# Sediment concentrations and sediment transport in case of irregular non-breaking waves with a current

Part A: Text

October 1987

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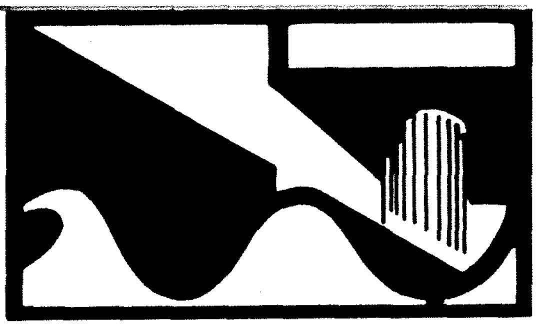

delft hydraulics

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# SEDIMENT CONCENTRATIONS AND SEDIMENT TRANSPORT IN CASE OF IRREGULAR NON-BREAKING WAVES WITH A CURRENT

## Part A: Text

Delft University of Technology - Delft Hydraulics

Preface

In this report an experimental programme, carried out to investigate sediment concentrations and sediment transport rates in case of irregular waves in combination with a current, is described. This programme is carried out as a joint effort of the Delft University of Technology and the Delft Hydraulics. For covenience this report is devided in two parts. Part A contains all text and part B contains all tables and Figures.

Literature references are mentioned by the name of the author(s) and the year of publication.

We would like to thank the employees of the Laboratory of Fluid Mechanics of the Delft University of Technology for their assistance while carrying out the experiments and Dr. Ir. L.C. van Rijn of the Delft Hydraulics for his guidance during the execution of the experiments and the elaboration of the experimental results.

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# 1 Introduction

## 1.1 General

In many coastal engineering problems the sediment transport plays a part. A transport gradient causes accretion or erosion. Various models, such as that of Bijker, Engelund and Hansen (van de Graaff and van Overeem, 1979) and Nielsen (1985) are available to estimate the sediment transport rate if the hydraulic and environmental conditions (wave height, current velocity and direction, sediment size) are known. Since reliable data under field conditions are extremely scarce, the reliability of these models is not known, while also no understanding of the basic relations between the sediment transport, current velocity and wave height can be obtained.

To extend the knowledge of the basic phenomena, a laboratory study was carried out. Fluid velocities and sediment concentrations have been measured in case of irregular non-breaking waves alone, and in combination with following or opposing currents.

## 1.2 Convective and diffusive sediment transport

The sediment transport rate can be computed from the sediment velocity and the sediment concentration distribution over the water depth. Assuming that the sediment velocity is equal to the fluid velocity, the sediment transport can, in principle, be computed from:

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

in which:

$Sx(x,t)$ = Local instantaneous sediment transport rate per unit width [Kg/ms]

$C(x,z,t)$ = 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]

$\eta$ = Water surface elevation [m]

$h$ = Water depth [m]

During these experiments only time- and bed-averaged concentrations and velocities have been measured (the reason for this is given in paragraph 2.3.5). Transport rates are computed based upon the time- and bed-averaged concentrations. As will be shown, the use of time- and bed-averaged concentrations causes a neglect of a part of the total sediment transport.

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

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

in which:

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

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

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

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

Substituting Eqs. (1.2) and (1.3) into Eq. (1.1) leads to:

$$Sx(x,t) = \int_0^{h(x)+\eta(x,t)} C(x,z,t)*U(x,z,t)\,dz =$$

$$= \int_0^{h(x)+\eta(x,t)} [\overline{\overline{C}}(z)*\overline{\overline{U}}(z) + C'(x,z,t)*\overline{\overline{U}}(z) + \overline{\overline{C}}(z)*U'(x,z,t) + C'(x,z,t)*U'(x,z,t)]\,dz =$$

$$= \int_0^{h(x)+\eta(x,t)} \overline{\overline{C}}(z)*\overline{\overline{U}}(z)\,dz + \int_0^{h(x)+\eta(x,t)} C'(x,z,t)*\overline{\overline{U}}(z)\,dz + \int_0^{h(x)+\eta(x,t)} \overline{\overline{C}}(z)*U'(x,z,t)\,dz + \int_0^{h(x)+\eta(x,t)} C'(x,z,t)*U'(x,z,t)\,dz$$

Averaging over time and bed and defining:

