60	0,00
Ratio H(1%)/Hsig	(-)	1,24	-
Waterdepth to mean bed a	(*10 -2 m)	51,07	0,15
Depth averaged Velocity v	(*10-2 m/s)	18,31	0,38

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,10	0,55
Ripple Length λ	(*10 -2 m)	7,87	3,29
Ripple Velocity ur	(*10 -6 m/s)	34,10	12,40
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,92	2,00	2760	286	5,90	0,50
2	5,87	3,00	1757	152	7,70	0,80
3	7,83	4,00	1157	83	9,50	0,30
4	10,77	5,50	697	51	11,60	0,50
5	15,27	7,80	370	14	15,20	0,70
6	23,30	11,90	150	5	18,20	0,90
7	34,85	17,80	55	3	20,10	0,10
8	46,99	24,00	28	2	21,30	0,40
9	59,13	30,20	23	0	21,00	0,30
10	72,84	37,20	22	1	20,20	0,80

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	64,40	9,25
Suspended Load Ls	(")	144,70	13,21
Total Load Lt	(")	209,10	22,45
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,45	0,34
Suspended Load Transport Ss	(")	12,16	1,74
Total Load Transport St	(")	12,61	2,08

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,92	2,00	10,57
2	5,87	3,00	11,92
3	7,83	4,00	13,52
4	10,77	5,50	13,67
5	15,27	7,80	16,78
6	23,30	11,90	18,19
7	34,85	17,80	20,35
8	46,99	24,00	22,58
9	59,13	30,20	22,87
10	72,84	37,20	22,30

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,22	116
1	9,77	114
2	10,20	115
3	9,37	111
4	9,26	110
5	9,55	112
6 to 10	8,57	106
mixture	10,22	116

PARTICLE DIAMETER

*BED MATERIAL (m) *10 -6*

D10	:	81
D50	:	111
D90	:	151

WATER SURFACE SLOPE : i= 0,25 *10 -4

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	: T 18,-20	Date	: 13-08-'87
Experimentno.	: 30	Watertemperature:	20,9 C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	17,99	0,22
Zero-cross Period Tz	(*10 -2 m)	1,87	0,03
Peak Period Tp	(*10 -2 m)	2,34	0,00
Ratio H(1%)/Hsig	(-)	1,30	-
Waterdepth to mean bed a	(*10 -2 m)	48,60	0,00
Depth averaged Velocity v	(*10-2 m/s)	-20,86	0,16

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,65	0,30
Ripple Length λ	(*10 -2 m)	5,95	1,49
Ripple Velocity ur	(*10 -6 m/s)	-22,96	4,03
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	3,70	1,80	5655	78	-5,04	0,65
2	5,76	2,80	3570	368	-6,84	0,24
3	7,82	3,80	2226	177	-8,15	0,10
4	10,91	5,30	1211	110	-10,55	0,32
5	15,64	7,60	582	68	-13,08	0,25
6	24,07	11,70	223	15	-16,60	0,33
7	36,21	17,60	99	7	-18,23	0,15
8	48,97	23,80	48	5	-23,45	0,08
9	61,73	30,00	31	5	-25,72	0,15
10	76,13	37,00	13	0	-27,67	0,10

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	79,31	0,38
Suspended Load Ls	(")	281,69	13,40
Total Load Lt	(")	361,00	13,78
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,39	0,28
Suspended Load Transport Ss	(")	-18,98	2,37
Total Load Transport St	(")	-19,37	2,65

CURRENT ALONE

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	3,70	1,80	-9,77
2	5,76	2,80	-11,73
3	7,82	3,80	-12,85
4	10,91	5,30	-14,24
5	15,64	7,60	-15,20
6	24,07	11,70	-16,94
7	36,21	17,60	-18,90
8	48,97	23,80	-20,25
9	61,73	30,00	-21,06
10	76,13	37,00	-21,63

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,22	116
1	8,44	105
2	7,88	101
3	8,21	103
4	7,58	100
5	7,35	98
6 to 10	6,99	93
mixture	8,30	104

PARTICLE DIAMETER
*BED MATERIAL (m) *10 -6*

D10 :	78
D50 :	112
D90 :	155

WATER SURFACE SLOPE : i= 0,37 *10 -4

Test	: T 18,-40	Date	: 23-10-'87
Experimentno.	: 55	Watertemperature:	- C

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	17,70	0,88
Zero-cross Period Tz	(*10 -2 m)	2,07	0,04
Peak Period Tp	(*10 -2 m)	2,47	0,08
Ratio H(1%)/Hsig	(-)	1,37	-
Waterdepth to mean bed a	(*10 -2 m)	50,33	0,35
Depth averaged Velocity v	(*10-2 m/s)	-39,51	0,50

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,54	0,99
Ripple Length λ	(*10 -2 m)	11,41	3,80
Ripple Velocity ur	(*10 -6 m/s)	-61,00	12,70
Ripple Shape		3-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN	STAND.DEV. *10 -3	VELOCITY V (M/S) MEAN	STAND.DEV. *10 -2
1	4,91	2,47	4347	169	-13,80	0,50
2	6,89	3,47	3657	256	-15,80	1,30
3	8,88	4,47	3193	174	-18,00	0,70
4	11,86	5,97	2677	142	-21,50	1,10
5	16,43	8,27	1788	232	-25,60	0,80
6	24,58	12,37	1065	84	-31,60	0,70
7	36,30	18,27	548	42	-38,80	0,20
8	48,62	24,47	257	16	-43,80	0,50
9	60,94	30,67	113	9	-48,10	0,30
10	74,85	37,67	49	5	-50,50	1,50

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	91,94	2,89
Suspended Load Ls	(")	405,59	27,56
Total Load Lt	(")	497,53	30,44
Bed Load Transport Sb	(*10 -3 kg/s.m)	-2,61	2,25
Suspended Load Transport Ss	(")	-93,28	9,96
Total Load Transport St	(")	-95,89	12,21

CURRENT ALONE

LEVEL NO.	Z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	VELOCITY V (M/S) *10 -2
1	5,56	2,80	-18,08
2	7,55	3,80	-21,68
3	9,54	4,80	-24,42
4	12,52	6,30	-27,46
5	17,09	8,60	-30,30
6	25,23	12,70	-33,50
7	36,96	18,60	-39,87
8	49,27	24,80	-42,73
9	61,59	31,00	-45,51
10	75,50	38,00	-45,76

WATER SURFACE SLOPE : i= 4,90 *10 -4

FALL VELOCITY OF SUSPENDED SEDIMENT AND BEDMATERIAL

LEVEL no.	w50 (M/S) *10 -3	D50 (M) *10 -6
bed	10,22	116
1	11,13	120
2	10,40	117
3	11,13	120
4	9,77	114
5	10,20	115
6 to 10	8,81	108
mixture	10,20	115

*PARTICLE DIAMETER BED MATERIAL (m) *10 -6*

D10	:	75
D50	:	111
D90	:	173

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

SAND BALANCE EXPERIMENTAL RESULTS

Test	:S 15,10	Date	:3,4,5,8-02-'88
Experimentno.	: WB	Watertemperature:	- C
Measuretime (min):	1380		
Wave-measurements (nrs.):	35		
Conc.+ Veloc.mea.m. (nrs.):	6		

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.	
Significant Waveheight Hsig	(*10-2 m)	15,07	0,86	
Zero-cross Period Tz	(*10 -2 m)	1,82	0,07	
Peak Period Tp	(*10 -2 m)	2,32	0,05	
Ratio H(1%)/Hsig	(-)	1,37	-	(ref.T 15,10)
Waterdepth to mean bed a	(*10 -2 m)	49,95	0,24	
Depth averaged Velocity v	(*10-2 m/s)	10,72	0,32	

RIPPLE PARAMETERS (ref. T 15,10)

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,86	0,32
Ripple Length λ	(*10 -2 m)	6,47	2,23
Ripple Velocity ur	(*10 -6 m/s)	15,21	5,42
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV. *10 -3	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV. *10 -2
1	3,16	1,58	1605	141	2,83	0,22
2	5,17	2,58	1033	112	4,39	0,40
3	7,17	3,58	655	88	5,78	0,35
4	10,17	5,08	375	61	6,74	0,71
5	14,77	7,38	166	23	8,83	0,26
6	22,98	11,48	56	8	10,98	0,58
7	34,79	17,38	19	2	12,45	0,34
8	47,21	23,58	8	1	12,51	0,35
9	59,62	29,78	6	1	12,05	0,44
10	73,63	36,78	5	2	11,46	0,39

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	25,65	1,68
Suspended Load Ls	(")	68,96	7,52
Total Load Lt	(")	94,60	9,20
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,06	0,04
Suspended Load Transport Ss	(")	3,10	0,63
Current-rel. Transport Scurr	(")	3,16	0,67

SAND BALANCE COMPUTATIONS

Porosity sand p	(-)	0,40		
Density of water rw	(kg/m3)	1000		
Density of sediment rs	(kg/m3)	2650		
Decrease sediment weight	(kg)	113,23		
				perc.(%)
Current-rel. Transport Scurr	(*10 -3 kg/s.m)		*3,16*	185
Wave-related Transport Swave	(")		*-1,45*	85
Total Load Transport St	(")		*1,71*	100

PARTICLE DIAMETER OF BED MATERIAL (*10 -6 m)

D10	:	76
D50	:	105
D90	:	145

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

Test	:S 15,-10	Date	:26,27,28-10-'87
Experimentno.	: TMB	Watertemperature:	- C
Measuretime (min):	746		
Wave-measurements (nrs.):	17		
Conc.+ Veloc.mea.m. (nrs.):	5		

WAVE AND CURRENT PARAMETERS

		MEAN	STAND.DEV.	
Significant Waveheight Hsig	(*10-2 m)	15,47	1,04	
Zero-cross Period Tz	(*10 -2 m)	2,01	0,07	
Peak Period Tp	(*10 -2 m)	2,55	0,07	
Ratio H(1%)/Hsig	(-)	1,36	-	(ref. T 15,-10)
Waterdepth to mean bed a	(*10 -2 m)	50,78	0,31	
Depth averaged Velocity v	(*10-2 m/s)	-11,45	0,33	

RIPPLE PARAMETERS (ref. T 15,-10)

		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	0,75	0,31
Ripple Length λ	(*10 -2 m)	6,17	1,65
Ripple Velocity ur	(*10 -6 m/s)	-12,13	-4,92
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/a (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 m	CONCENTRATION c (kg/m3) MEAN *10 -3	STAND.DEV.	VELOCITY v (m/s) MEAN *10 -2	STAND.DEV.
1	3,51	1,78	2485	239	-2,44	0,46
2	5,47	2,78	1675	210	-3,11	0,43
3	7,44	3,78	1095	146	-3,96	0,36
4	10,40	5,28	619	50	-4,82	0,20
5	14,93	7,58	260	12	-6,29	0,55
6	23,00	11,68	70	6	-8,20	0,68
7	34,62	17,58	18	1	-10,73	0,55
8	46,83	23,78	6	1	-12,77	0,37
9	59,04	29,98	4	1	-13,76	0,26
10	72,82	36,98	2	0	-15,26	0,21

LOADS AND TRANSPORTS

		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	36,10	2,76
Suspended Load Ls	(")	117,04	11,03
Total Load Lt	(")	153,14	13,80
Bed Load Transport Sb	(*10 -3 kg/s.m)	-0,14	0,09
Suspended Load Transport Ss	(")	-3,69	0,82
Current-rel. Transport Scurr	(")	-3,83	0,90

SAND BALANCE COMPUTATIONS

Measure-length of bed X	(m)	15,20	
Measure-area of bed	(m2)	12,16	
Porosity sand p	(-)	0,40	
Density of sediment rs	(kg/m3)	2650	
Decrease average bed level	(*10 -2 m)	0,63	(+/-0,1)

			perc.(%)
Current-rel. Transport Scurr	(*10 -3 kg/s.m)	-3,83	112
Wave-related Transport Swave	(")	0,42	12
Total Load Transport St	(")	-3,40	100

Test	:S 15,20	Date	:28-08-'87
Experimentno.	: 38	Watertemperature:	- C
Measuretime (min):	171		
Wave-measurements (nrs.):	2		
Conc.+ Veloc.mea.m. (nrs.):	2		

WAVE AND CURRENT PARAMETERS		MEAN	STAND.DEV.
Significant Waveheight Hsig	(*10-2 m)	14,45	-
Zero-cross Period Tz	(*10 -2 m)	2,05	-
Peak Period Tp	(*10 -2 m)	2,42	-
Ratio H(1%)/Hsig	(-)	1,39	- (ref. T 15,20)
Waterdepth to mean bed a	(*10 -2 m)	51,75	0,00
Depth averaged Velocity v	(*10-2 m/s)	20,00	0,77

RIPPLE PARAMETERS		MEAN	STAND.DEV
Ripple Height η	(*10 -2 m)	1,17	0,49
Ripple Length λ	(*10 -2 m)	7,98	2,46
Ripple Velocity ur	(*10 -6 m/s)	29,65	9,85
Ripple Shape		2,5-dimensional	

CONCENTRATIONS AND VELOCITIES

LEVEL NO.	z/A (-) (*10 +2)	HEIGHT TO MEAN BED z *10 -2 M	CONCENTRATION C (KG/M3) MEAN *10 -3	STAND.DEV.	VELOCITY V (M/S) MEAN *10 -2	STAND.DEV.
1	4,73	2,45	2285	205	6,97	1,52
2	6,67	3,45	1675	78	8,25	0,86
3	8,60	4,45	1120	28	9,20	0,59
4	11,50	5,95	760	6	11,74	0,95
5	15,94	8,25	476	4	14,55	0,83
6	23,86	12,35	200	4	17,64	0,98
7	35,27	18,25	74	0	20,88	0,81
8	47,25	24,45	44	2	22,79	1,29
9	59,23	30,65	30	7	23,63	1,04
10	72,75	37,65	24	6	23,84	0,62

LOADS AND TRANSPORTS		MEAN	STAND.DEV.
Bed Load Lb	(*10 -3 kg/m2)	58,93	21,38
Suspended Load Ls	(")	156,96	17,96
Total Load Lt	(")	215,89	39,34
Bed Load Transport Sb	(*10 -3 kg/s.m)	0,40	0,32
Suspended Load Transport Ss	(")	14,63	3,13
Current-rel. Transport Scurr	(")	15,03	3,45

SAND BALANCE COMPUTATIONS			
Measure-length of bed X	(m)	16,55	
Measure-area of bed	(m2)	13,24	
Porosity sand p	(-)	0,40	
Density of sediment rs	(kg/m3)	2650	
Decrease average bed level	(*10 -2 m)	0,44 (+/-0,1)	

			perc.(%)
Current-rel. Transport Scurr	(*10 -3 kg/s.m)	*15,03*	133
Wave-related Transport Swave	(")	*-3,74*	33
Total Load Transport St	(")	*11,28*	100

*PARTICLE DIAMETER OF SEDIMENT (*10 -6 m)*

D10	:	78
D50	:	107
D90	:	147

from: Delft University of Technology / Delft Hydraulics,
by : H.F.A.van Kampen, E.N.Nap.

TABLES and FIGURES

FOR COMPARISON OF THE EXPERIMENTAL RESULTS

(see chapter 4 and 6)

(averaged values)

D50= 100mu
a= 0.5 m
H= Hsig

Hsig = Significant Wave Height
Tp,rel= Wave spectrum Peak Period, relative to the current
L = Wave Length
Um = Depth-averaged velocity
Ub = Amplitude of Orbital Horizontal Velocity

	Hsig *10 -2 [m]	Tp,rel [s]	L [m]	Um *10 -2 [m/s]	Ub *10 -2 [m/s]	Ab *10 -2 [m]
T 7.5,0	7,38	2,32	4,65	-	14,00	5,20
T 7.5,10	7,31	2,43	5,10	9,96	14,10	5,50
T 7.5,-10	7,10	2,21	4,44	-9,37	13,80	4,80
T 7.5,20	7,51	2,54	5,39	19,06	14,90	6,00
T 7.5,-20	7,05	2,04	4,11	-18,43	13,20	4,30
T 7.5,40	7,67	2,88	4,44	36,40	15,60	7,20
T 7.5,-40	7,23	1,90	3,79	-38,84	13,20	4,00
T 10,0	10,33	2,32	4,68	-	19,40	7,20
T 10,10	10,39	2,44	5,12	9,85	20,40	7,90
T 10,-10	10,17	2,19	4,44	-10,60	19,90	6,90
T 10,20	10,10	2,56	5,32	20,27	20,30	8,30
T 10,-20	10,46	2,02	3,79	-19,81	19,70	6,40
T 10,40	9,46	2,71	5,71	34,72	19,10	8,30
T 10,-40	10,30	1,90	3,79	-38,85	18,80	5,70
T 15,0	15,38	2,32	4,57	-	29,50	10,90
T 15,10	14,74	2,71	5,74	9,18	30,10	13,00
T 15,-10	14,87	2,19	4,46	-12,12	28,60	10,00
T 15,20	14,92	2,85	6,07	19,29	30,20	13,70
T 15,-20	14,81	2,09	4,25	-20,84	26,80	9,30
T 15,40	13,99	2,75	5,87	38,63	28,20	12,40
T 15,-40	14,19	2,19	4,52	-38,02	26,80	9,30
T 18,0	18,08	2,32	5,09	-	33,90	13,10
T 18,10	17,97	2,71	5,70	8,60	36,30	15,60
T 18,-10	17,92	2,18	4,45	-13,10	34,20	11,90
T 18,20	18,00	2,82	6,08	18,31	36,30	16,30
T 18,-20	17,99	2,11	4,27	-20,86	34,40	11,60
T 18,-40	17,70	2,07	4,23	-39,51	32,80	10,80

TABLE 4.1

TOTAL LOADS & TOTAL TRANSPORT RATES

(mean values)

Lt = Total Load
St = Total Sediment Transport

Experiment	Lt *10 -3 kg/m2	St *10 -3 kg/m2
T 0,40	21,52	5,18
T 0,-40	34,46	-8,67
T 7.5,0	13,60	-
T 7.5,10	12,16	0,27
T 7.5,-10	14,56	-0,36
T 7.5,20	20,86	1,85
T 7.5,-20	32,00	-2,97
T 7.5,40	152,09	34,16
T 7.5,-40	142,69	-33,26
T 10,0	67,50	-
T 10,10	45,34	1,16
T 10,-10	65,80	-1,64
T 10,20	79,10	7,69
T 10,-20	84,95	-6,97
T 10,40	235,67	48,99
T 10,-40	255,35	-52,03
T 15,0	230,75	-
T 15,10	133,65	2,31
T 15,-10	208,38	-5,45
T 15,20	157,09	11,23
T 15,-20	237,03	-14,38
T 15,40	447,79	99,35
T 15,-40	454,51	-86,97
T 18,0	416,02	-
T 18,10	242,27	4,11
T 18,-10	348,33	-7,32
T 18,20	209,10	12,61
T 18,-20	361,00	-19,37
T 18,-40	497,53	-95,89

TABLE 4.2

(averaged values)

r = Ripple height
l = Ripple length
Um = Depth-averaged velocity
Ub = Amplitude of orbital hor. velocity
D50= Median diameter of sediment

D50= 100mu
a= 0.5 m
d= 1,65
g= 9,81 m/s2
H= Hsig

	r *10 -2 [m]	l *10 -2 [m]	l1/l2 [-]	r/l [-]	Um/Ub [-]	Um^2 dgD50 [-]	Ub^2 dgD50 [-]
T 0,40	1,22	10,48	1,06	0,116	-	83,12	0,00
T 0,-40	1,16	9,82	1,10	0,118	-	79,40	0,00
T 7.5,0	1,04	6,37	1,19	0,163	0,00	0,00	12,11
T 7.5,10	0,99	6,62	1,32	0,150	0,71	5,67	11,37
T 7.5,-10	0,95	6,28	1,04	0,151	-0,68	5,42	11,77
T 7.5,20	1,27	8,44	1,29	0,150	1,28	21,17	12,94
T 7.5,-20	0,83	6,83	1,11	0,122	-1,40	18,90	9,70
T 7.5,40	1,15	9,40	1,22	0,122	2,33	75,79	13,92
T 7.5,-40	1,48	0,89	1,19	0,166	-2,94	83,21	9,61
T 10,0	0,90	6,34	1,09	0,142	0,00	0,00	24,47
T 10,10	0,95	6,63	1,04	0,143	0,48	5,60	24,03
T 10,-10	0,80	5,95	0,99	0,134	-0,53	6,31	22,24
T 10,20	1,19	8,14	1,23	0,146	1,00	25,38	25,46
T 10,-20	0,85	6,34	0,96	0,134	-1,01	21,84	21,60
T 10,40	1,44	11,08	1,33	0,130	1,82	68,33	20,68
T 10,-40	1,39	11,03	1,12	0,126	-2,07	82,52	19,32
T 15,0	0,75	6,58	1,00	0,114	0,00	0,00	55,99
T 15,10	0,86	6,47	0,94	0,133	0,30	4,87	52,31
T 15,-10	0,75	6,17	0,97	0,122	-0,42	8,25	45,94
T 15,20	1,10	7,79	1,05	0,141	0,64	21,09	51,69
T 15,-20	0,62	6,34	0,97	0,098	-0,75	23,96	42,94
T 15,40	1,51	11,84	1,39	0,128	1,37	87,80	46,79
T 15,-40	1,85	14,50	1,05	0,128	-1,42	79,03	39,27
T 18,0	0,70	5,99	1,04	0,117	0,00	0,00	71,69
T 18,10	0,88	6,72	1,05	0,131	0,24	4,35	77,53
T 18,-10	0,70	6,77	0,80	0,103	-0,38	9,55	65,10
T 18,20	1,10	7,87	1,08	0,140	0,50	18,66	73,34
T 18,-20	0,65	5,95	1,11	0,109	-0,61	24,00	65,27
T 18,-40	1,54	11,41	1,00	0,135	1,20	86,88	59,88

TABLE 4.3

Ks determination from:
1. fit = curve-fitting from measured velocities.
2. V.B.= Vanoni-Brooks method.

D50= 100mu
a= 0.5 m

Experiment	r *10 -2 [m]	Ks fit *10 -2 [m]	fit/r [-]	Ks V.B. *10 -2 [m]	V.B./r [-]
T 0,40	1,22	9,08	7,44	-	-
T 0,-40	1,16	-	-	-	-
T 7.5,10	0,99	11,22	11,33	5,47	5,53
T 7.5,-10	0,95	5,74	6,04	-	-
T 7.5,20	1,27	7,16	5,64	2,48	1,95
T 7.5,-20	0,83	5,87	7,07	-	-
T 7.5,40	1,15	-	-	-	-
T 7.5,-40	1,48	13,00	8,78	-	-
T 10,10	0,95	5,31	5,59	3,50	3,68
T 10,-10	0,80	2,61	3,26	-	-
T 10,20	1,19	8,22	6,91	3,65	3,07
T 10,-20	0,85	3,43	4,04	-	-
T 10,40	1,44	12,54	8,71	4,72	3,28
T 10,-40	1,39	9,24	6,65	-	-
T 15,10	0,86	4,49	5,22	4,89	5,69
T 15,-10	0,75	4,32	5,76	-	-
T 15,20	1,10	8,55	7,77	3,72	3,38
T 15,-20	0,62	6,20	10,00	-	-
T 15,40	1,51	-	-	8,01	5,30
T 15,-40	1,85	12,97	7,01	-	-
T 18,10	0,88	4,46	5,07	2,06	2,34
T 18,-10	0,70	2,74	3,91	-	-
T 18,20	1,10	8,78	7,98	-	-
T 18,-20	0,65	5,02	7,72	-	-
T 18,-40	1,54	15,35	9,97	-	-
Averaged			6,60		3,80

TABLE 6.1

SHEAR VELOCITY- AND ROUGHNESS LENGHT SCALE VALUES

D50 = 100 mu

U*c = Shear velocity for current alone
U*c,w = Shear velocity for current in combination with waves
z0 = Roughness lenght scale for current alone
z1 = Roughness lenght scale for current in combination with waves

	U*c 10-2 [m/s]	U*c,w 10-2 [m/s]	z0 10-2 [m]	z1 10-2 [m]	z1/z0 - [-]	U*c,w/U*c - [-]
T7.5,10	1.08	1.35	0.34	0.86	2.53	1.25
T7.5,-10	0.81	1.21	0.17	0.99	5.82	1.49
T7.5,20	1.78	2.25	0.22	0.61	2.77	1.26
T7.5,-20	1.55	2.25	0.18	0.73	4.06	1.45
T7.5,40	-	-	-	-	-	-
T7.5,-40	4.01	4.14	0.39	0.47	1.21	1.03
T10,10	0.87	1.42	0.16	0.97	6.06	1.64
T10,-10	0.76	-	0.08	-	-	-
T10,20	2.08	2.72	0.25	0.74	2.96	1.31
T10,-20	1.46	2.29	0.10	0.66	6.60	1.57
T10,40	3.81	3.99	0.38	0.55	1.45	1.05
T10,-40	3.82	4.28	0.28	0.53	1.89	1.12
T15,10	0.76	1.59	0.14	1.27	9.07	2.09
T15,-10	0.88	1.68	0.13	1.22	9.38	1.93
T15,20	1.91	2.73	0.26	0.87	3.35	1.43
T15,-20	1.65	2.77	0.19	1.03	5.42	1.68
T15,40	-	-	-	-	-	-
T15,-40	3.98	4.58	0.39	0.73	1.87	1.15
T18,10	0.87	-	0.14	-	-	-
T18,-10	0.84	-	0.08	-	-	-
T18,20	1.92	2.67	0.27	0.90	3.33	1.39
T18,-20	1.58	2.89	0.15	1.09	7.27	1.83
T18,-40	4.45	5.38	0.47	1.08	2.29	1.21

TABLE 6.2.A

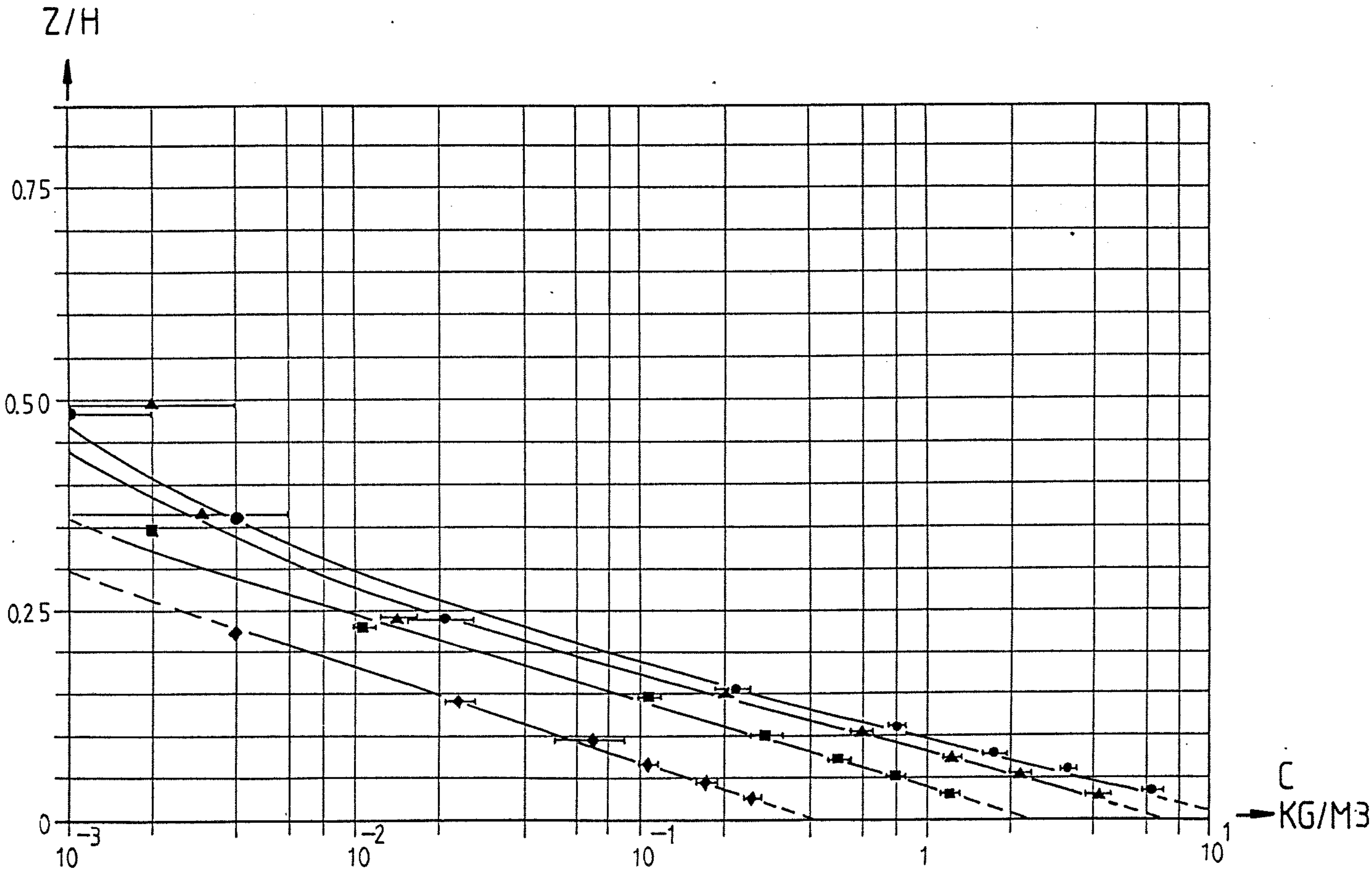
SHEAR VELOCITY- AND ROUGHNESS LENGHT SCALE VALUES

D50 = 200mu

U*c = Shear velocity for current alone
U*c,w = Shear velocity for current in combination with waves
z0 = Roughness lenght scale for current alone
z1 = Roughness lenght scale for current in combination with waves

	U*c 10-2 [m/s]	U*c,w 10-2 [m/s]	z0 10-2 [m]	z1 10-2 [m]	z1/z0 - [-]	U*c,w/U*c - [-]
T7.5,10	1.06	1.38	0.19	0.59	3.10	1.30
T7.5,20	2.14	2.84	0.30	0.82	2.73	1.33
T7.5,40	3.20	3.66	0.08	0.14	1.75	1.14
T10,10	0.99	1.72	0.18	1.06	5.89	1.73
T10,-10	1.21	1.79	0.23	1.08	4.70	1.48
T10,20	2.25	2.99	0.32	0.90	2.81	1.33
T10,-20	2.76	3.23	0.46	1.16	2.53	1.17
T10,-40	4.62	4.29	0.35	0.29	0.84	0.93
T12,10	0.83	1.46	0.15	0.87	5.89	1.76
T12,-10	1.02	1.71	0.23	1.38	6.09	1.76
T12,20	2.38	2.76	0.41	0.66	1.61	1.16
T12,-20	2.32	2.85	0.22	0.72	3.28	1.23
T12,-40	3.46	4.34	0.12	0.39	3.25	1.25
T15,10	1.02	1.88	0.24	1.35	5.63	1.84
T15,-10	1.25	2.11	0.32	1.72	5.38	1.69
T15,20	2.21	2.93	0.26	0.81	3.11	1.33
T15,-20	2.13	3.11	0.21	1.02	4.86	1.46
T18,-20	1.90	2.55	0.13	0.78	5.99	1.34
T18,-40	4.18	4.77	0.31	0.59	1.92	1.14

TABLE 6.2.B



Um = 0

♦ Hs = .075 (m)

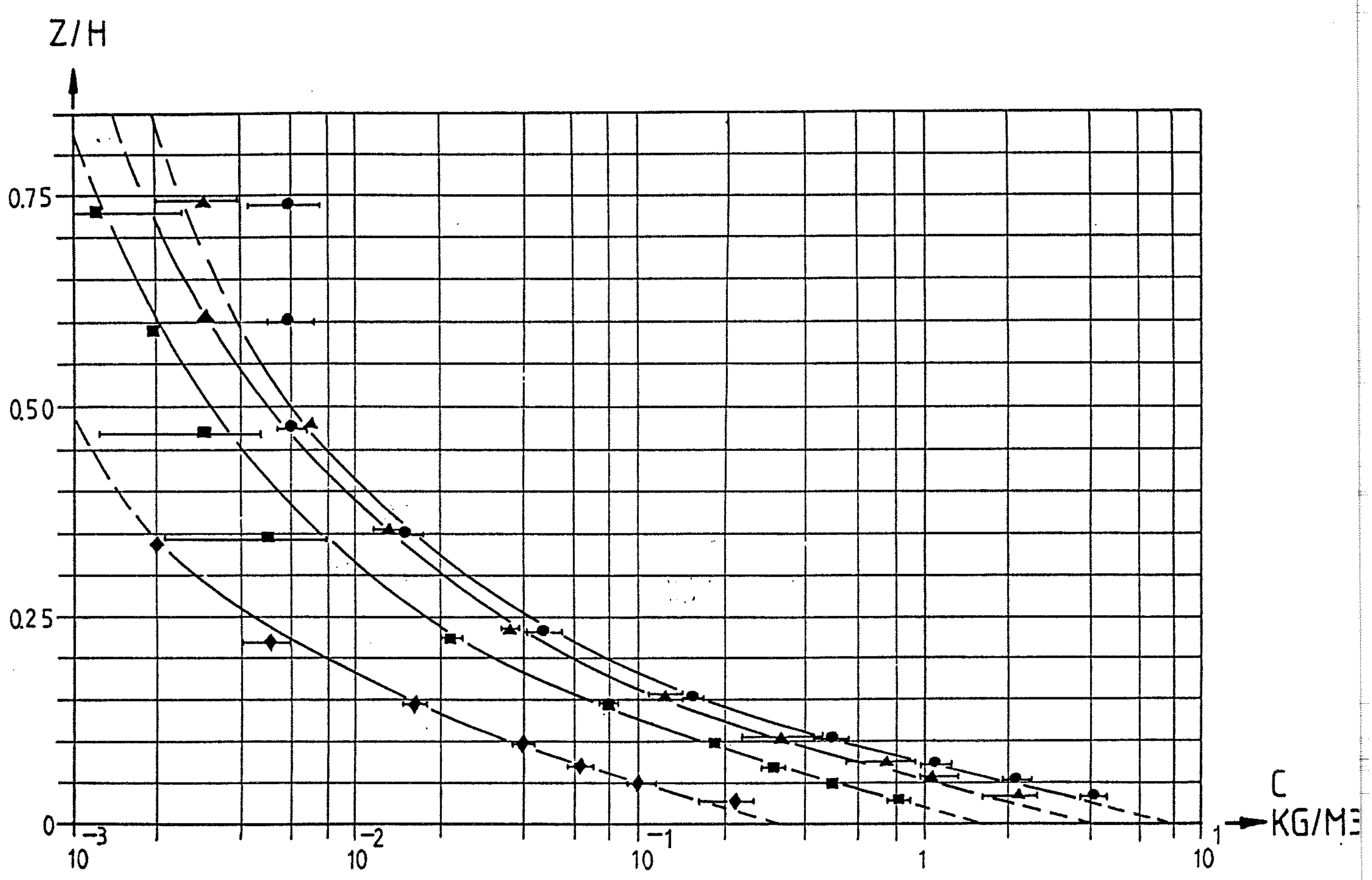
■ Hs = .10 (m)

▲ Hs = .15 (m)

● Hs = .18 (m)

TIME AND BED AVERAGED CONCENTRATIONS

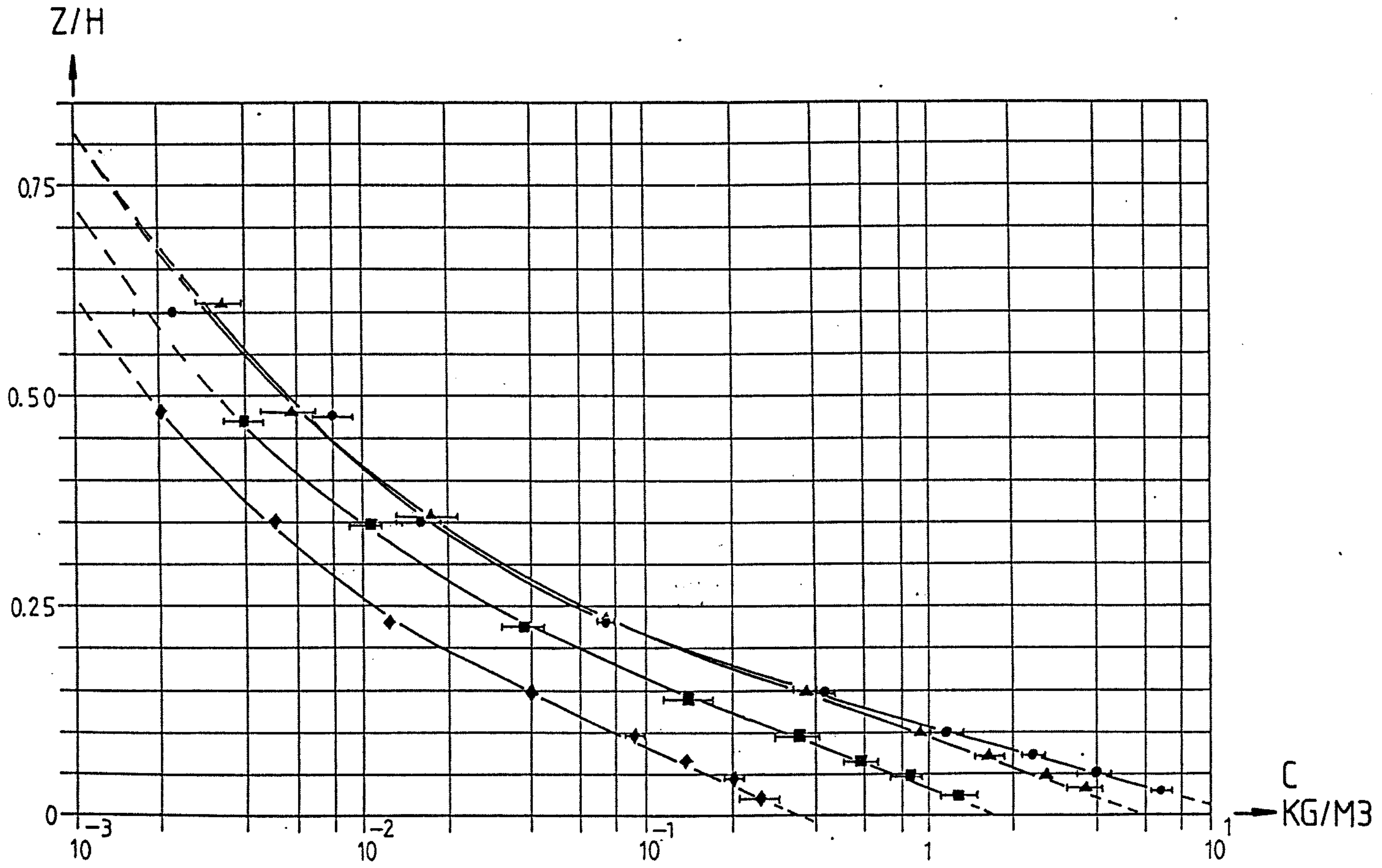
FIGURE 4.1.A



Um = .10 (m/s)
♦ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

TIME AND BED AVERAGED CONCENTRATIONS

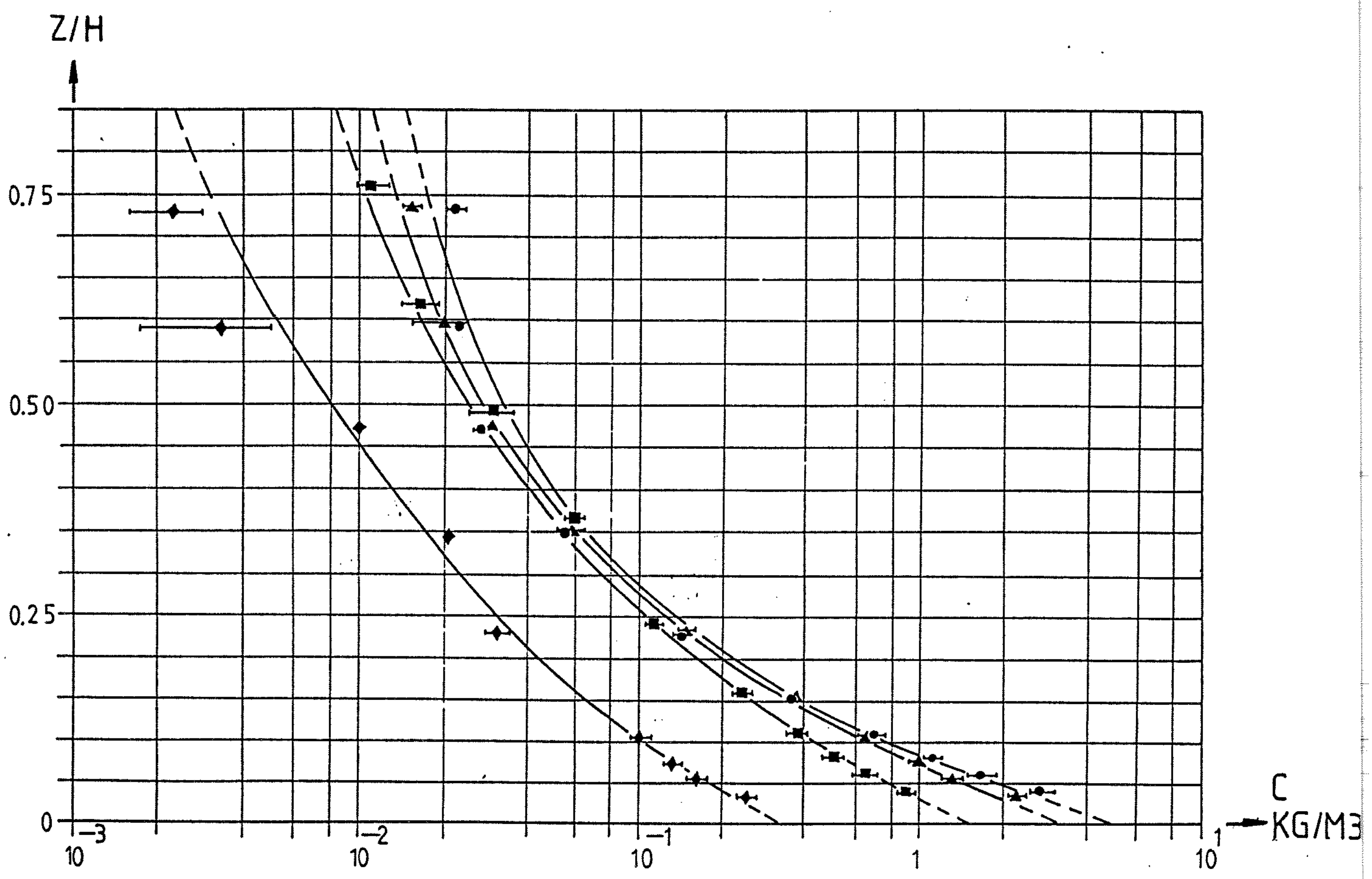
FIGURE 4.1.B



Um = -.20 (m/s)
◆ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

TIME AND BED AVERAGED CONCENTRATIONS

FIGURE 4.1.C

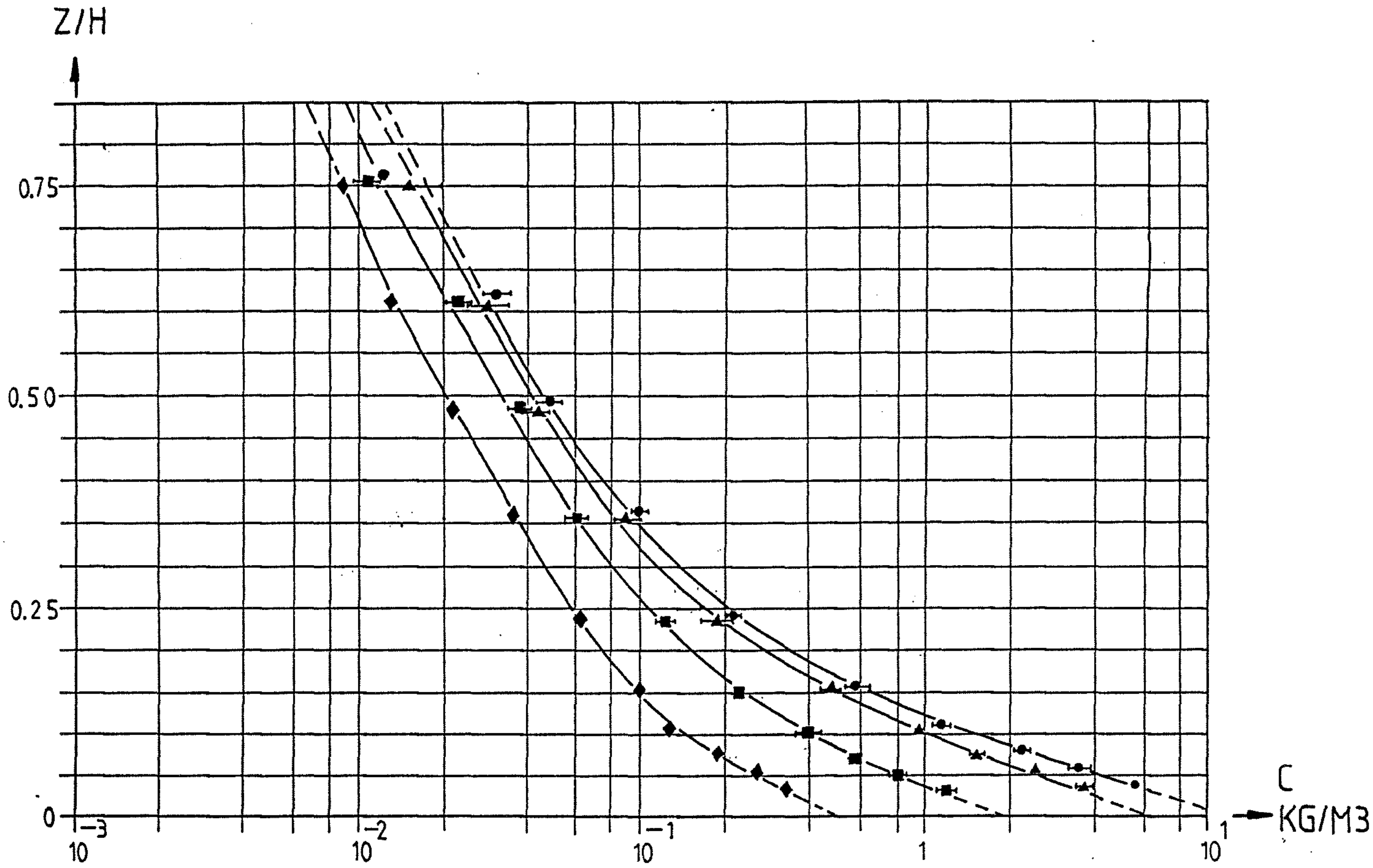


◆ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

Um = .20 (m/s)

TIME AND BED AVERAGED CONCENTRATIONS

FIGURE 4.1.D



Um = -.20 (m/s)

◆ Hs = .075 (m)

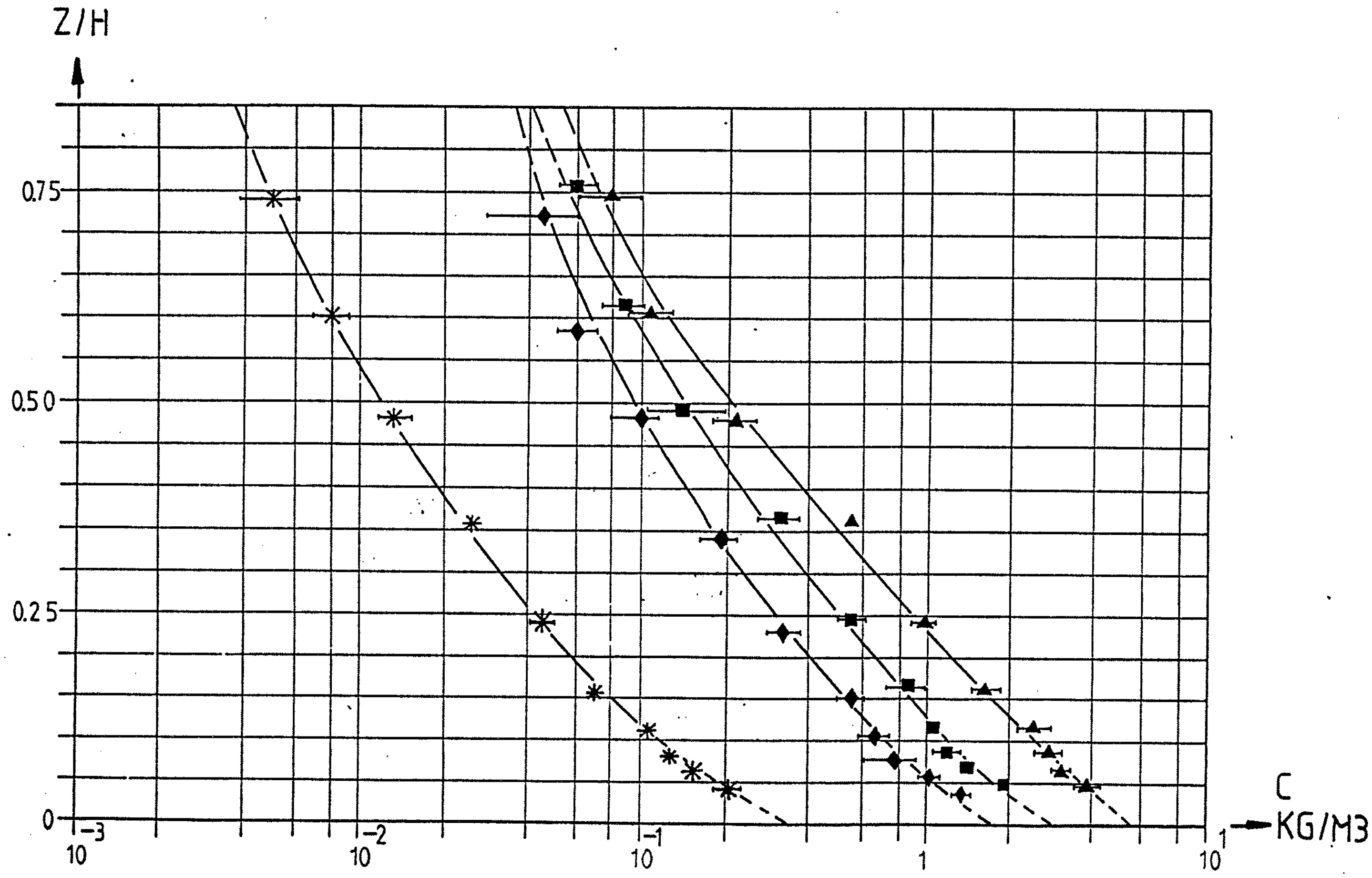
■ Hs = .10 (m)

▲ Hs = .15 (m)

● Hs = .18 (m)

TIME AND BED AVERAGED CONCENTRATIONS

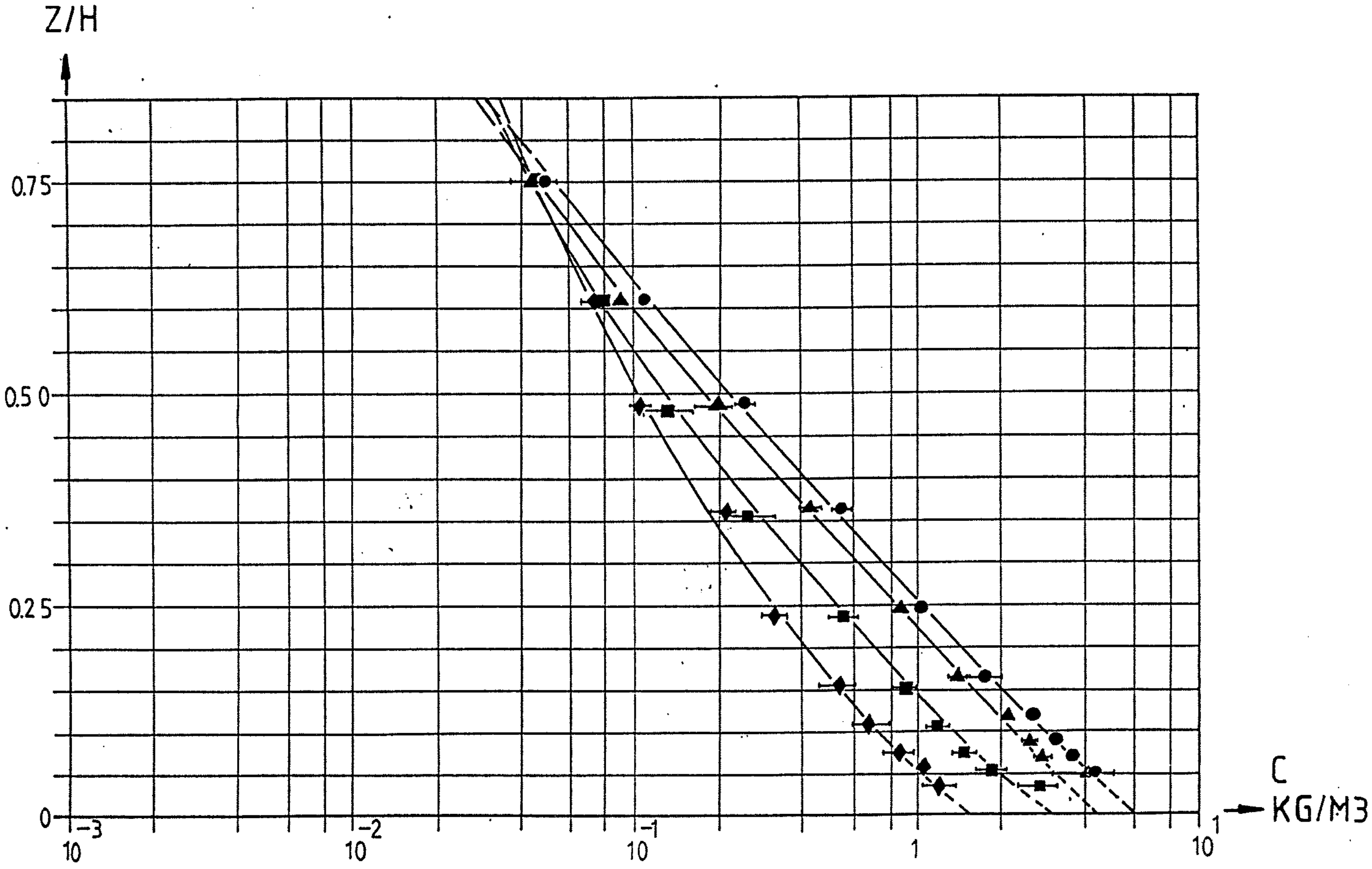
FIGURE 4.1.E



Um = .40 (m/s)
♦ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

TIME AND BED AVERAGED CONCENTRATIONS

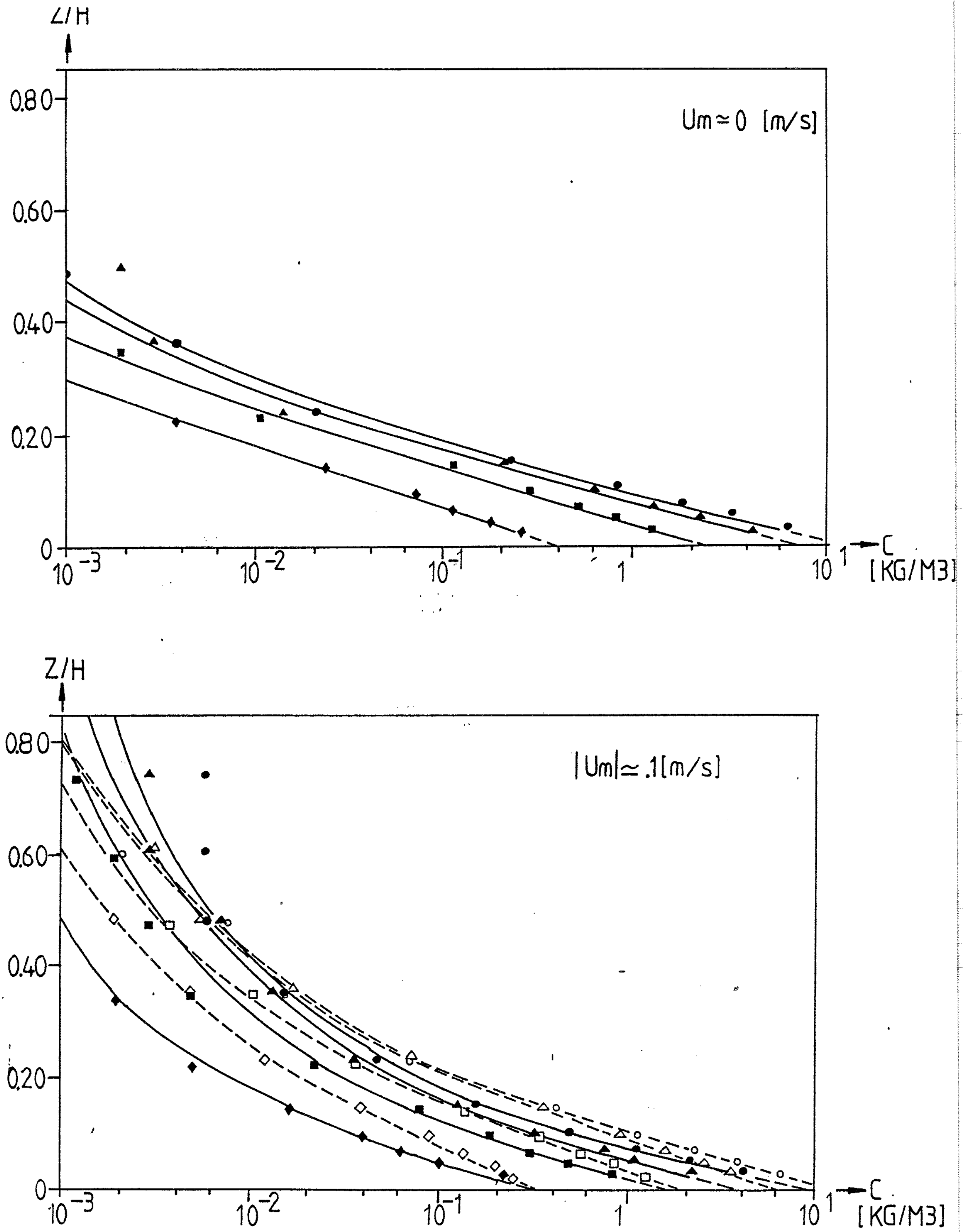
FIGURE 4.1.F



Um = -.40 (m/s)
◆ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

TIME AND BED AVERAGED CONCENTRATIONS

FIGURE 4.1.G



Hs = .075 (m) following ◆ opposing ◇

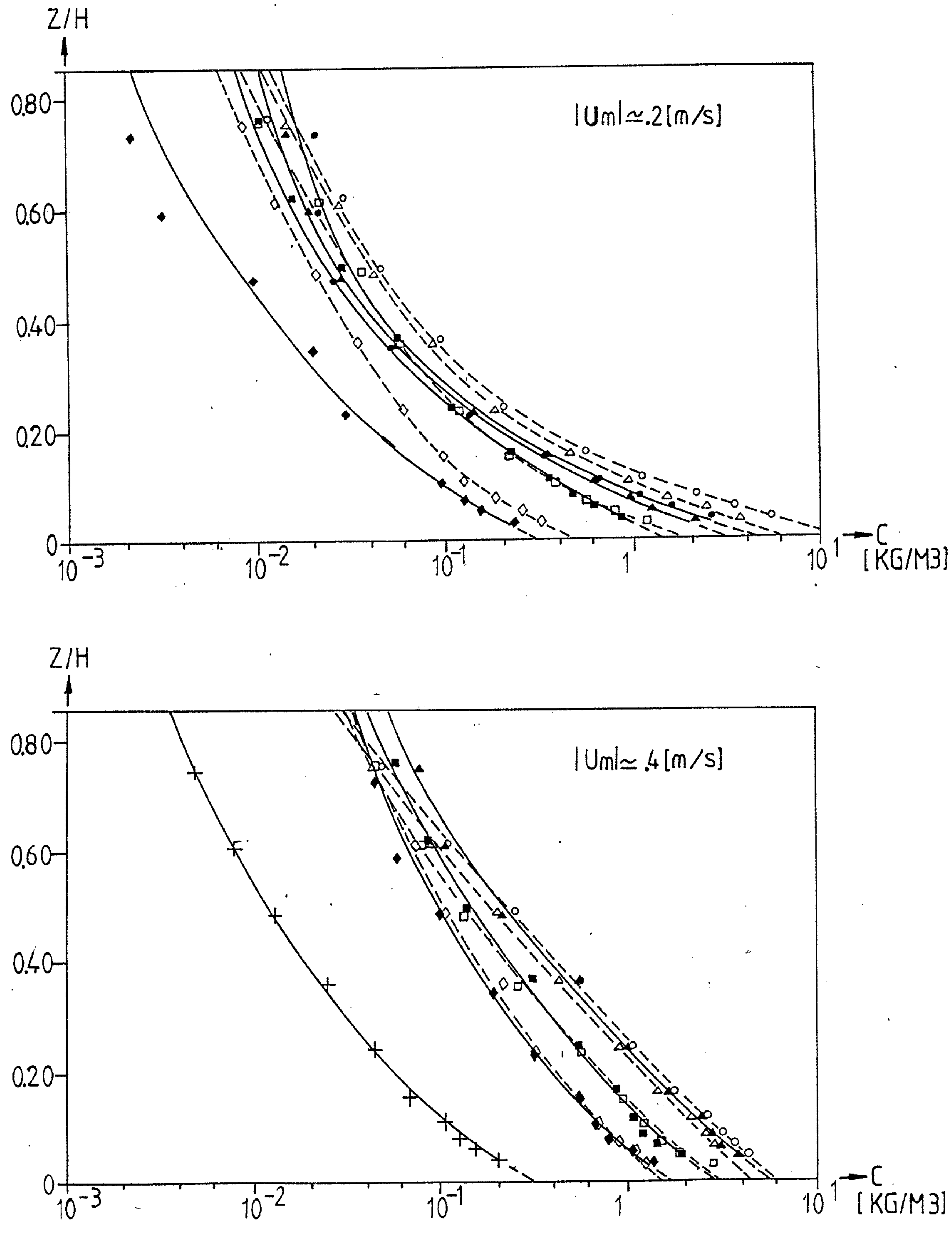
Hs = .10 (m) following ■ opposing □

Hs = .15 (m) following ▲ opposing △

Hs = .18 (m) following ● opposing ○

INFLUENCE OF WAVEHEIGHT ON THE CONCENTRATION PROFILE

FIGURE 4.2.A



Hs = .075 (m) following ◆ opposing ◇

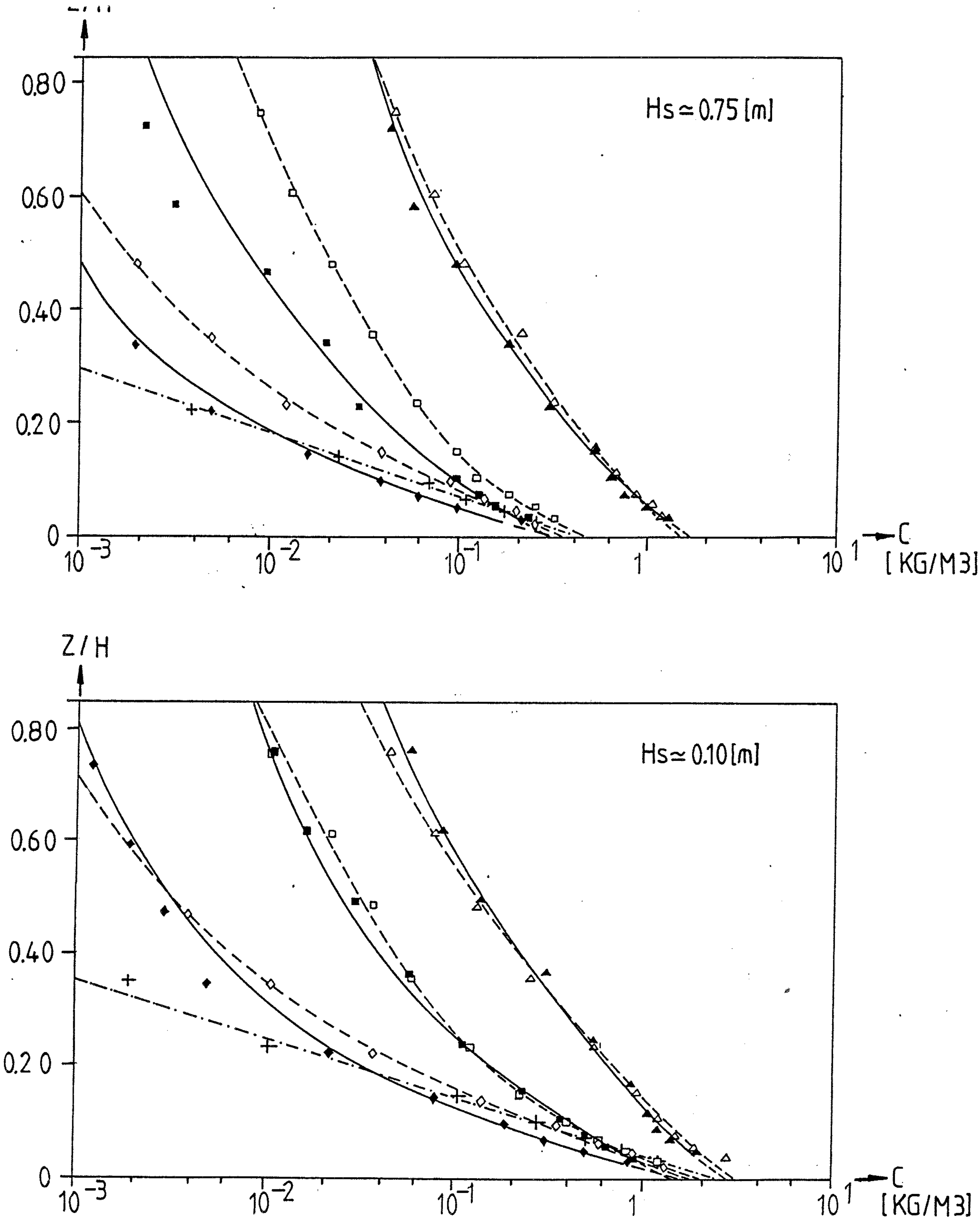
Hs = .10 (m) following ■ opposing □

Hs = .15 (m) following ▲ opposing △

Hs = .18 (m) following ● opposing ○

INFLUENCE OF WAVEHEIGHT ON THE CONCENTRATION PROFILE

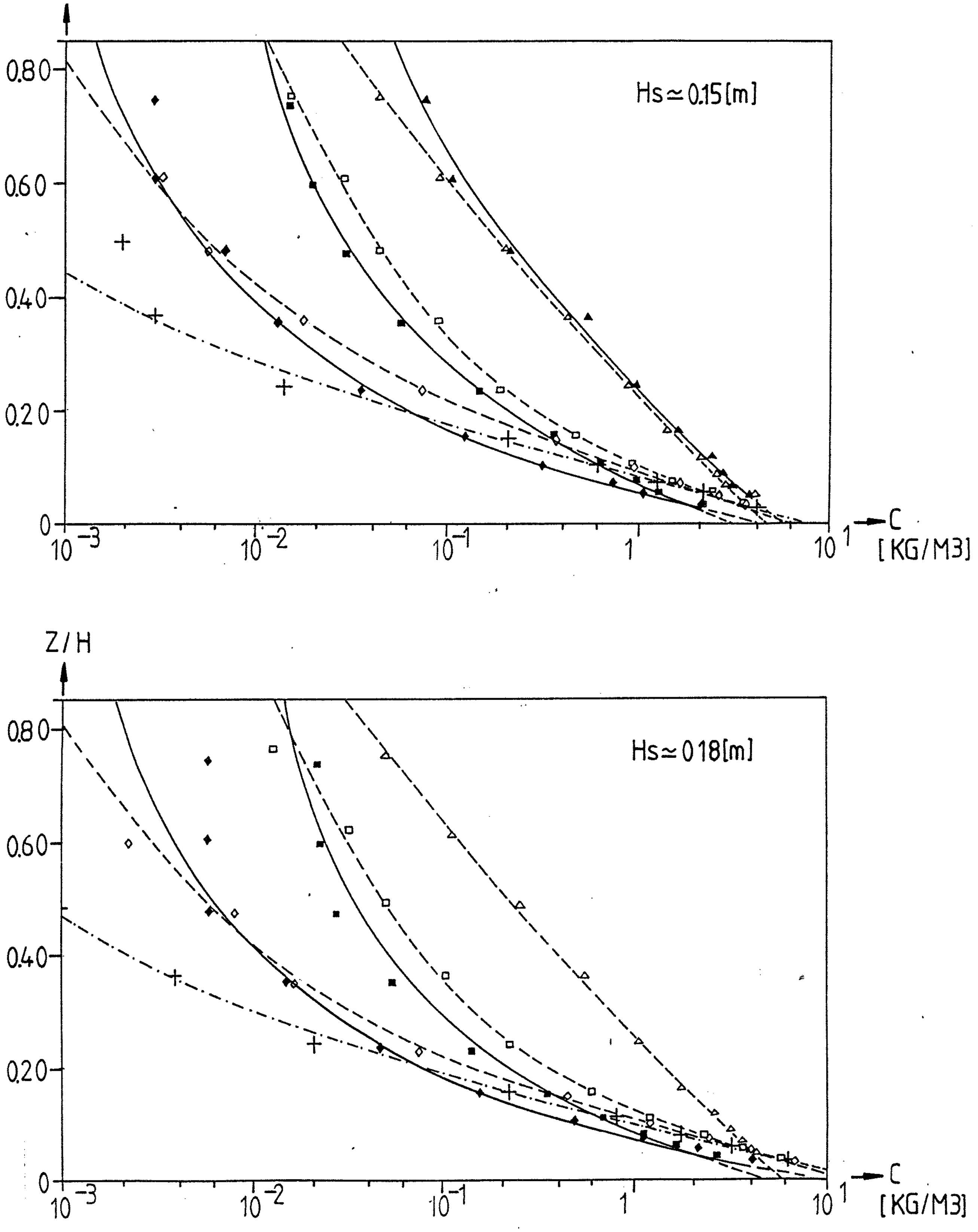
FIGURE 4.2.B



Um = 0 +
Um = .1 ◆ -.1 ◇ (m/s)
Um = .2 ■ -.2 □ (m/s)
Um = .4 ▲ -.4 △ (m/s)

INFLUENCE OF DEPTH AVERAGED VELOCITY
ON CONCENTRATION PROFILE

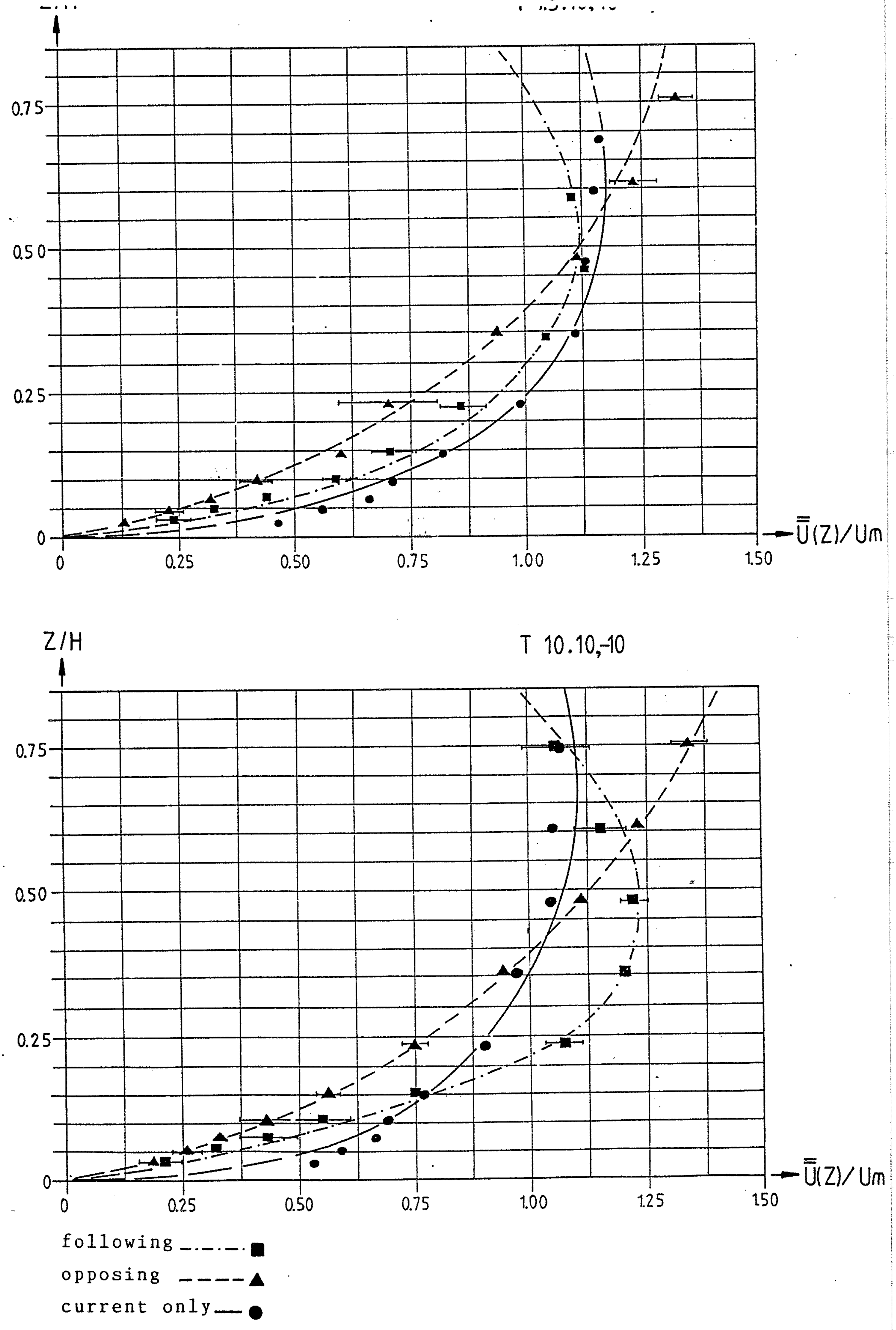
FIGURE 4.3.A



Um = 0 +
Um = .1 ◆ −.1 ◇ (m/s)
Um = .2 ■ −.2 □ (m/s)
Um = .4 ▲ −.4 △ (m/s)