$Stot = \overline{\overline{\overline{Sx}}}(x,t)$, yields: (1.4)

$$Stot = \int_0^h \overline{\overline{\overline{C}(z)*\overline{\overline{U}}(z)}}\,dz + \int_0^h \overline{\overline{\overline{\overline{U}}(z)*C'(x,z,t)}}\,dz + \int_0^h \overline{\overline{\overline{\overline{C}}(z)*U'(x,z,t)}}\,dz +$$

$$+ \int_0^h \overline{\overline{C'(x,z,t)*U'(x,z,t)}}\,dz =$$

$$Stot = \int_0^h \overline{\overline{\overline{\overline{C}}(z)*\overline{\overline{U}}(z)}}\,dz + \int_0^h \overline{\overline{C'(x,z,t)*U'(x,z,t)}}\,dz =$$

$$= Sconvective + Sdiffusive \qquad (1.5)$$

As shown, the total sediment transport consists of a steady part, called convective transport, and a non-steady part which, although actually not a diffusion, is called diffusive transport. In the present study only the time- and bed-averaging method has been used, which means that the $\overline{\overline{C}}(z)$ and $\overline{\overline{U}}(z)$ variables and hence the convective sediment transport are determined. To examine the importance of the diffusive part of the transport, sand balance experiments were executed.

## 1.3 Objective of the experiments

1) To gain insight into the relations between sediment transport, wave height and current velocity by the execution of flume experiments with measurements of fluid velocities and concentrations.

2) Verification of a number of sediment transport models with the use of the flume experiments.

3) Investigation of the relative importance of the convective and diffusive sediment transport.

# 2 Experimental set up and preliminary tests

## 2.1 Flume and hydraulic conditions

### 2.1.1 Flume

The experiments were conducted in a flume of the Laboratory of Fluid Mechanics of the Faculty of Civil Engineering of the Delft University of Technology. The flume has a total length of approximately 45 [m], a width of 0.8 [m] and a depth of 1.0 [m]. Irregular waves can be generated by a sophisticated wave generator in combination with a following or opposing current. Flow was supplied by a constant-head system in the laboratory (maximum discharge of 500 [l/s]). The flume layout is shown in Fig. 2.1.

The flume consisted of various sections (see also Fig. 2.1):

A - Section with the wave generator.

B - In- and outflow section

C - Test section with a horizontal sand bed (length 25 [m] thickness 0.1 [m])

D - Section with wave damping structure consisting of a convex steel structure upon which wooden laths were mounted.

E - In- and outflow section

The inlet section B, used for inflow in case of a following current, was equiped with guiding vanes. In section E, used for inflow in case of an opposing current, guiding vanes were not used because of the presence of the wave damping structure directly after the inlet.

After leaving the flume the water was recirculated through a settling tank where most of the sediment load was trapped.

### 2.1.2 Generation of current

All gate valves numbered 1 had to be open and gate valves numbered 2 had to be closed to generate a following current. To generate an opposing current, gate valves 1 had to be closed and gate valves 2 had to be open.
In case of waves in combination with a following current a permanent overflow weir, placed just upstream section E, was used. By manipulating gate valve 1 for inflow the desired discharge was obtained. After that the desired water depth (0.5 [m]) was obtained by adjusting the height of the weir. A permanent weir could not be used in case of an opposing current because the waves can not pass this barrier. Instead of a permanent weir, a temporary weir was used. This temporary weir served to maintain the water depth to prevent damage to the sand bed when adjusting the correct discharge. After the temporary weir was put in place, the desired discharge was adjusted by manipulating gate valve 2 for inflow. When the discharge was correct, gate valve 2 for outflow is shut a little to equalize the water depth before and after the temporary weir. The weir was removed and by manipulating gate valve 2 for outflow the correct water depth was adjusted.

### 2.1.3 Wave spectrum shape

Waves were generated by a wave paddle, the (irregular) movements of the wave paddle generated the irregular waves. The specrum of the electronical signal driving the wave paddle could be adjusted with the use of a noise generator and a filter unit. The noise generator produced a white noise; with the use of the filters it was possible to create a spectrum which was sent to the electric equipment of the wave paddle. The filter unit consisted of a combination of (parallel or serial) low frequencies passage and high frequencies passage filters, each having their own adjustable period and damping factor. The filter periods and damping factors were kept constant during these experiments.

A single topped spectrum with a peak frequency of 0.4 [Hz], having a steep slope at the lower frequencies and a less steep slope at the higher frequencies, was adjusted and used during these experiments (see Fig. 3.1).

### 2.1.4 Wave reflection

To find the optimum position of the wave damping structure and to get an impression of the magnitude of the wave reflection, some tests with regular waves (no current superimposed on the waves), wave periods of 2, 2.5 and 3 [s], were conducted. With the use of two wave height meters, interspaced one meter and placed in the measuring section, it was possible to calculate the reflection coefficient (defined as the ratio of the reflected wave height and the incident wave height). By adjusting the position of the wave damping structure, the reflection coefficient could be reduced to about 0.1.