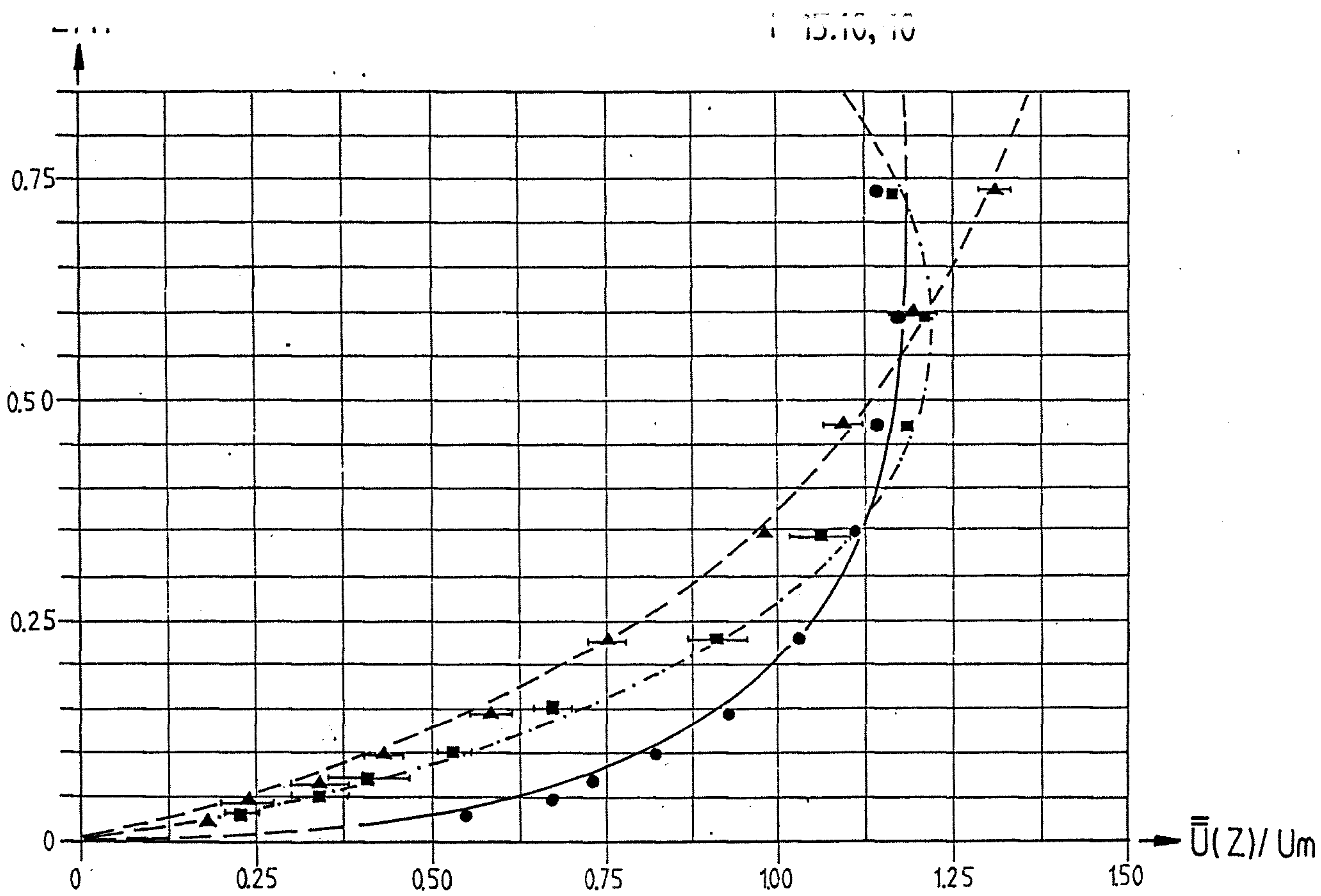
INFLUENCE OF DEPTH AVERAGED VELOCITY
ON CONCENTRATION PROFILE

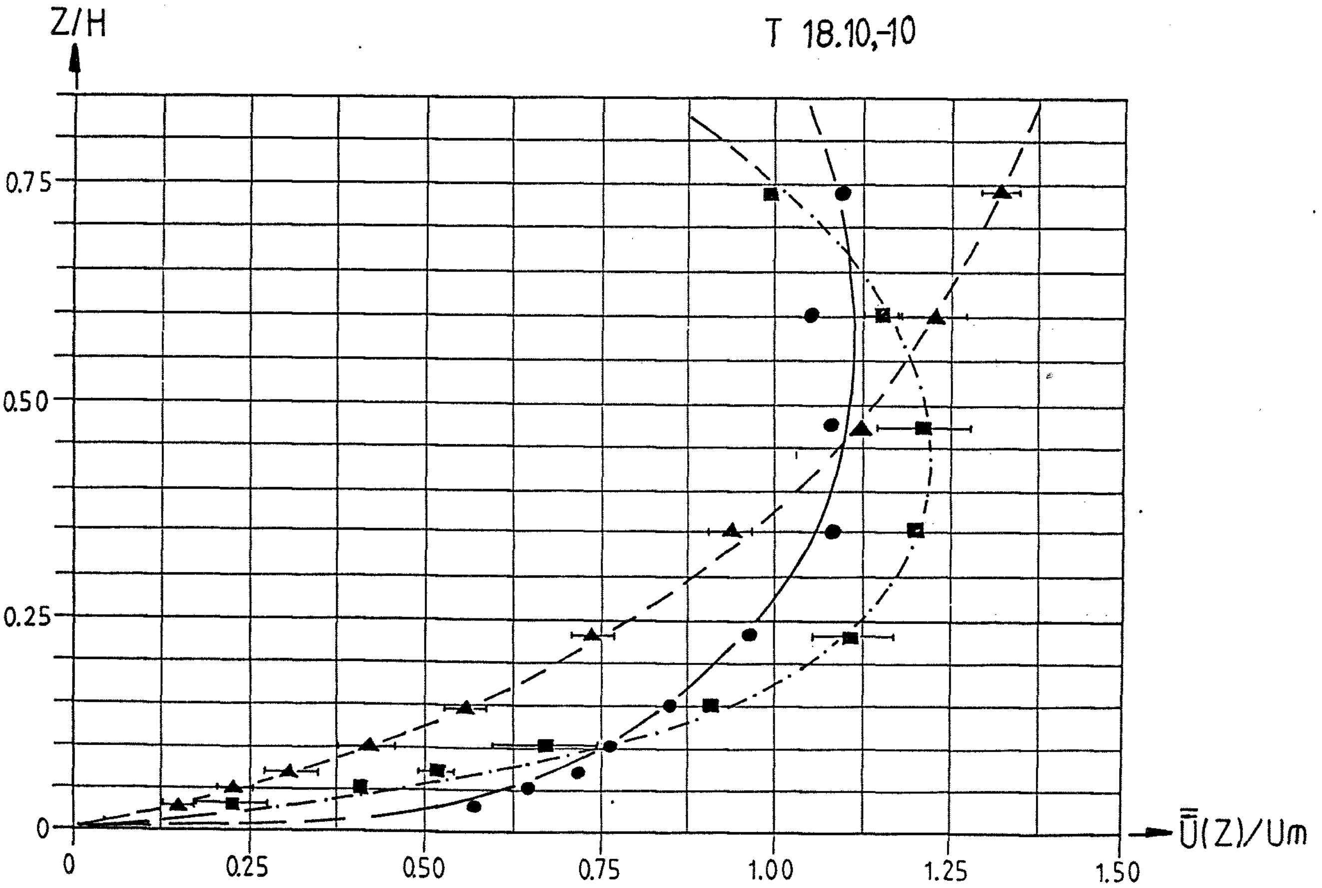
FIGURE 4.3.B



TIME AND BED AVERAGED VELOCITY PROFILES

FIGURE 4.4.A

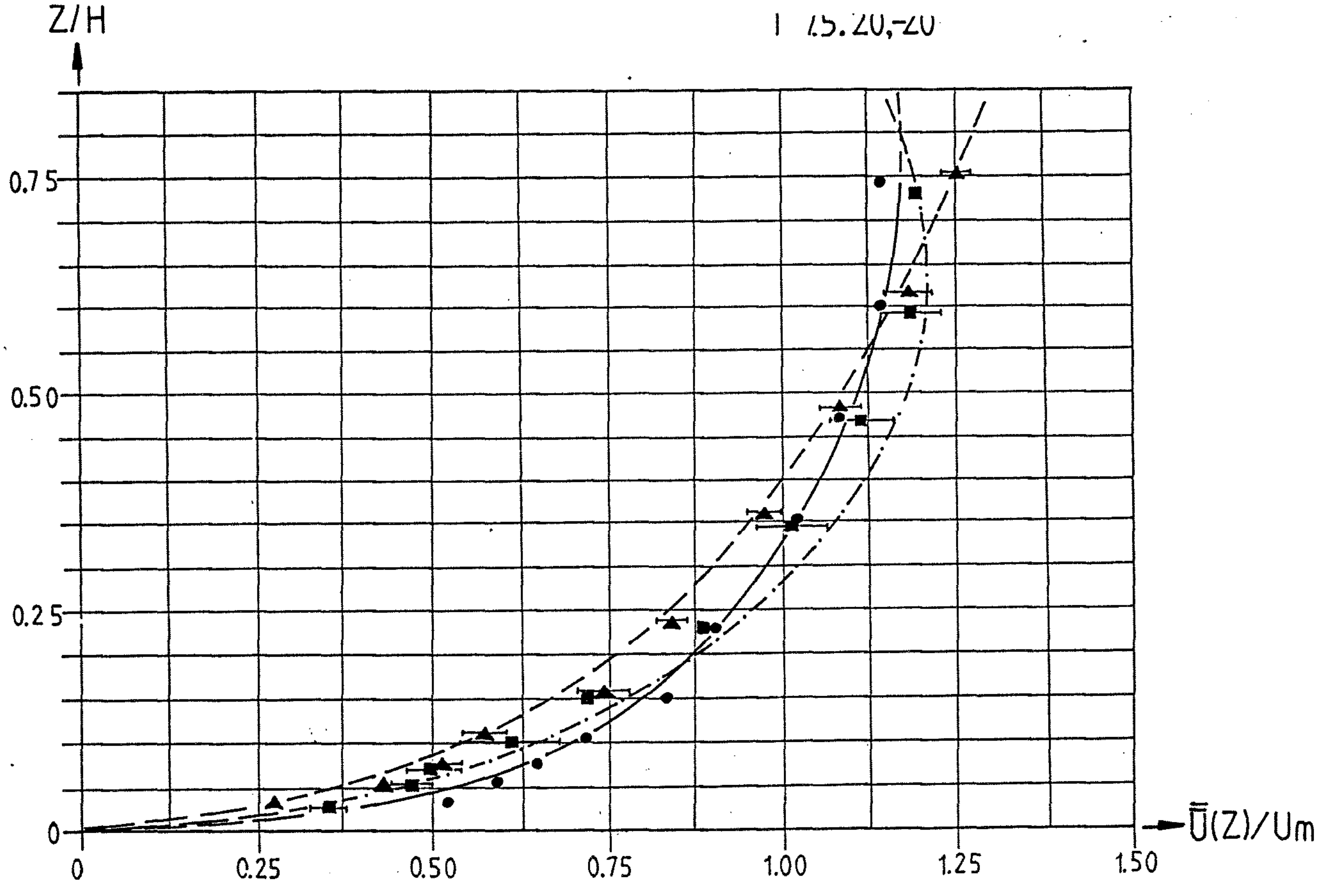


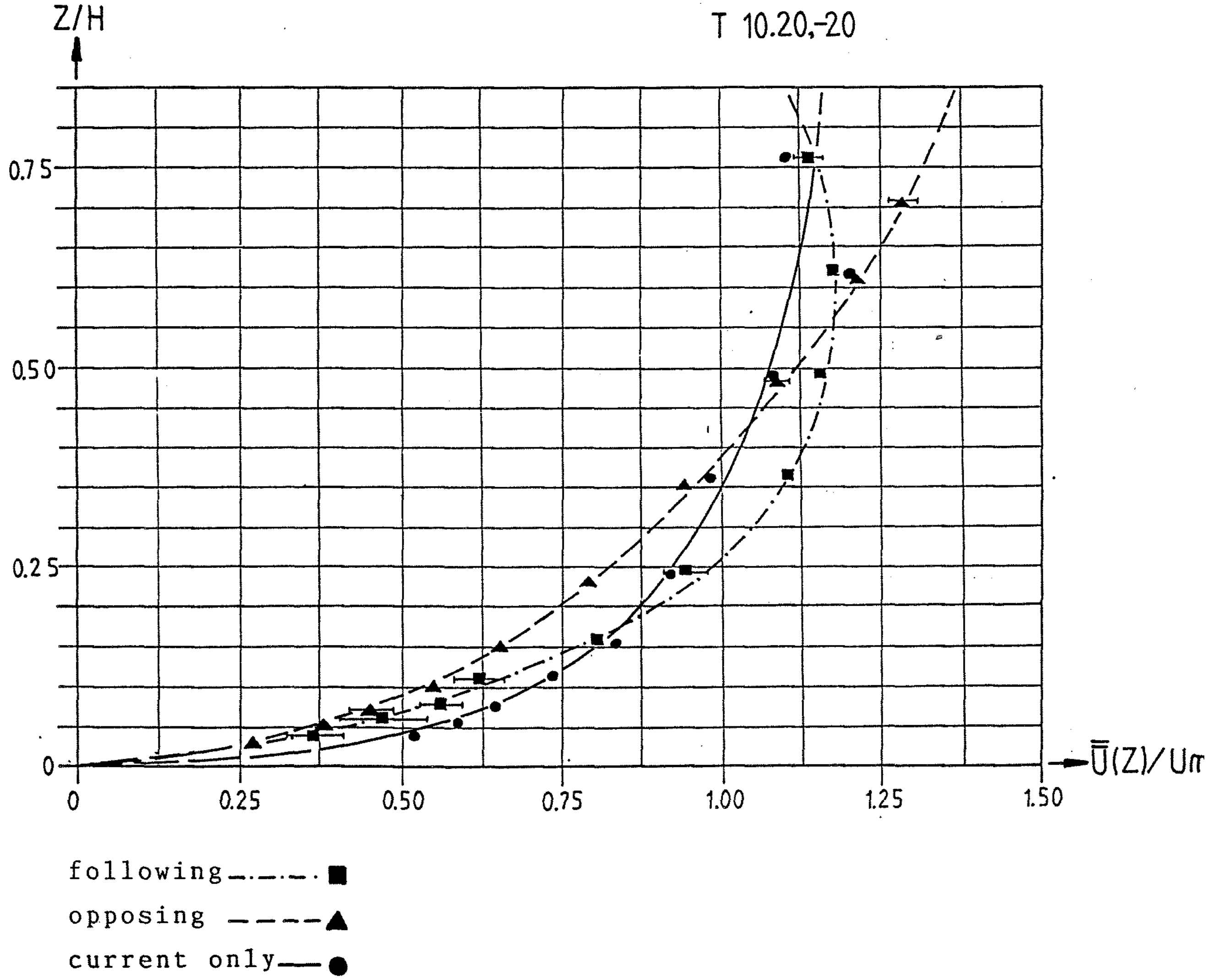


following —·—·—■
opposing — — —▲
current only ——●

TIME AND BED AVERAGED VELOCITY PROFILES

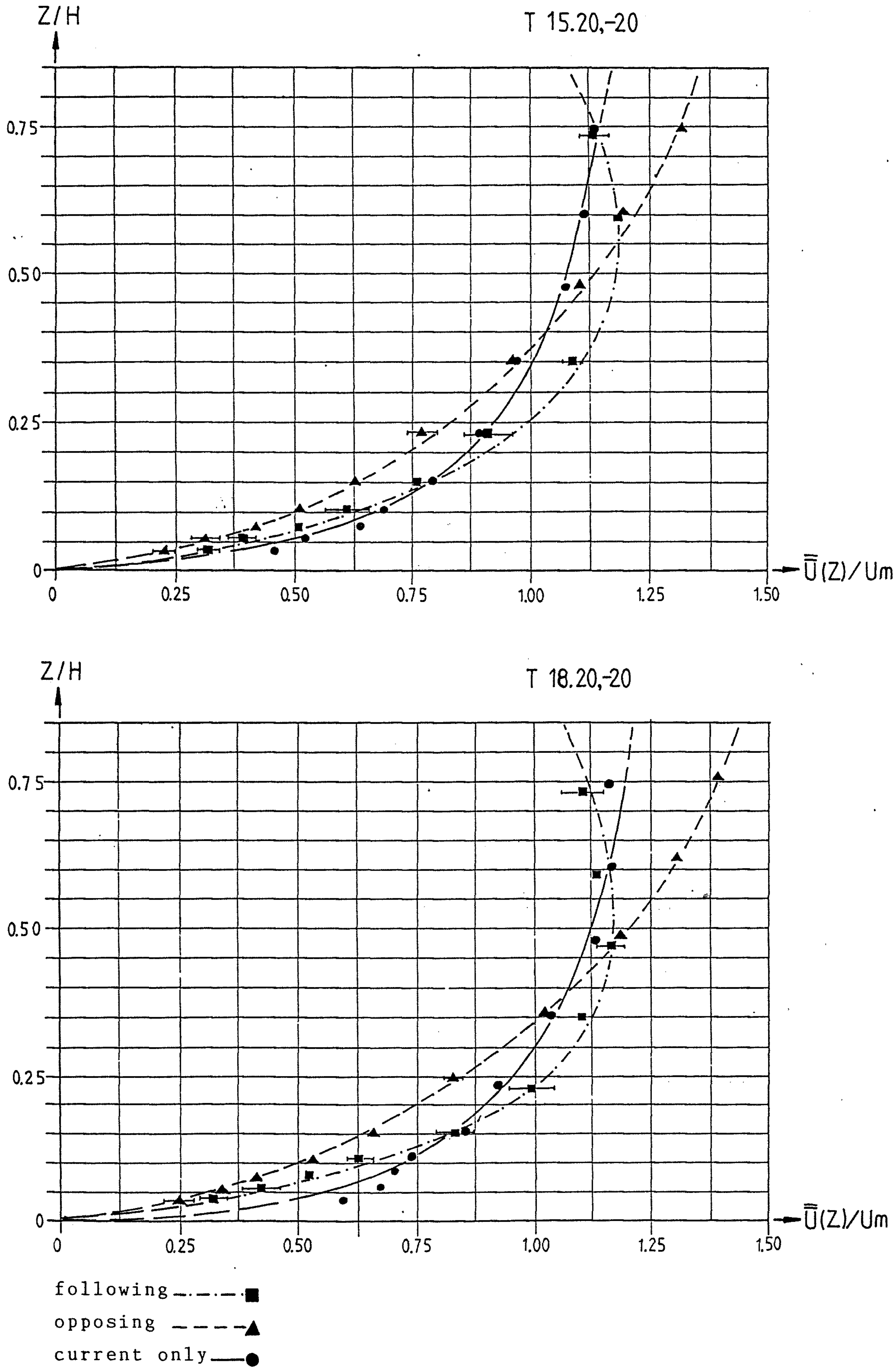
FIGURE 4.4.B





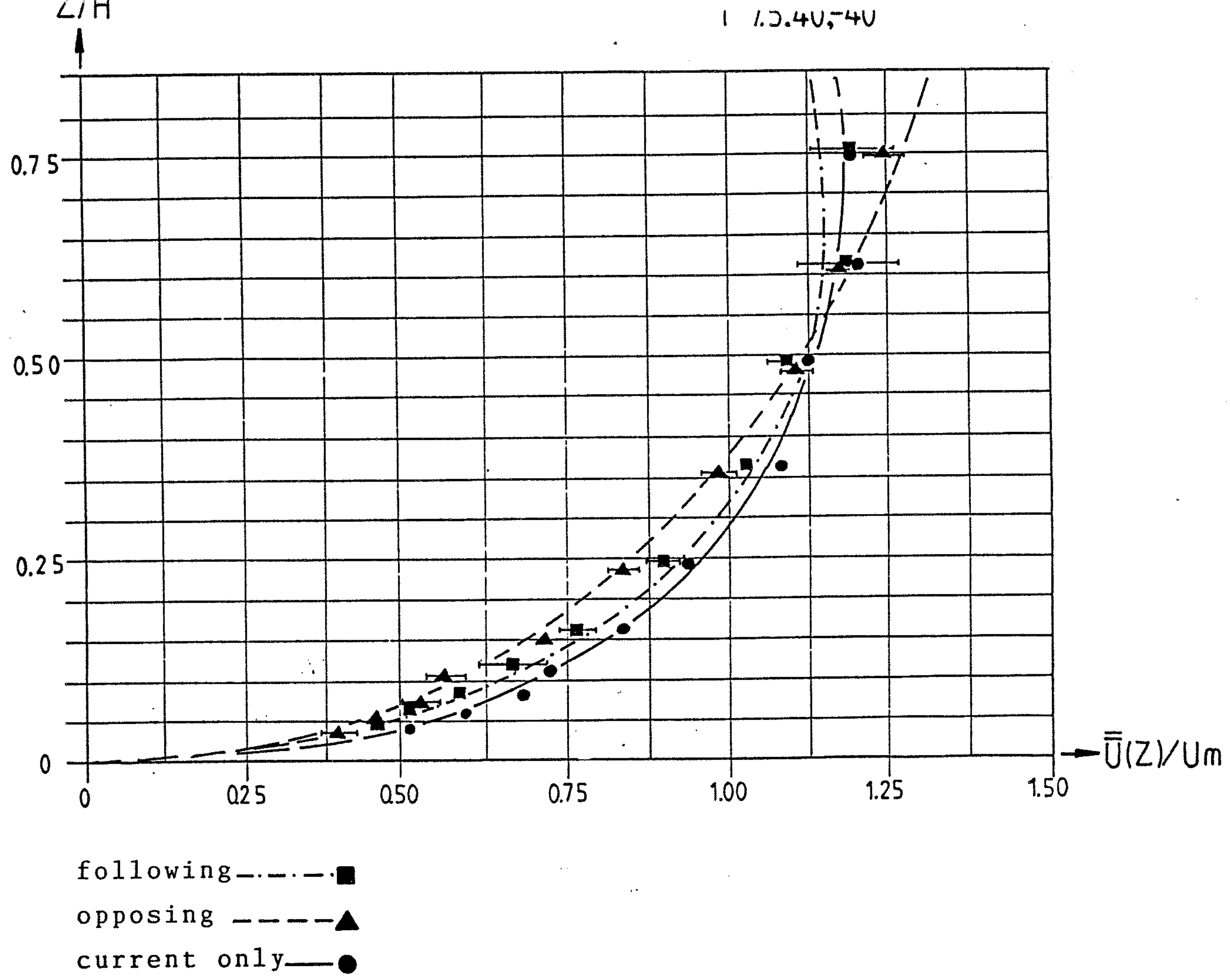
TIME AND BED AVERAGED VELOCITY PROFILES

FIGURE 4.4.C

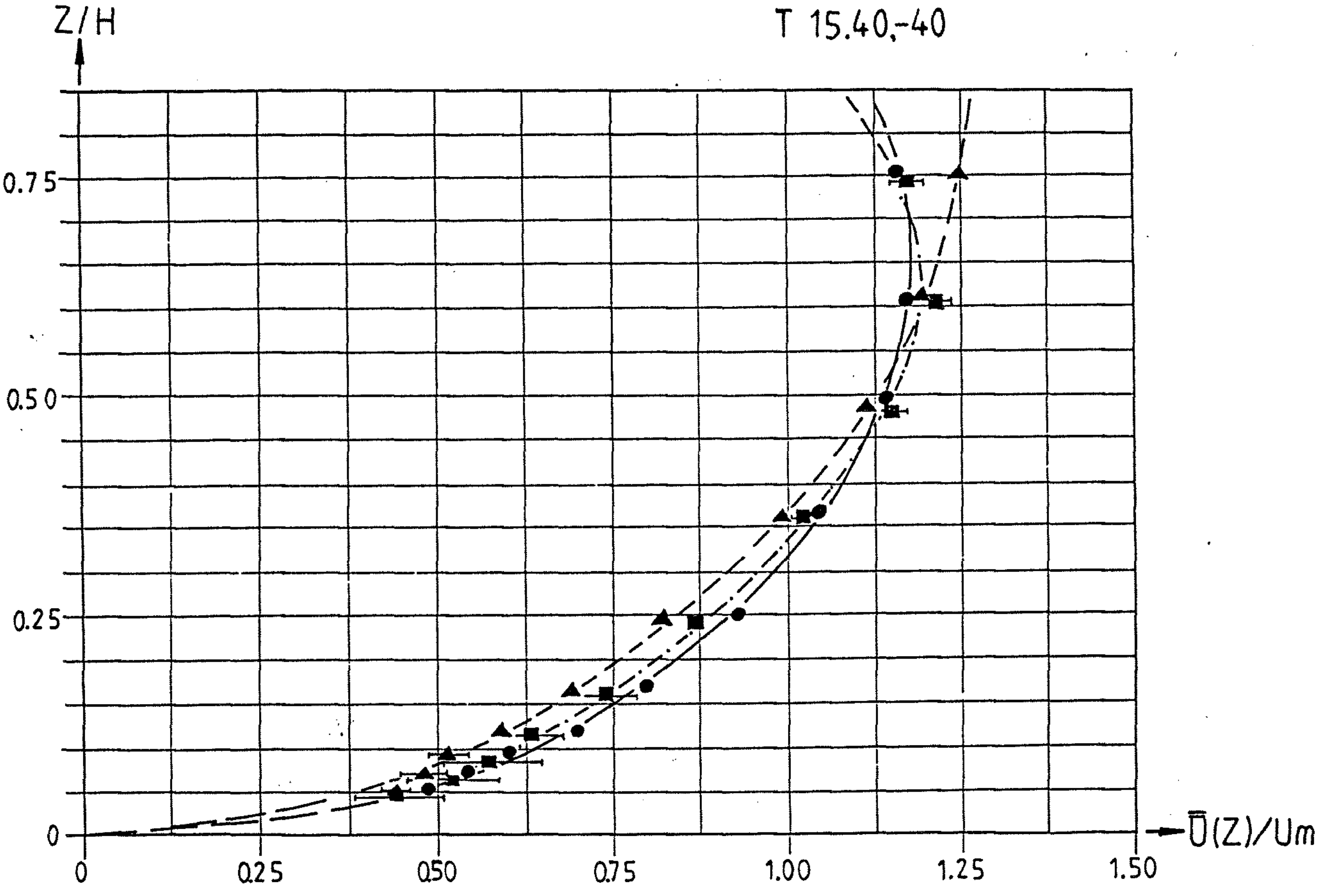


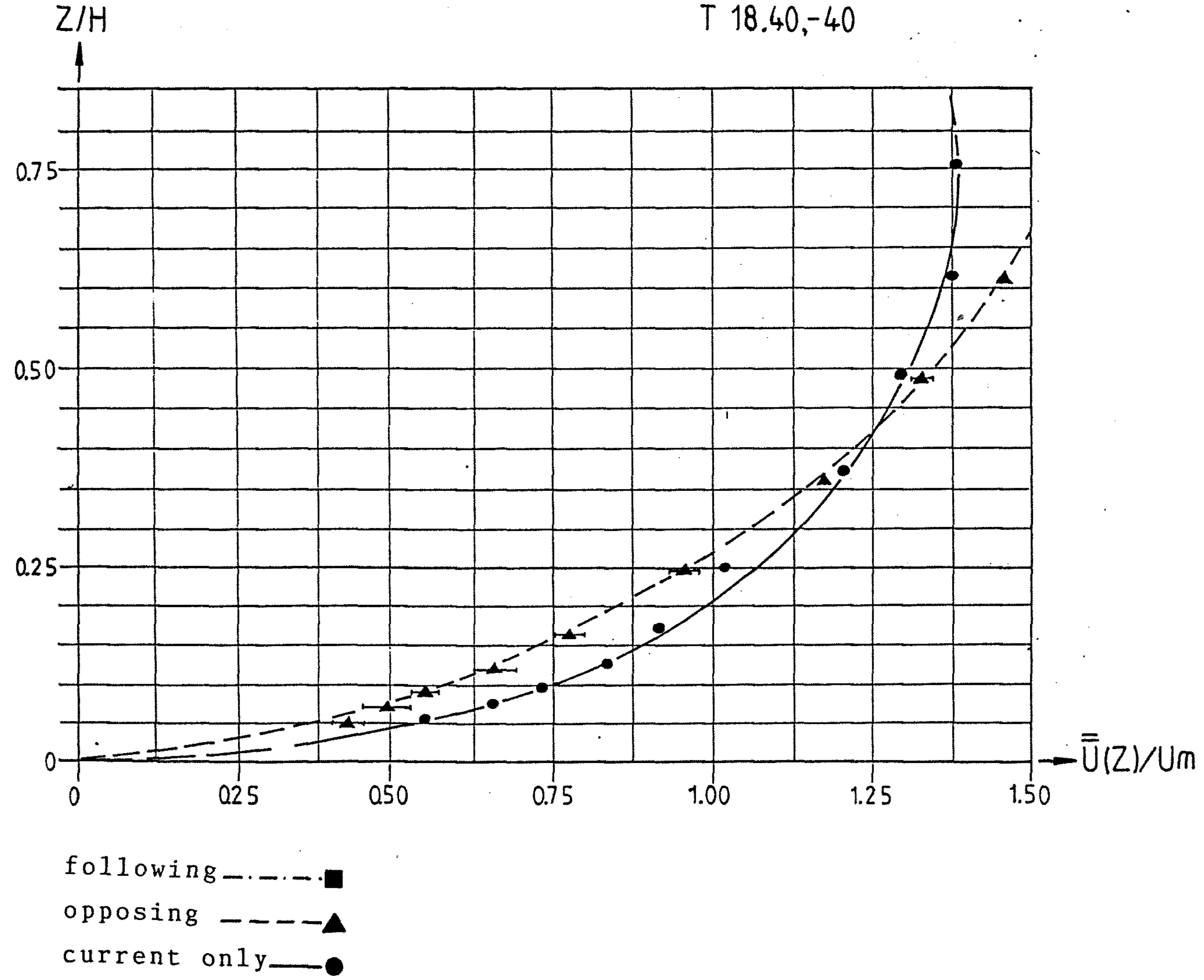
TIME AND BED AVERAGED VELOCITY PROFILES

FIGURE 4.4.D



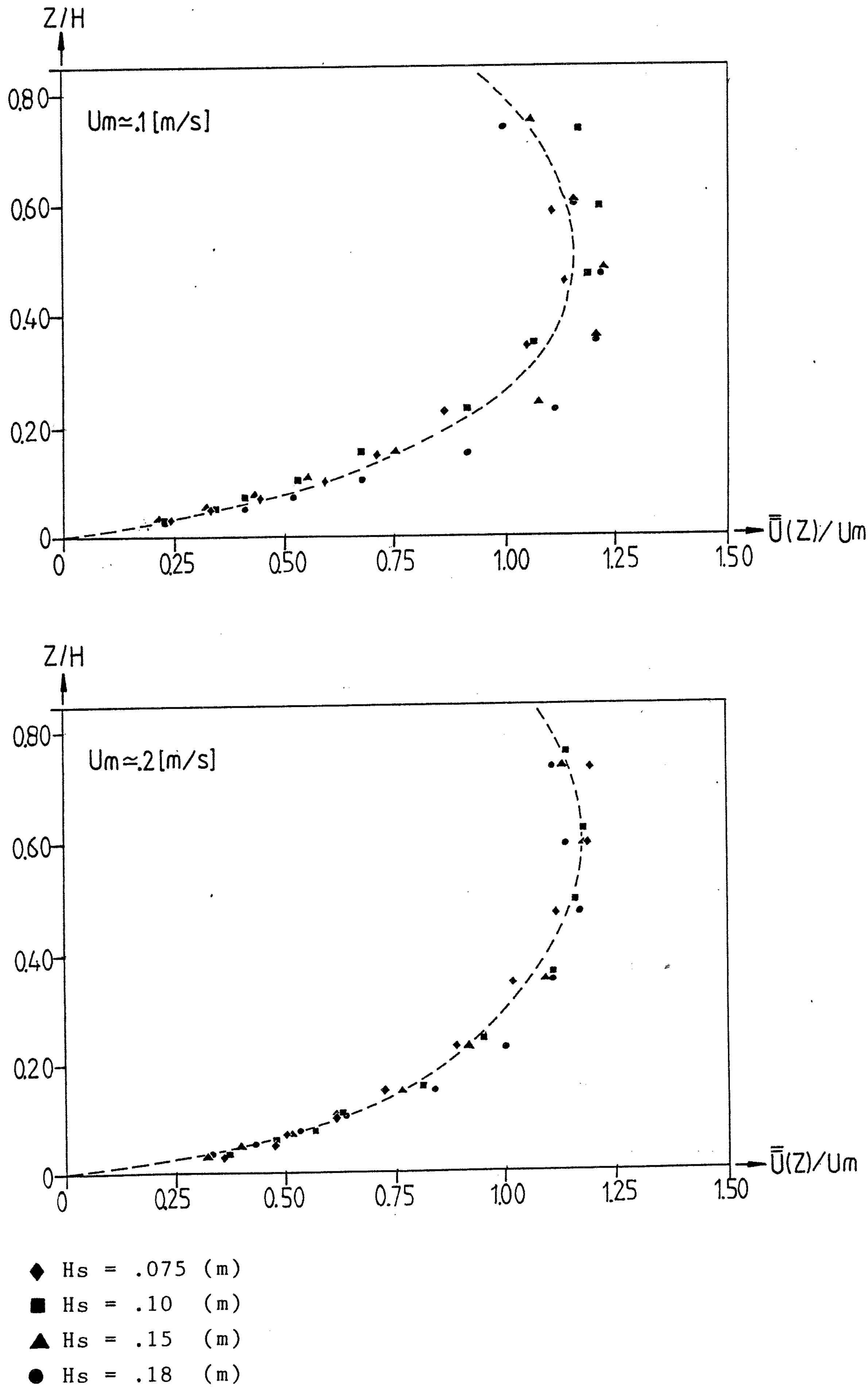
TIME AND BED AVERAGED VELOCITY PROFILES





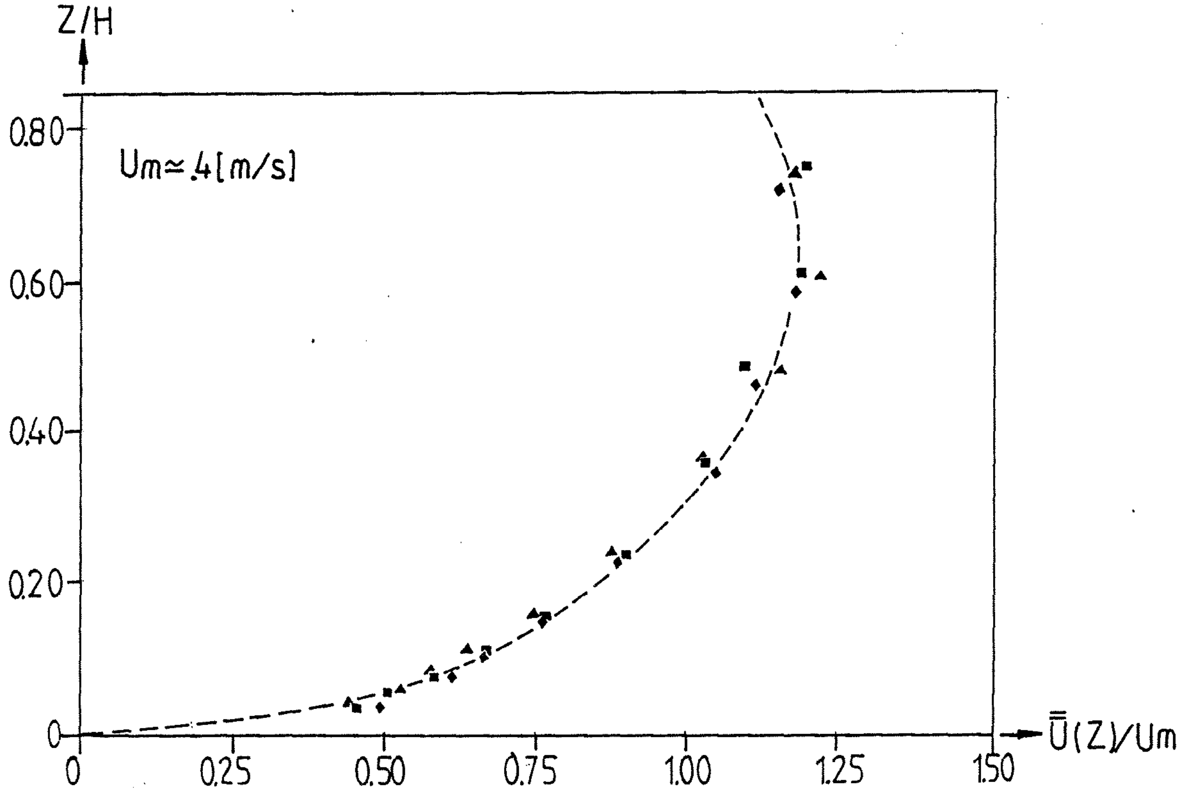
TIME AND BED AVERAGED VELOCITY PROFILES

FIGURE 4.4.E



INFLUENCE OF WAVEHEIGHT ON THE VELOCITY PROFILE
FOR WAVES PROPAGATING WITH THE CURRENT

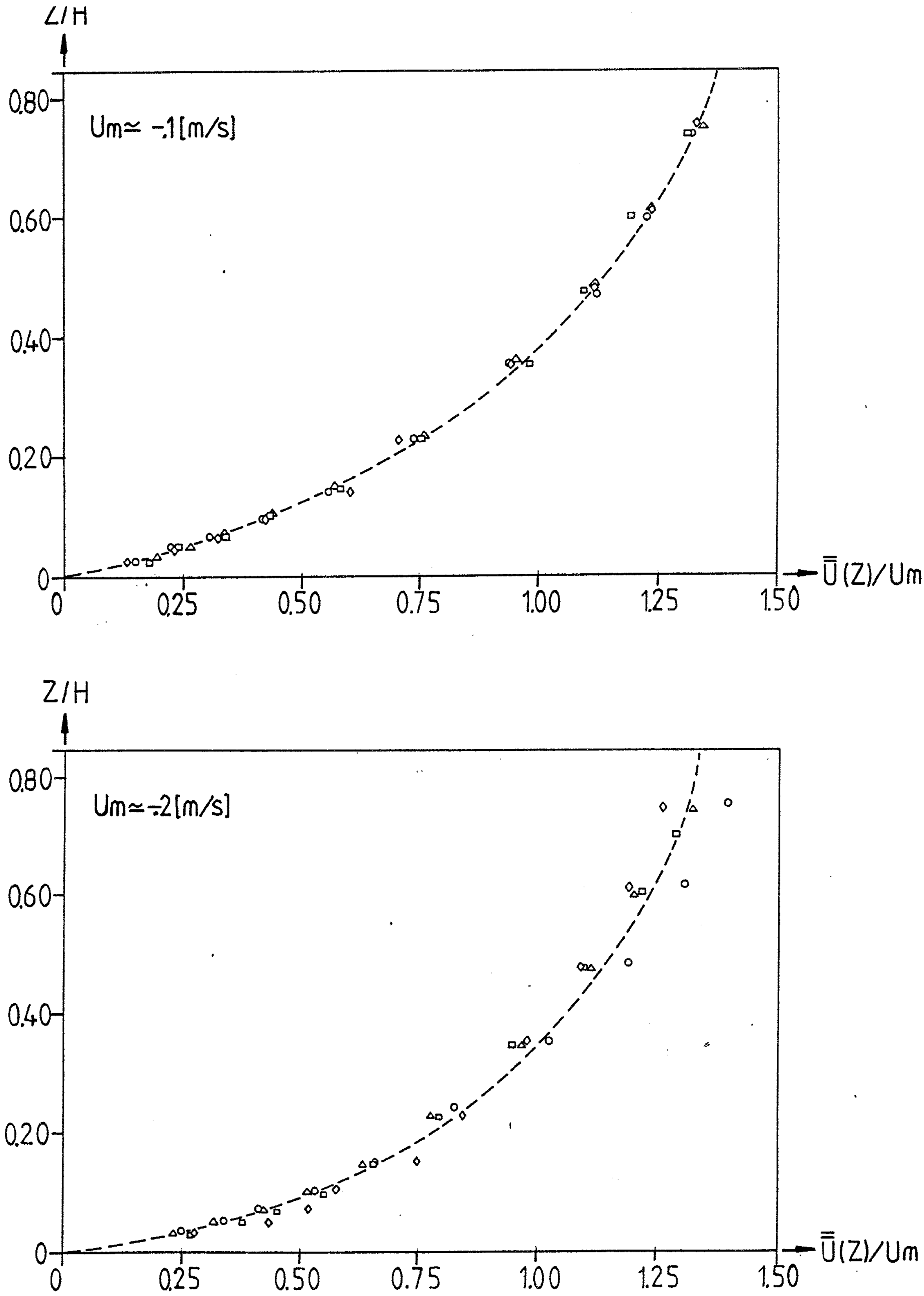
FIGURE 4.4.F



◆ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

INFLUENCE OF WAVEHEIGHT ON THE VELOCITY PROFILE
FOR WAVES PROPAGATING WITH THE CURRENT

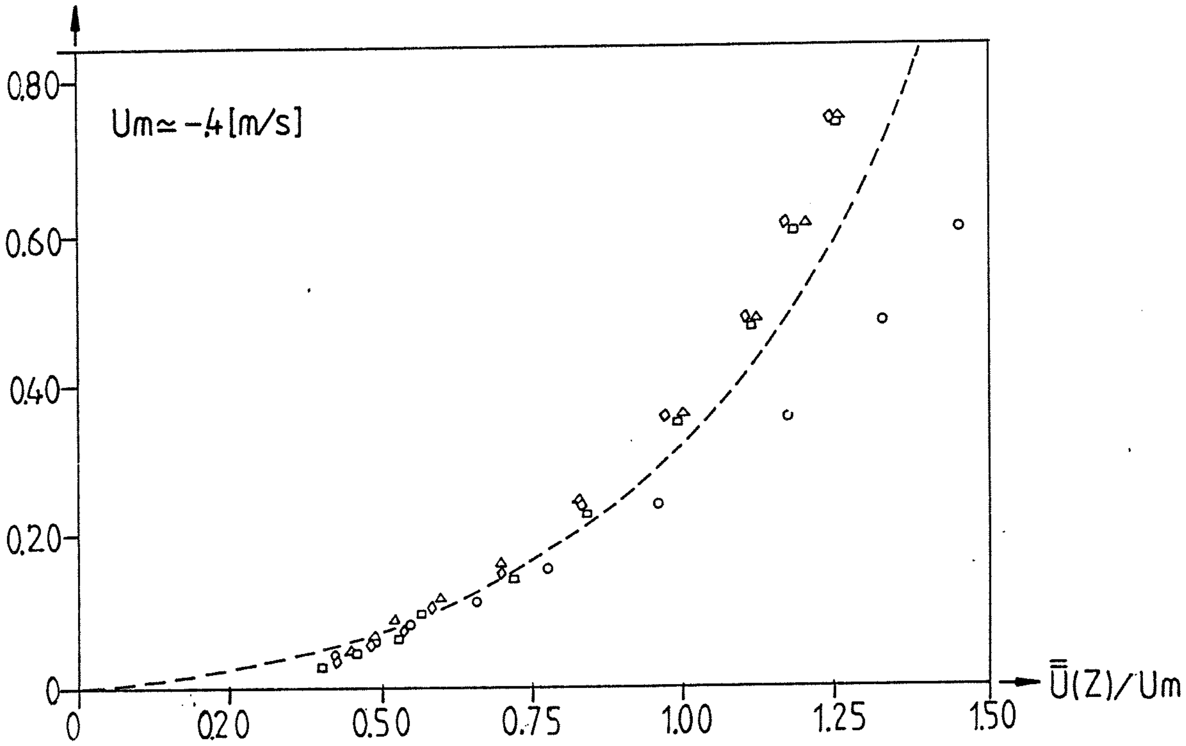
FIGURE 4.4.G



◆ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

INFLUENCE OF WAVEHEIGHT ON THE VELOCITY PROFILE
FOR WAVES PROPAGATING AGAINST THE CURRENT

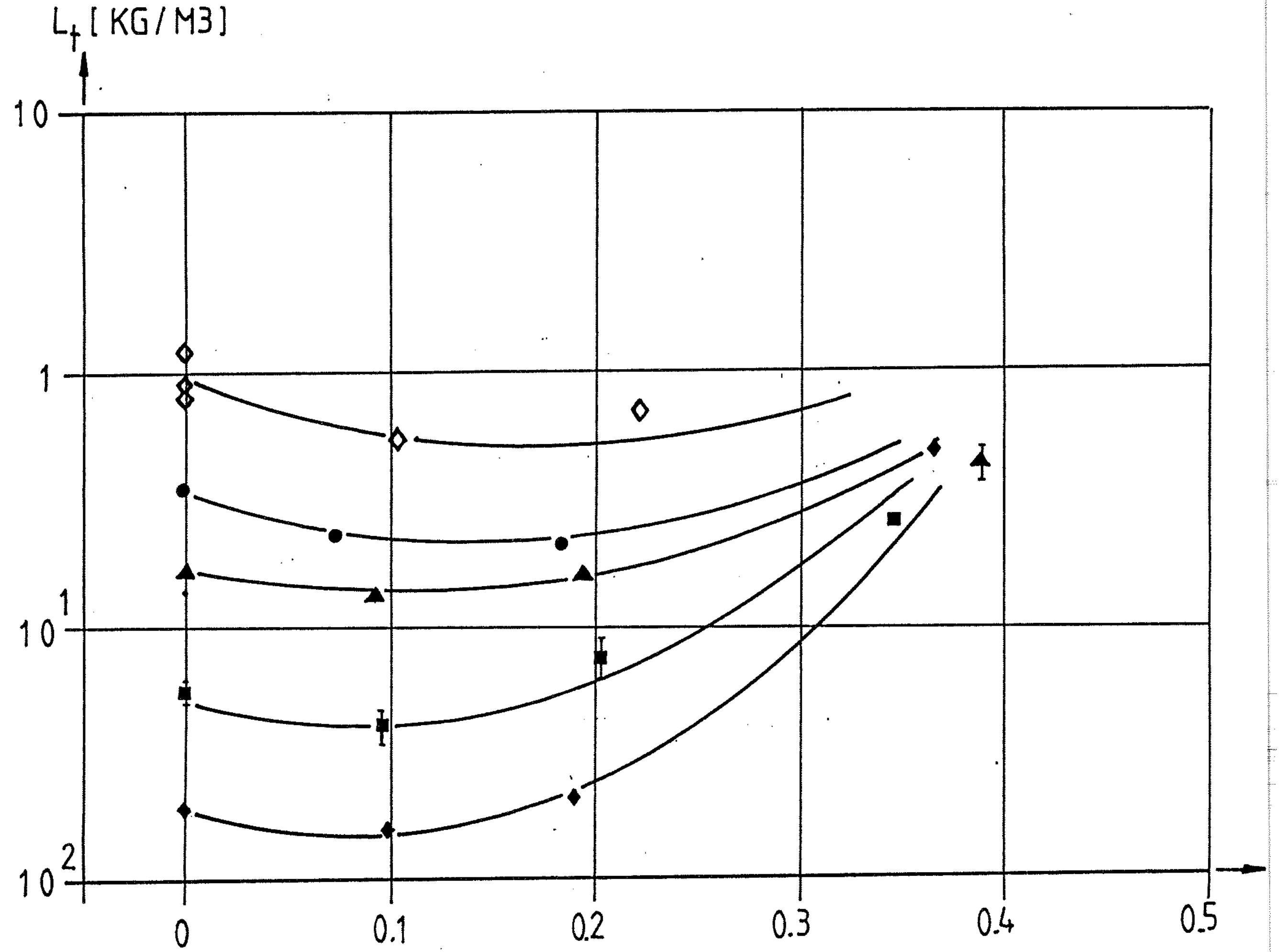
FIGURE 4.4.H



♦ Hs = .075 (m)
■ Hs = .10 (m)
▲ Hs = .15 (m)
● Hs = .18 (m)

INFLUENCE OF WAVEHEIGHT ON THE VELOCITY PROFILE
FOR WAVES PROPAGATING AGAINST THE CURRENT

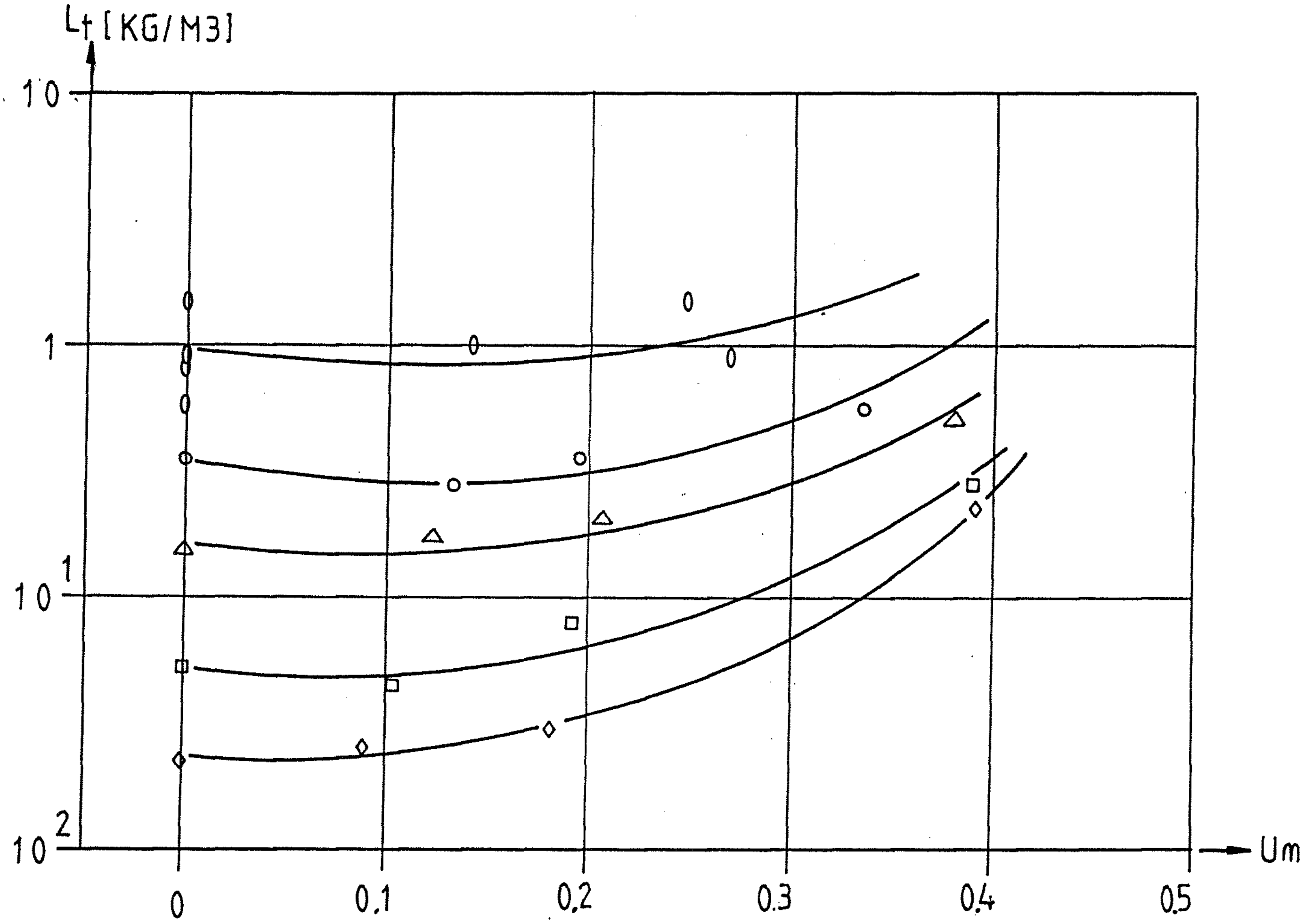
FIGURE 4.4.I



- ♦ Hs = .075 (m)
- ■ Hs = .10 (m)
- ▲ Hs = .15 (m)
- ● Hs = .18 (m)
- ⬮ Hs = .25 (m)

TOTAL LOAD FOR WAVES PROPAGATING WITH THE CURRENT

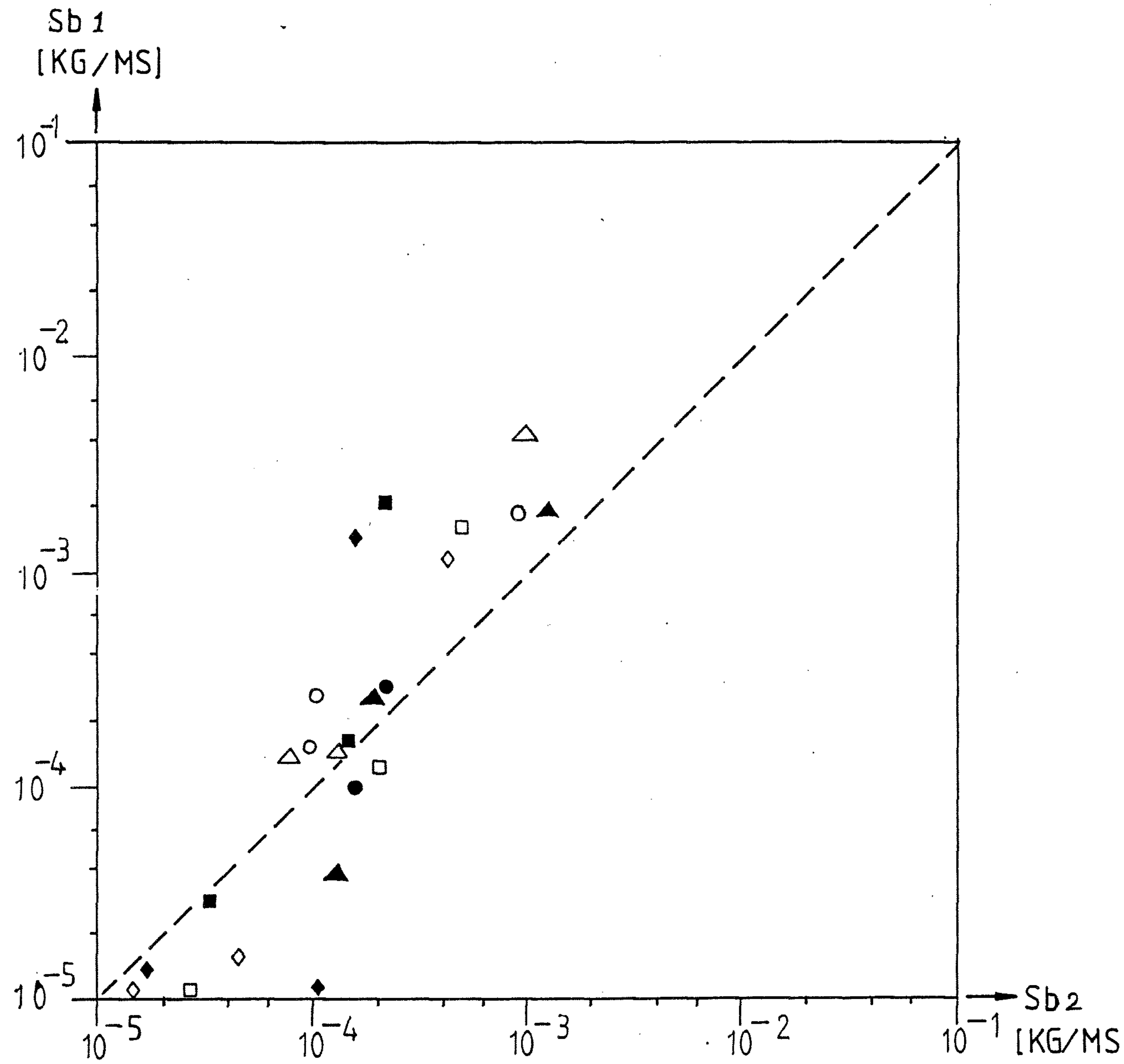
FIGURE 4.5.A



◇ Hs = .075 (m)
□ Hs = .10 (m)
△ Hs = .15 (m)
○ Hs = .18 (m)
0 Hs = .25 (m)

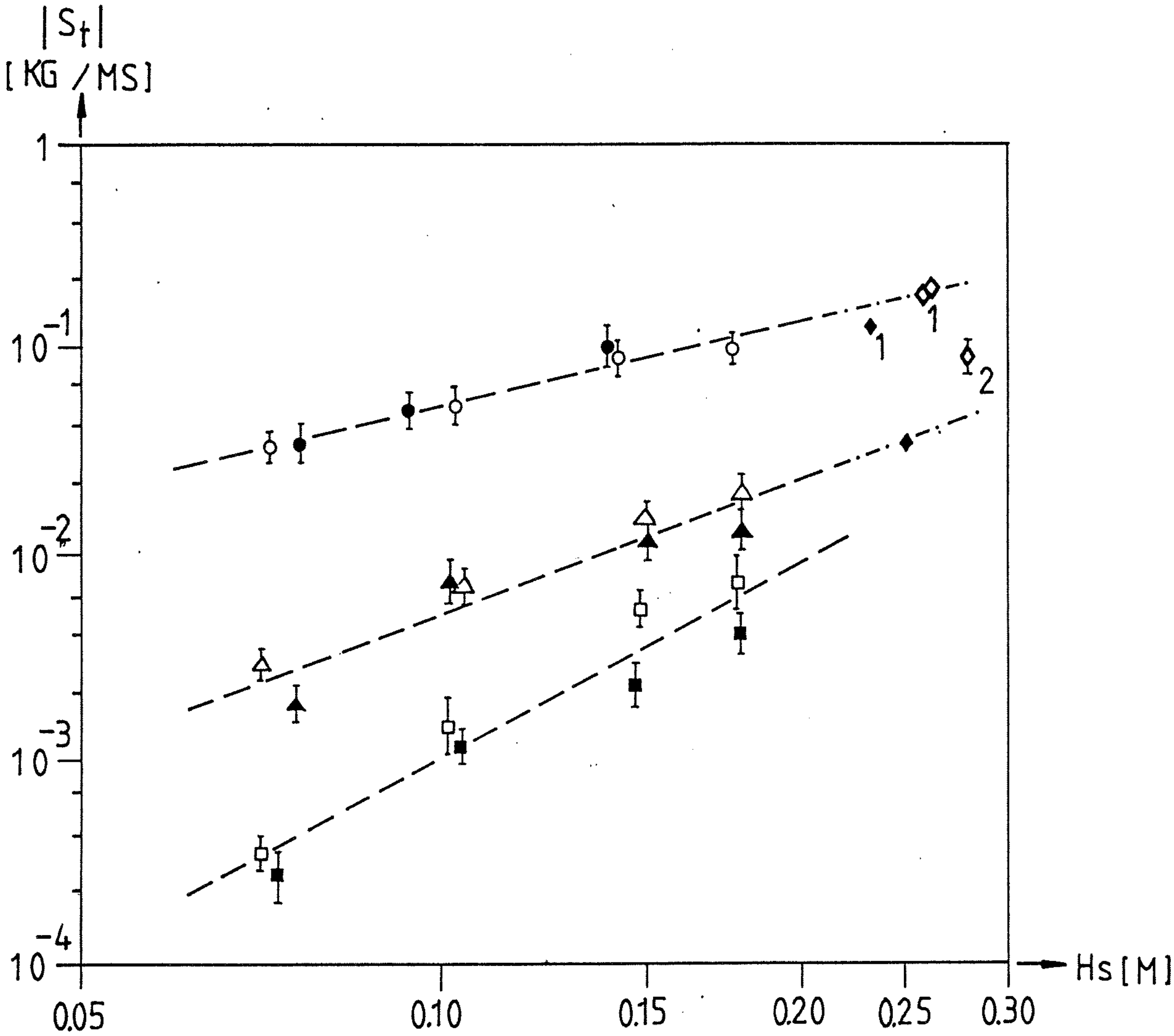
TOTAL LOAD FOR WAVES PROPAGATING AGAINST THE CURRENT

FIGURE 4.5.B



COMPARISON OF TWO CALCULATION METHODS FOR
THE BED LOAD TRANSPORT

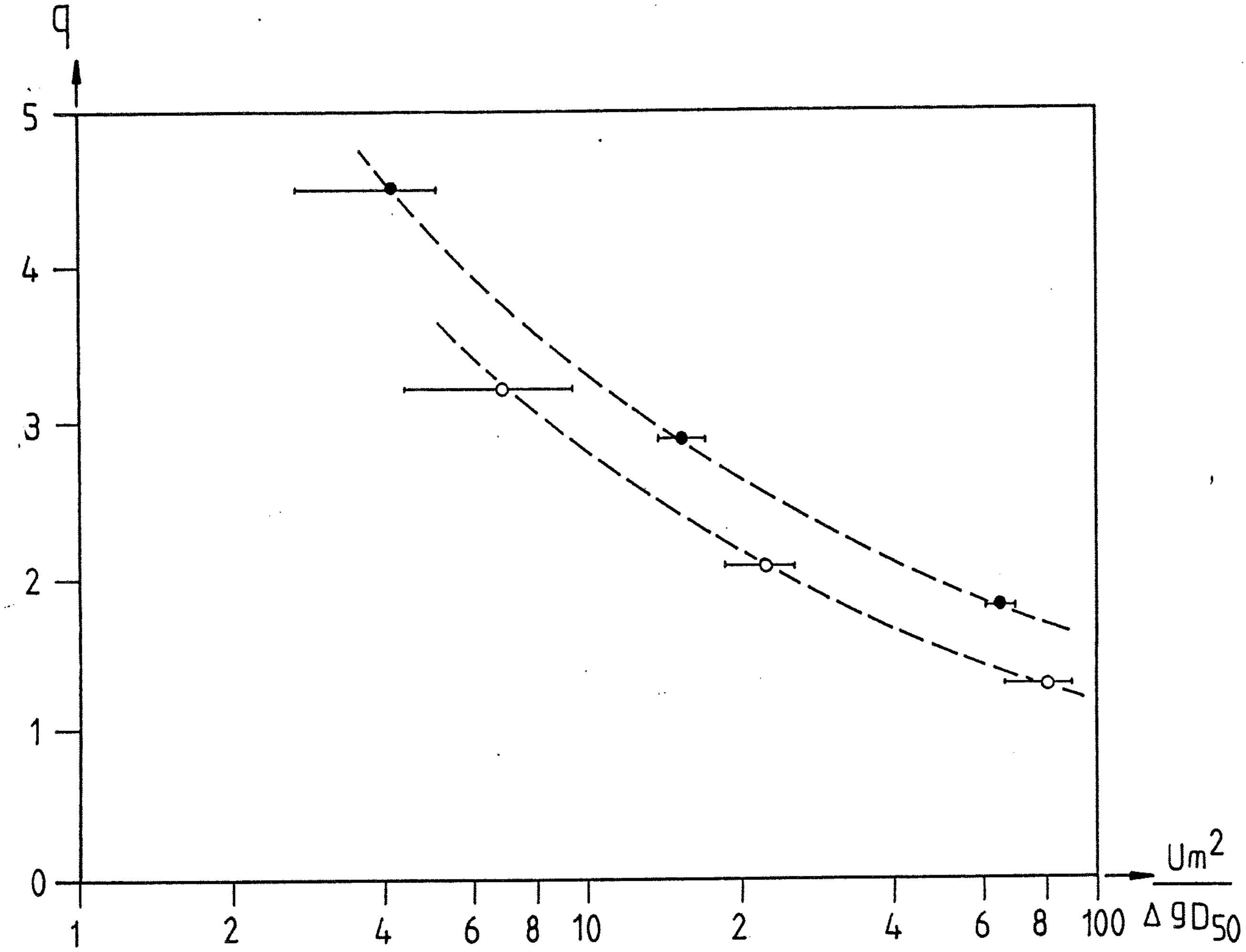
FIGURE 4.6



Um = .1 ■ -.1 □ (m/s)
Um = .2 ▲ -.2 △ (m/s)
Um = .4 ● -.4 ○ (m/s)
Bosman
1) Um = .25 ◆ -.25 ◇ (m/s)
2) Um = -.15 ◇ (m/s)

INFLUENCE OF WAVEHEIGHT ON THE TOTAL LOAD TRANSPORT

FIGURE 4.7.A

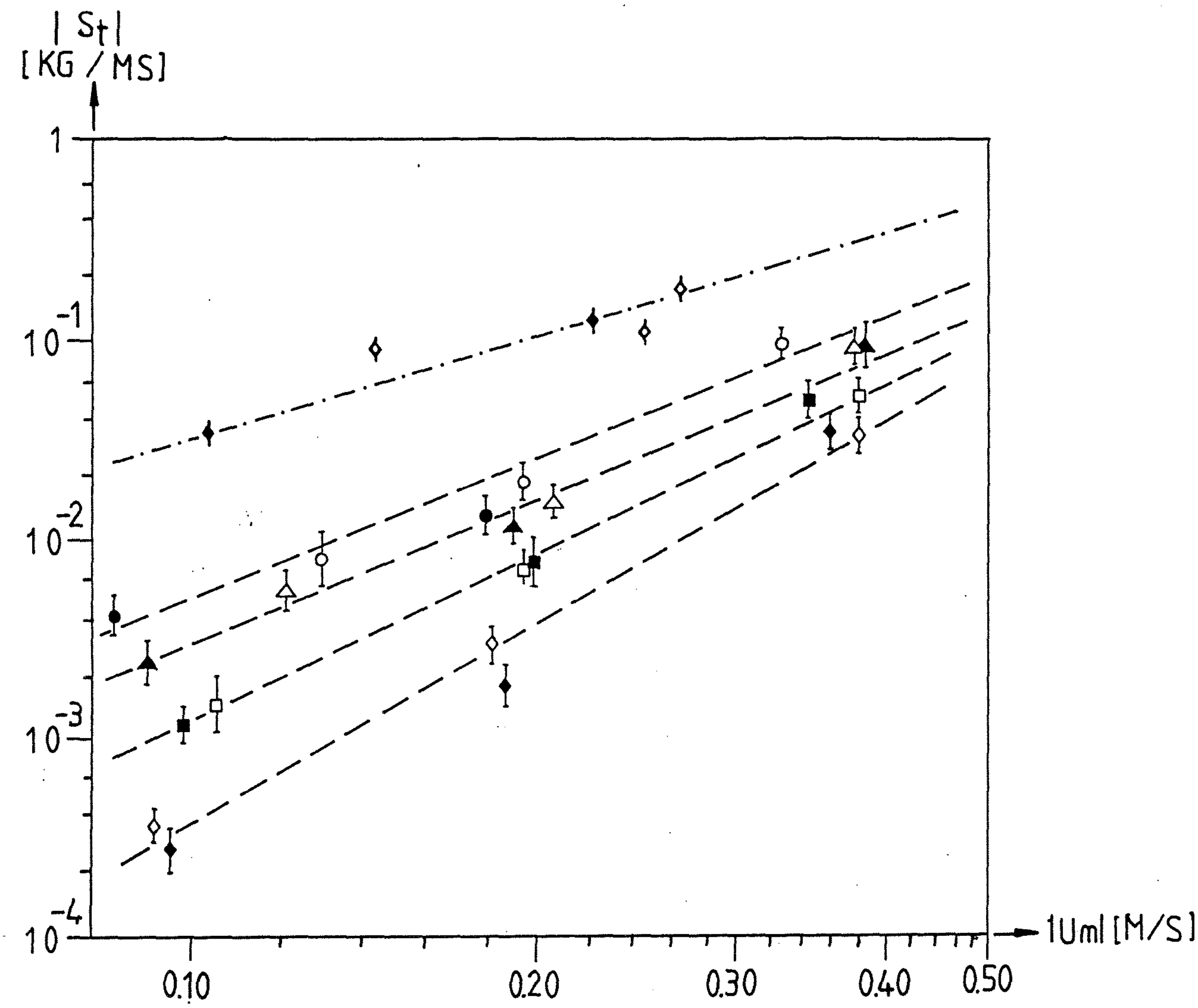


● 200 mu

○ 100 mu

INFLUENCE OF THE DEPTH AVERAGED VELOCITY ON
WAVEHEIGHT PROPORTION FACTOR

FIGURE 4.7.B



Hs = .075 (m) following ◆ opposing ◇

Hs = .10 (m) following ■ opposing □

Hs = .15 (m) following ▲ opposing △

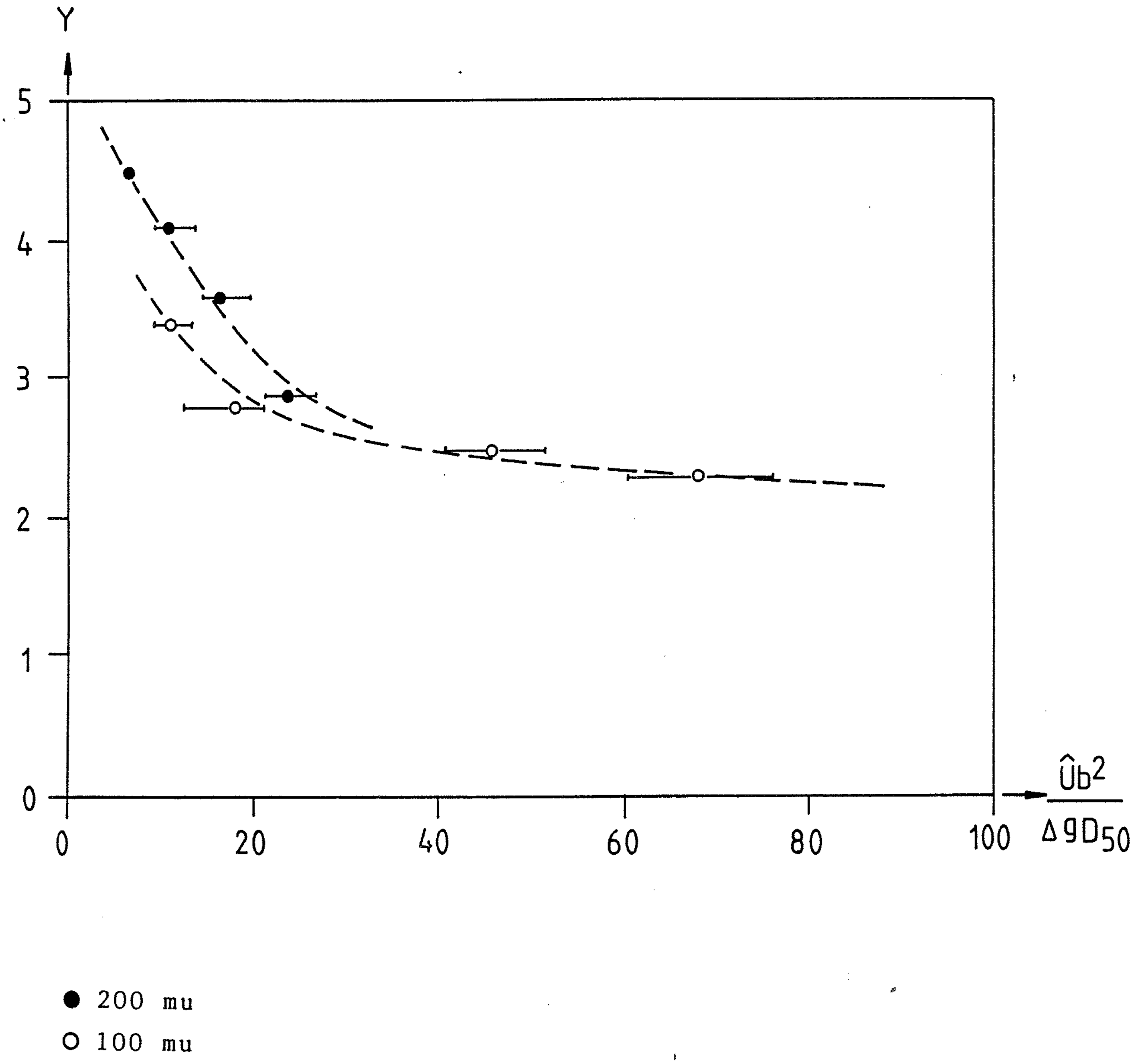
Hs = .18 (m) following ● opposing ○

Bosman

Hs = .25 (m) following ◆ opposing ◇

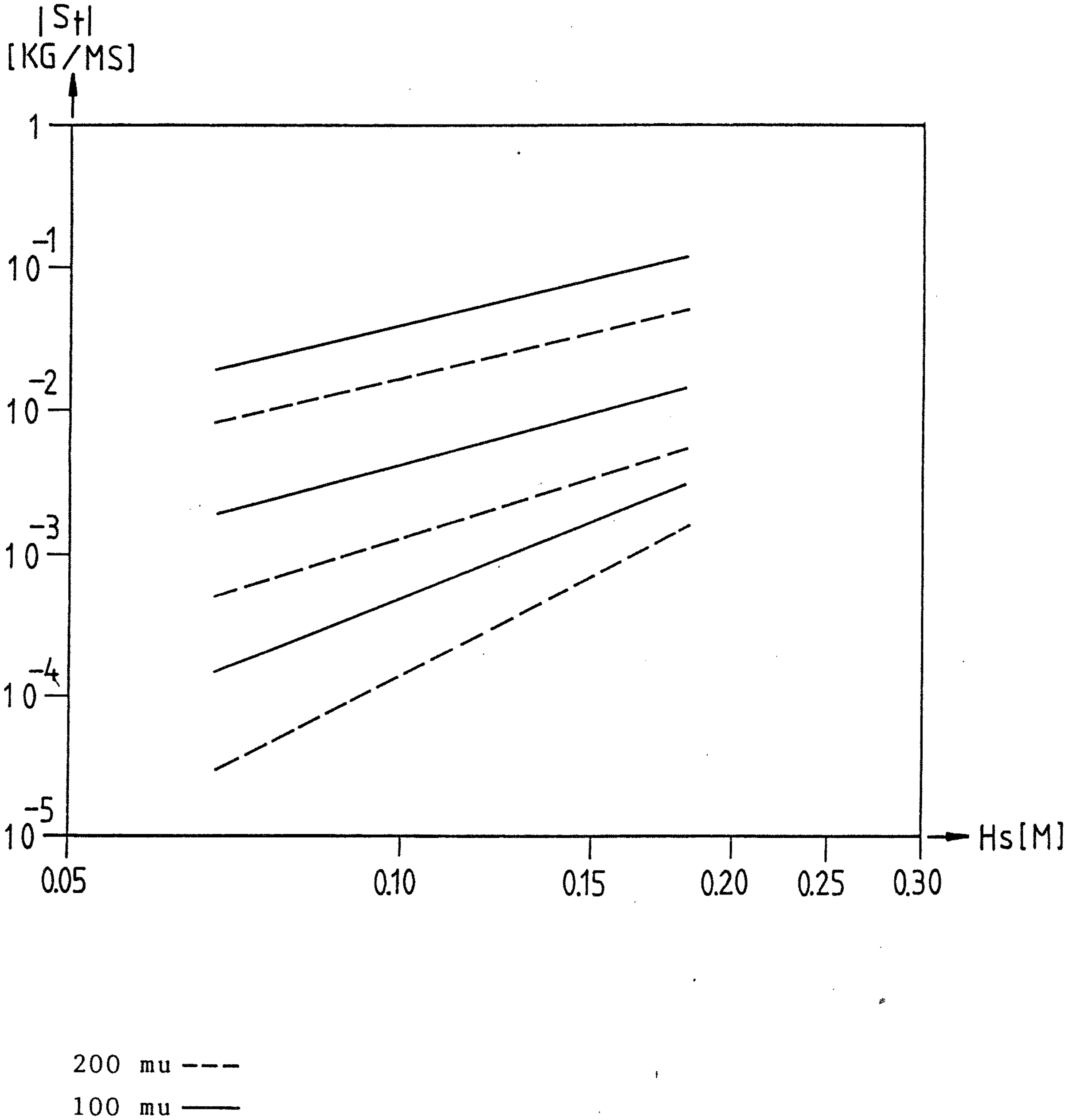
INFLUENCE OF DEPTH AVERAGED VELOCITY ON
THE TOTAL LOAD TRANSPORT

FIGURE 4.7.C



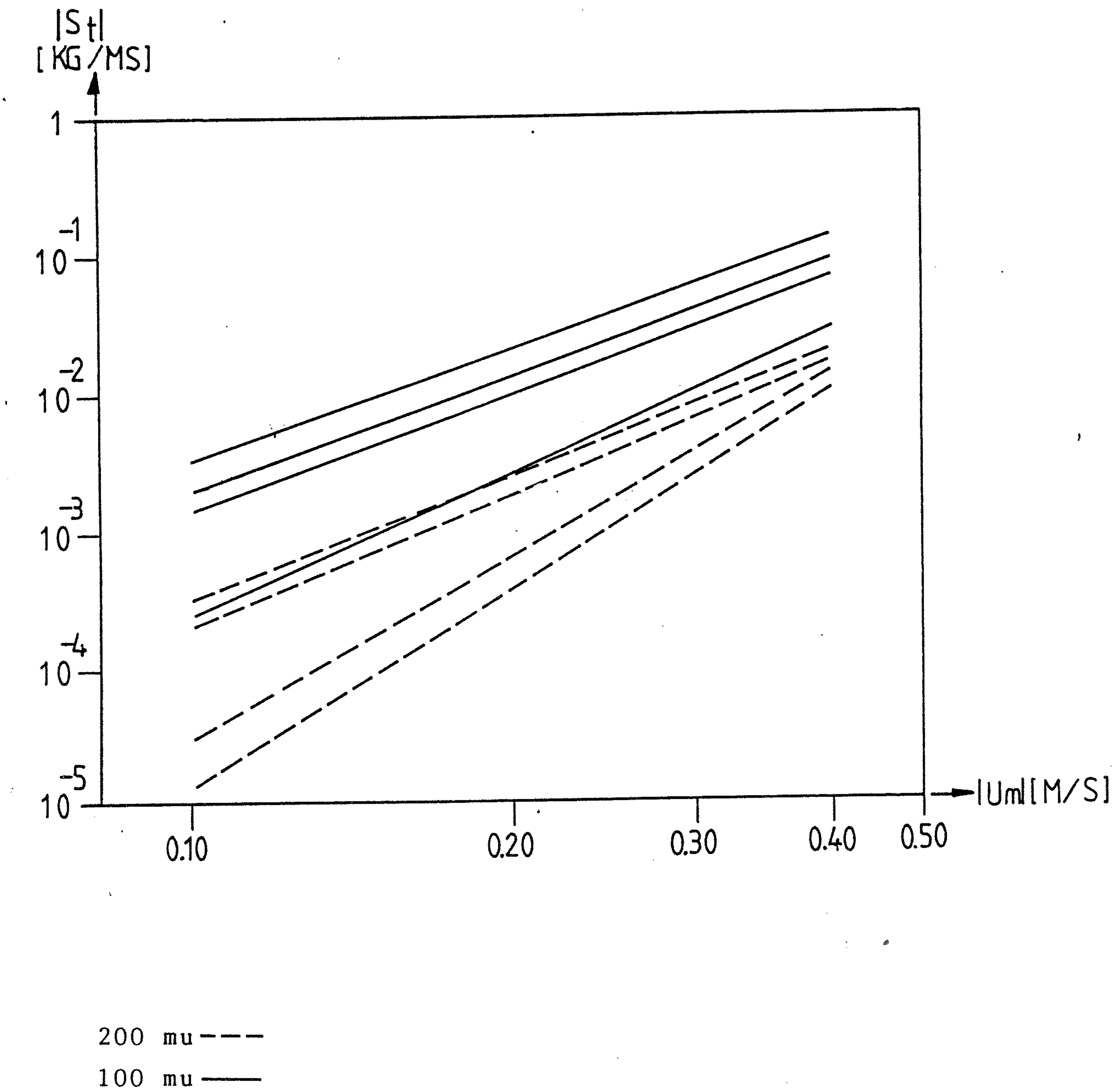
INFLUENCE OF WAVEHEIGHT ON DEPTH AVERAGED
VELOCITY PROPORTION FACTOR

FIGURE 4.7.D



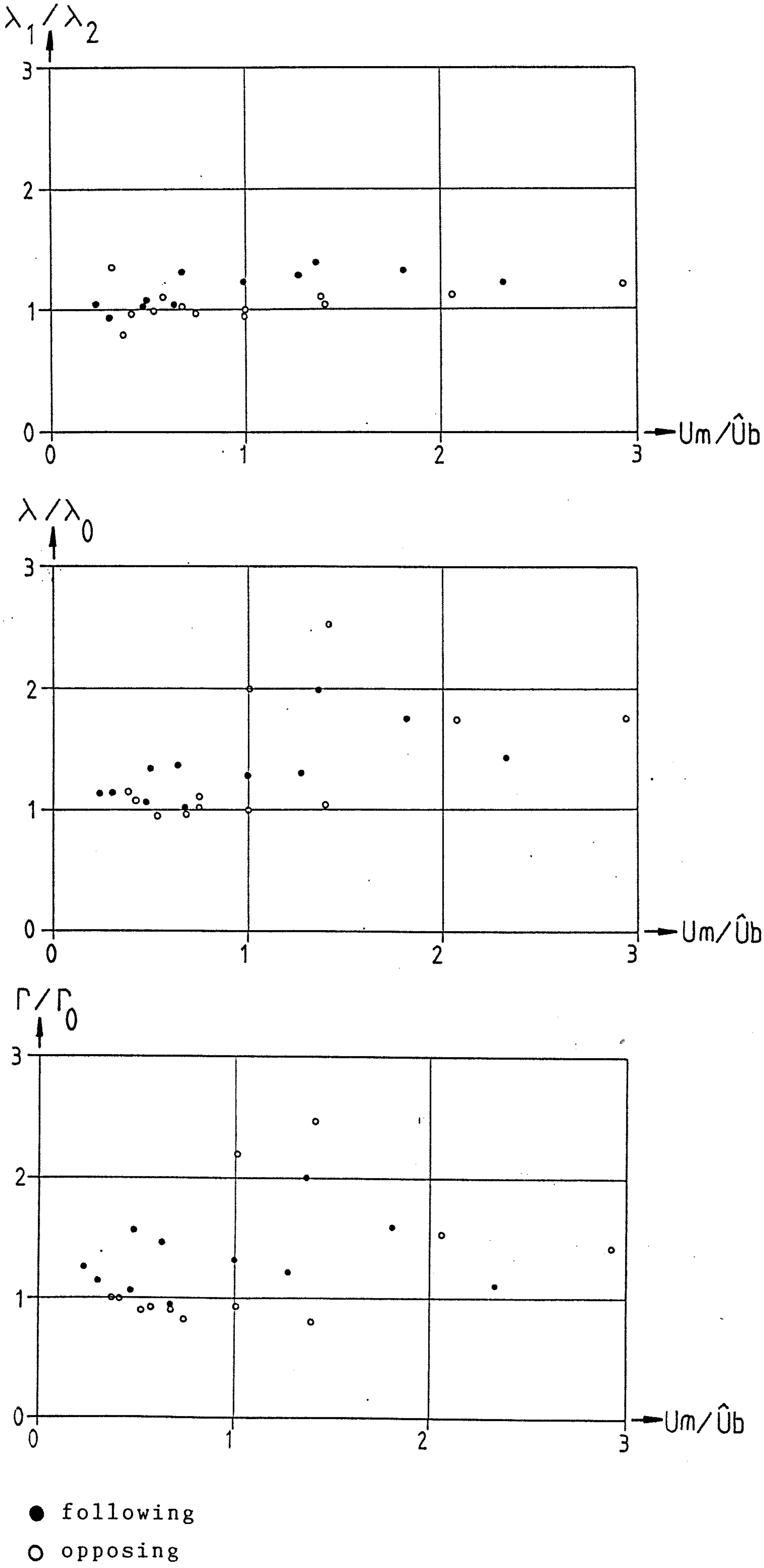
COMPARISON OF WAVEHEIGHT INFLUENCE ON
TOTAL LOAD TRANSPORT FOR 100MU AND 200MU

FIGURE 4.7.E



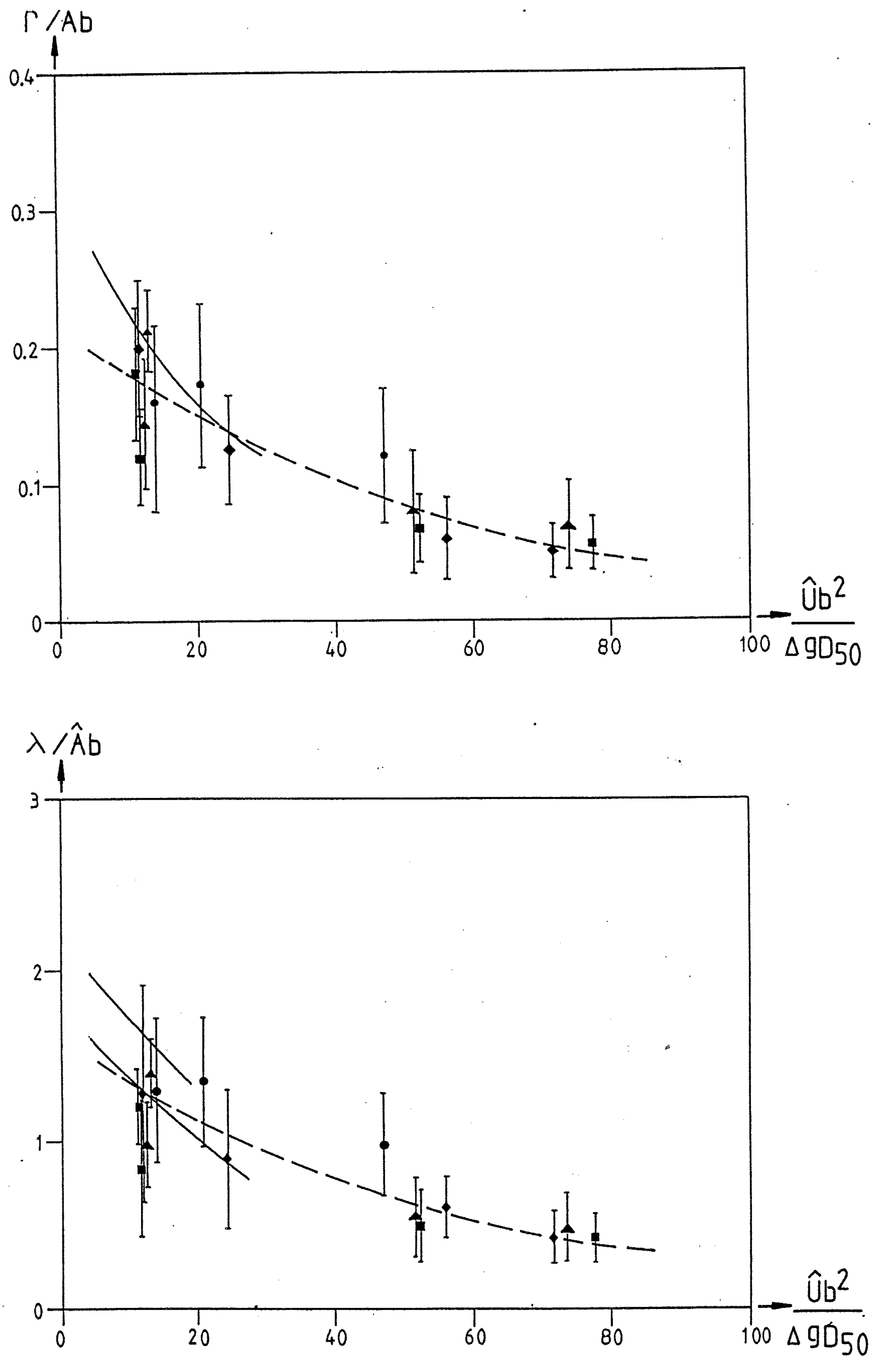
COMPARISON OF DEPTH AVERAGED VELOCITY INFLUENCE ON TOTAL LOAD TRANSPORT FOR 100MU AND 200MU

FIGURE 4.7.F



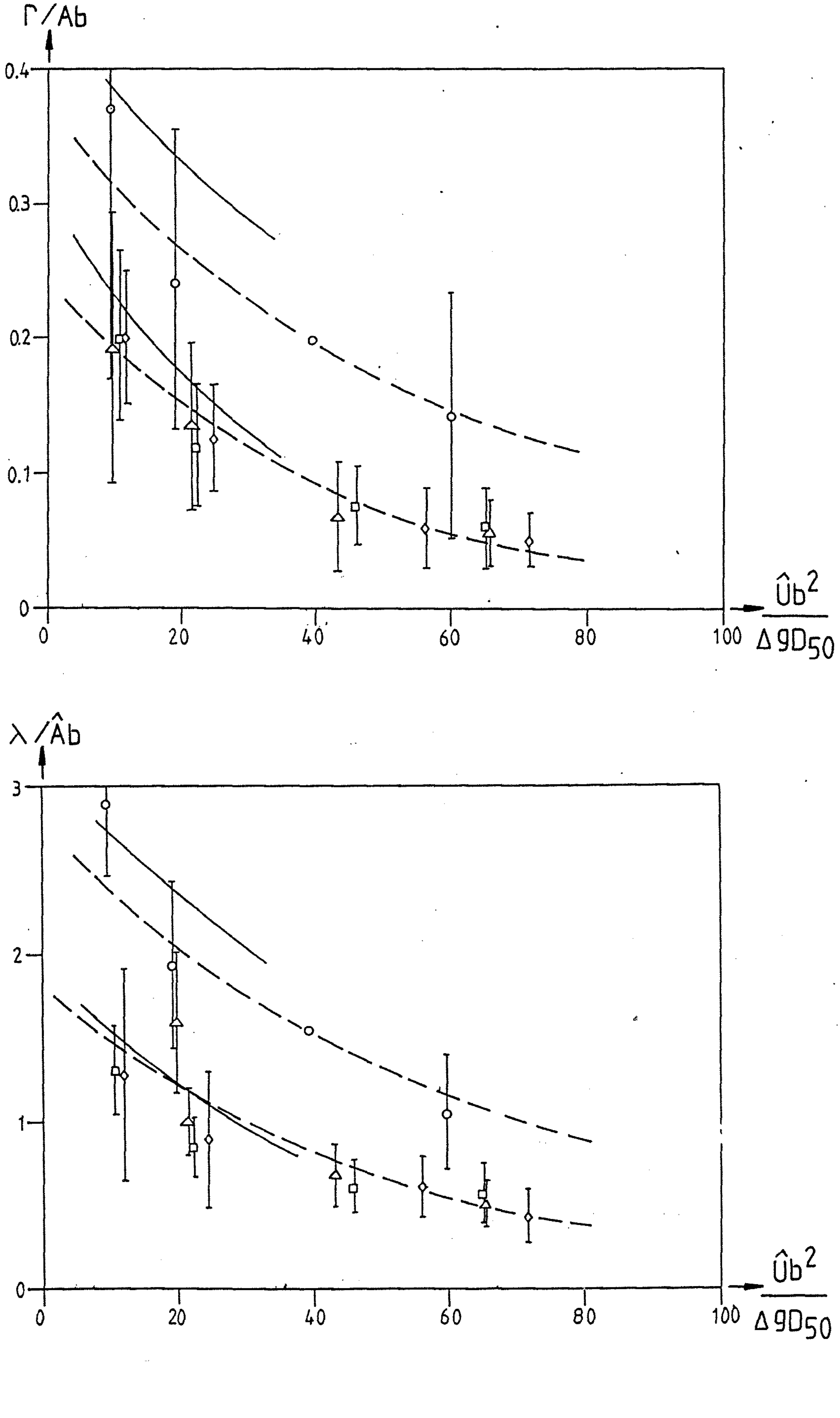
RIPPLE CHARACTERISTICS

FIGURE 4.8.A



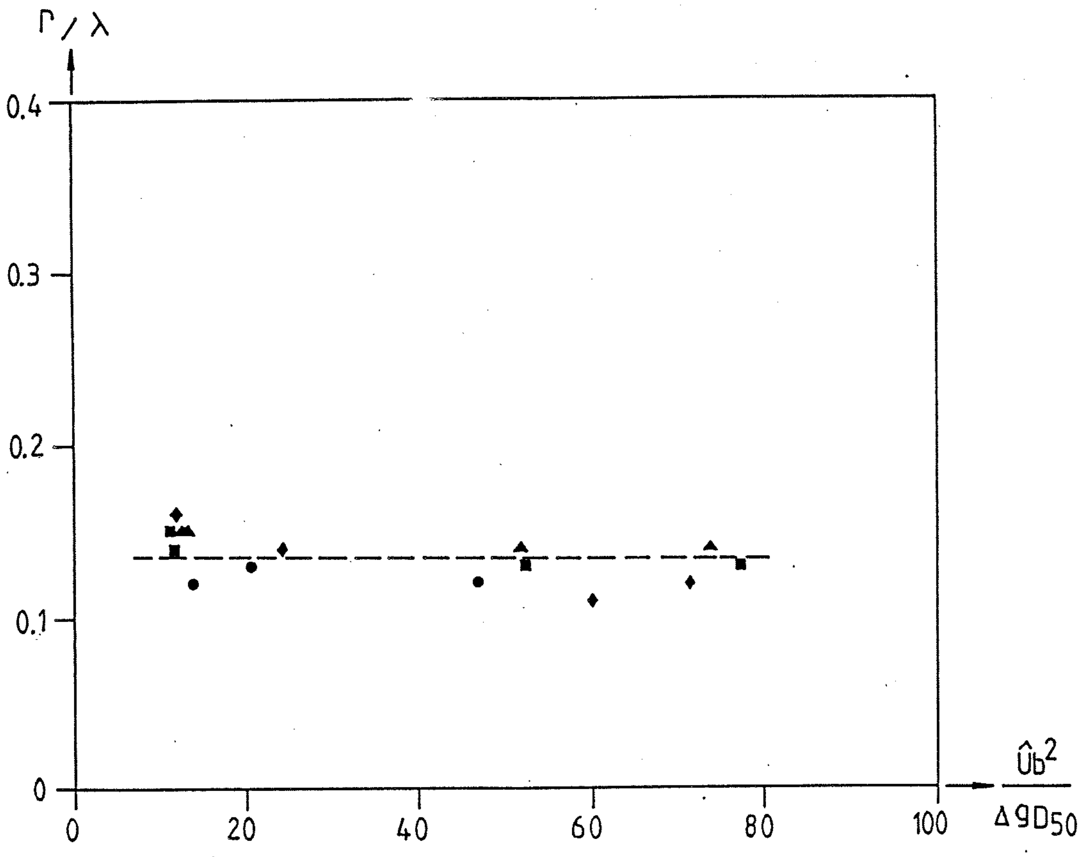
INFLUENCE OF WAVEHEIGHT ON RIPPLE HEIGHT
AND RIPPLE STEEPNESS FOR WAVES PROPAGATING
WITH THE CURRENT

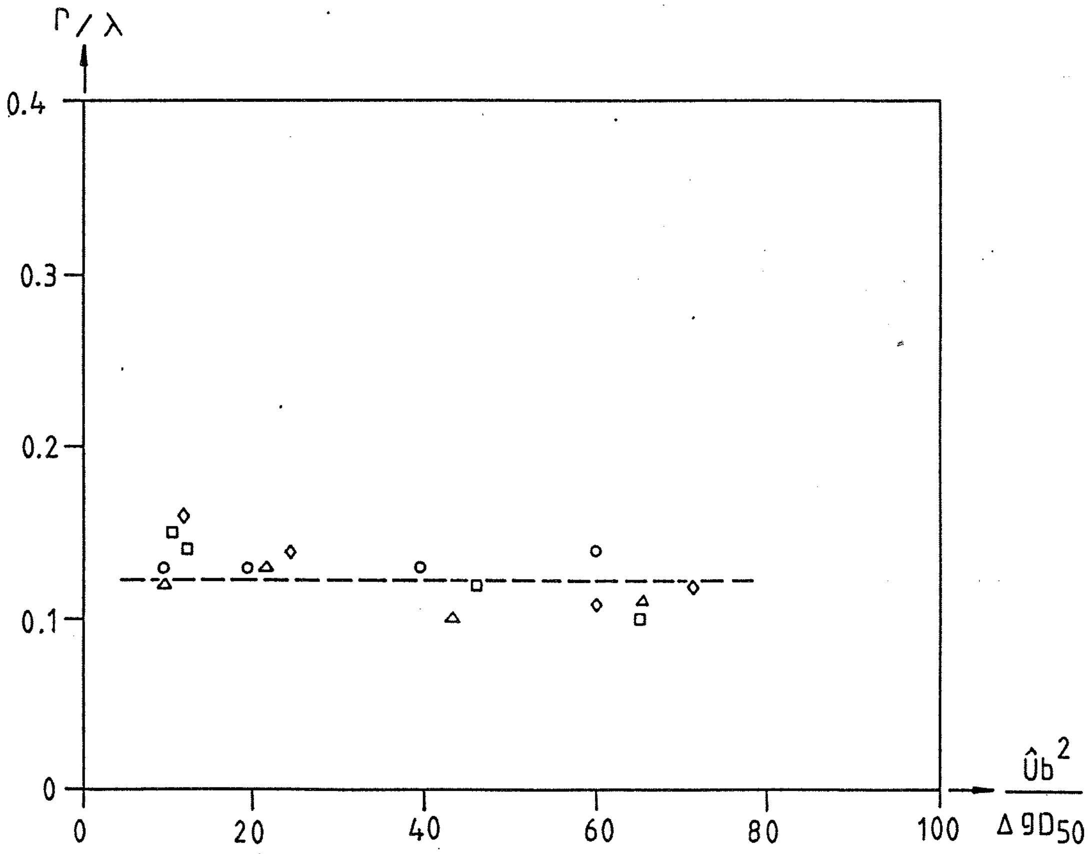
FIGURE 4.8.B



INFLUENCE OF WAVEHEIGHT ON RIPPLE HEIGHT
AND RIPPLE STEEPNESS FOR WAVES PROPAGATING
AGAINST THE CURRENT

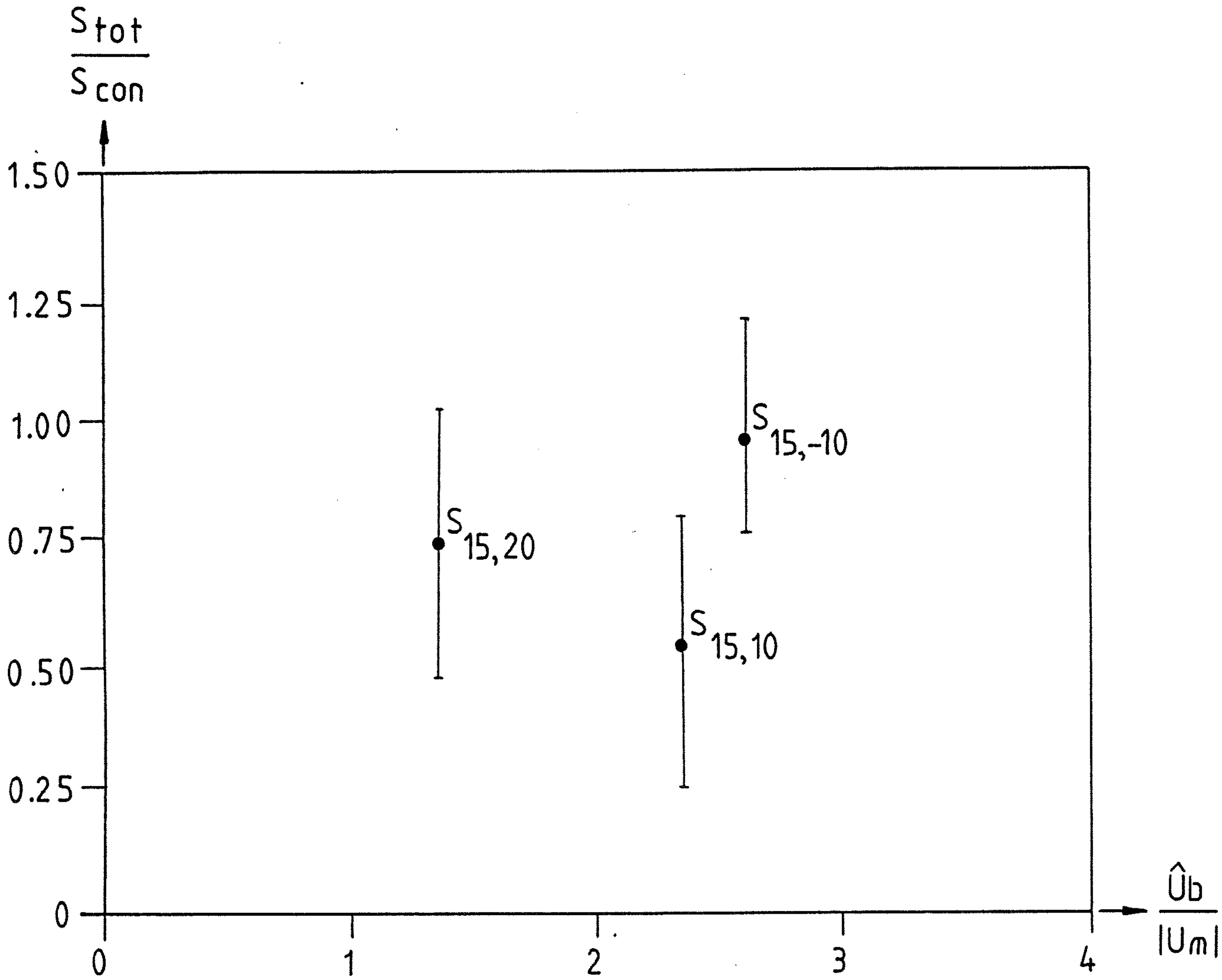
FIGURE 4.8.C





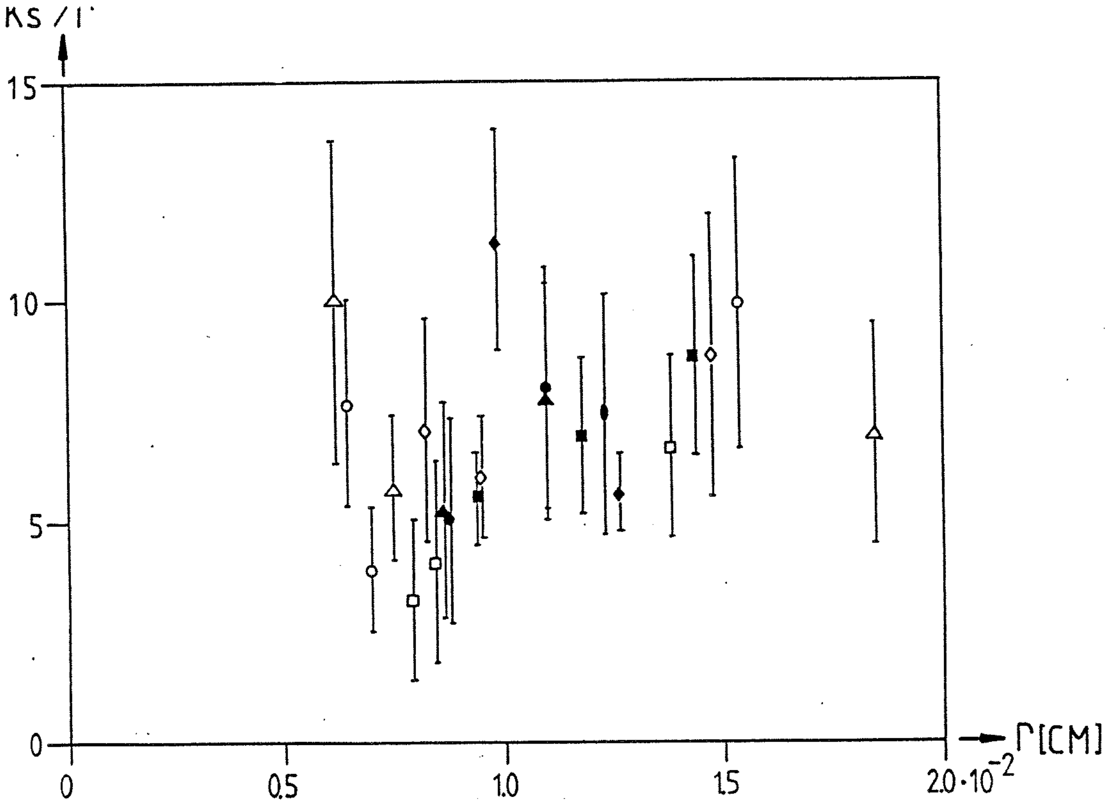
INFLUENCE OF WAVEHEIGHT ON RIPPLE STEEPNESS