### 2.1.5 Measuring section

The water entering the flume had no initial sediment load, the concentration profile had to be build up completely in the section with the sand bed. To provide enough length to reach equilibrium concentrations in the lower half of the depth, the measuring section 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 at cross section 16 and in case of an opposing current the measuring section was situated at cross section 12 (see Fig. 2.1).

### 2.2 Sediment

Before the sand was brought into the flume, the silt was washed out. To eliminate pebbles and shells, the sand was washed (using water) in the flume through a large sieve with a sieve diameter of 3 [mm]. After that the sandbed was leveled.

Comparison of the particle size diameters before and after the first experiment with a depth-averaged fluid velocity of 0.4 [m/s] showed an increase in the median particle size of the bed material, probably as a result of the trapping of fine particles in the settling tank. After this experiment little variation in particle size distribution of the bed material at the measuring section was observed.

The characteristics of the bed material, based on samples of all experiments, are given in the following table in which Dx is the sieve diameter passed by x% by weight.

| Dx | mean [μm] | stand. dev. [μm] | min. [μm] | max. [μm] |
|---|---|---|---|---|
| D10 | 151 | 5.9 | 146 | 170 |
| D50 | 206 | 5.3 | 200 | 223 |
| D90 | 296 | 14.5 | 269 | 323 |

It appears that the largest variation occurs at the larger particle diameters. This is probably a result of the method of sampling. A large sample contains more material from the deeper regions of the sand bed which will probably be somewhat coarser.

Fig. 2.2 shows the size distribution of the bed material of experiment T 10 -10. The particle diameters of this experiment closely match the overall mean values of D10, D50 and D90.

Although there was little variation in the particle diameters at the measuring section, there was found to be some segregation over the flume length. Both in experiments with waves following a current and in experiments with waves opposing a current, it was observed that the bed material became finer in current direction. This segregation may be explained by the fact that the water entering the flume had no initial sediment load. Fine material at the beginning of the sand bed is easily stirred up, brought into suspension and deposited downstream. Since there is no supply of fine material, the bed material gradually becomes coarser at the beginning of the sand bed. Downstream, fine sediment is also easily stirred up but there is also deposition of material stirred up upstream.

At regular times the sand bed was resupplied using the accumulated sand in the settling tank. After resupplying, the bed was mixed and leveled again.

## 2.3 Measuring instruments, measuring methods and accuracy

Fig. 2.3 shows an overview of the electronic measuring instruments used in the experiments. The instruments will be discussed successively with the parameters that were measured during the experiments.

### 2.3.1 Discharge

The discharge was measured using a Rehbock weir, see Fig. 2.1. Usually the inaccuracy of a Rehbock weir is very small. The geometry of the present Rehbock weir was however not fully correct. This caused an underestimation of the discharge of approximately 5%. This had no serious consequences because the aim of measuring the discharge was only to get an estimation (on the spot) of the desired current velocity. In later calculations the depth-averaged fluid velocity, derived from the velocity distribution over the water depth, was used.

### 2.3.2 Mean bed level

Mean bed level at the measuring section was determined using a profile follower (profo) and an integrator to integrate the electronical output signal of the profo. The gauging rod of a profo keeps, when moving over a sand bed, a fixed distance to the bed ("keel clearance") and consequently follows the bed forms. By integrating the output signal of the profo, mean bed level can be determined.
Because the "keel clearance" of a profo is different for different

materials, it was not possible to measure mean bed level relative to the flume bottom. Mean bed level had to be determined relative to a reference point on the sand bed. Before explaining the determination of mean bed level, firstly the calibration of the integrator will be explained. The calibration was done using a calibration block with a height difference of exactly 0.1 [m] (see Fig. A).

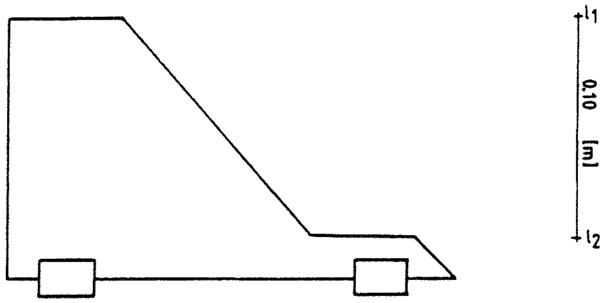



Fig. A: Calibration block

The profo is placed above the two levels l1 and l2 successively. At each level an integration is executed during T seconds. The integrator displays the numbers n1 and n2. These numbers are proportional to the integration time T; n1 = w1*T and n2 = w2*T with w1 and w2 the time independent parts. The difference $\Delta n$ = n1 - n2 = (w1 - w2)*T= $\Delta w$*T is a measure for the height difference $\Delta l$ (= 0.1 [m]). The time independent ratio q = $\Delta w / \Delta l$ is the general conversion factor.

When of any point in the flume the bed height can be determined, it is possible to determine the mean bed level at any other place in the flume (see Fig. B).

To determine the bed height of the reference point, the water height to the flume bottom, a, and the water height to the sand bed, d, were measured with a measuring tape. The magnitude of $\delta_r$ is known:

$\delta_r$ = a - d. When integrating over T seconds at the reference point, the number n3 (= w3*T) is displayed. Integrating during T seconds over the distance L using a lineair moving carriage at the measuring section displays the number n4 (= w4*T).

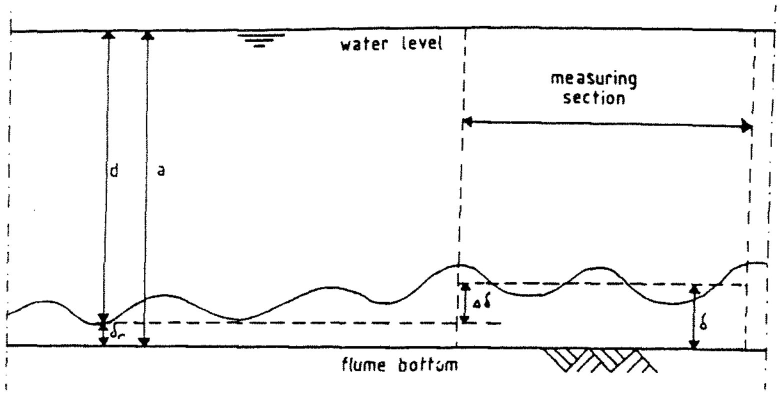



Fig. B: Method of determining mean bed level

The height difference between the reference point and mean bed level at the measuring section is equal to (w4 - w3)/q, so mean bed level at the measuring section can be computed from:

$$\delta = \delta_r + (w4 - w3)/q \quad (2.1)$$

in which:

| | | |
|---|---|---|
| $\delta$ | = Mean bed level at measuring section | [m] |
| $\delta_r$ | = Height relative to the flume bottom of reference point | [m] |
| q | = General conversion factor | [V/m] |
| w3 | = Time independent part of integrated profo output when integrating at the reference point | [V] |
| w4 | = Time independent part of the integrated profo output when integrating at the measuring section | [V] |

The mean bed level was determined in three longitudinal sections to average out variations in transverse direction (see Fig. C). This procedure was carried out before and after each concentration and velocity measurement to get a time-averaged mean bed level for each test.

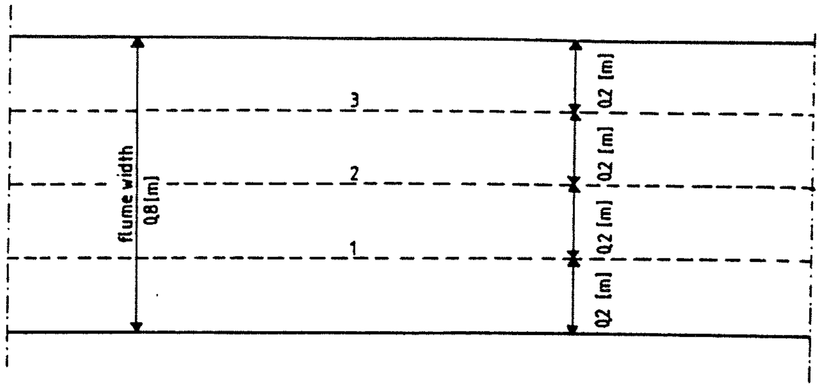



Fig. C: Distribution of longitudinal sections over the flume width

The calibration of the reference point was excecuted in still water so the water level was not fluctuating and the parameters a and d could be measured with an accuracy of 0.5 [mm]. This caused an error in $\delta_r$ of $\sqrt{0.5^2 + 0.5^2} \simeq 0.7$ [mm] as a result of the calibration of the reference point. Integrating several times in the same longitudinal section at the measuring section using a moving carriage showed a variation in $\delta$ of 1.0 [mm] depending on the point were the integration started. Averaging over three longitudinal sections reduces this error to $1/3 \sqrt{3*1^2} \simeq 0.6$ [mm]. Averaging of the mean bed levels measured before and after a test (time averaging) then further reduces this error to $1/2 \sqrt{2*0.6^2} \simeq 0.4$ [mm]. For the resulting error in mean bed level at the measuring section, averaged over three longitudinal sections and averaged over the time, it now holds: $\Delta\delta = \sqrt{0.7^2 + 0.4^2} \simeq 0.8$ [mm].