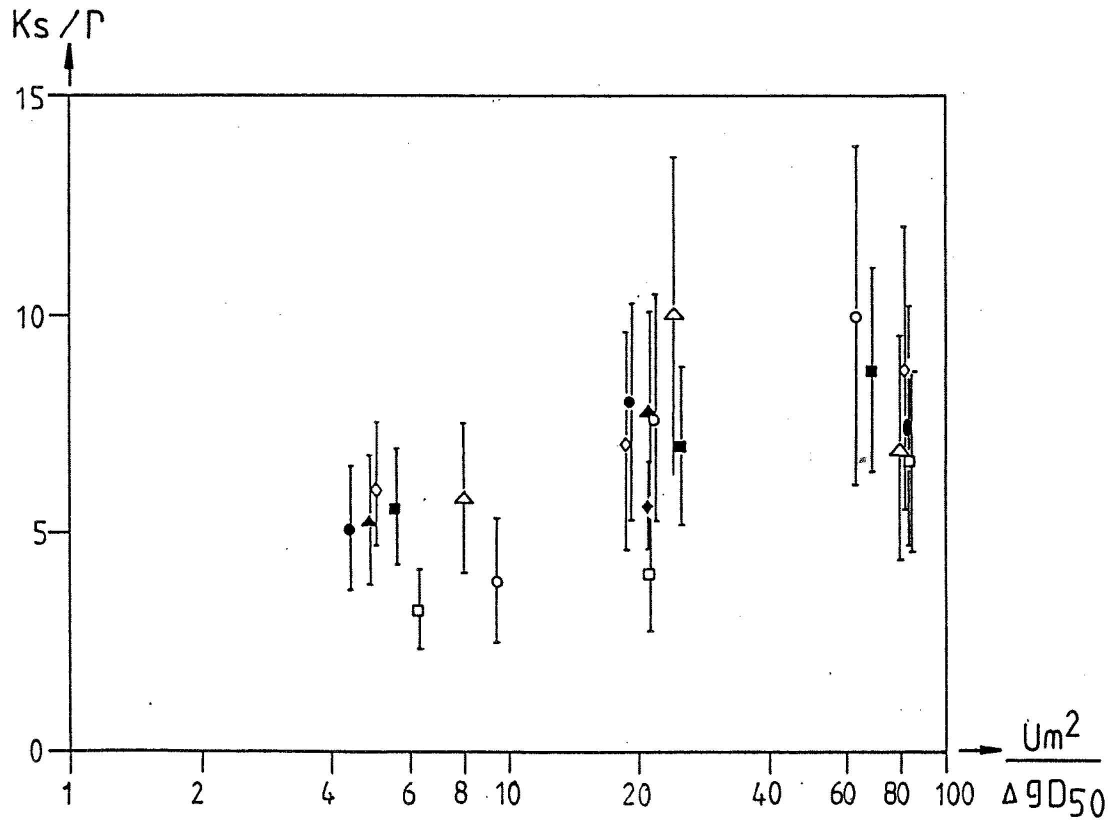
FIGURE 4.8.D



THE SAND-BALANCE RESULTS

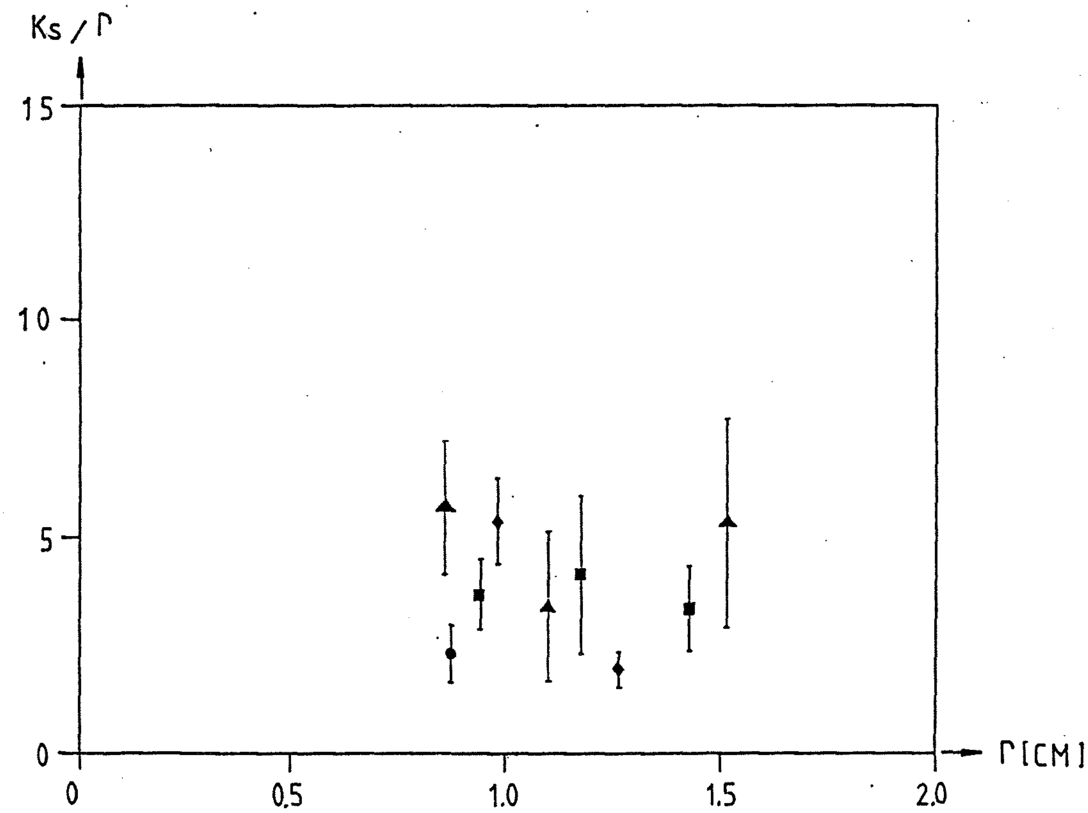
FIGURE 5.1

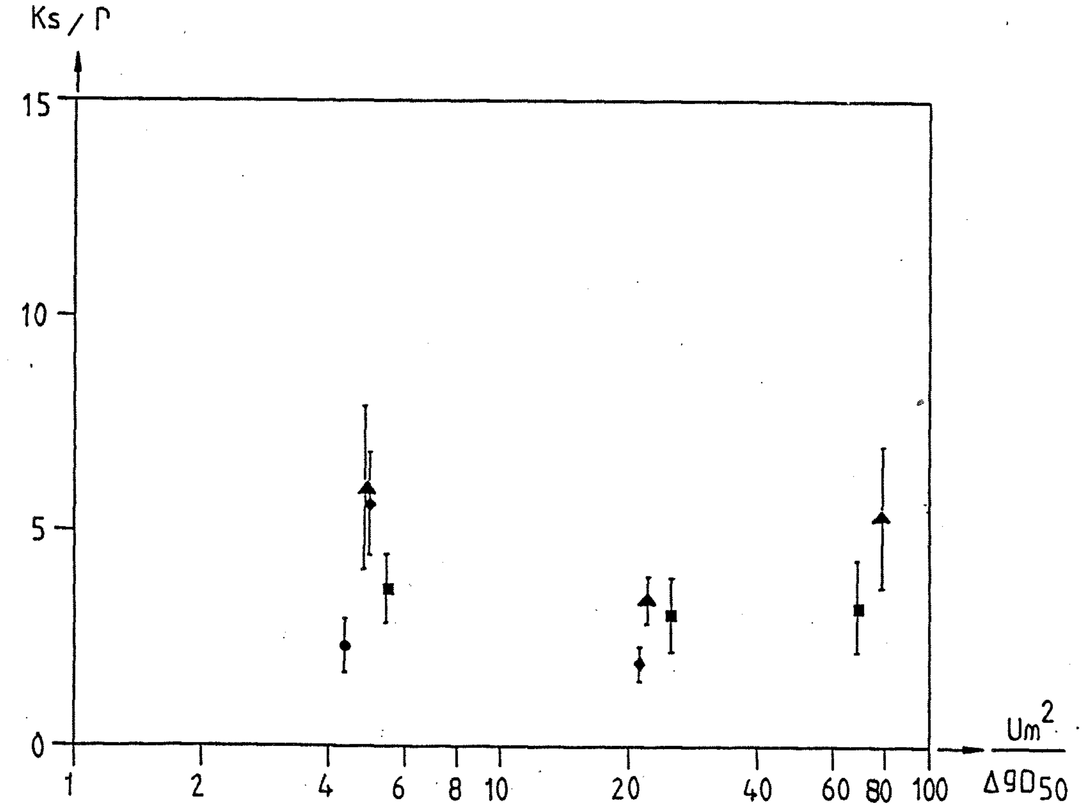




INFLUENCE OF RIPPLE HEIGHT AND DEPTH AVERAGED VELOCITY ON RELATIVE BEDROUGHNESS FROM THE LOGARITHMIC VELOCITY DISTRIBUTION

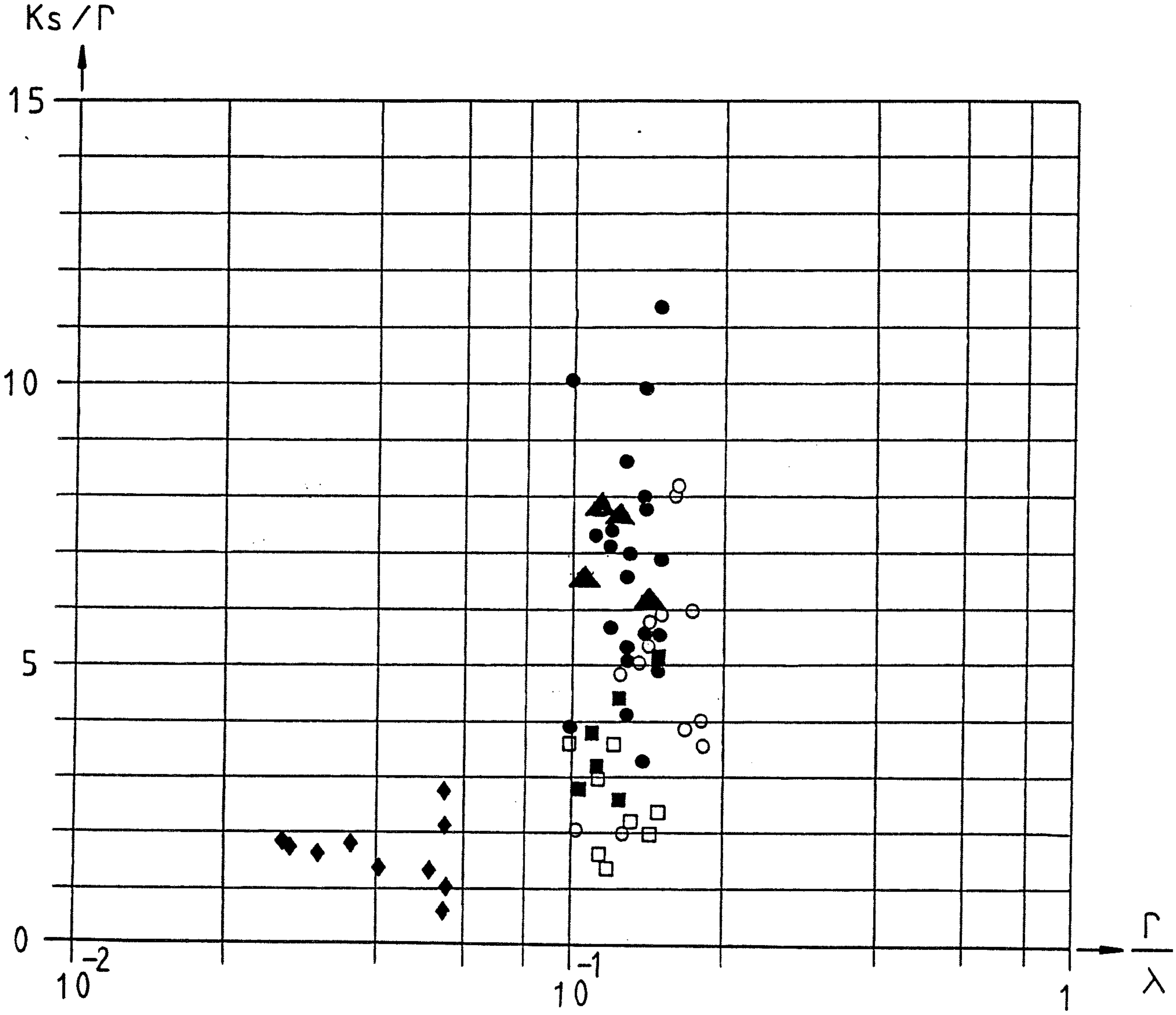
FIGURE 6.1.A





INFLUENCE OF RIPPLE HEIGHT AND DEPTH AVERAGED VELOCITY ON RELATIVE BEDROUGHNESS FROM THE VANONI/BROOKS-METHOD

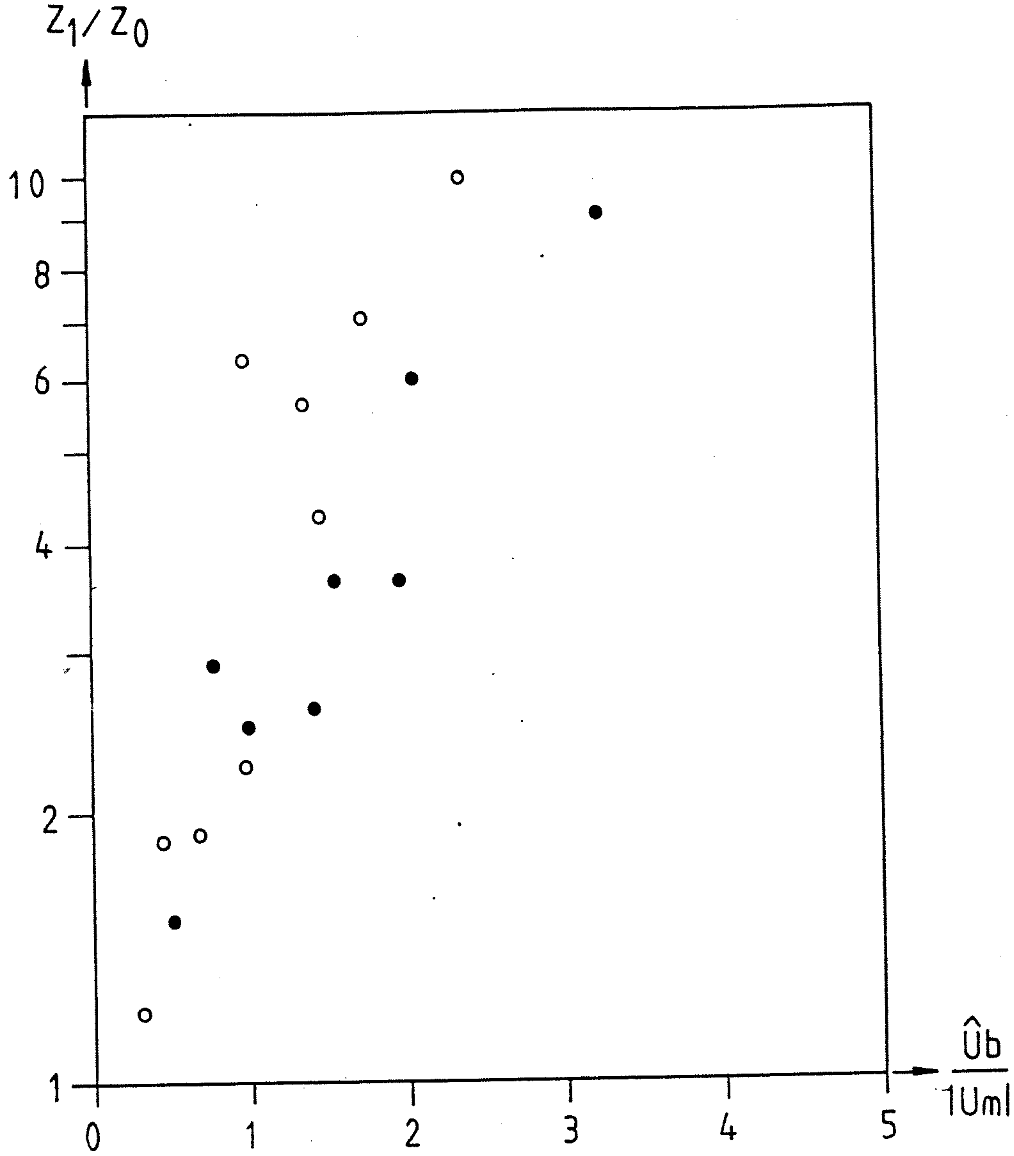
FIGURE 6.1.B



● 100-mu-study
○ 200-mu-study
◆ Pakistan irrigation channels 150-300 mu
▲ Vanoni-Brooks 140 mu
■ Barton-Lin 180 mu
□ Ackers 180 mu

INFLUENCE OF RIPPLE STEEPNESS ON RELATIVE BEDROUGHNESS

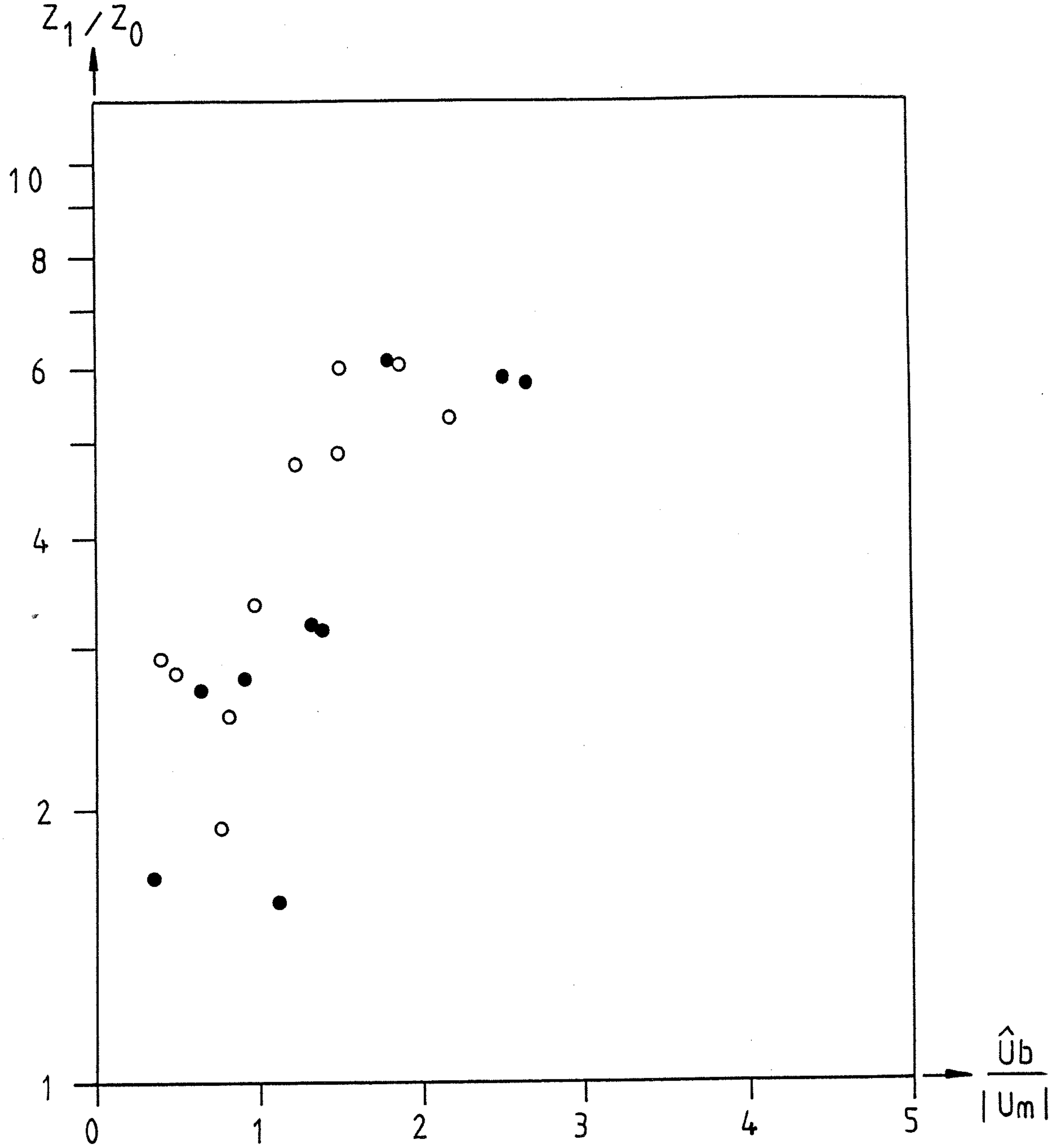
FIGURE 6.1.C



● following
○ opposing

THE APPARENT ROUGHNESS INCREASE
D50 = 100 MU

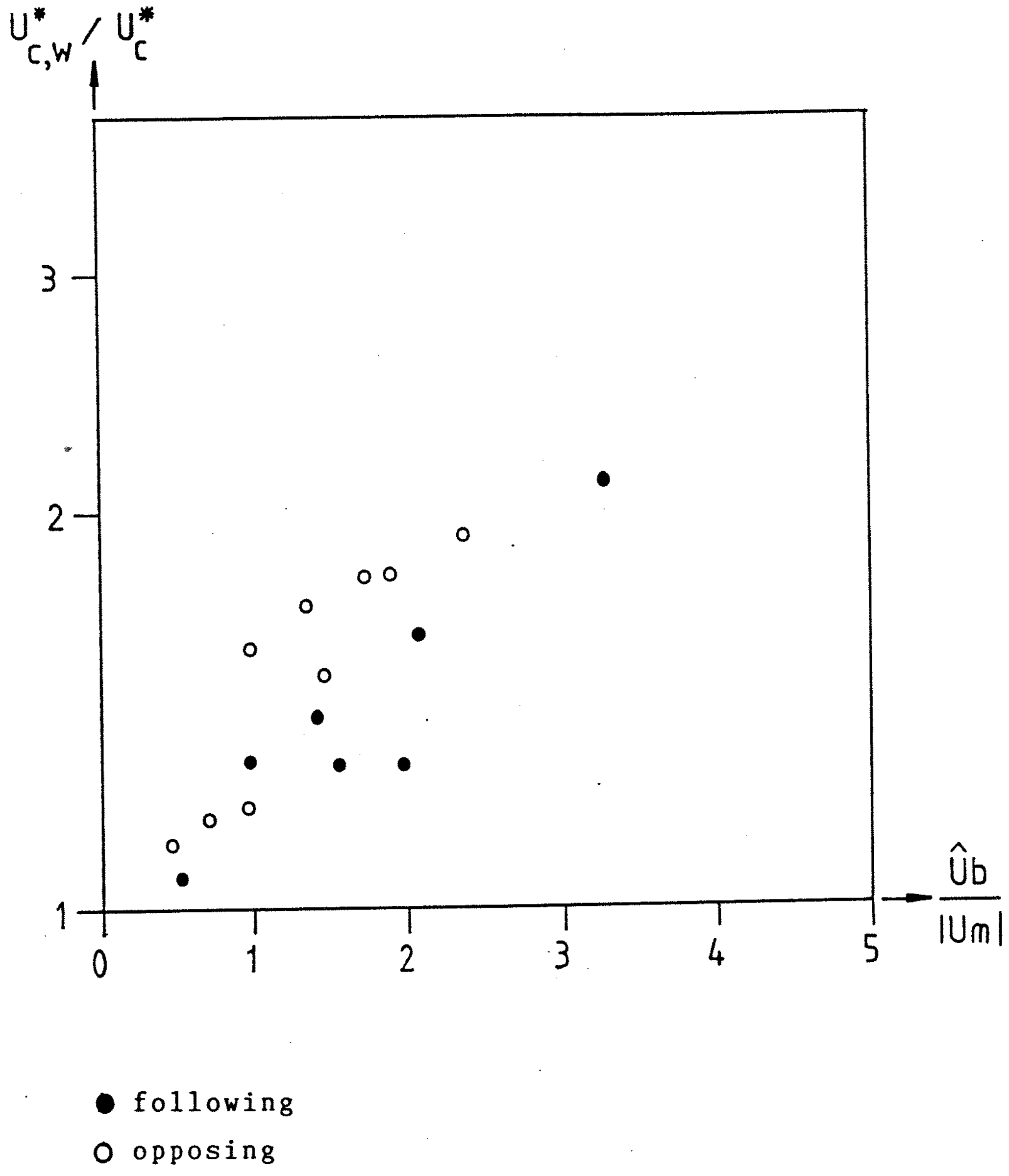
FIGURE 6.2.A



● following
○ opposing

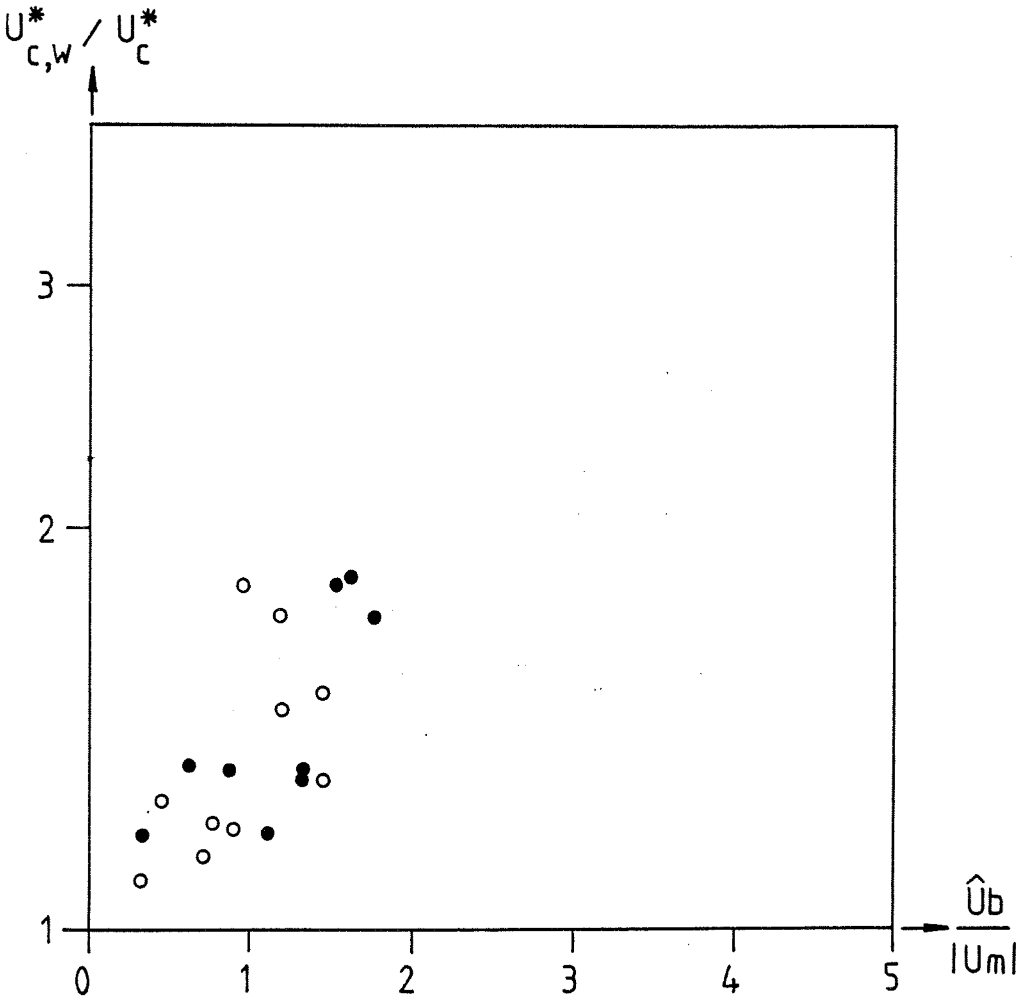
THE APPARENT ROUGHNESS INCREASE
D50 = 200 MU

FIGURE 6.2.B



BED SHEAR VELOCITY INCREASE

D50 = 100 MU



● following

○ opposing

BED SHEAR VELOCITY INCREASE

D50 = 200 MU

TABLES and FIGURES

FROM THE SEDIMENT TRANSPORT MODELS AND THEIR

COMPARISON WITH THE EXPERIMENTAL RESULTS

(see chapter 7)

BAGNOLD-BAILARD-concept COMPUTATIONS

D50= 100mu a= 0.5 m	S(meas) *10 -3 kg/m.s	Ks= 3*r S(Bailard) *10 -3 kg/m.s	Ks= 3*r Sc/Sm	Ks= 7*r S(Bailard) *10 -3 kg/m.s	Ks= 7*r Sc/Sm
H= Hrms					
T 7.5,10	0,27	5,63	20,9	5,63	20,9
T 7.5,-10	-0,36	-1,09	3,0	-1,09	3,0
T 7.5,20	1,85	11,08	6,0	11,08	6,0
T 7.5,-20	-2,97	-4,00	1,3	-4,00	1,3
T 7.5,40	34,16	55,47	1,6	28,60	0,8
T 7.5,-40	-33,26	-15,57	0,5	-15,57	0,5
T 10,10	1,16	26,66	23,0	17,73	15,3
T 10,-10	-1,64	-1,98	1,2	-1,36	0,8
T 10,20	7,69	57,79	7,5	32,89	4,3
T 10,-20	-6,97	-15,32	2,2	-9,34	1,3
T 10,40	48,99	41,87	0,9	41,87	0,9
T 10,-40	-52,03	-28,35	0,5	-28,35	0,5
T 15,10	2,31	56,14	24,3	114,60	49,6
T 15,-10	-5,45	2,07	-0,4	2,04	-0,4
T 15,20	11,23	98,38	8,8	91,71	8,2
T 15,-20	-14,38	-15,96	1,1	-32,61	2,3
T 15,40	99,35	214,35	2,2	140,95	1,4
T 15,-40	-86,97	-53,80	0,6	-53,80	0,6
T 18,10	4,11	96,05	23,4	191,92	46,7
T 18,-10	-7,32	+7,84	1,1	+15,75	2,2
T 18,20	12,61	154,08	12,2	294,86	23,4
T 18,-20	-19,37	-19,01	1,0	-19,01	1,0
T 18,-40	-95,89	-87,09	0,9	-347,60	3,6

ENGELUND-HANSEN COMPUTATIONS

D50= 100mu a= 0.5 m	S(meas) *10 -3 kg/m.s	Ks= 3*r S(E-H) *10 -3 kg/m.s	Ks= 3*r Sc/Sm	Ks= 7*r S(E-H) *10 -3 kg/m.s	Ks= 7*r Sc/Sm
H= Hsig					
T 7.5,10	0,27	11,15	41,3	14,49	53,7
T 7.5,-10	-0,36	-12,27	34,1	-13,51	37,5
T 7.5,20	1,85	41,17	22,3	42,35	22,9
T 7.5,-20	-2,97	-21,97	7,4	-26,38	8,9
T 7.5,40	34,16	107,75	3,2	175,25	5,1
T 7.5,-40	-33,26	-123,69	3,7	-145,71	4,4
T 10,10	1,16	23,78	20,5	69,69	60,1
T 10,-10	-1,64	-22,12	13,5	-60,07	36,6
T 10,20	7,69	77,76	10,1	146,36	19,0
T 10,-20	-6,97	-56,25	8,1	-120,19	17,2
T 10,40	48,99	188,13	3,8	273,13	5,6
T 10,-40	-52,03	-312,81	6,0	-323,63	6,2
T 15,10	2,31	41,05	17,8	133,86	57,9
T 15,-10	-5,45	-54,39	10,0	-182,83	33,5
T 15,20	11,23	121,97	10,9	402,81	35,9
T 15,-20	-14,38	-81,34	5,7	-257,31	17,9
T 15,40	99,35	496,00	5,0	1150,00	11,6
T 15,-40	-86,97	-751,58	8,6	-873,57	10,0
T 18,10	4,11	64,74	15,8	203,12	49,4
T 18,-10	-7,32	-83,96	11,5	-265,78	36,3
T 18,20	12,61	175,45	13,9	560,14	44,4
T 18,-20	-19,37	-139,05	7,2	-425,94	22,0
T 18,-40	-95,89	-991,00	10,3	-1863,00	19,4
H= Hrms					
T 7.5,10	0,27	4,48	16,6	3,98	14,7
T 7.5,-10	-0,36	-4,16	11,6	-3,68	10,2
T 7.5,20	1,85	14,30	7,7	14,15	7,6
T 7.5,-20	-2,97	-8,87	3,0	-8,78	3,0
T 7.5,40	34,16	68,69	2,0	82,25	2,4
T 7.5,-40	-33,26	-62,28	1,9	-83,42	2,5
T 10,10	1,16	11,07	9,5	15,87	13,7
T 10,-10	-1,64	-10,30	6,3	-15,79	9,6
T 10,20	7,69	39,56	5,1	44,16	5,7
T 10,-20	-6,97	-28,28	4,1	-35,50	5,1
T 10,40	48,99	100,80	2,1	112,61	2,3
T 10,-40	-52,03	-123,69	2,4	-144,26	2,8
T 15,10	2,31	17,75	7,7	63,20	27,4
T 15,-10	-5,45	-24,11	4,4	-75,15	13,8
T 15,20	11,23	56,66	5,0	152,80	13,6
T 15,-20	-14,38	-37,79	2,6	-127,11	8,8
T 15,40	99,35	274,00	2,8	405,00	4,1
T 15,-40	-86,97	-307,33	3,5	-322,59	3,7
T 18,10	4,11	27,41	6,7	93,81	22,8
T 18,-10	-7,32	-36,29	5,0	-124,62	17,0
T 18,20	12,61	78,64	6,2	270,93	21,5
T 18,-20	-19,37	-62,35	3,2	-204,02	10,5
T 18,-40	-95,89	-529,00	5,5	-619,00	6,5

TABLE 7.[illegible]

NIELSEN model COMPUTATIONS

D50= 100mu a= 0.5 m	S(meas) *10 -3 kg/m.s	Ks= 3*r S(Nielsen) *10 -3 kg/m.s	Ks= 3*r Sc/Sm	Ks= 7*r S(Nielsen) *10 -3 kg/m.s	Ks= 7*r Sc/Sm
H= Hsig					
T 7.5,10	0,27	0,81	3,0	0,89	3,3
T 7.5,-10	-0,36	-0,93	2,6	-1,06	2,9
T 7.5,20	1,85	17,59	9,5	27,66	15,0
T 7.5,-20	-2,97	-1,68	0,6	-0,61	0,2
T 7.5,40	34,16	129,40	3,8	263,80	7,7
T 7.5,-40	-33,26	-264,00	7,9	-806,00	24,2
T 10,10	1,16	3,84	3,3	3,97	3,4
T 10,-10	-1,64	-2,14	1,3	-2,02	1,2
T 10,20	7,69	121,00	15,7	184,00	23,9
T 10,-20	-6,97	-23,11	3,3	-26,63	3,8
T 10,40	48,99	422,60	8,6	886,30	18,1
T 10,-40	-52,03	-698,00	13,4	-1653,00	31,8
T 15,10	2,31	11,08	4,8	12,55	5,4
T 15,-10	-5,45	-12,22	2,2	-12,39	2,3
T 15,20	11,23	255,10	22,7	340,50	30,3
T 15,-20	-14,38	-26,32	1,8	-26,22	1,8
T 15,40	99,35	7034,00	70,8	16263,00	163,7
T 15,-40	-86,97	-4865,00	55,9	-11888,00	136,7
T 18,10	4,11	26,44	6,4	35,46	8,6
T 18,-10	-7,32	-18,77	2,6	-19,56	2,7
T 18,20	12,61	411,90	32,7	564,00	44,7
T 18,-20	-19,37	-103,30	5,3	-113,10	5,8
T 18,-40	-95,89	-15909,00	165,9	-37037,00	386,2
H= Hrms					
T 7.5,10	0,27	0,16	0,6	0,19	0,7
T 7.5,-10	-0,36	-0,19	0,5	-0,23	0,6
T 7.5,20	1,85	4,17	2,3	7,09	3,8
T 7.5,-20	-2,97	-0,40	0,1	-0,61	0,2
T 7.5,40	34,16	38,14	1,1	104,90	3,1
T 7.5,-40	-33,26	-114,00	3,4	-395,00	11,9
T 10,10	1,16	0,71	0,6	0,77	0,7
T 10,-10	-1,64	-0,41	0,3	-0,41	0,3
T 10,20	7,69	23,16	3,0	38,72	5,0
T 10,-20	-6,97	-4,75	0,7	-6,11	0,9
T 10,40	48,99	107,50	2,2	281,40	5,7
T 10,-40	-52,03	-213,00	4,1	-580,00	11,1
T 15,10	2,31	2,06	0,9	2,03	0,9
T 15,-10	-5,45	-2,35	0,4	-2,20	0,4
T 15,20	11,23	48,00	4,3	60,00	5,3
T 15,-20	-14,38	-5,44	0,4	-5,07	0,4
T 15,40	99,35	1429,00	14,4	3569,00	35,9
T 15,-40	-86,97	-1055,00	12,1	-3009,00	34,6
T 18,10	4,11	4,91	1,2	5,40	1,3
T 18,-10	-7,32	-3,62	0,5	-3,36	0,5
T 18,20	12,61	76,30	6,1	93,47	7,4
T 18,-20	-19,37	-21,26	1,1	-20,91	1,1
T 18,-40	-95,89	-2982,00	31,1	-7466,00	77,9

TABLE 7.3.A

NIELSEN model COMPUTATIONS

D50= 100mu a= 0.5 m	S(meas) *10 -3 kg/m.s	Ks= 3*r S(Nielsen) *10 -3 kg/m.s	Ks= 3*r Sc/Sm	Ks= 7*r S(Nielsen) *10 -3 kg/m.s	Ks= 7*r Sc/Sm
H= Hprob					
T 7.5,10	0,27	0,47	1,7	0,51	1,9
T 7.5,-10	-0,36	-0,54	1,5	-0,61	1,7
T 7.5,20	1,85	1,03	0,6	15,79	8,5
T 7.5,-20	-2,97	-0,95	0,3	-1,20	0,4
T 7.5,40	34,16	72,03	2,1	150,00	4,4
T 7.5,-40	-33,26	-151,00	4,5	-485,00	14,6
T 10,10	1,16	2,17	1,9	2,52	2,2
T 10,-10	-1,64	-1,19	0,7	-1,23	0,8
T 10,20	7,69	70,57	9,2	117,50	15,3
T 10,-20	-6,97	-12,82	1,8	-15,47	2,2
T 10,40	48,99	243,00	5,0	520,00	10,6
T 10,-40	-52,03	-417,00	8,0	-1008,00	19,4
T 15,10	2,31	6,46	2,8	8,10	3,5
T 15,-10	-5,45	-6,89	1,3	-7,81	1,4
T 15,20	11,23	150,10	13,4	222,00	19,8
T 15,-20	-14,38	-14,44	1,0	-15,49	1,1
T 15,40	99,35	4177,00	42,0	1106,00	11,1
T 15,-40	-86,97	-2998,00	34,5	-8075,00	92,8
T 18,10	4,11	16,15	3,9	4,99	1,2
T 18,-10	-7,32	-10,65	1,5	-12,39	1,7
T 18,20	12,61	246,00	19,5	375,00	29,7
T 18,-20	-19,37	-58,51	3,0	-68,70	3,5
T 18,-40	-95,89	-9729,00	101,5	-27326,00	285,0

D50= 200mu
Ks from Nielsen method
a= 0.5 m

	S(meas) *10 -3 kg/m.s	S(Nielsen) *10 -3 kg/m.s	Sc/Sm
H= Hprob			
T 7.5,10	0,03	0,37	12,3
T 7.5,20	0,40	2,43	6,1
T 7.5,40	12,90	72,03	5,6
T 10,10	0,15	2,31	15,4
T 10,-10	-0,11	-1,44	13,1
T 10,20	1,20	8,96	7,5
T 10,-20	-0,91	-6,16	6,8
T 10,40	23,60	189,00	8,0
T 10,-40	-29,00	-84,50	2,9
T 15,10	0,84	5,92	7,0
T 15,-10	-0,95	8,00	-8,4
T 15,20	5,24	52,80	10,1
T 15,-20	-3,23	-45,80	14,2
T 15,-40	-47,90	-277,00	5,8
T 18,-20	-4,10	-70,40	17,2
T 18,-40	-69,20	-360,00	5,2

TABLE 7.3.B

BIJKER model COMPUTATIONS

D50= 100mu a= 0.5 m	S(meas) *10 -3 kg/m.s	Ks= 3*r S(Bijker) *10 -3 kg/m.s	Ks= 3*r Sc/Sm	Ks= 7*r S(Bijker) *10 -3 kg/m.s	Ks= 7*r Sc/Sm
H= Hprob					
T 7.5,10	0,27	1,44	5,3	1,00	3,7
T 7.5,-10	-0,36	-1,48	4,1	-0,94	2,6
T 7.5,20	1,85	4,01	2,2	2,41	1,3
T 7.5,-20	-2,97	-3,17	1,1	-2,22	0,7
T 7.5,40	34,16	14,75	0,4	10,65	0,3
T 7.5,-40	-33,26	-13,50	0,4	-9,45	0,3
T 10,10	1,16	2,99	2,6	2,46	2,1
T 10,-10	-1,64	-3,01	1,8	-2,73	1,7
T 10,20	7,69	7,99	1,0	5,19	0,7
T 10,-20	-6,97	-7,23	1,0	-5,82	0,8
T 10,40	48,99	15,30	0,3	10,22	0,2
T 10,-40	-52,03	-20,33	0,4	-13,10	0,3
T 15,10	2,31	4,39	1,9	4,23	1,8
T 15,-10	-5,45	-3,66	0,7	-6,05	1,1
T 15,20	11,23	10,60	0,9	8,65	0,8
T 15,-20	-14,38	-11,71	0,8	-11,94	0,8
T 15,40	99,35	27,04	0,3	17,31	0,2
T 15,-40	-86,97	-23,57	0,3	-13,97	0,2
T 18,10	4,11	5,68	1,4	4,99	1,2
T 18,-10	-7,32	-8,84	1,2	-8,42	1,2
T 18,20	12,61	11,96	0,9	9,80	0,8
T 18,-20	-19,37	-15,50	0,8	-14,58	0,8
T 18,-40	-95,89	-32,74	0,3	-19,59	0,2
H= Hrms					
T 7.5,10	0,27	1,52	5,6	0,79	2,9
T 7.5,-10	-0,36	-1,48	4,1	-0,75	2,1
T 7.5,20	1,85	4,32	2,3	2,41	1,3
T 7.5,-20	-2,97	-3,28	1,1	-1,97	0,7
T 7.5,40	34,16	17,23	0,5	11,30	0,3
T 7.5,-40	-33,26	-14,00	0,4	-9,76	0,3
T 10,10	1,16	3,62	3,1	2,82	2,4
T 10,-10	-1,64	-3,54	2,2	-3,04	1,9
T 10,20	7,69	10,42	1,4	6,16	0,8
T 10,-20	-6,97	-8,94	1,3	-6,71	1,0
T 10,40	48,99	18,53	0,4	11,27	0,2
T 10,-40	-52,03	-22,98	0,4	-13,10	0,3
T 15,10	2,31	5,21	2,3	5,92	2,6
T 15,-10	-5,45	-7,50	1,4	-8,25	1,5
T 15,20	11,23	12,73	1,1	11,46	1,0
T 15,-20	-14,38	-13,56	0,9	-16,24	1,1
T 15,40	99,35	31,90	0,3	19,84	0,2
T 15,-40	-86,97	-28,26	0,3	-15,87	0,2
T 18,10	4,11	6,85	1,7	6,59	1,6
T 18,-10	-7,32	-10,49	1,4	-11,19	1,5
T 18,20	12,61	14,39	1,1	13,37	1,1
T 18,-20	-19,37	-18,21	0,9	-18,89	1,0
T 18,-40	-95,89	-40,49	0,4	-22,66	0,2

BIJKER model COMPUTATIONS

D50= 100mu a= 0.5 m	S(meas) *10 -3 kg/m.s	Ks= 3*r S(Bijker) *10 -3 kg/m.s	Ks= 3*r Sc/Sm	Ks= 7*r S(Bijker) *10 -3 kg/m.s	Ks= 7*r Sc/Sm
H= Hsig					
T 7.5,10	0,27	3,54	13,1	2,59	9,6
T 7.5,-10	-0,36	-3,75	10,4	-2,41	6,7
T 7.5,20	1,85	9,61	5,2	5,53	3,0
T 7.5,-20	-2,97	-7,55	2,5	-5,27	1,8
T 7.5,40	34,16	23,97	0,7	16,72	0,5
T 7.5,-40	-33,26	-21,30	0,6	-13,26	0,4
T 10,10	1,16	6,15	5,3	5,74	4,9
T 10,-10	-1,64	-6,29	3,8	-6,48	4,0
T 10,20	7,69	15,07	2,0	10,70	1,4
T 10,-20	-6,97	-14,09	2,0	-12,58	1,8
T 10,40	48,99	25,37	0,5	16,54	0,3
T 10,-40	-52,03	-22,98	0,4	-20,04	0,4
T 15,10	2,31	8,44	3,7	7,69	3,3
T 15,-10	-5,45	-12,06	2,2	-11,37	2,1
T 15,20	11,23	18,62	1,7	15,50	1,4
T 15,-20	-14,38	-21,83	1,5	-21,32	1,5
T 15,40	99,35	39,42	0,4	26,04	0,3
T 15,-40	-86,97	-38,07	0,4	-21,27	0,2
T 18,10	4,11	10,31	2,5	8,23	2,0
T 18,-10	-7,32	-16,36	2,2	-14,29	2,0
T 18,20	12,61	20,58	1,6	16,20	1,3
T 18,-20	-19,37	-27,70	1,4	-23,99	1,2
T 18,-40	-95,89	-48,69	0,5	-29,19	0,3

TABLE 7.4.B

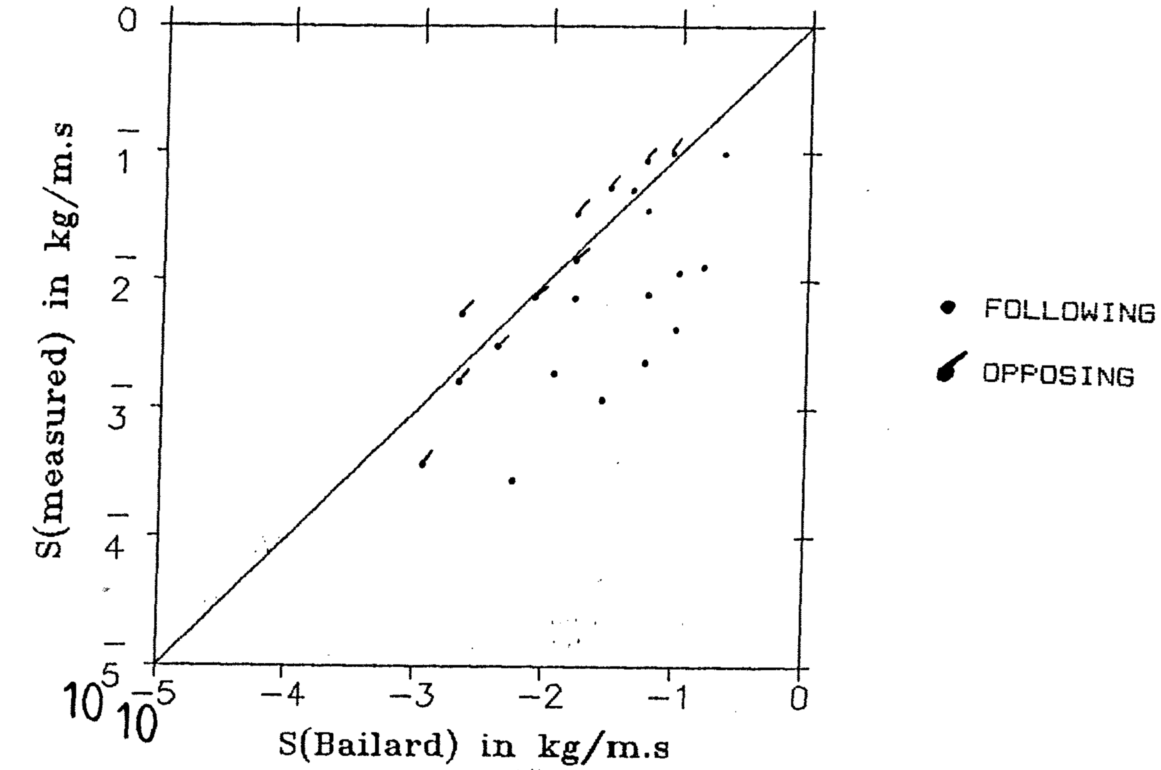
MODIFIED BIJKER MODEL RESULTS

a= 0.5 m Ks= 7*r H= Hrms	S(meas) *10 -3 kg/m.s	S(Bijker) *10 -3 kg/m.s	Sc/Sm
D50= 100mu			
T 7.5,10	0,27	0,16	0,6
T 7.5,-10	-0,36	-0,17	0,5
T 7.5,20	1,85	1,83	1,0
T 7.5,-20	-2,97	-0,92	0,3
T 7.5,40	34,16	36,22	1,1
T 7.5,-40	-33,26	-32,49	1,0
T 10,10	1,16	2,07	1,8
T 10,-10	-1,64	-2,07	1,3
T 10,20	7,69	12,64	1,6
T 10,-20	-6,97	-10,20	1,5
T 10,40	48,99	43,79	0,9
T 10,-40	-52,03	-63,20	1,2
T 15,10	2,31	6,71	2,9
T 15,-10	-5,45	-10,70	2,0
T 15,20	11,23	30,96	2,8
T 15,-20	-14,38	-32,30	2,2
T 15,40	99,35	132,00	1,3
T 15,-40	-86,97	-96,35	1,1
T 18,10	4,11	1,35	0,3
T 18,-10	-7,32	-15,76	2,2
T 18,20	12,61	36,85	2,9
T 18,-20	-19,37	-41,88	2,2
T 18,-40	-95,89	-158,00	1,6