### 2.3.3 Water level and depth measurements

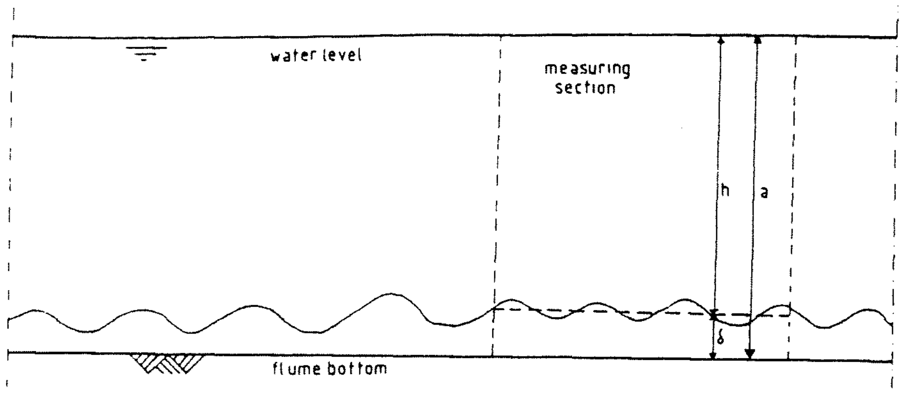



Fig. D: Mean bed level and mean waterdepth.

The water height relative to the flume bottom, a, was measured with the use of a measuring division on the flume window. Mean bed level at the measuring section, $\delta$, was determined as explained in the former paragraph. From these two parameters the water depth relative to mean bed level can be determined as:

$$h = a - \delta \tag{2.2}$$

Small water level fluctuations caused a measuring error in height a of 1 [mm]. Because a and $\delta$ are independent, the error in water depth is approximately equal to $\sqrt{1^2 + 0.8^2} \simeq 1.3$ [mm].

### 2.3.4 Wave parameters and spectrum

Water level variations were measured with an electric resistance probe. In each experiment, a wave registration of approximately 200 waves was made with a pen recorder, see Fig. 2.4. With the use of the precision tuner, the pen recorder was adjusted in such a way that a lowering of the wave probe of 0.1 [m] corresponded (on the desired scale) with a lowering on the pen recorder of 0.1 [m]. The procedure was repeated with an elevation of 0.1 [m] so the calibration was rather accurate. The wave registration was used to determine the ratio H1%/Hs (H1% is the wave height exceeded by 1% of the waves)

The wave spectra were determined near the location where the concentrations and velocities were measured. Via a fourier transform of the auto-covariation function of the water surface elevation the spectra were obtained. From prelimenary tests it appeared that there was almost no wave energy in frequencies above 2 [Hz]. To prevent aliasing, the sampling period had to be chosen in such a way that the Nyquist frequency, fNyq., was equal to 2 [Hz]. This led to a sampling period of 0.25 [s]. For safety reasons, an electronic filter was used before sampling to eliminate possible contributions of frequencies higher than 2 [Hz].

The spectra were determined using the highest resolution (smallest frequencyband $\Delta f$) possible; $\Delta f$ = fNyq./1024. From preliminary tests it appeared that the characteristic wave parameters (Hs, Tz), derived from the measured spectra, did not change noticeably when applying measuring periods larger than 30 minutes, therefore the measuring period was chosen to be 30 minutes.

In each experiment, the wave spectrum was determined three times. After the wave generator was switched on, the water surface elevation was sampled during 30 minutes and stored into the memory of a micro computer. When the sampling was completed, the wave spectrum and the wave parameters were computed by the micro computer.

Although the spectra measured were not "narrow" in a statistical sense, the wave height distribution can be described by a Rayleigh distribution because the measured wave spectra were single topped (Battjes, 1982). In case of Rayleigh distributed wave heights, the characteristic wave parameters can be computed from the wave spectrum, as follows:

$$Hs = 4\sqrt{M0} \qquad (2.3)$$

$$Tz = \sqrt{(M0/M2)} \qquad (2.4)$$

$$Tp = 1/fp \qquad (2.5)$$

in which:

Hs = Significant wave height [m]

Tz = Zero-crossing period [s]

Tp = Wave spectrum peak period [s]

fp = Wave spectrum peak frequency [Hz]

Mn = nth order moment of wave spectrum $[m^2 Hz^n]$

2.3.5 Time- and bed-averaging

Bosman (1982 and 1985) measured local and instantaneous concentrations. He concluded that there was a random variation in the concentration pattern of 50 to 100%. The local instantaneous concentrations appeared to be very sensitive for the local conditions. For some applications, the much easier to measure time- and bed-averaged concentrations are sufficient. Therefore, a time- and bed-averaging method was applied.