D50= 200mu			
T 7.5,10	0,03	0,01	0,2
T 7.5,20	0,40	0,17	0,4
T 7.5,40	12,90	20,29	1,6
T 10,10	0,15	0,31	2,1
T 10,-10	-0,11	-0,20	1,8
T 10,20	1,20	1,02	0,9
T 10,-20	-0,91	-0,69	0,8
T 10,40	23,60	33,40	1,4
T 10,-40	-29,00	-28,87	1,0
T 12,10	0,56	0,52	0,9
T 12,-10	-0,22	-0,47	2,1
T 12,20	2,03	4,83	2,4
T 12,-20	-1,78	-2,79	1,6
T 12,40	30,01	47,40	1,6
T 12,-40	-32,60	-38,81	1,2
T 15,10	0,84	1,83	2,2
T 15,-10	-0,95	-2,75	2,9
T 15,20	5,24	11,06	2,1
T 15,-20	-3,23	-12,00	3,7
T 15,-40	-47,90	-51,88	1,1
T 18,-20	-4,10	-21,29	5,2
T 18,-40	-69,20	-67,82	1,0

TABLE 7.5

The BAILARD model
comparison of measured and computed
results, H=Hrms, Ks= 3*r, D50=100mu



The BAILARD model
comparison of measured and computed
results, H=Hrms, Ks= 7*r, D50=100mu

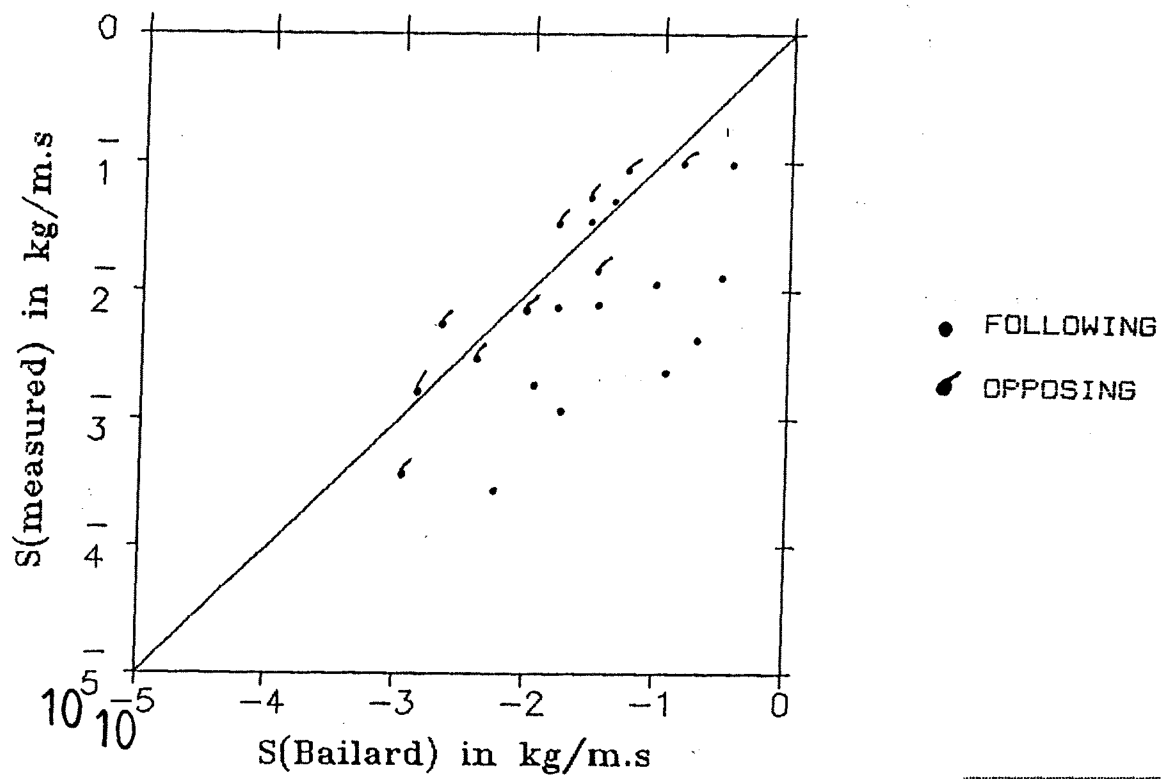
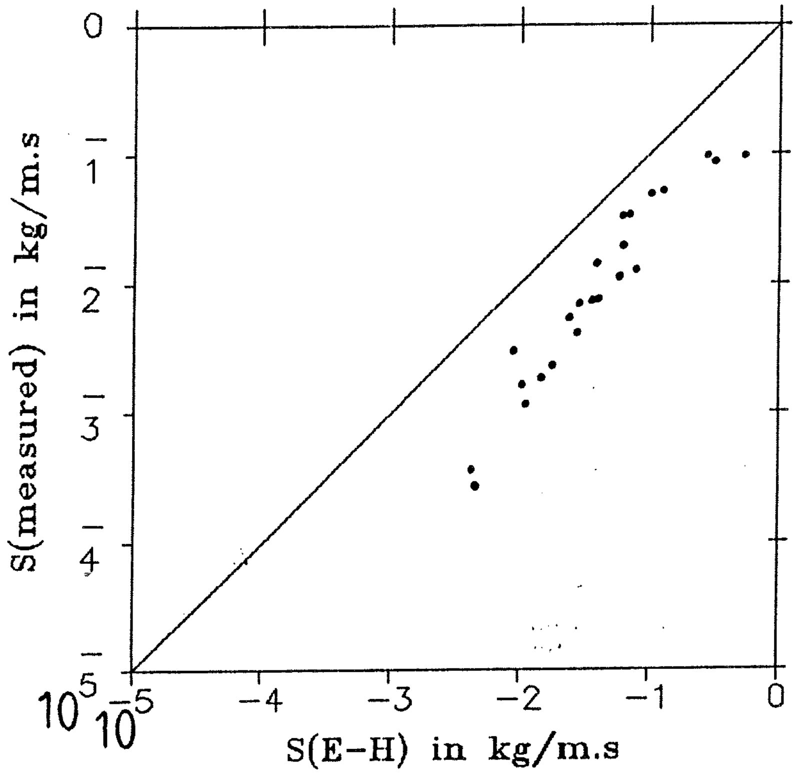
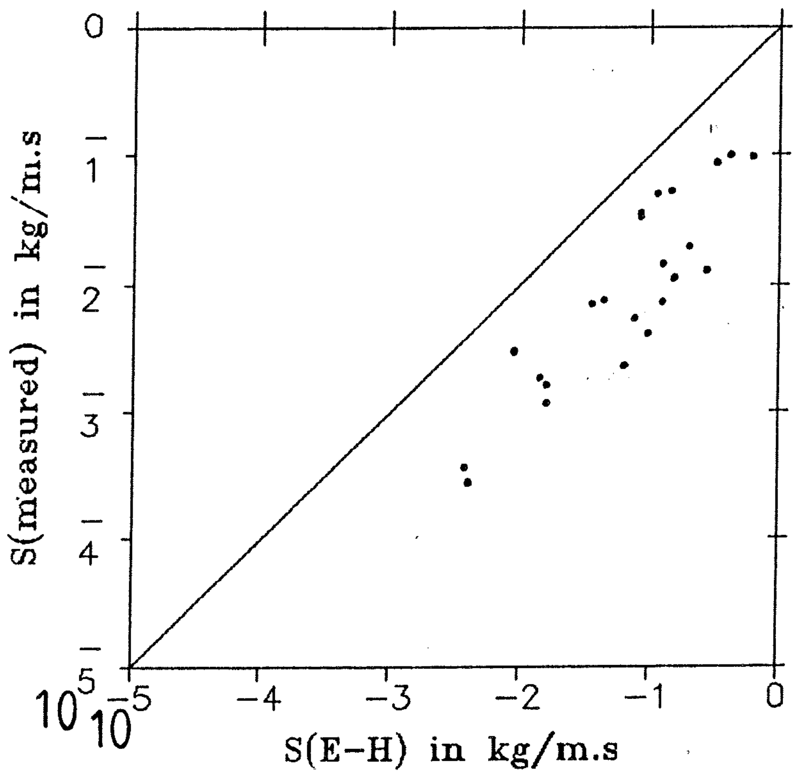


FIGURE 7.1

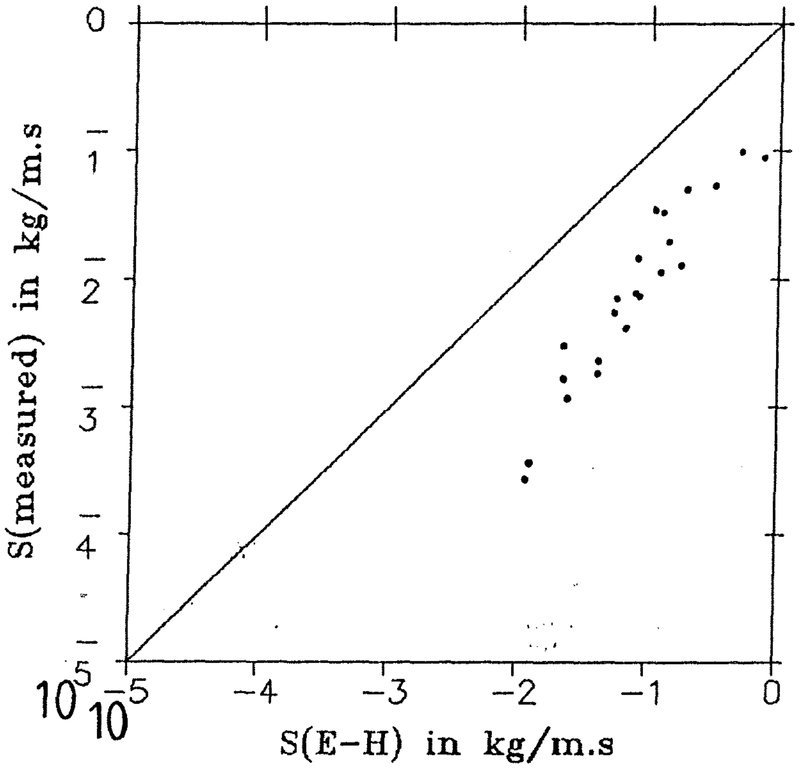
The Modified ENGELUND–HANSEN model comparison of measured and computed results, H=Hrms, Ks= 3*r, D50=100mu



The Modified ENGELUND–HANSEN model comparison of measured and computed results, H=Hrms, Ks= 7*r, D50=100mu



The Modified ENGELUND–HANSEN model comparison of measured and computed results, H=Hsig, Ks= 3*r, D50=100mu



The Modified ENGELUND–HANSEN model comparison of measured and computed results, H=Hsig, Ks= 7*r, D50=100mu

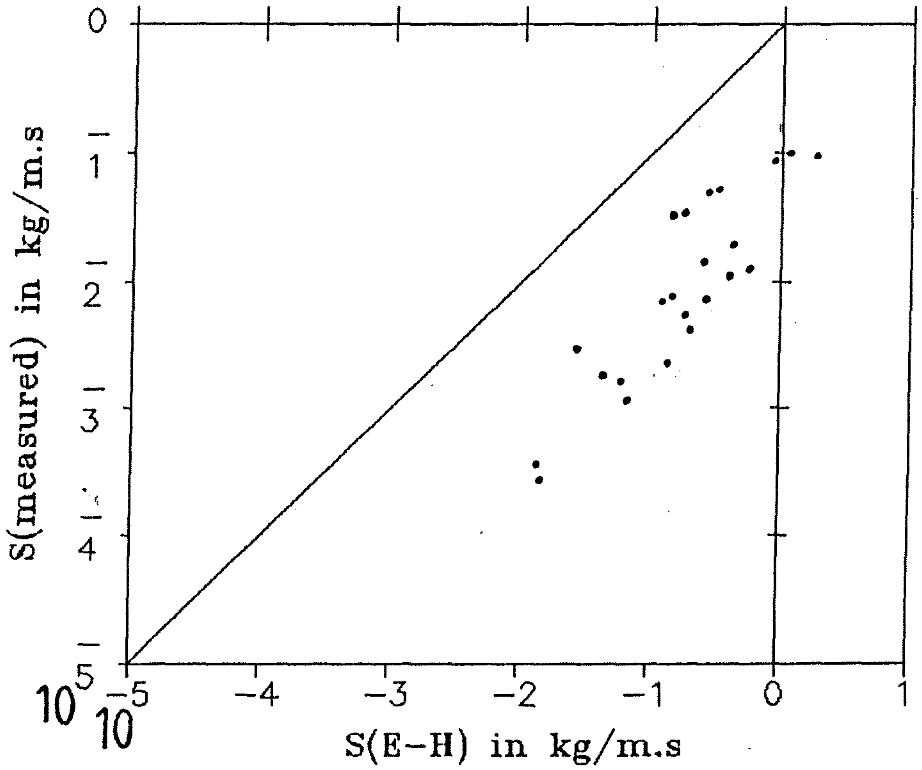
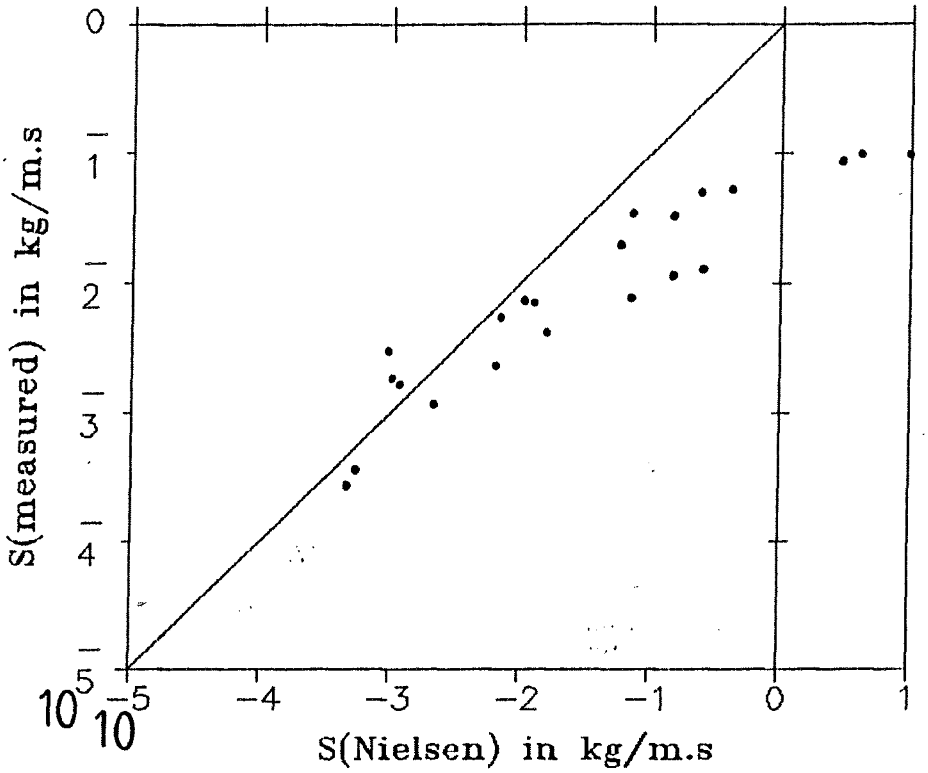


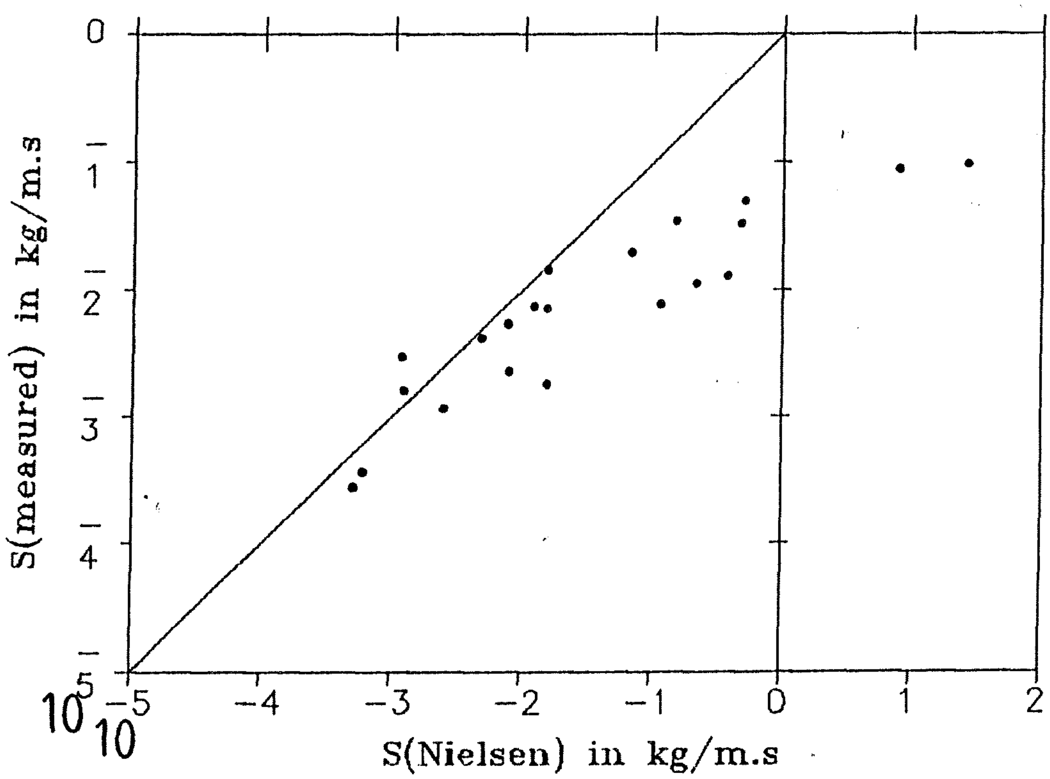
FIGURE 7.2.B

The NIELSEN model
comparison of measured and computed
results, H=Hprob, Ks=3*r, D50=100mu



source: NAP & van KAMPEN

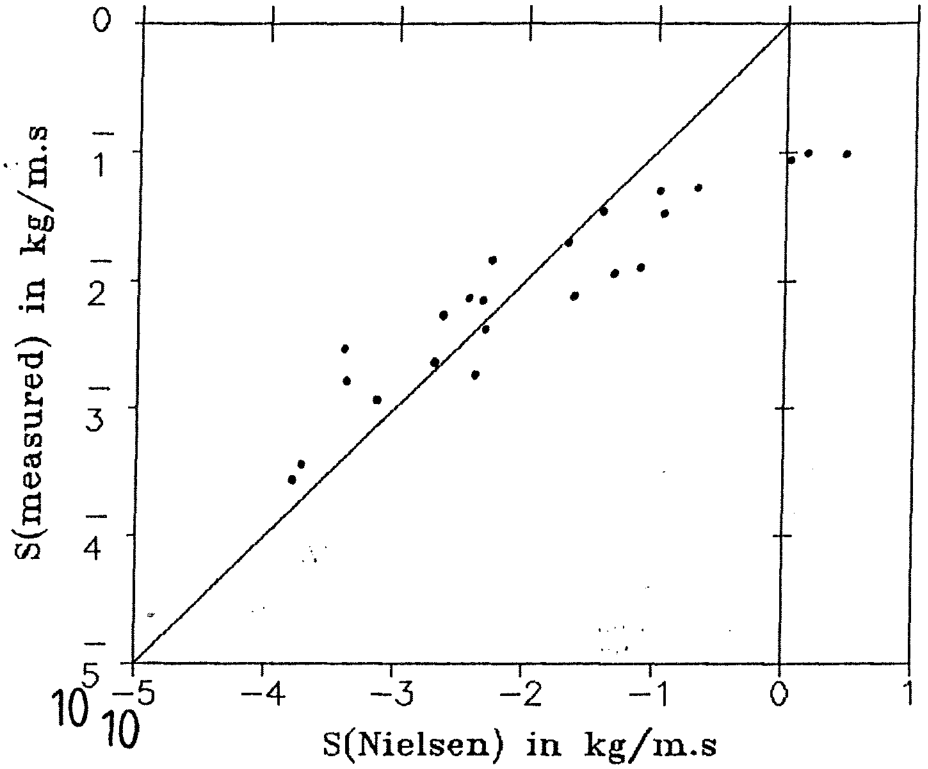
The NIELSEN model
comparison of measured and computed
results, H=Hprob, Ks=7*r, D50=100mu



source: NAP & van KAMPEN

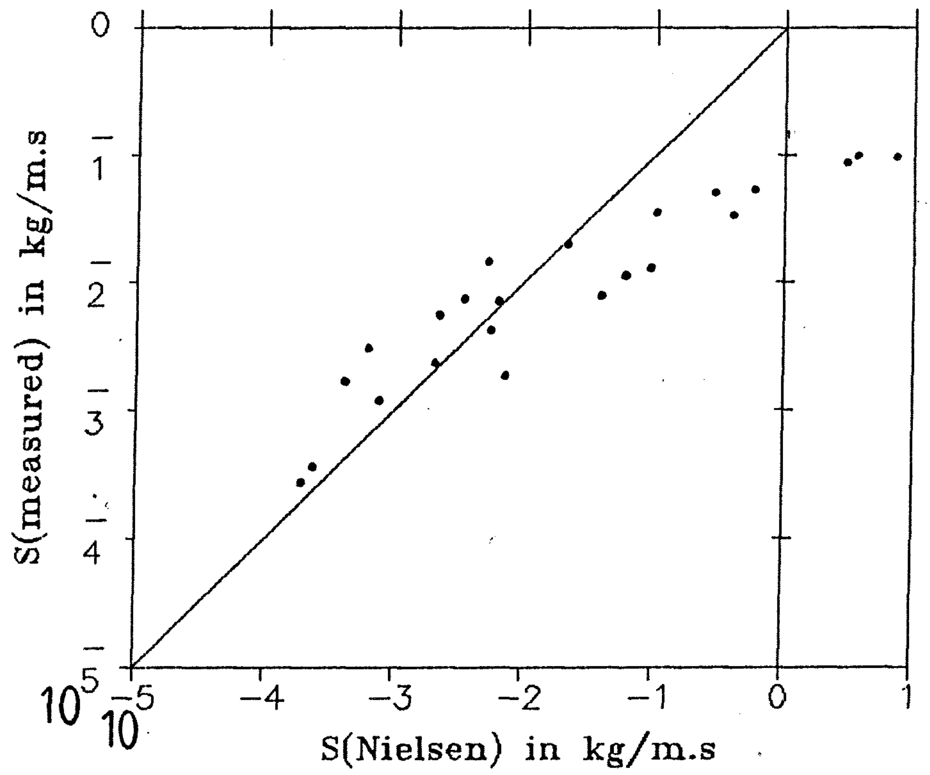
FIGURE 7.3.A

The NIELSEN model
comparison of measured and compueted
results, H=Hrms, Ks= 3*r, D50=100mu



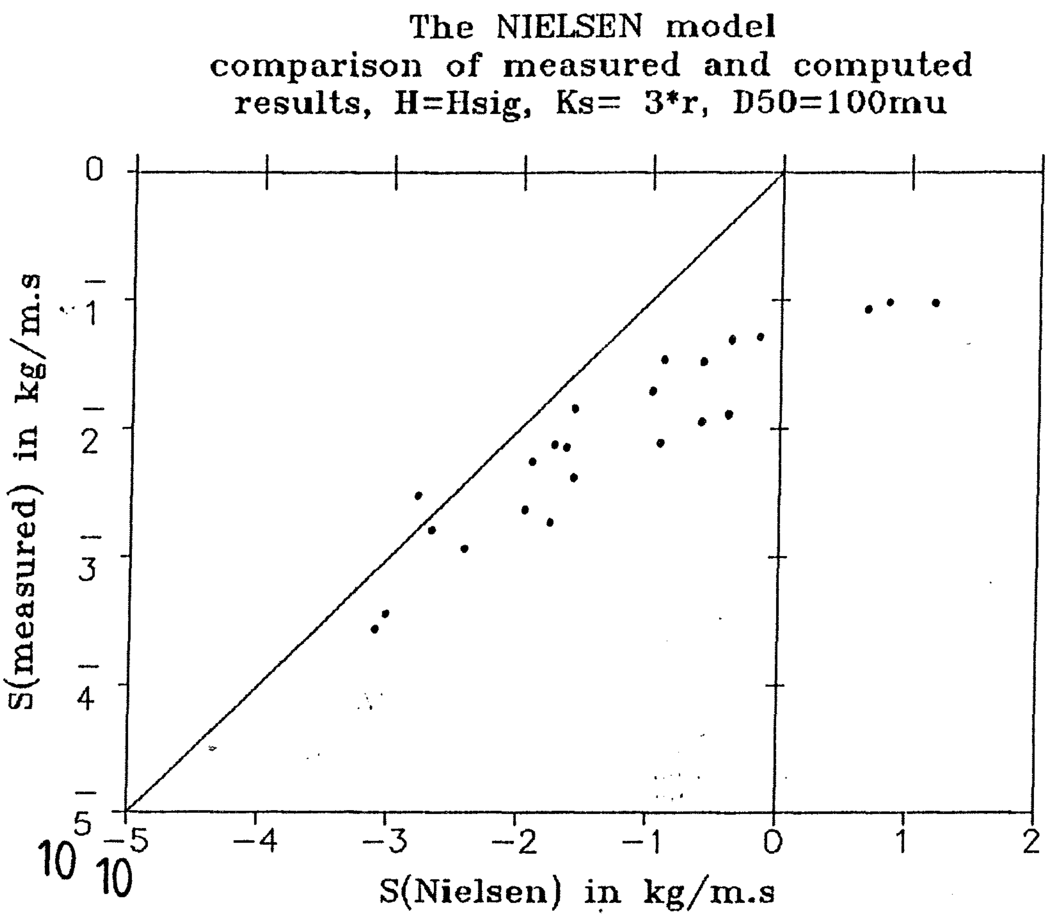
:e: NAP & van KAMPEN

The NIELSEN model
comparison of measured and computed
results, H=Hrms, Ks= 7*r, D50=100mu

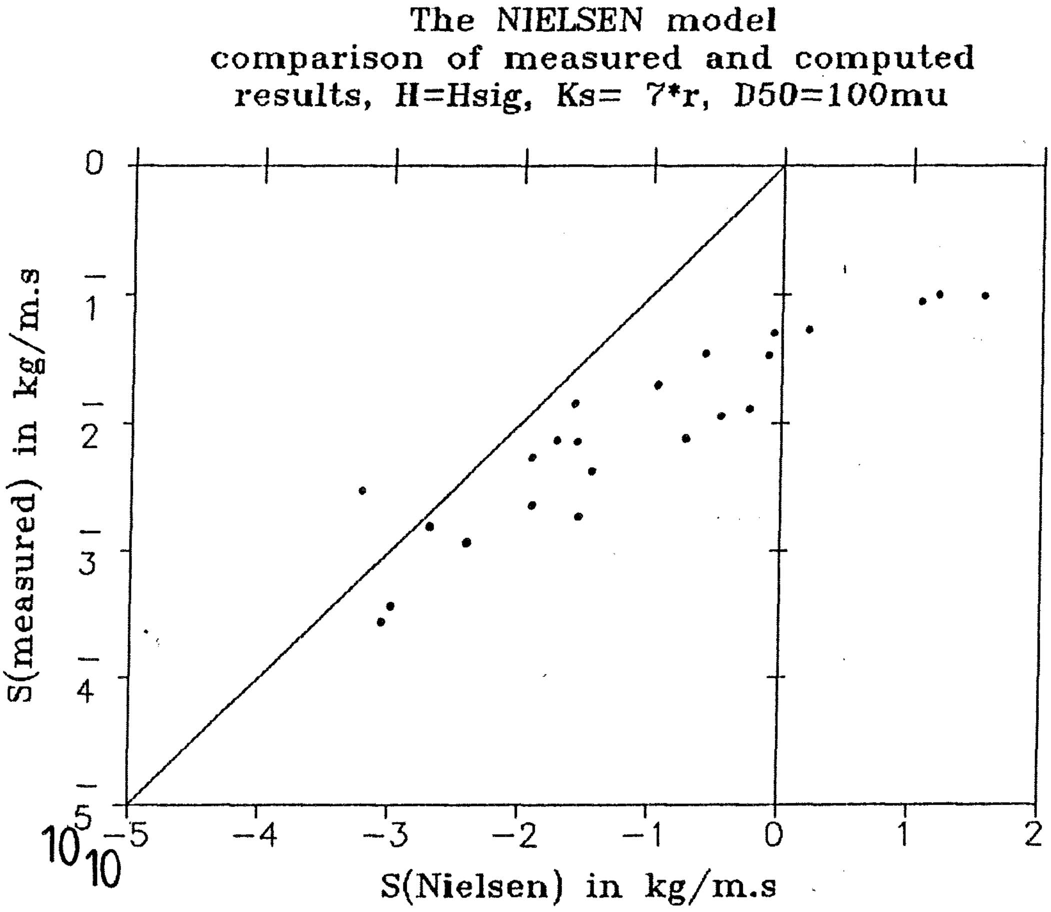


:e: NAP & van KAMPEN

FIGURE 7.3.B



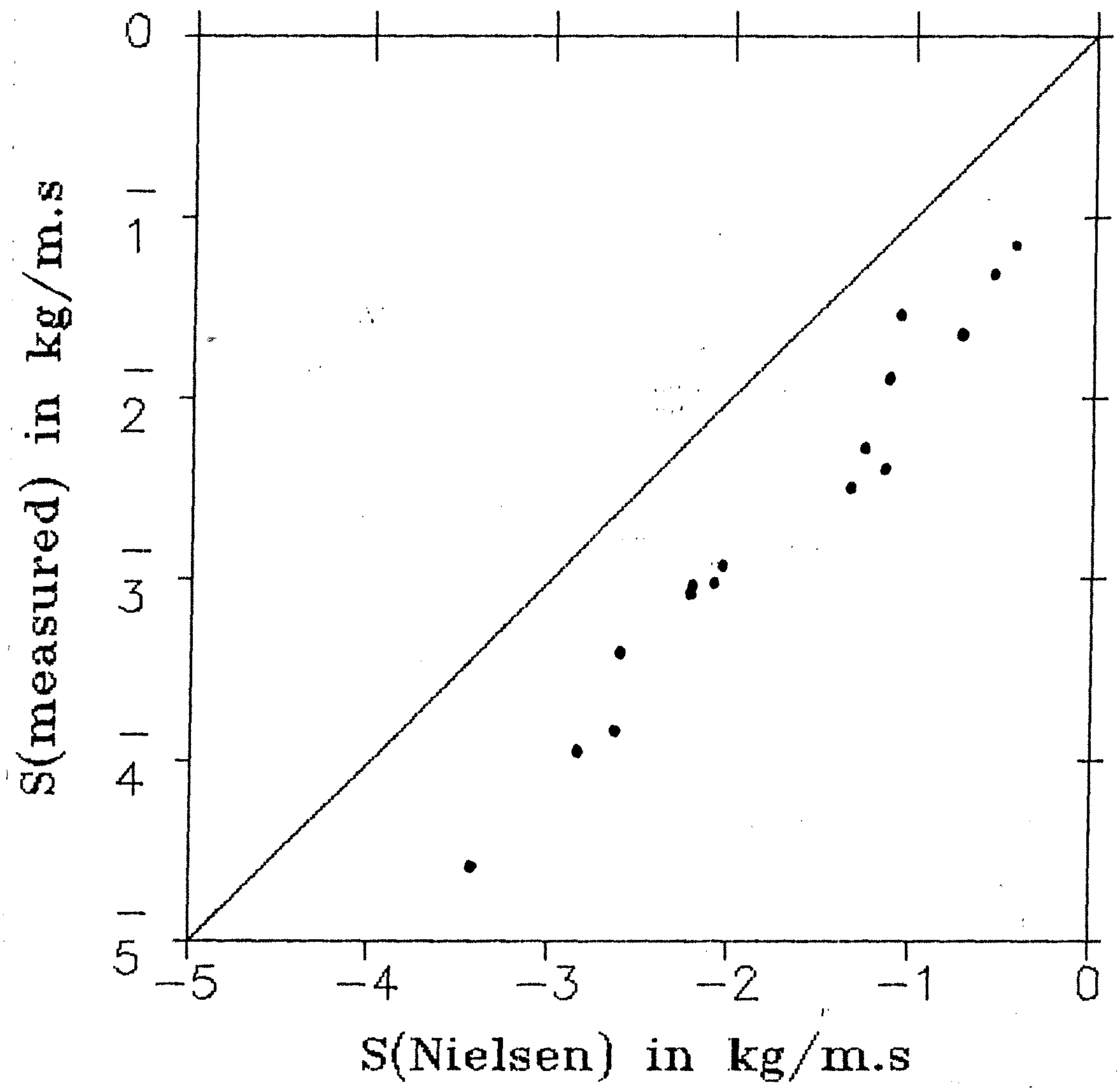
source: NAP & van KAMPEN



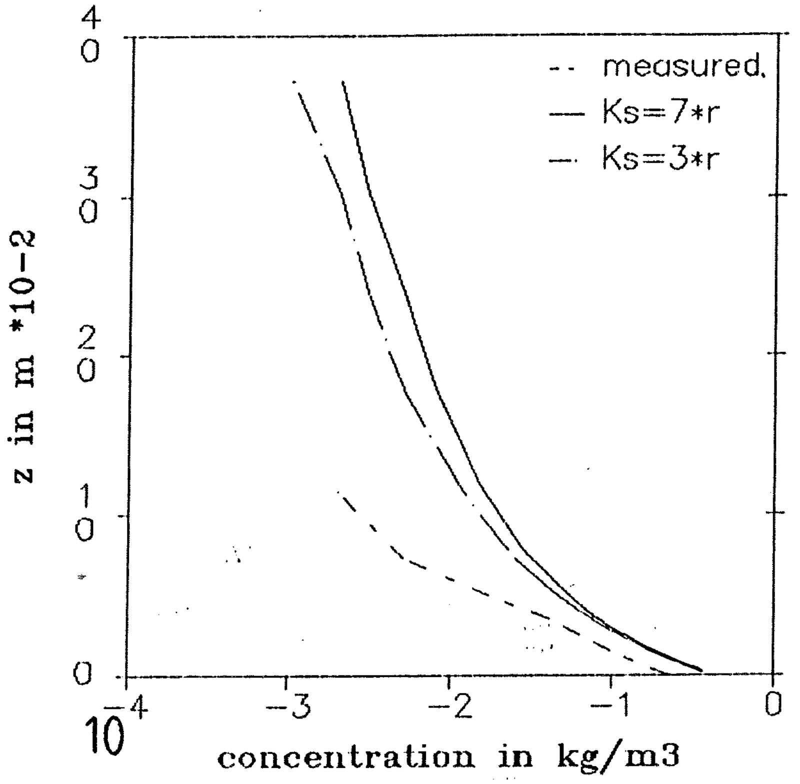
source: NAP & van KAMPEN

FIGURE 7.3.C

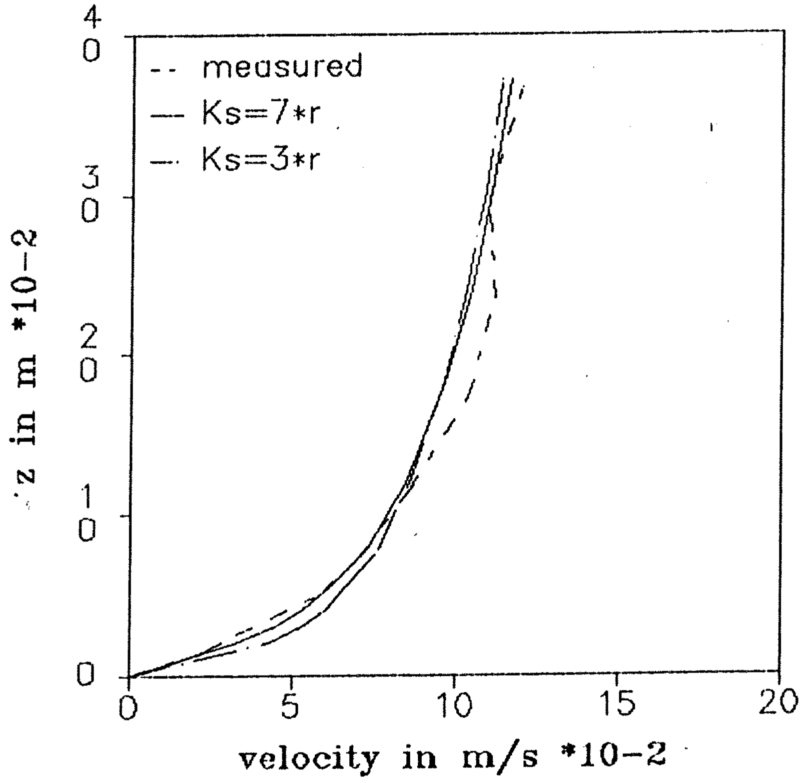
The NIELSEN model
comparison of measured and computed
results, H=Hprob, Ks(Nielsen), D50=200mu



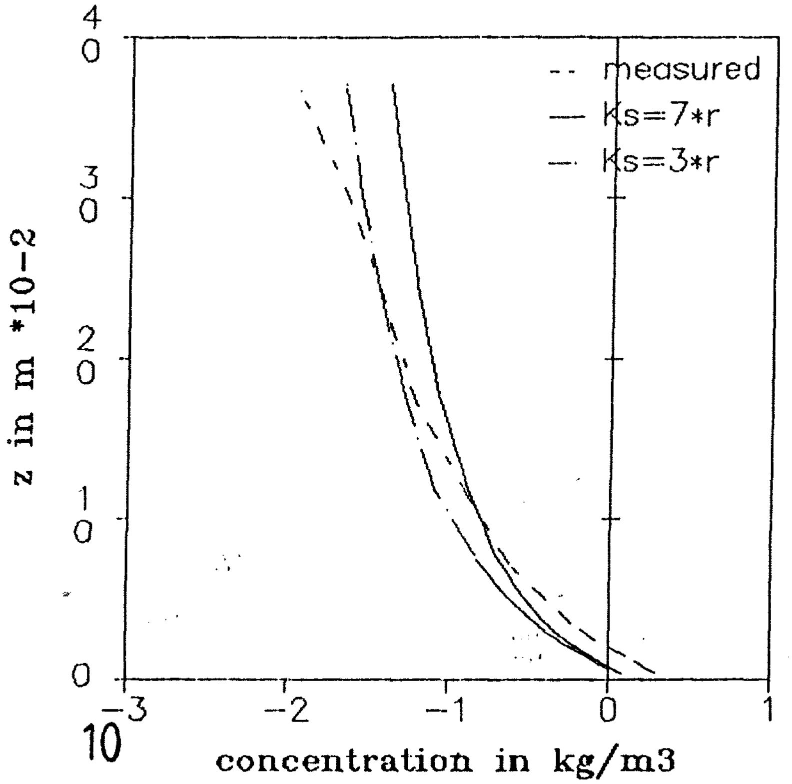
The NIELSEN model
comparison of concentration distribution
T 7.5,10 , H=Hsig, D50=100mu



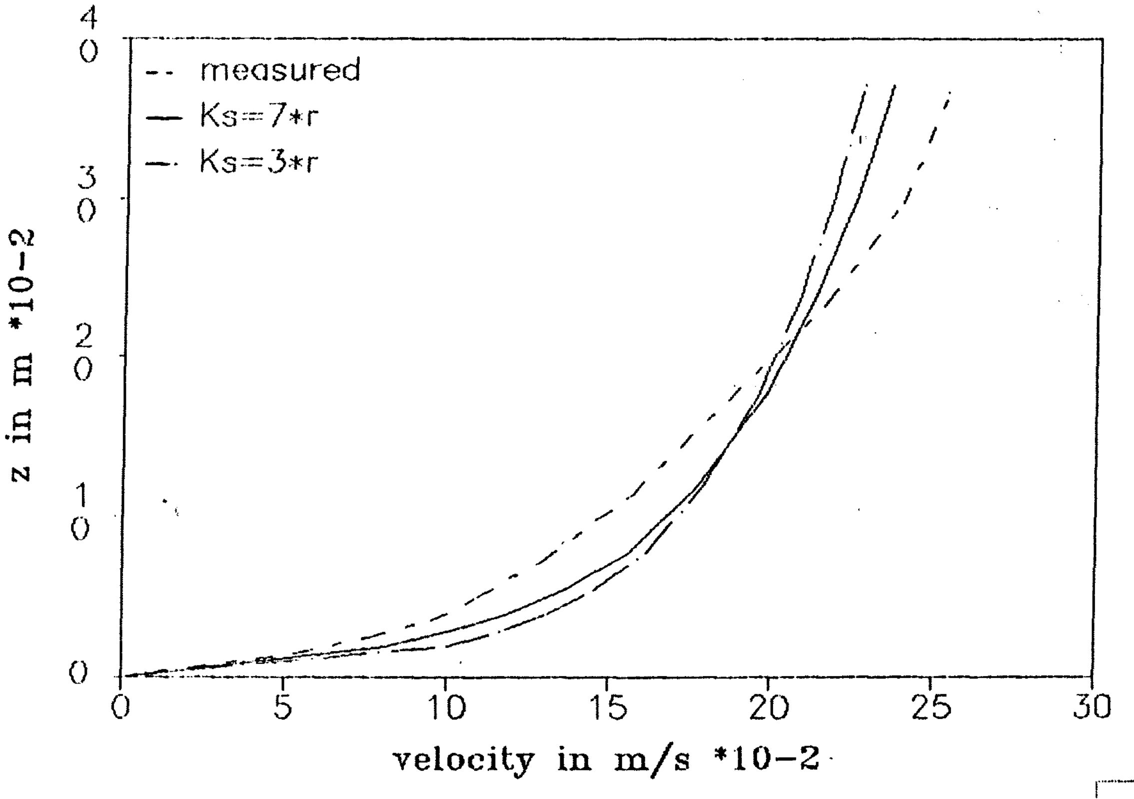
The NIELSEN model
comparison of velocity distributions
T 7.5,10 , H=Hsig, D50=100mu



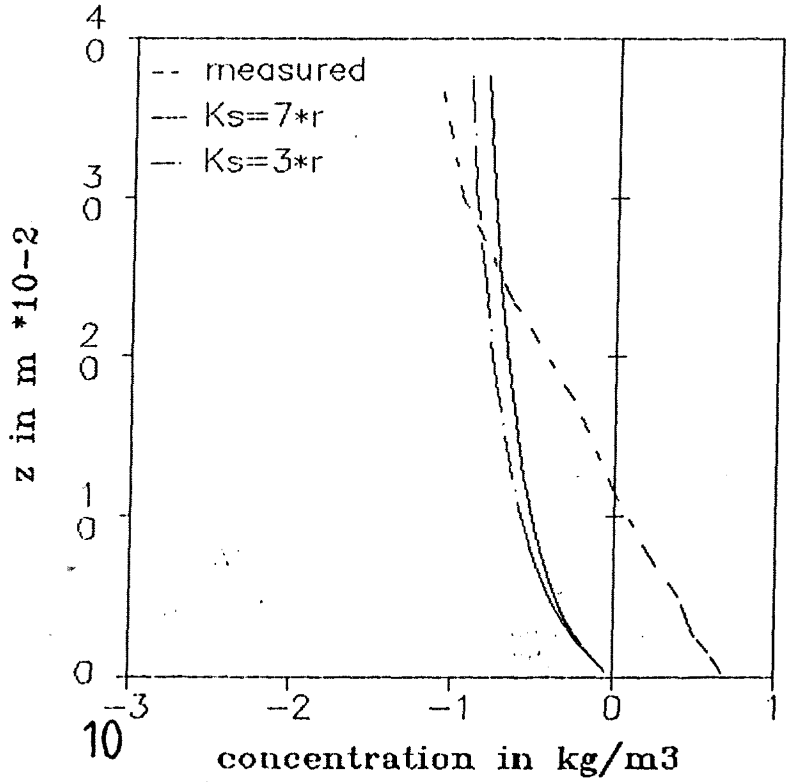
The NIELSEN model
comparison of concentration distribution
T 10,-20 , H=Hsig, D50=100mu



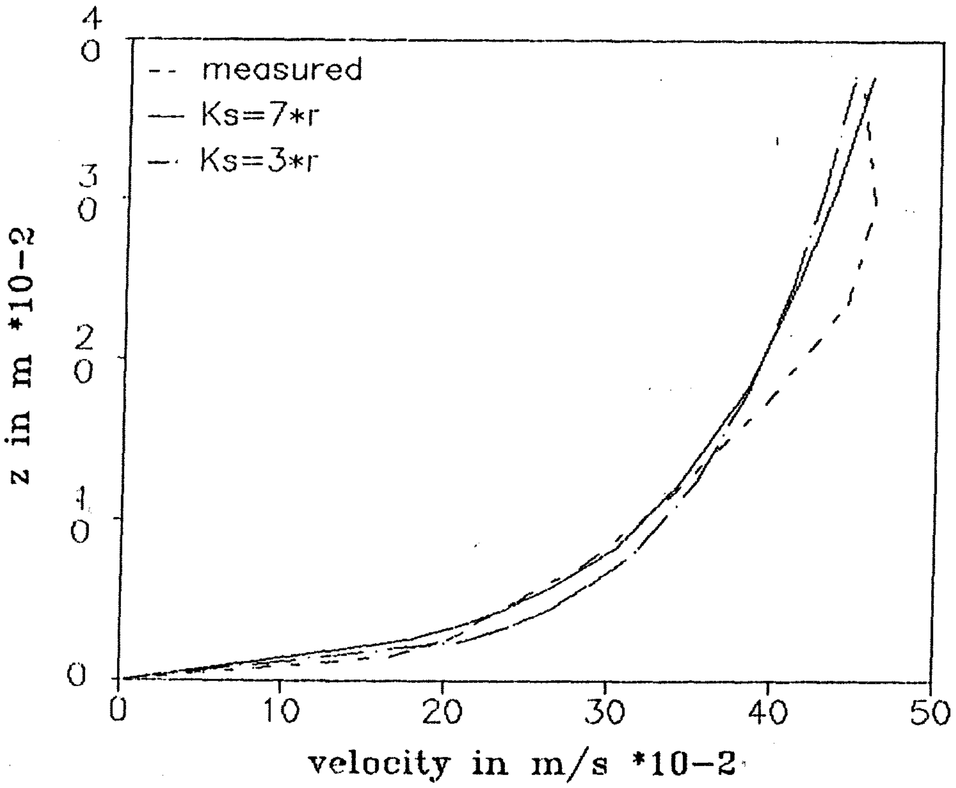
The NIELSEN model
comparison of velocity distributions
T 10,-20 , H=Hsig, D50=100mu