Time-averaging was performed by using a pump sampling instrument consisting of an array of 10 intake tubes. Details are presented in paragraph 2.3.6. Bed-averaging was performed by mounting the concentration sampler on an oscillating carriage. The velocity of the moving carriage should be small compared with the fluid velocities and large compared with the bed form migration velocity, so order 0.01 [m/s].

A special test was performed to determine the proper time-averaging period and bed-averaging distance. Tests were executed in which the concentrations were determined over 60 minutes using suction periods of 3 minutes. This was done with an oscillating carriage at two levels near the sand bed. The results of this test are given in table 2.1. After 15 minutes, the concentration differed 10 percent of the final value after 60 minutes. Based on this, a sampling period of approximately 15 minutes was selected. This period correponds with approximately 300 to 400 waves.

To study the influence of the bed forms on the sediment concentrations, time-averaged concentrations were measured at 5 heights (in vertical direction) with a non-moving carriage above 4 adjacent ripple tops and above 4 adjacent ripple troughs. In addition, the time-averaged concentrations were measured with an oscillating carriage to apply bed-averaging over the traject in which the selected ripples were situated. The results of this test are given in table 2.2. As can be observed, the relative standard deviation of the averaged individual concentration distributions is 20 to 50%, depending on the height above the bed. However, when the individual concentrations are averaged, they show a strong agreement with the concentrations measured with an oscillating carriage. The relative concentration differences in the lowest 4 points are less than 10%. Based on this, a bed-averaging distance of 0.6 [m] (3 to 5 ripple lengths) was selected.

### 2.3.6 Sediment concentration measurements

The sediment concentrations were determined using a pump sampling instrument. This instrument consists of an array of 10 brass intake tubes of 3 [mm] internal diameter, see Fig. 2.5. In the present investigation 10 intake tubes were used to determine the concentration distribution. Tests of Steetzel (1984) showed that even with tube distances of 10 [mm] the disturbance of the concentration distribution and the mutual influence of the tubes is negligible.

Because the waves cause a continuous change of flow direction, it is only possible to pump without a preference direction by placing the intake tubes in transverse direction with respect to the plane of orbital motion. Because the sediment particles can not completely follow the curved trajectories of the water particles to the intake tubes, the trapping ratio T.R. (the sediment concentration in the sample divided by the undisturbed concentration in the flume) will be smaller than unity. The trapping ratio strongly depends on the ratio between the intake velocity and the ambient velocity in the flume. Tests of Bosman et al (1987) showed that the T.R. goes to a final value if the intake velocity is larger than three times the ambient flow velocity. If this condition is satisfied, there is only a moderate sensitivety of the T.R. on the sediment characteristics (size and shape). This trapping ratio as determined under steady flow conditions is valid in case of waves as well (Bosman, v/d Velden and Hulsbergen, 1987).

The sediment concentrations were measured in the following way. First of all, the concentration sampler was adjusted at the correct height with the use of a gauging rod connected to the concentration sampler. The gauging rod was lowered and placed on a chosen ripple top (Fig. 2.6). With the use of the reading scale of the gauging rod, the concentration sampler was adjusted at such a height that the lowest intake tube of the concentration sampler was placed 0.01 [m] above the chosen ripple top. In each experiment three concentration and three velocity profiles were measured (three tests). Because the lowest intake tube of the concentration sampler had to pass safely all ripples in the bed-averaging traject, the height of the concentration sampler had to be adusted before each test.

After the height adjustment of the concentration sampler, the carriage was set in an oscillating motion (bed-averaging) and 10 samples of 10 litres were simultaneously pumped into graduated plastic buckets. To obtain intake velocities that are large enough, peristaltic pumps were used (see Fig. 2.7). The lowest intake velocity obtained with these pumps was approximately 1.4 [m/s] which is sufficient under the boundary conditions (Hs and Um) used in this investigation. After filling, the water in the buckets was poured off and the remaining sand particles were washed in a volume meter (see Fig. 2.8). This volume meter consists of a series of 10 small calibrated glass cylinders with decreasing diameters. The wet sediment volume was measured by reading the height of the sediment sample washed into the volume meter. By calibration this wet sediment volume is known to correspond with a certain amount of dry sediment mass. The ratio of this dry mass and the volume of the water-sediment mixture pumped into the bucket gives the concentration in the bucket in [Kg/m3]. The flume concentrations can be computed from the bucket concentrations, as follows:

$$C = C_{flume} = K2 * C_{meas.} = K2 * (K1 * V_{wet}/V) = (K2 * K1 * h * 0.25 * \pi * d^2)/V \quad (2.6)$$

in which:

| | | | |
|---|---|---|---|
| Cflume | = | Sediment concentration in the flume | [Kg/m3] |
| Cmeas. | = | Sediment concentration in the buckets | [Kg/m3] |
| K1 | = | Dry mass / wet volume correction factor | [Kg/m3] |
| K2 | = | Trapping correction factor (= 1/T.R.) | [-] |
| Vwet | = | Wet sediment volume | [m3] |
| V | = | Volume of the sediment-water mixture pumped out | [m3] |
| h | = | Reading of the volume meter, height of the sediment sample washed into the volume meter | [m] |
| d | = | Diameter of the calibrated glass cylinder | [m] |

The K2 factor for the sediment used in the present investigation is 1.39.

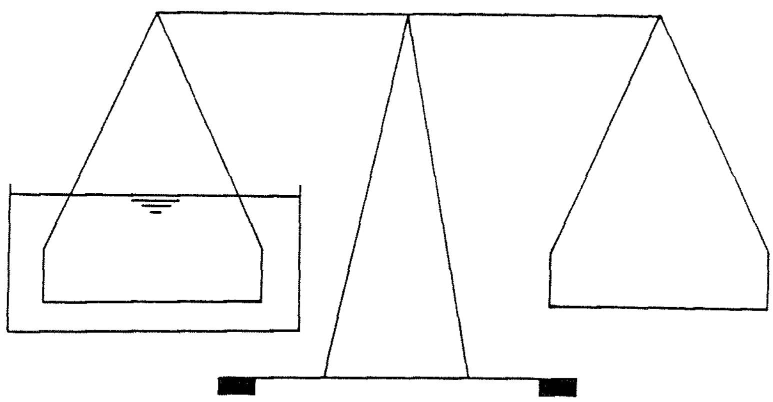


Fig. E: Principle of under water balance

The method of determining the concentrations with the volume meter is accurate within 5% (random error due to the differences in consolidation). To check the accuracy of the volume meter, some comparative tests between the volume meter and an under water balance were carried out. Using the under water balance, the sediment weight under water is weighed in a reservoir attached to a balance, see Fig. E

With the under water balance, the weight under water of the sediment is determined:

$$Wmeas. = (\rho_s - \rho)*Vs*g$$
$$= ((\rho_s - \rho)/\rho_s)*Vs*\rho_s*g$$
$$= ((\rho_s - \rho)/\rho_s)*Ws$$
$$\Rightarrow \quad Ws = (\rho_s/(\rho_s - \rho)*Wmeas. = 1.606*Wmeas. \qquad (2.7)$$

with:

| | | | |
|---|---|---|---|
| Wmeas. | = | Measured weight under water of the sediment | [N] |
| Ws | = | Dry sediment weight | [N] |
| $\rho_s$ | = | Sediment density (assumed to be 2650) | [Kg/m3] |
| $\rho$ | = | Density of water (= 1000) | [Kg/m3] |
| Vs | = | Sediment volume | [m3] |
| g | = | Acceleration of gravity (= 9.81) | [m/s2] |

The results of the comparative tests are given in table 2.3. As can be observed, the sediment mass determined with the under water balance agrees rather well with the mass determined with the volume meter.

To be able to determine the median fall velocity of the sediment, the sediment samples were catched in sample bottles after the reading of the volume meter. The samples corresponding to the intake tubes 6 to 10 were catched in one bottle because of the little volume of the individual samples.

2.3.7 Water velocity measurements

The velocities were measured with an Electro-Magnetic Velocity meter (E.M.S.), see Fig. 2.9. An electro-magnetic field is generated by this instrument, the degree of disturbance of this field by the moving water is a measure for the velocity of this water. The E.M.S. has its measuring volume 3 [mm] below the probe.
The velocities were measured at the same heights above mean bed level as the concentrations, starting with the lowest point (near the sand bed) and working upwards (to the water level). The E.M.S. was positioned at the same heights as the concentration meter by relating the reading of the gauging rod of the concentration sampler when placed at the still water level with the reading of the E.M.S. when the probe was placed at still water level. By raising the E.M.S. probe successively (after each measurement) all measurements have been completed. The position of the velocity meter and the concentration sampler is given in Fig. F.