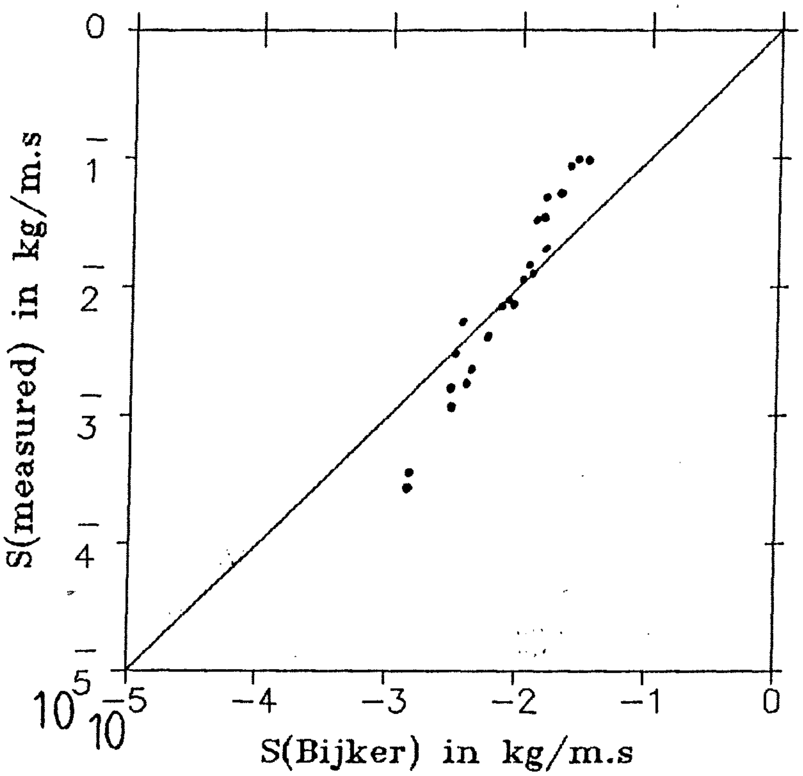
The NIELSEN model
comparison of concentration distribution
T 15,40 , H=Hrms, D50=100mu



The NIELSEN model
comparison of velocity distributions
T 15,40 , H=Hrms, D50=100mu

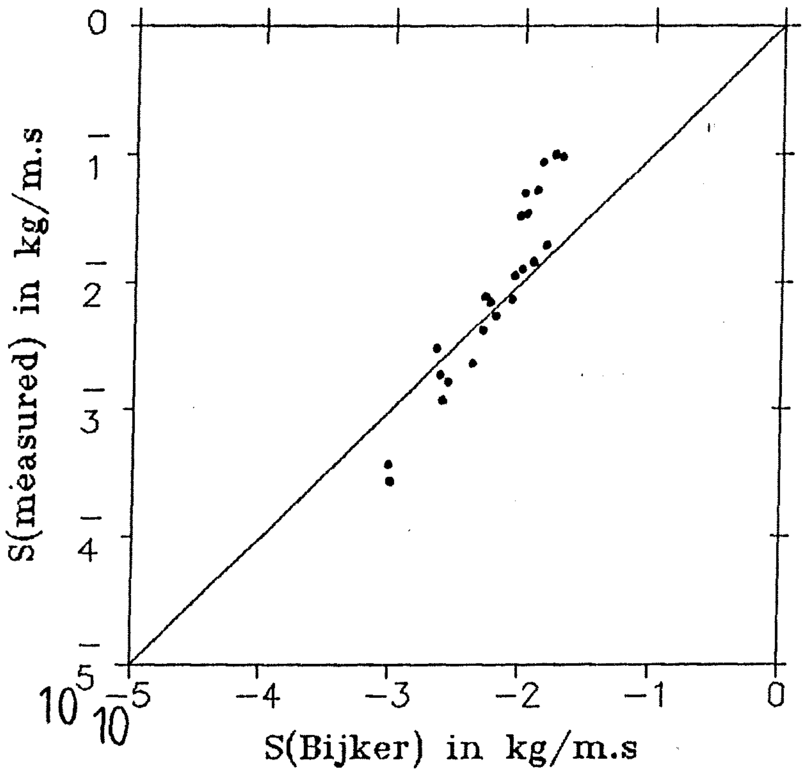


The BIJKER model
comparison of measured and computed
results, H=Hprob, Ks=3*r, D50=100mu

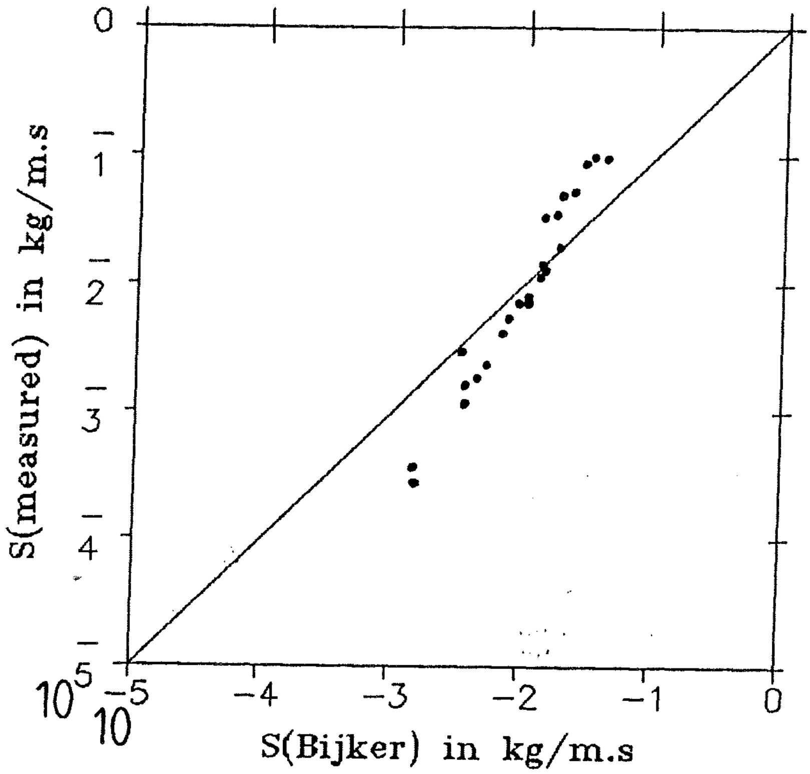


ce: NAP & van KAMPEN

The BIJKER model
comparison of measured and computed
results, H=Hprob, Ks=7*r, D50=100mu

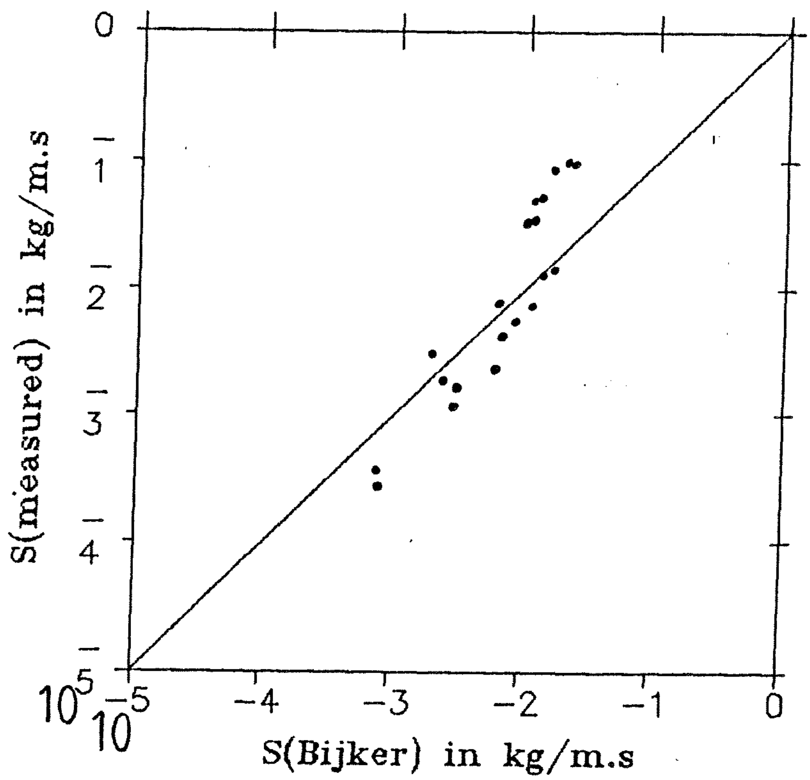


The BIJKER model
comparison of measured and computed
results, H=Hrms, Ks= 3*r, D50=100mu

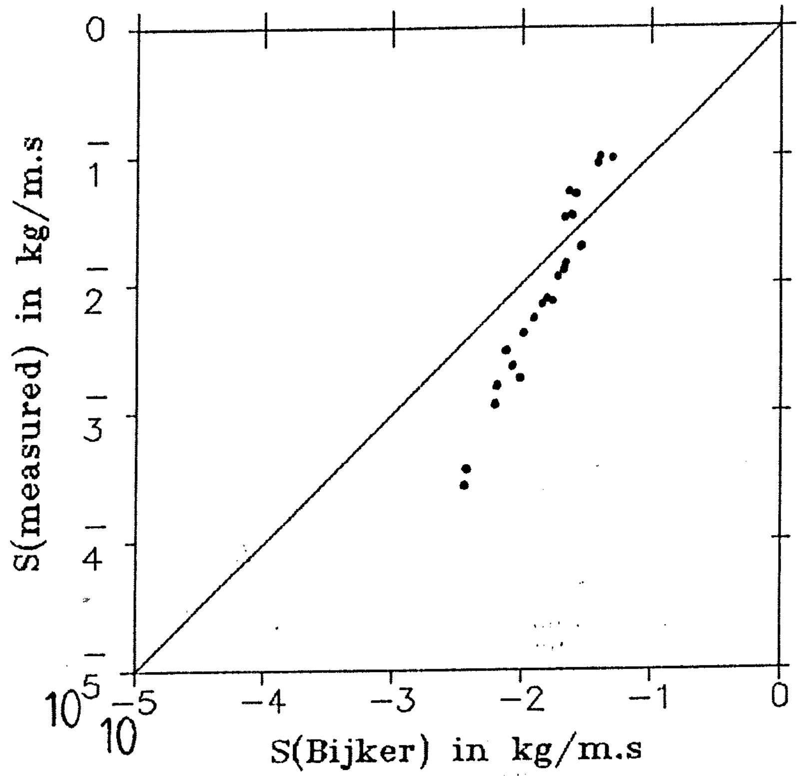


source: NAP & van KAMPEN

The BIJKER model
comparison of measured and computed
results, H=Hrms, Ks= 7*r, D50=100mu



The BIJKER model
comparison of measured and computed
results, H=Hsig, Ks= 3*r, D50=100mu



ce: NAP & van KAMPEN

The BIJKER model
comparison of measured and computed
results, H=Hsig, Ks= 7*r, D50=100mu

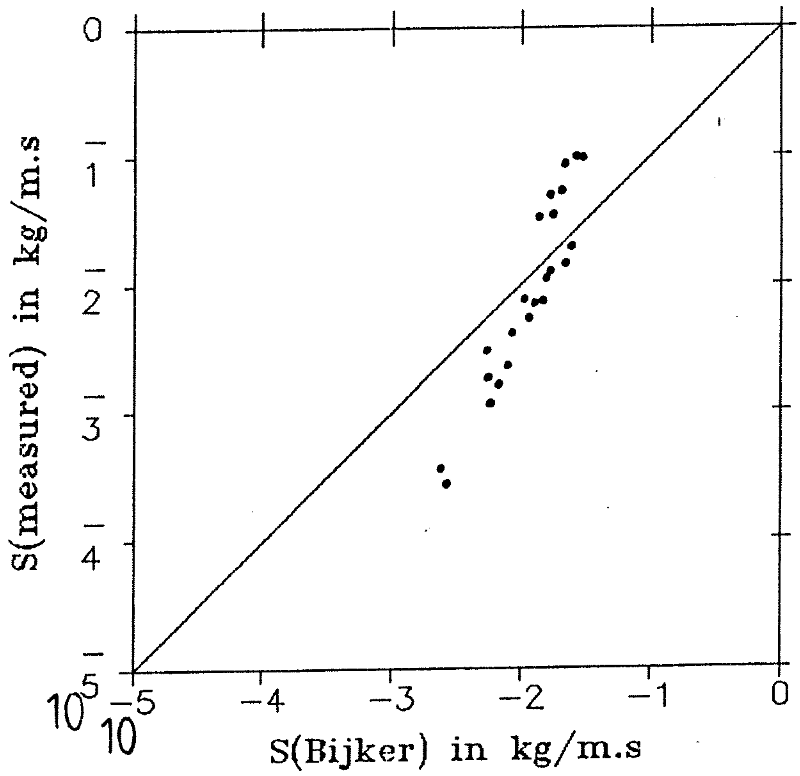


FIGURE 7.4.C

The BIJKER model
Comparison of the results using
H= Hprob, Hrms, Hsig and Ks= 3*r, 7*r

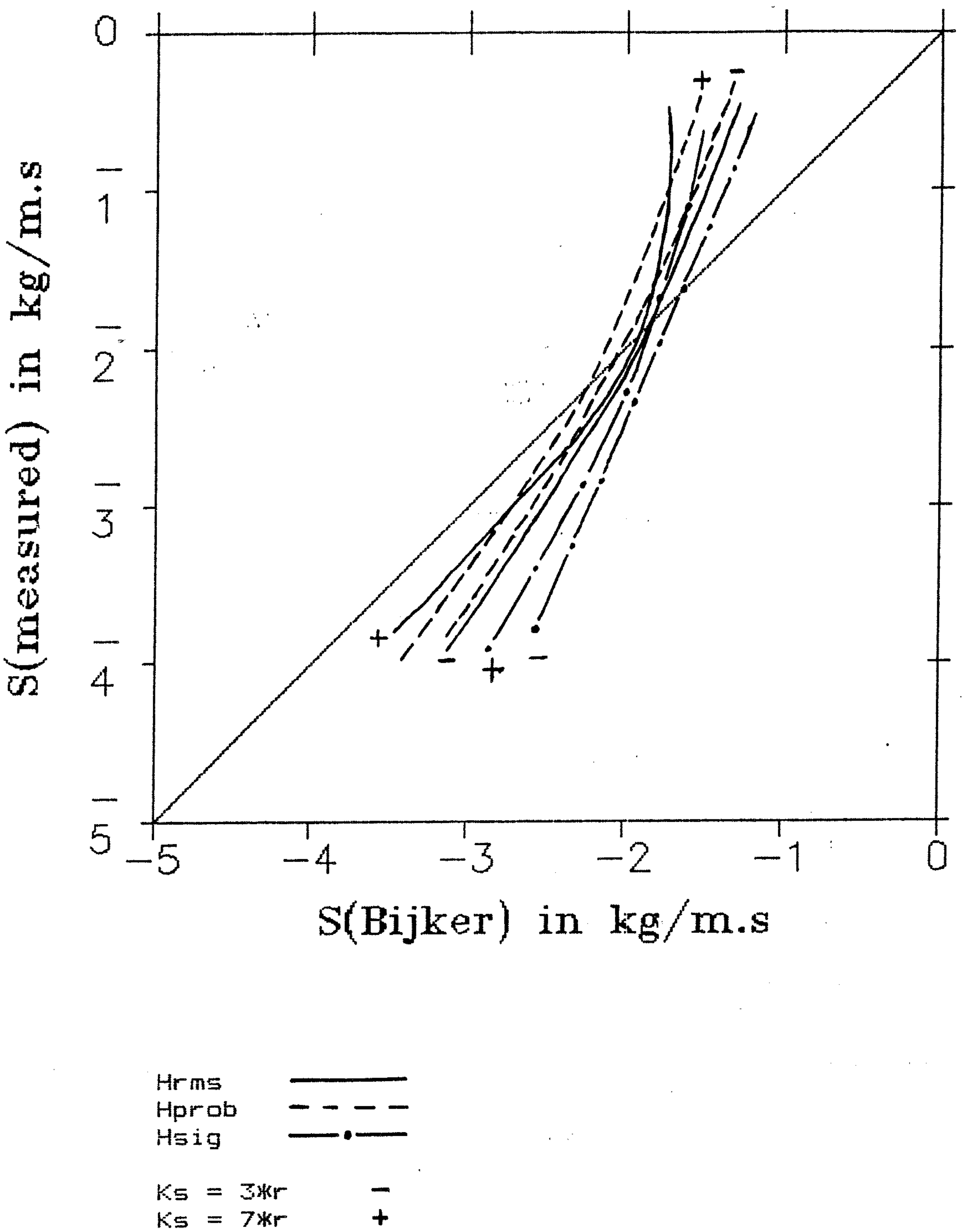
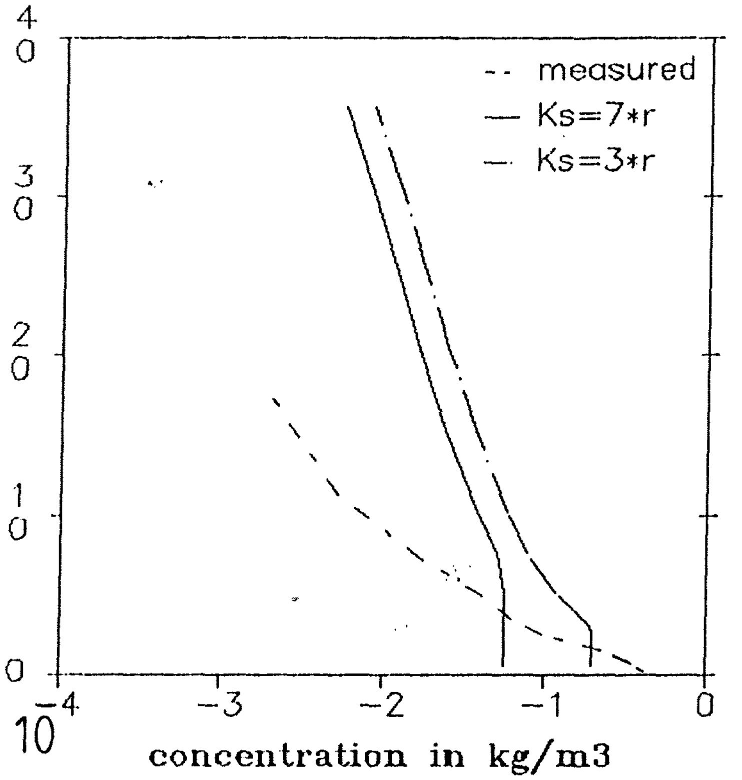
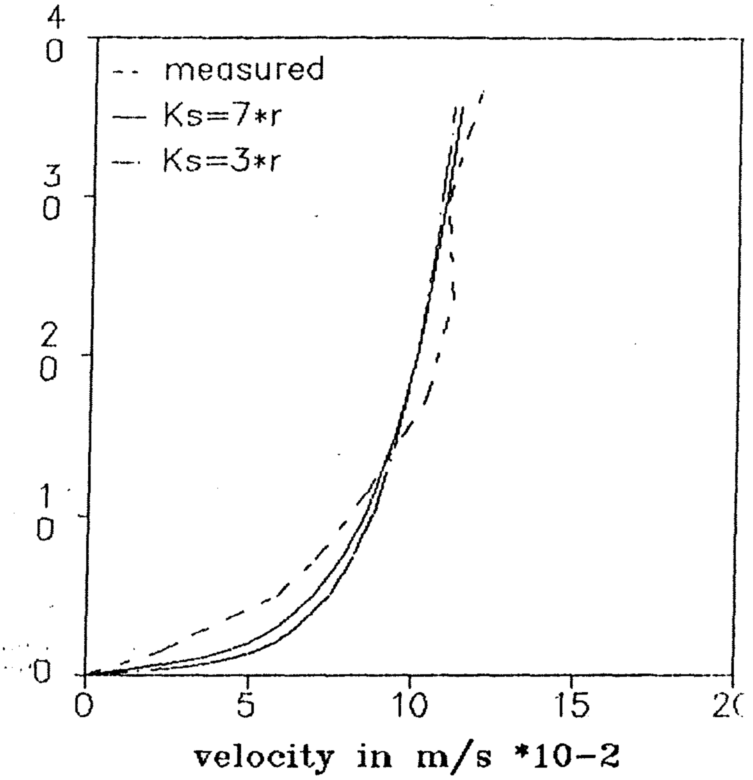


FIGURE 7.4 D

The BIJKER model
comparison of concentration distribution
T 7.5,10 , H=Hrms, D50=100mu



The BIJKER model
comparison of velocity distributions
T 7.5,10 , H=Hrms, D50=100mu



The BIJKER model
comparison sed.transport distributions
T 7.5,10, H=Hrms, D50=100mu

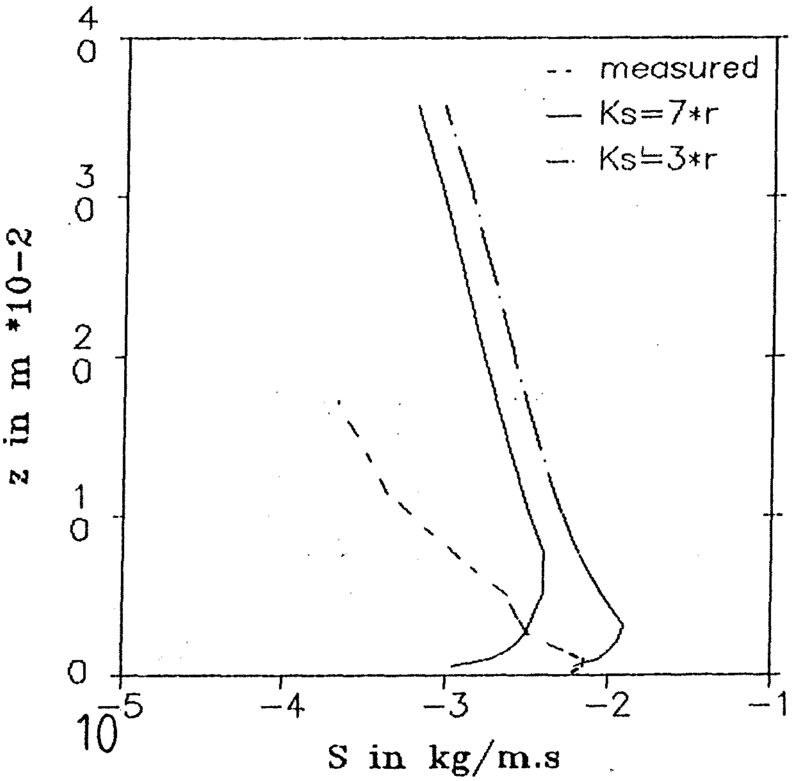
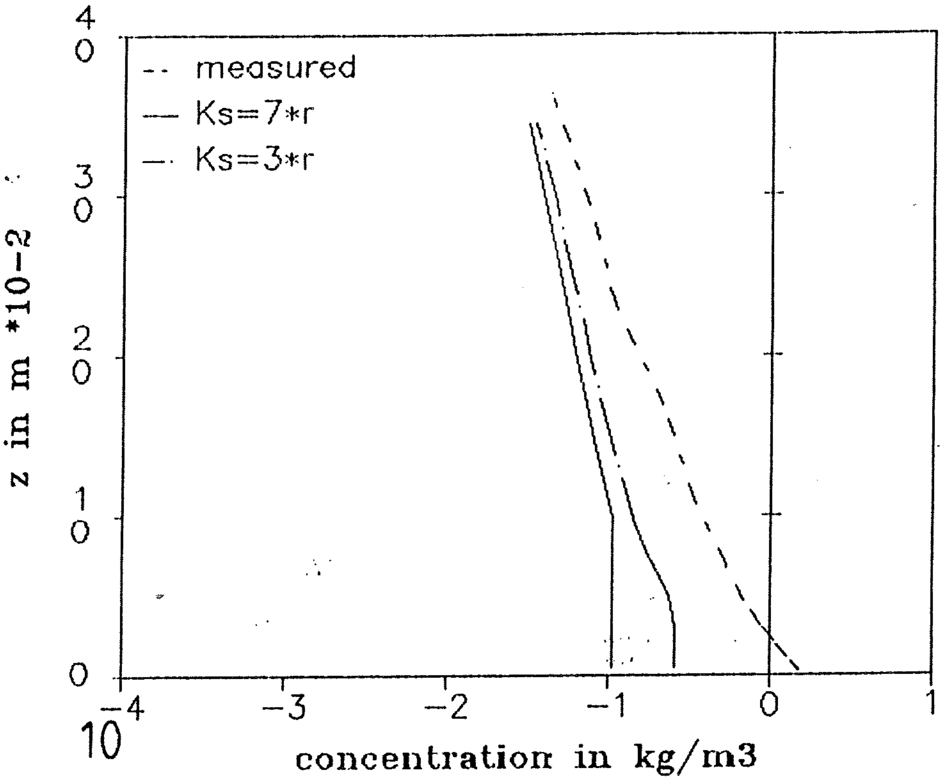
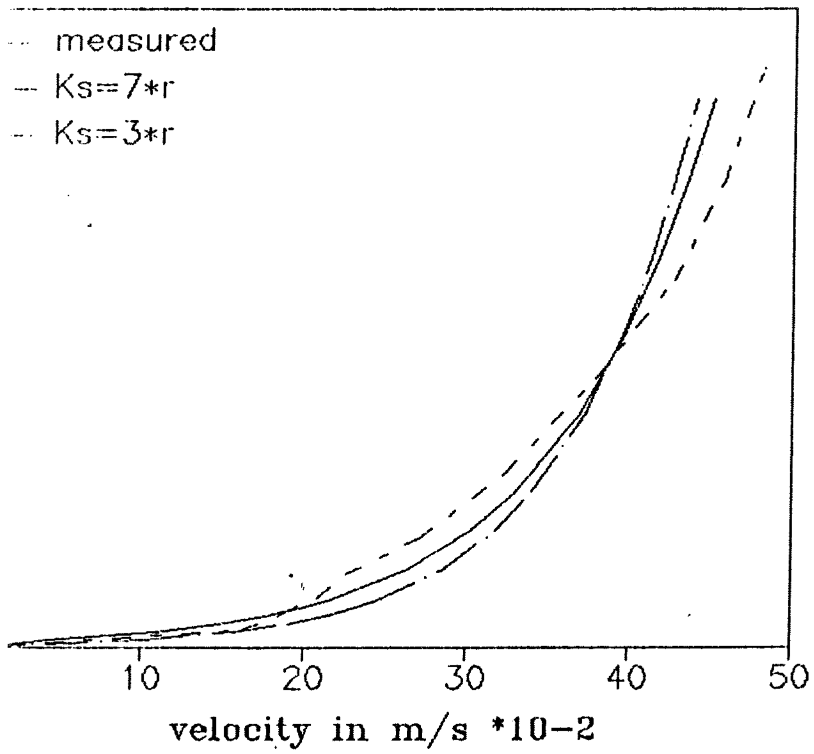


FIGURE 3.4.5

The BIJKER model
comparison of concentration distribution
T 7.5,-40 , H=Hrms, D50=100mu



The BIJKER model
comparison of velocity distributions
T 7.5,-40 , H=Hrms, D50=100mu



The BIJKER model
comparison sed.transport distribution
T 7.5,-40 , H=Hrms, D50=100mu

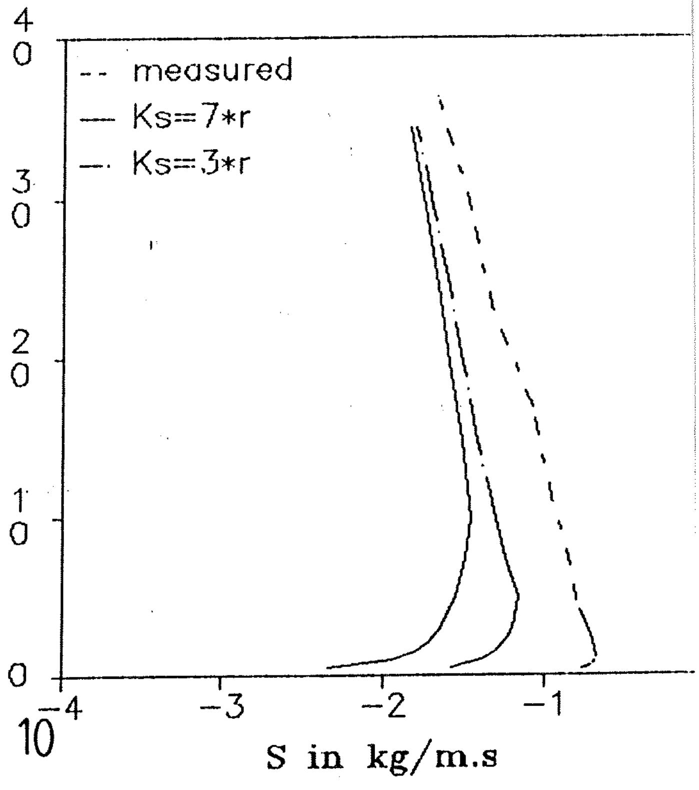
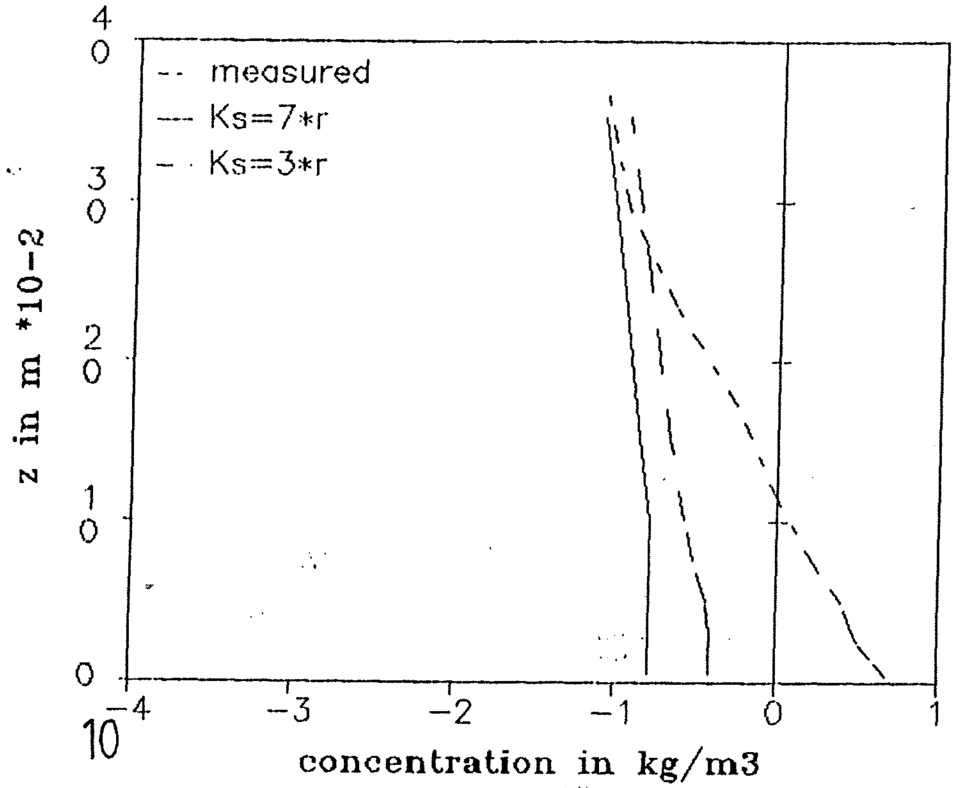
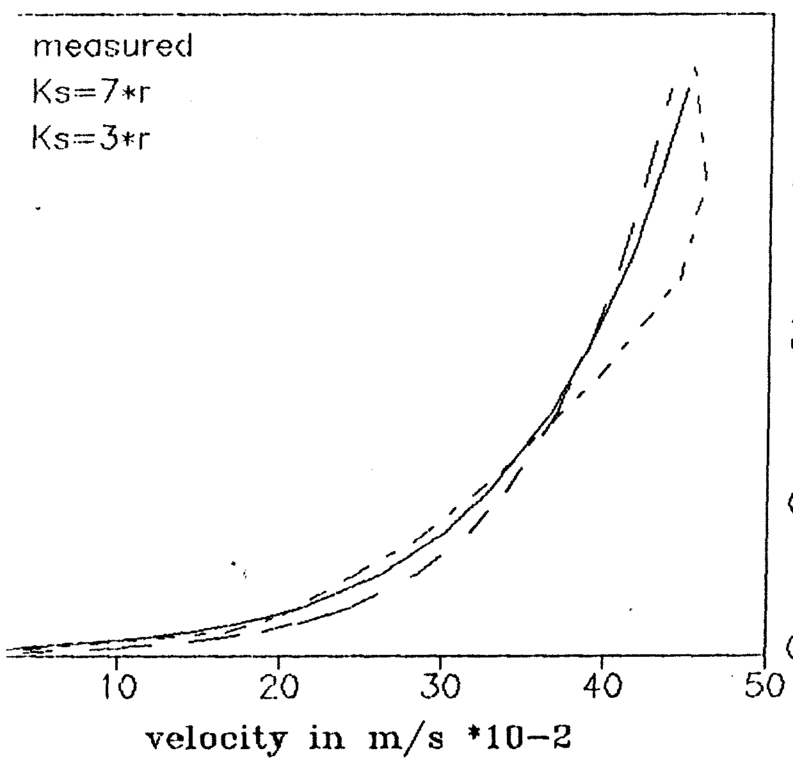


FIGURE 4.F

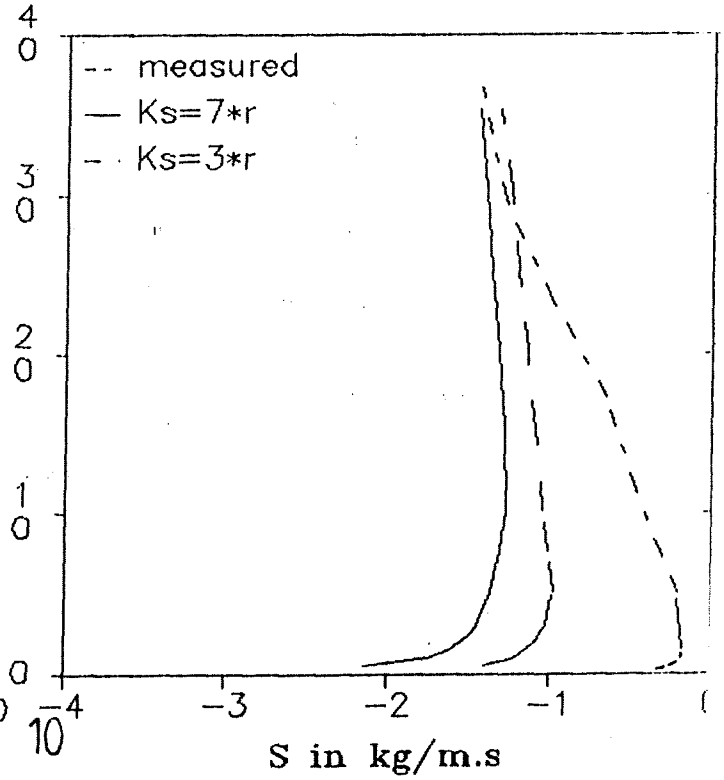
The BIJKER model
comparison of concentration distribution
T 15,40 , H=Hrms, D50=100mu

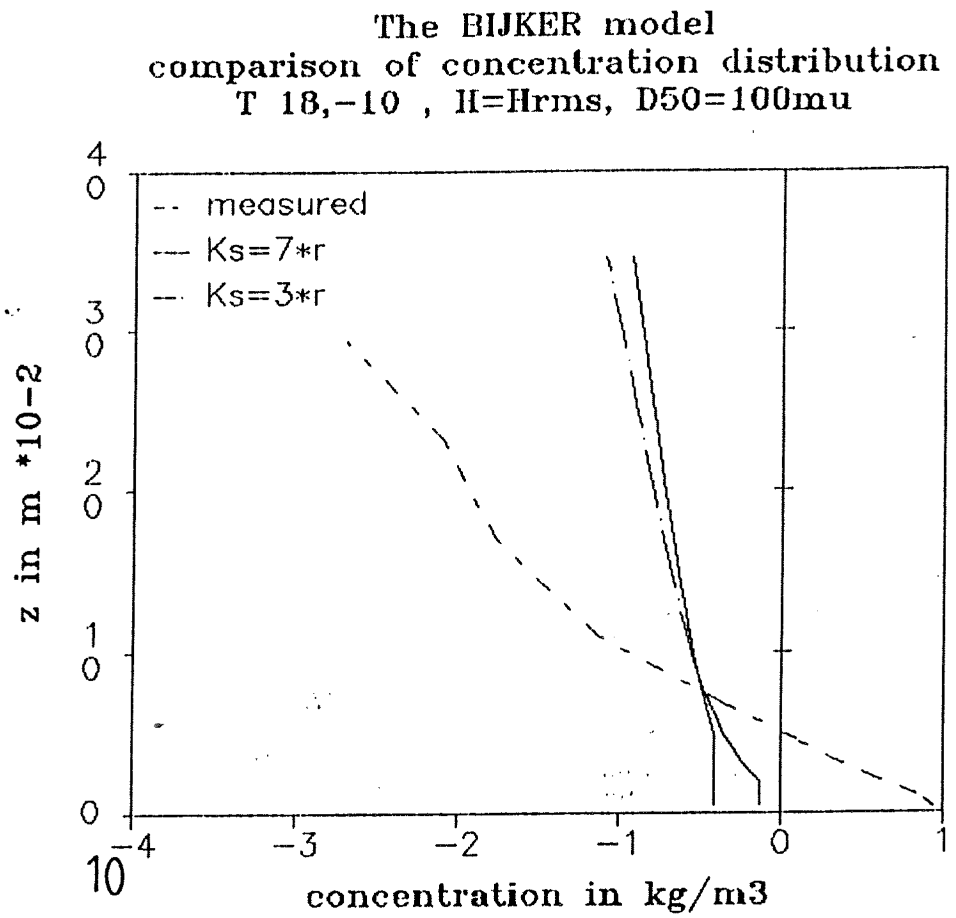


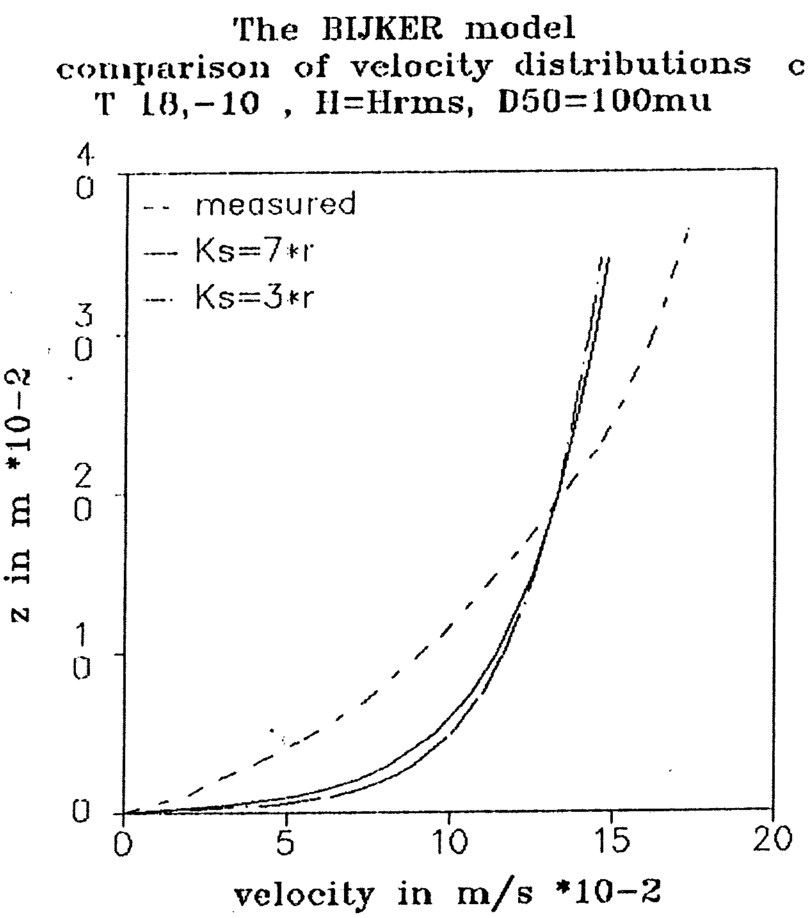
The BIJKER model
comparison of velocity distributions
T 15,40 , H=Hrms, D50=100mu



The BIJKER model
comparison sed.transport distributions
T 15,40 , H=Hrms, D50=100mu




The BIJKER model
comparison of concentration distribution
T 18,-10 , H=Hrms, D50=100mu
-- measured
— Ks=7*r
-· Ks=3*r
z in m *10-2
concentration in kg/m3
10


The BIJKER model
comparison of velocity distributions
T 18,-10 , H=Hrms, D50=100mu
-- measured
— Ks=7*r
-· Ks=3*r
z in m *10-2
velocity in m/s *10-2

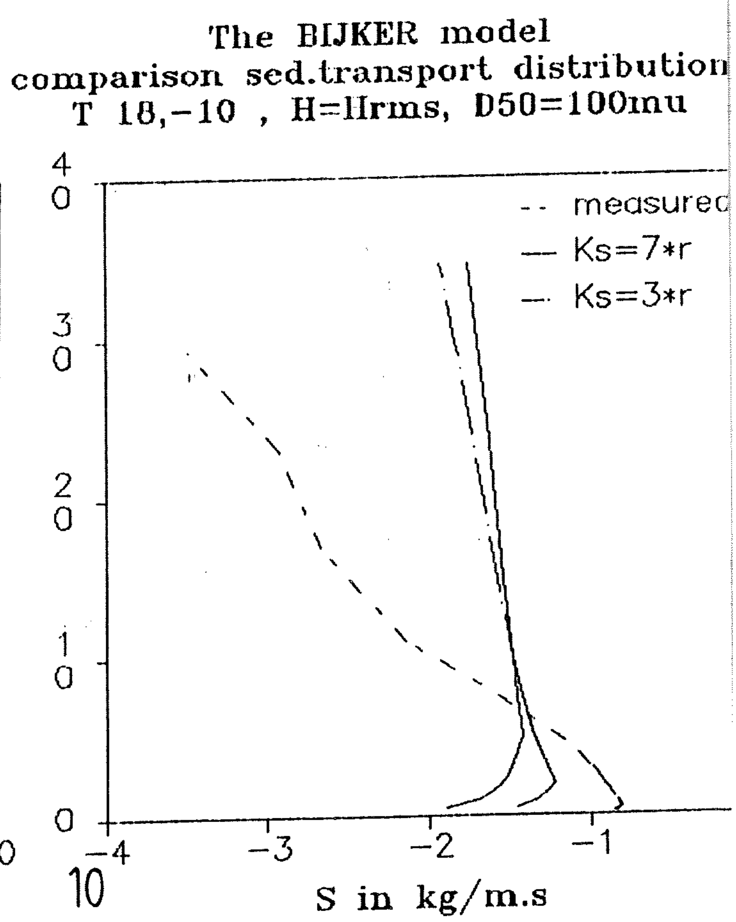
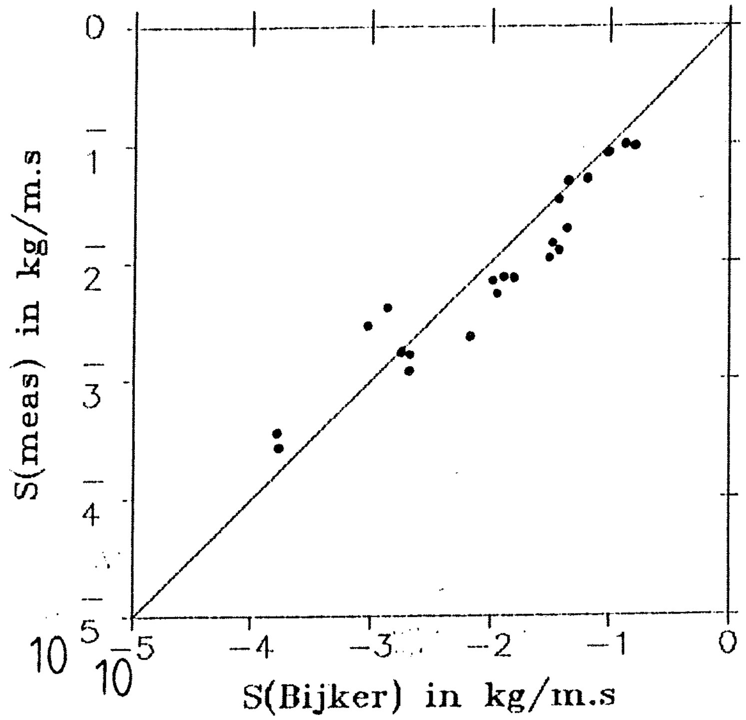

The BIJKER model
comparison sed.transport distribution
T 18,-10 , H=Hrms, D50=100mu
-- measured
— Ks=7*r
-· Ks=3*r
S in kg/m.s
10

FIGURE 7.4.H

MODIFIED BIJKER MODEL
comparison of computed and measured
results for D50= 100mu, H= Hrms



source: Nap & van Kampen

MODIFIED BIJKER MODEL
comparison of computed and measured
results for D50= 200 mu, H= Hrms

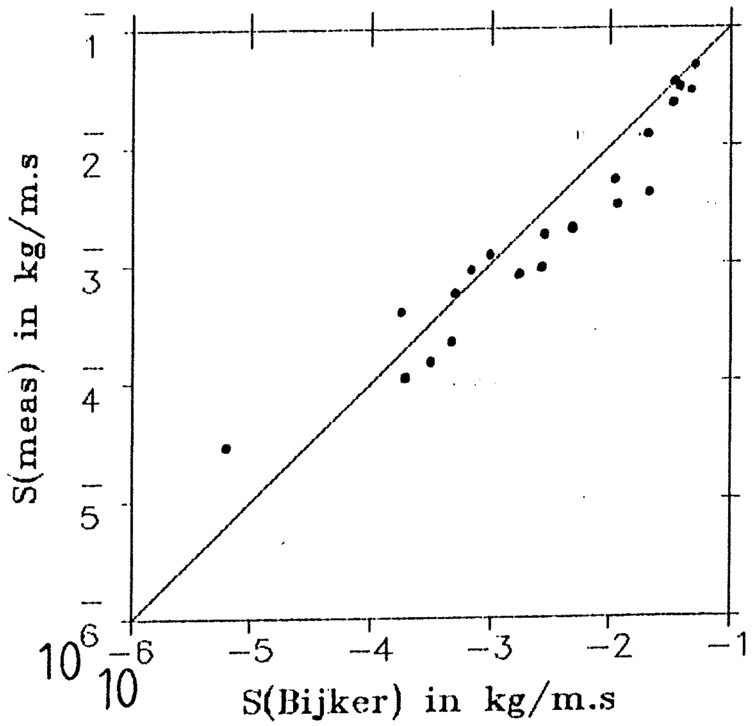
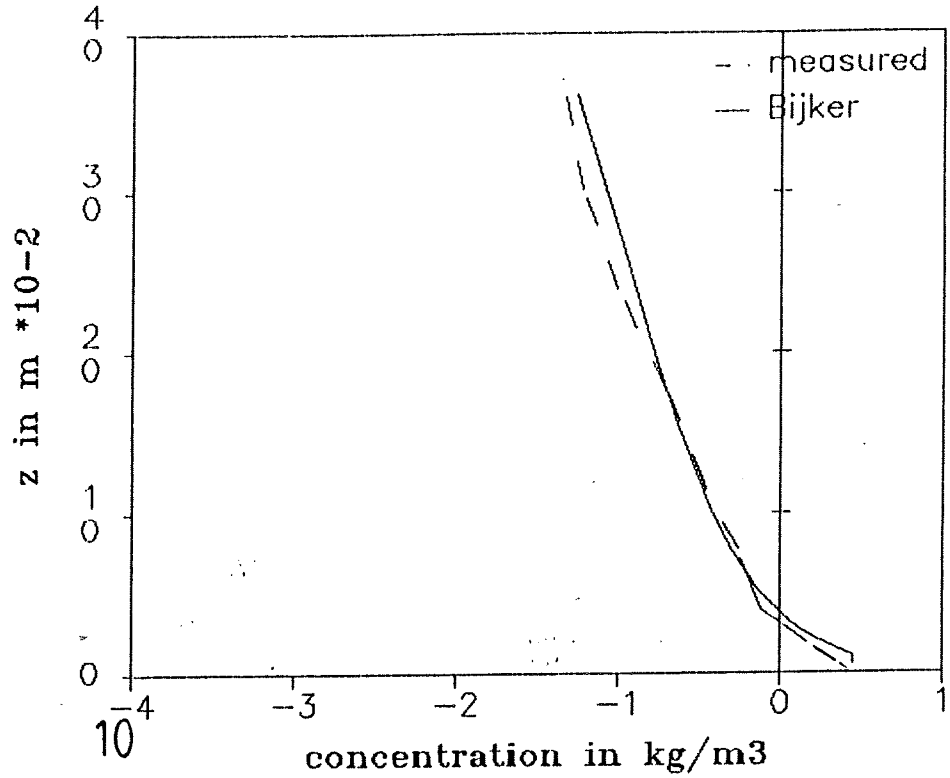
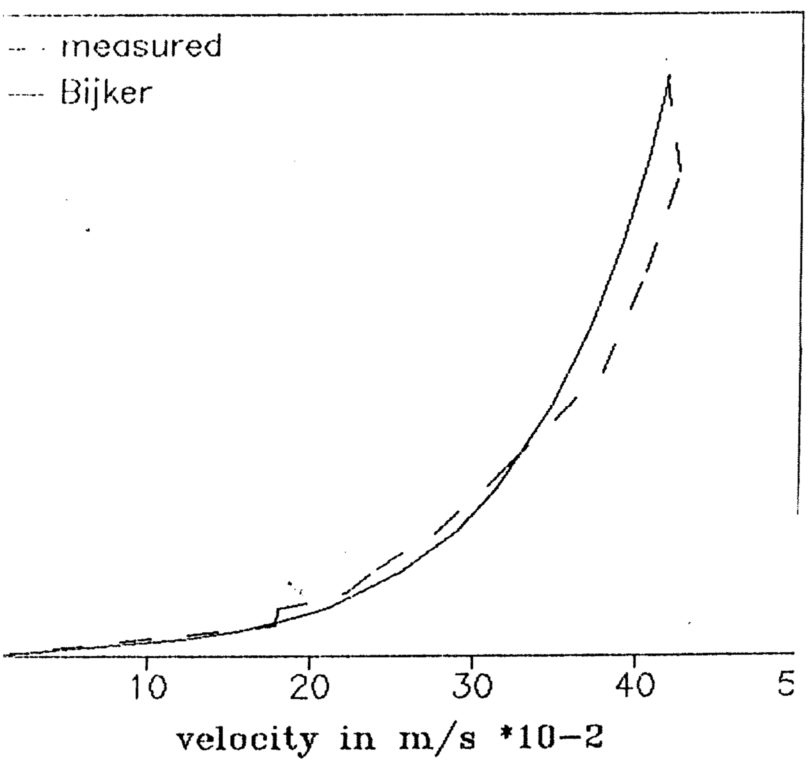


FIGURE 7.5.A

The Modified Bijker model
comparison of concentration distribution
T 7.5,40 , H=Hrms, D50=100mu



The Modified Bijker model
comparison of velocity distributions
T 7.5,40 , H=Hrms, D50=100mu



The Modified BIJKER model
comparison sed.transport distribution
T 7.5,40 , H=Hrms, D50=100mu

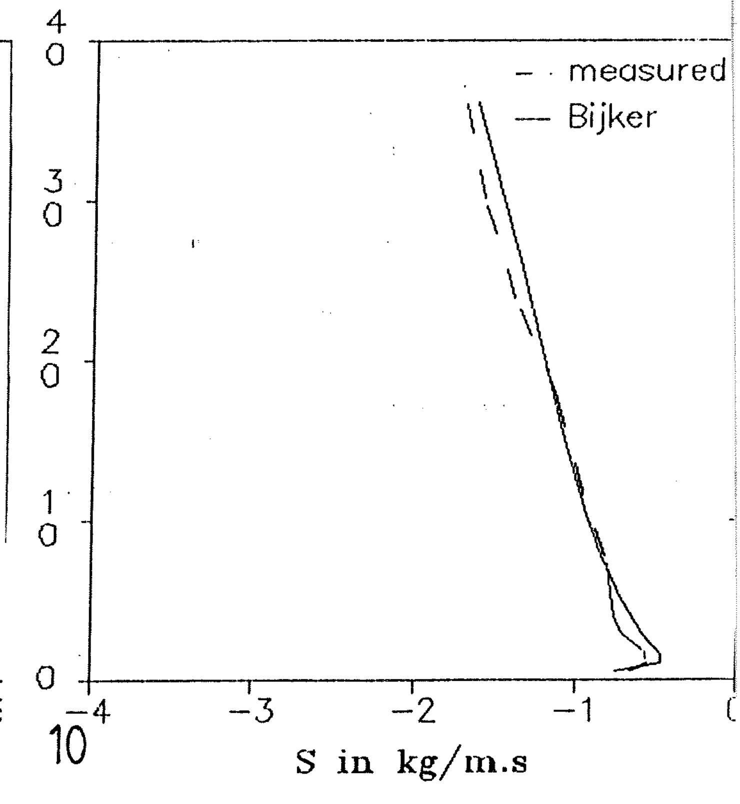
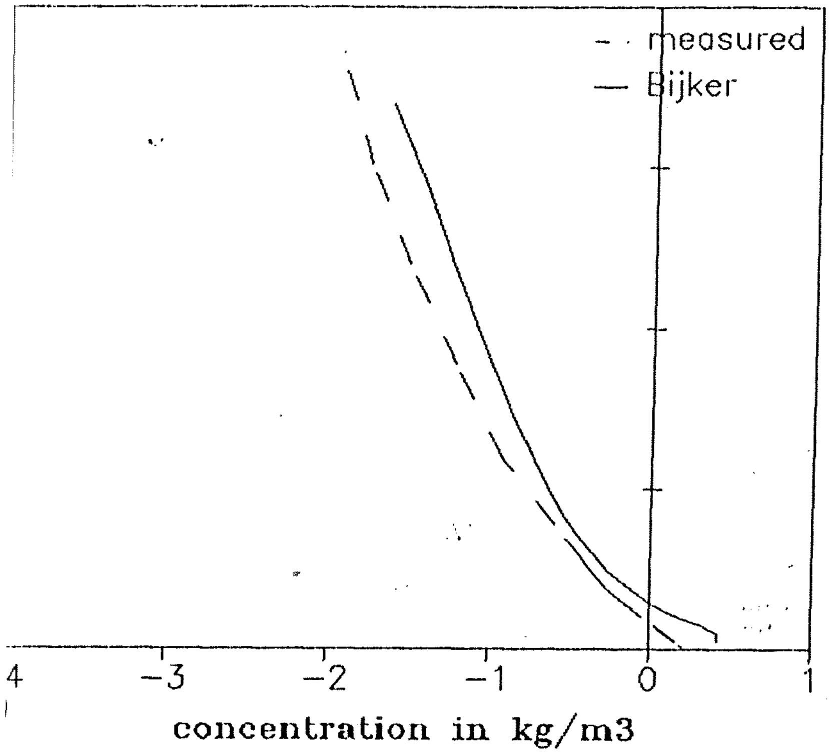
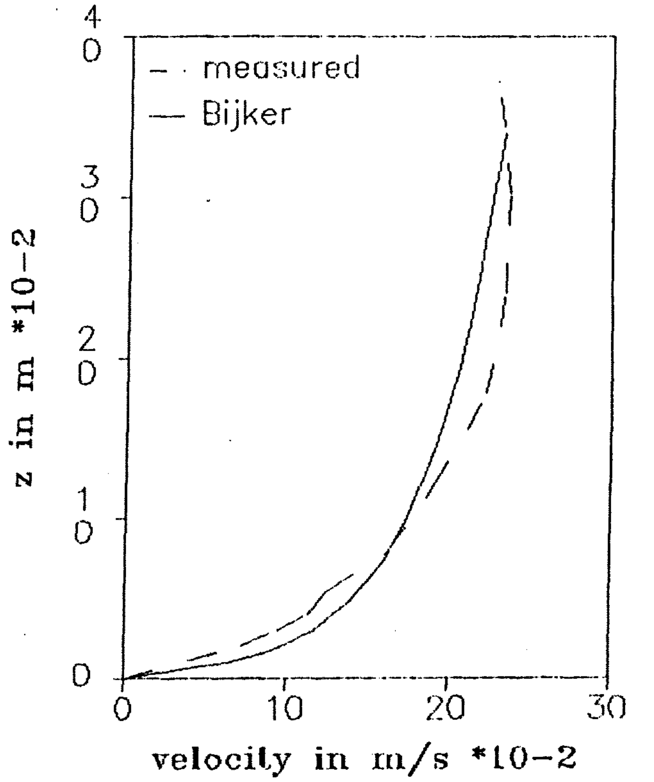


FIGURE 7.5.B

The Modified BIJKER model
comparison of concentration distribution
T 10,20 , H=Hrms , D50=100mu



The Modified Bijker model
comparison of velocity distribution
T 10,20 , H= Hrms, D50=100mu



The Modified BIJKER model
comparison sed.transport distributions
T 10,20 ,H= Hrms, D50=100mu

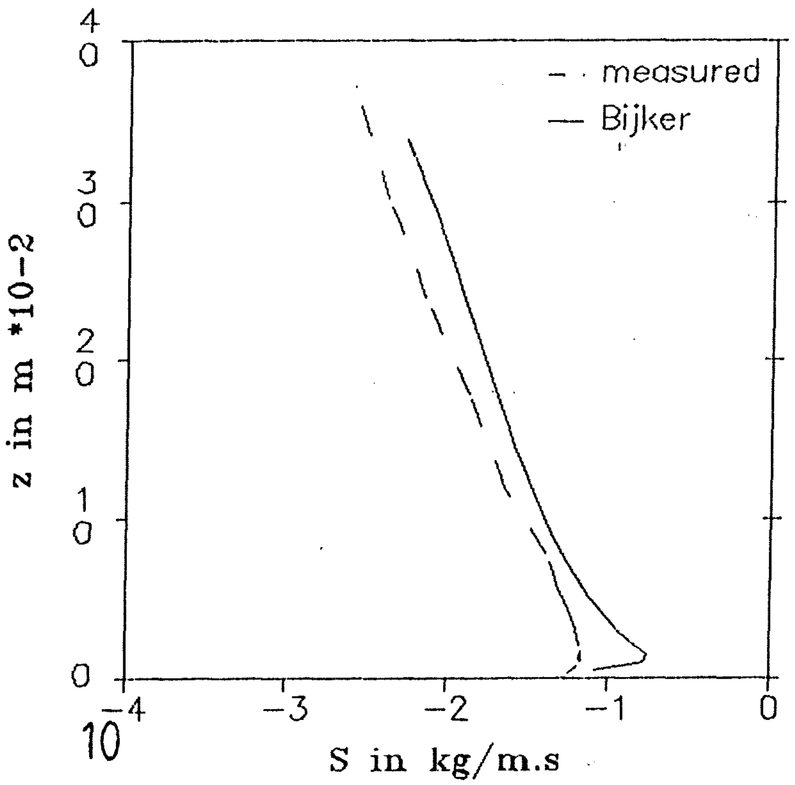
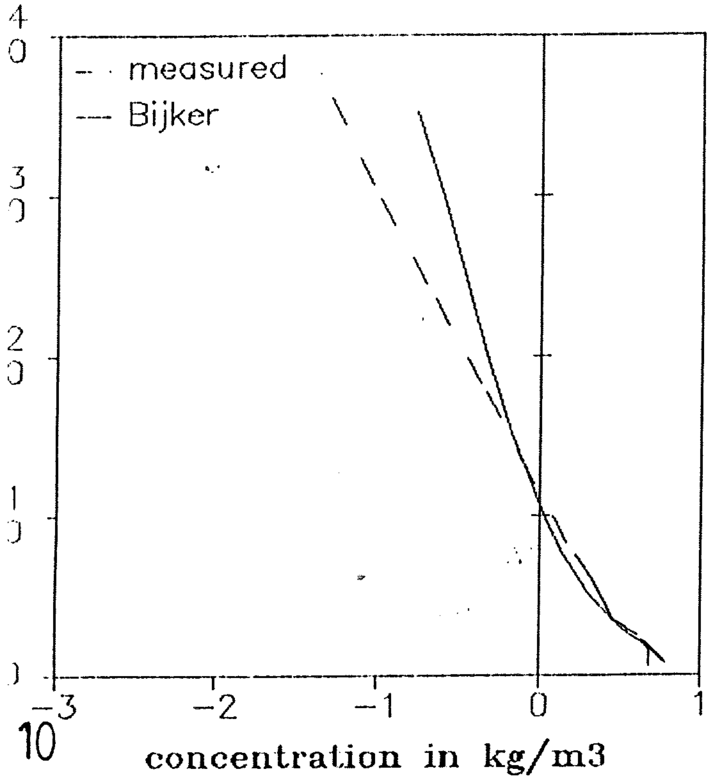
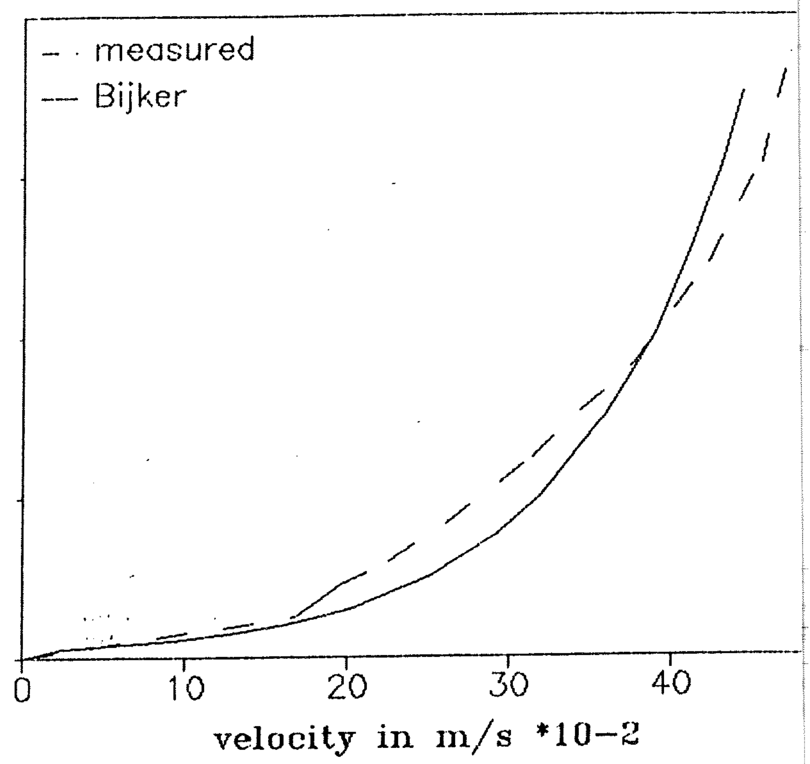


FIGURE 7.5.C

The Modified Bijker model
mparison of concentration distribution
T 15,-40 , H= Hrms, D50=100mu



The Modified Bijker model
comparison of velocity distributions
T 15,-40 ,H= Hrms, D50=100mu



The Modified BIJKER model
comparison sed.transport distributions
T 15,-40 , H= Hrms, D50=100mu

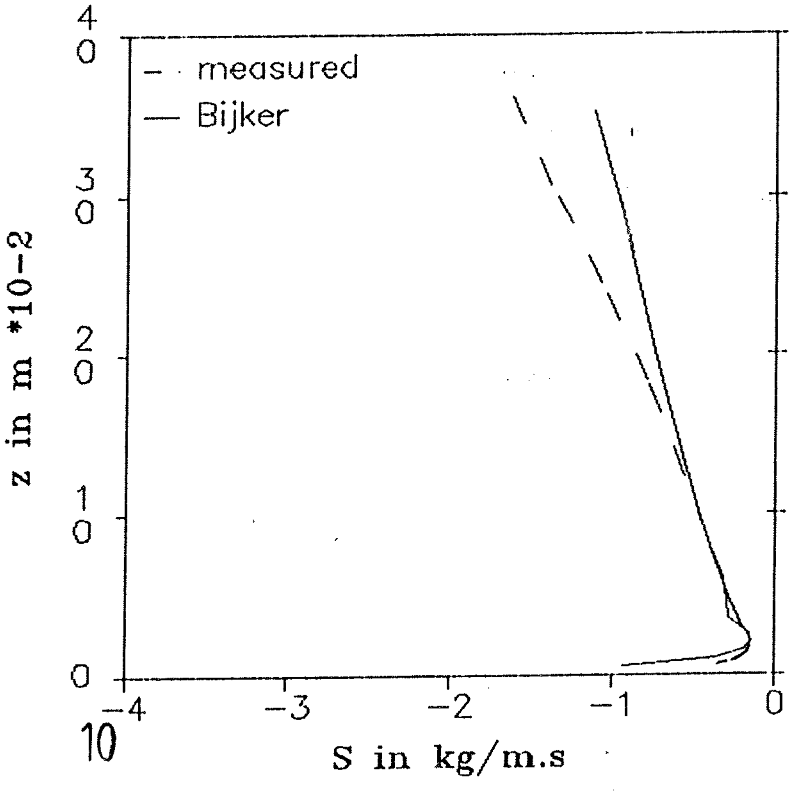
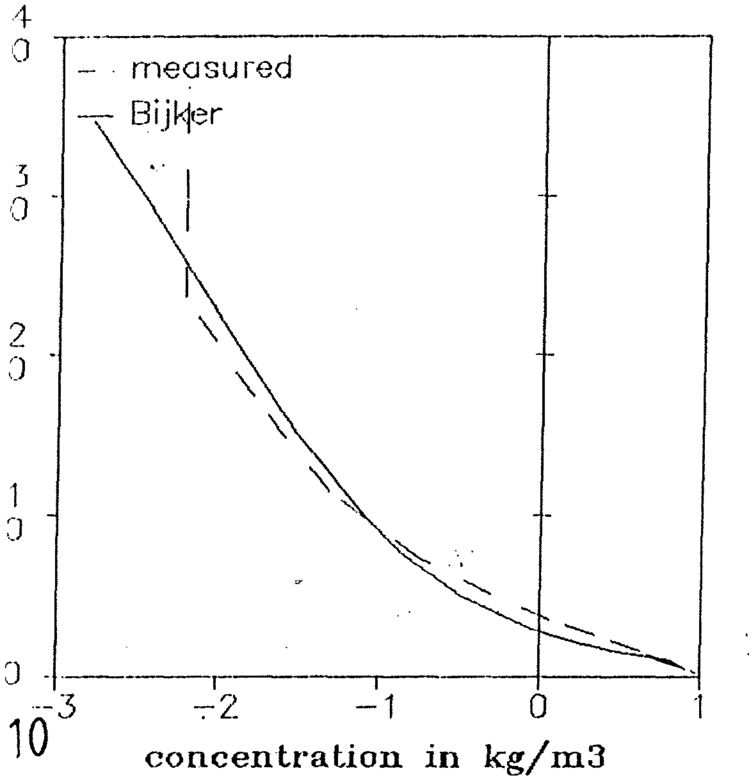
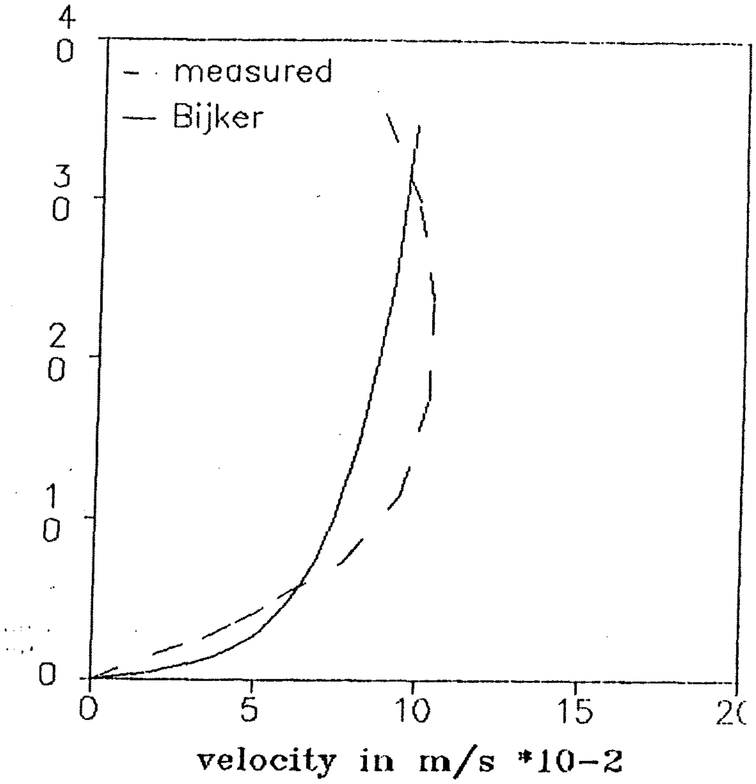


FIGURE 7.5 D

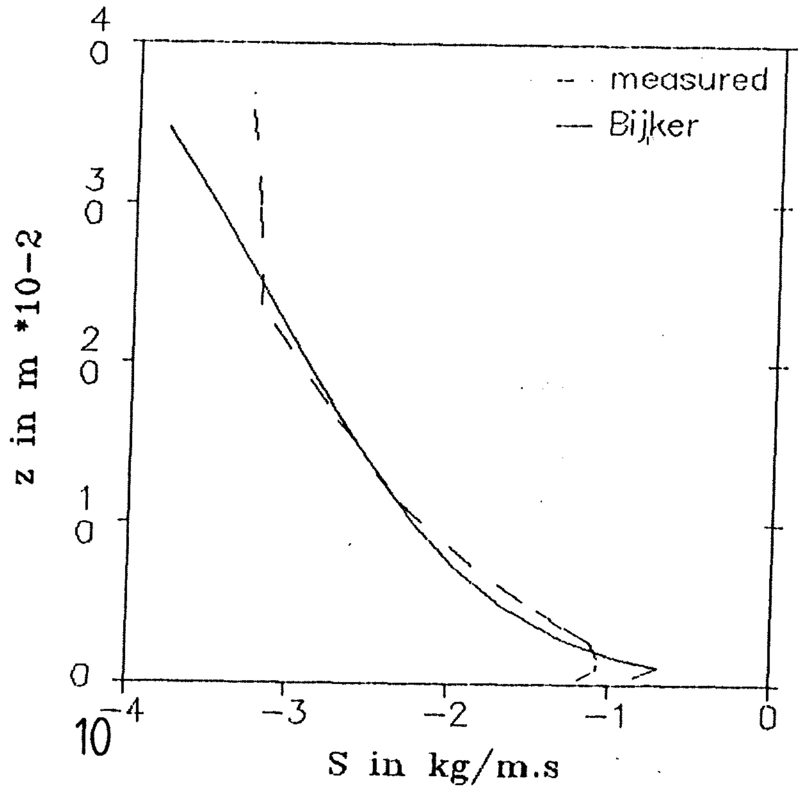
The Modified Bijker model
ıparison of concentration distribution
T 18,10 ,H= Hrms, D50=100mu



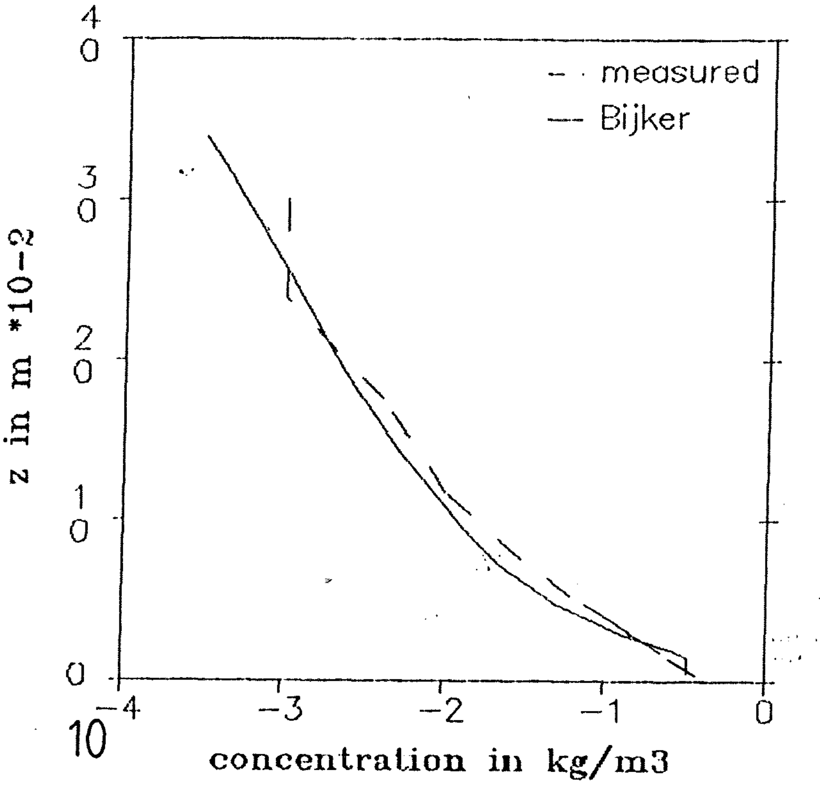
The Modified Bijker model
comparison of velocity distributions
T 18,10 ,H= Hrms, D50=100mu



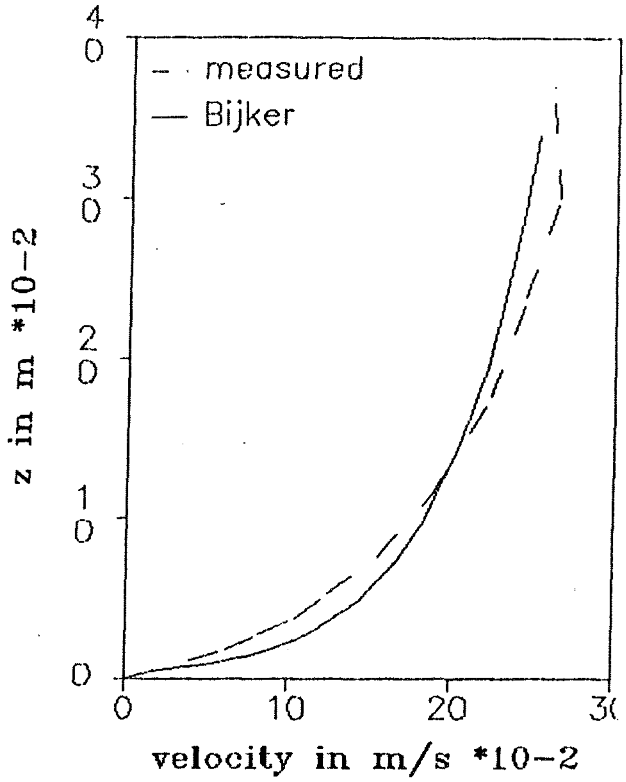
The Modified BIJKER model
comparison sed.transport distributions
T 18,10 ,H= Hrms, D50=100mu



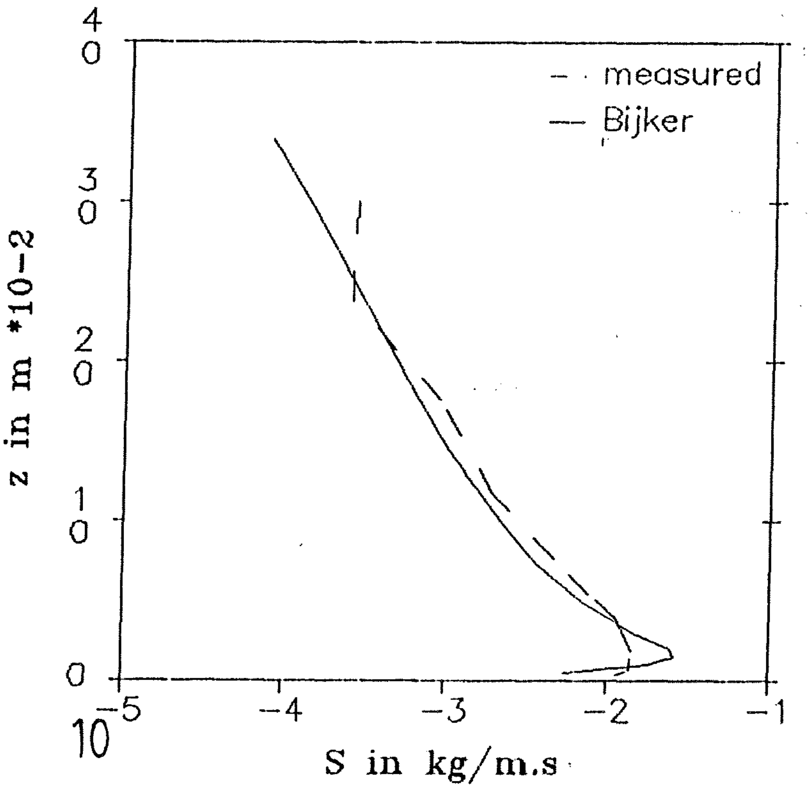
The Modified BIJKER model
comparison of concentration distribution
T 10,20 ,H= Hrms, D50=200mu



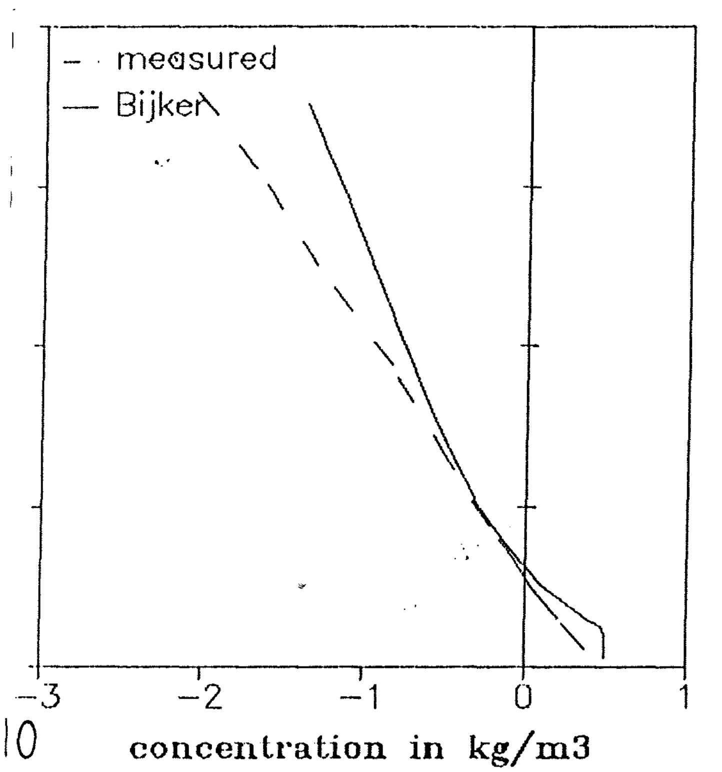
The Modified Bijker model
comparison of velocity distributi
T 10,20 , H= Hrms, D50=200m



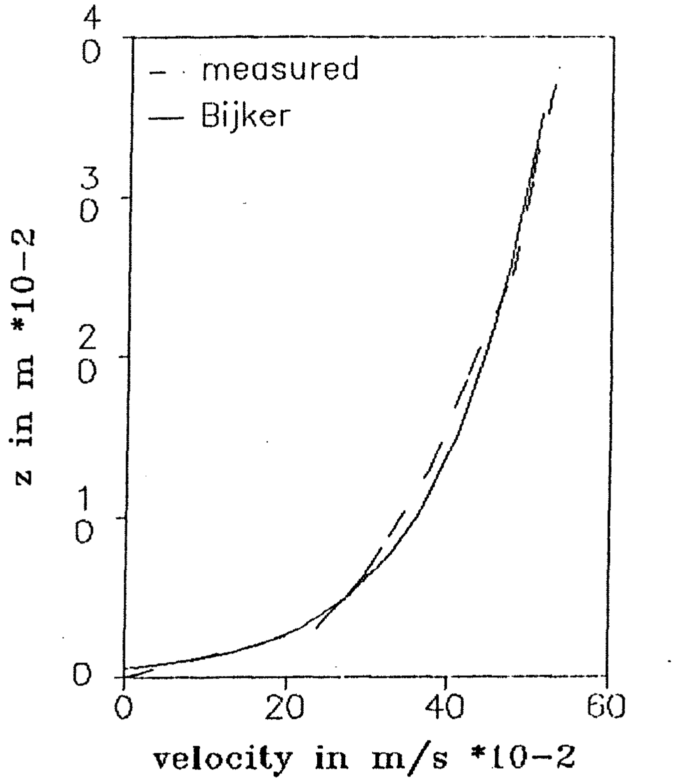
The Modified BIJKER model
comparison sed.transport distributions
T 10,20 , H= Hrms, D50=200mu



The Modified BIJKER model
parison of concentration distribution
T 15,-40 ,H= Hrms, D50=200mu



The Modified Bijker model
comparison of velocity distributions
T 15,-40 ,H= Hrms, D50=200mu



The Modified BIJKER model
comparison sed.transport distributions
T 15,-40 ,H= Hrms, D50=200mu

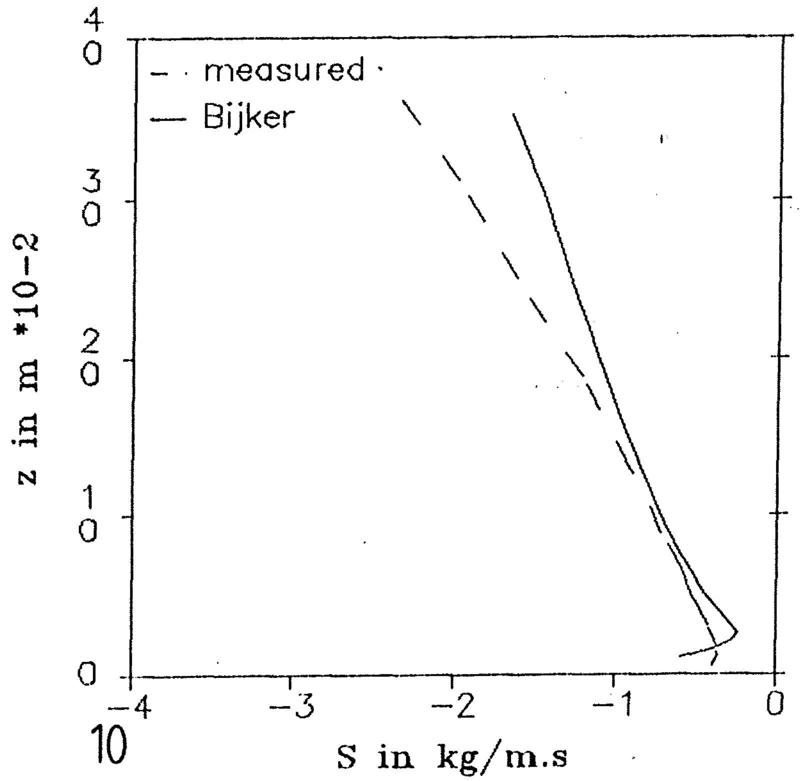


FIGURE 7.5.G

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

D50 =100mu

H = Hrms
Ks = 7*r

C(z)m = C(z) measured
C(z)Bm = C(z) Bijker modified

T7.5,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	221	97
2	97	40
3	63	22
4	40	12
5	17	5
6	5	2
7	2	1
8	0	0
9	0	0
10	0	0

T7.5,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	267	170
2	208	56
3	147	28
4	92	14
5	40	6
6	13	3
7	5	2
8	2	1
9	0	0
10	0	0

T7.5,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	259	302
2	172	176
3	142	121
4	103	80
5	60	50
6	31	27
7	21	14
8	10	8
9	3	5
10	2	2

T7.5,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	352	154
2	276	85
3	192	56
4	135	35
5	101	21
6	62	11
7	36	5
8	22	3
9	14	2
10	9	1

TABLE 7.6.A

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T7.5,40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1437	1805
2	1056	1237
3	768	944
4	666	696
5	541	492
6	335	315
7	194	194
8	98	126
9	60	83
10	44	50

T7.5,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1270	1588
2	1045	1086
3	861	830
4	684	614
5	527	437
6	335	281
7	215	175
8	107	114
9	74	75
10	43	43

T10,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	822	1242
2	489	505
3	319	276
4	185	144
5	80	70
6	22	27
7	5	10
8	3	5
9	2	2
10	1	1

T10,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1363	1532
2	861	526
3	586	269
4	359	134
5	147	63
6	38	24
7	11	9
8	4	4
9	0	2
10	0	1

TABLE 7.6.B

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T10,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	896	1483
2	655	946
3	503	683
4	388	472
5	247	308
6	118	177
7	59	96
8	30	56
9	17	32
10	11	16

T10,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1250	1951
2	812	1012
3	577	652
4	400	404
5	233	238
6	129	122
7	61	60
8	38	31
9	23	17
10	11	8

T10,40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1950	2067
2	1525	1485
3	1270	1159
4	1082	869
5	856	622
6	547	399
7	322	245
8	153	157
9	88	101
10	59	57

T10,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	2787	3273
2	1810	2188
3	1547	1653
4	1231	1212
5	918	856
6	548	546
7	270	336
8	141	218
9	81	142
10	45	82

TABLE 7.6.C

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T15,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	2190	3224
2	1115	1385
3	649	769
4	339	401
5	130	192
6	36	75
7	14	27
8	7	11
9	3	5
10	3	2

T15,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	3673	3723
2	2703	1677
3	1773	971
4	948	532
5	377	273
6	73	116
7	18	46
8	6	20
9	3	9
10	0	3

T15,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	2160	4796
2	1400	2805
3	986	1917
4	645	1252
5	372	772
6	156	414
7	58	211
8	29	116
9	20	65
10	16	31

T15,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	3693	4371
2	2503	2434
3	1603	1616
4	951	1024
5	475	613
6	195	317
7	91	155
8	43	82
9	29	44
10	16	19

TABLE 7.6.D

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T15,40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	3880	4797
2	3180	3574
3	2837	2865
4	2503	2216
5	1688	1642
6	995	1103
7	545	713
8	225	481
9	111	326
10	79	1983

T15,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	4085	3690
2	2870	2759
3	2560	2210
4	2115	1702
5	1460	1252
6	870	831
7	432	527
8	197	349
9	90	232
10	43	137

T18,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	4151	4627
2	2170	1905
3	1130	1037
4	488	532
5	176	252
6	47	97
7	16	35
8	6	14
9	6	6
10	6	2

T18,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	6823	5478
2	3980	2400
3	2369	1382
4	1237	785
5	434	392
6	174	168
7	17	69
8	8	31
9	2	14
10	0	5

TABLE 7.6.E

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T18,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	2760	5733
2	1757	3388
3	1157	2315
4	697	1501
5	370	914
6	150	480
7	55	238
8	28	128
9	23	69
10	22	32

T18,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	5655	5432
2	3570	3089
3	2226	2073
4	1211	1326
5	582	800
6	223	416
7	99	204
8	48	108
9	31	57
10	13	25

T18,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	4347	5637
2	3657	4214
3	3193	3376
4	2677	2604
5	1788	1918
6	1065	1276
7	548	813
8	257	540
9	113	361
10	49	214

TABLE 7.6.F

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

D50 =200mu

H = Hrms
Ks = 7*r

C(z)m = C(z) measured
C(z)Bm = C(z) Bijker modified

T7.5,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	27	8
2	12	2
3	5	1
4	1	1
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0

T7.5,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	41	30
2	23	15
3	13	9
4	8	5
5	5	3
6	1	1
7	0	1
8	0	0
9	0	0
10	0	0

T7.5,40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	778	1436
2	466	844
3	319	577
4	222	376
5	136	230
6	58	122
7	21	62
8	9	33
9	4	18
10	2	9

TABLE 7.6.G

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T10,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	116	377
2	53	109
3	27	48
4	10	19
5	3	7
6	0	2
7	0	1
8	0	0
9	0	0
10	0	0

T10,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	115	116
2	60	38
3	35	17
4	18	3
5	5	1
6	1	0
7	0	0
8	0	0
9	0	0
10	0	0

T10,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	224	329
2	152	144
3	109	81
4	61	42
5	30	21
6	10	8
7	4	3
8	1	1
9	0	0
10	0	0

T10,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	137	112
2	98	62
3	73	39
4	46	23
5	24	12
6	9	5
7	3	2
8	1	1
9	0	0
10	0	0

TABLE 7.6.H

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T10,40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	679	1551
2	560	1063
3	483	791
4	370	556
5	236	365
6	117	207
7	53	109
8	24	61
9	11	35
10	5	17

T10,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	925	1075
2	698	780
3	562	601
4	416	436
5	281	299
6	152	170
7	71	91
8	30	51
9	15	28
10	7	13

T12,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	344	633
2	190	173
3	104	70
4	47	26
5	18	8
6	1	2
7	0	0
8	0	0
9	0	0
10	0	0

T12,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	228	307
2	131	107
3	84	50
4	41	21
5	12	8
6	2	2
7	0	1
8	0	0
9	0	0
10	0	0

TABLE 7.6.I

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T12,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	351	1244
2	239	588
3	167	343
4	95	187
5	45	94
6	15	39
7	5	15
8	1	6
9	0	3
10	0	1

T12,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	274	722
2	194	344
3	160	202
4	96	111
5	50	56
6	19	23
7	6	9
8	3	4
9	1	2
10	0	1

T12,40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1154	2363
2	893	1585
3	701	1163
4	521	805
5	398	519
6	179	288
7	79	150
8	34	82
9	17	46
10	8	21

T12,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1301	2013
2	1006	1354
3	795	997
4	608	695
5	419	453
6	209	255
7	89	134
8	38	75
9	17	41
10	6	19

TABLE 7.6.J

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T15,10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	593	1593
2	373	527
3	226	239
4	116	98
5	32	36
6	4	10
7	2	2
8	0	1
9	0	0
10	0	0

T15,-10

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	699	1178
2	443	472
3	305	239
4	177	110
5	66	45
6	8	13
7	1	4
8	0	1
9	0	0
10	0	0

T15,20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	810	2139
2	551	1078
3	397	650
4	266	362
5	128	184
6	38	76
7	9	28
8	3	12
9	1	5
10	8	0

T15,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	517	1736
2	357	907
3	258	559
4	190	317
5	93	164
6	39	68
7	11	26
8	4	10
9	1	5
10	0	1

TABLE 7.6.K

CONCENTRATION PROFILES CALCULATED WITH THE MODIFIED BIJKER FORMULA

T15,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	1563	2380
2	1311	1682
3	1069	1276
4	862	915
5	583	613
6	322	355
7	143	192
8	49	109
9	20	62
10	6	30

T18,-20

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	774	3741
2	514	1849
3	377	1103
4	235	609
5	119	308
6	40	126
7	9	48
8	3	20
9	1	8
10	0	3

T18,-40

Tube [nr.]	C(z)m [kg/m3] *10-3	C(z)Bm [kg/m3] *10-3
1	2242	2698
2	1804	1999
3	1532	1562
4	1218	1148
5	860	785
6	476	461
7	228	250
8	87	142
9	38	80
10	12	38

TABLE 7.6.L