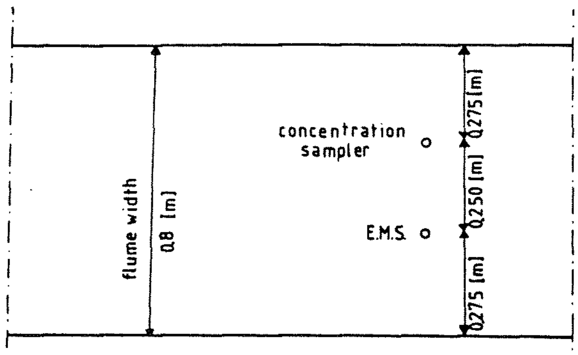



Fig. F: Measuring position of concentration sampler and velocity meter (plan view)

The time-averaged velocity was determined using a mean value meter (M.V.M.). The M.V.M. determines electronically the average of an input signal over an adjustable time period. Prelimenary test showed that time-averaging over 256 seconds (corresponding with approximately 100 waves) gave reproducible results. The intention was also to measure the RMS-value of the horizontal fluctuating components of the velocity at each measuring level. However, it appeared that the E.M.S. was influenced by vibrations induced by the oscillating carriage. For that reason it was not possible to measure accurate RMS-values.

In prelimenary tests the E.M.S. was compared to a Laser Doppler velocity meter. This was done in another flume without a sand bed because the LD velocity meter was hindered by suspended sediment particles. It proved that the higher velocities (> 0.1 [m/s]) were measured quite accurate by the E.M.S. (maximum relative difference between the velocities measured with the LD and E.M.S. of 3%). At the lower velocities (< 0.1 [m/s]) the E.M.S. velocities were found to be somewhat larger than the time-averaged velocities measured with the LD meter (maximum relative difference of 10%). Based on these tests, the available calibration curve of the E.M.S. probe was corrected after which the maximum relative difference between the LD velocities and the E.M.S. velocities was less than 3.5% for both the higher and lower velocities.

The movements of the carriage on which the E.M.S was mounted caused an error in time-averaged velocity. As will be shown, this error is rather small. The error in the time-averaged velocity is minimal if the carriage is moving exactly the same amount of time to the right as to the left during the measuring period (256 [s]). This means that the distance of 0.6 [m] (bed-averaging distance) is covered an even number of times or that a whole number of oscillations have been performed. Similarly, the error in time-averaged velocity is maximal if the distance of 0.6 [m] is covered an odd number of times. This means a net covered distance of 0.6 [m] during 256 [s] so the maximum possible error in time-averaged velocity as a result of the moving of the carriage is 0.6/256 = 0.00234 [m/s]. During the present investigations the carriage was moving with a velocity of 0.02 [m/s], meaning that in 256 [s] the distance of 0.6 [m] was covered 8.53 times. The net displacement of the carriage during 256 [s] was 0.53*0.6 = 0.32 [m] causing an error in time-averaged velocity of 0.32/256 = 0.00125 [m/s]. This error of 0.00125 [m/s] is indeed approximately the value found when determining the time-averaged velocity in still water.

2.3.8 Position of measuring points over the depth

In Fig. G the relation between the depth parameters is shown.

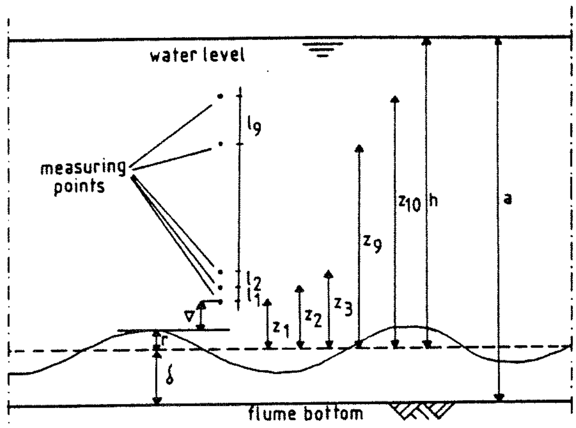



Fig. G: Relation between depth parameters

The parameters $\delta$, a and h have been discussed in paragraphs 2.3.2 and 2.3.3. The parameter d is found from the difference between the reading when the foot of the gauging rod of the concentration sampler is placed at the still water level and the reading when the foot of the gauging rod is placed at the chosen ripple top, so:

$$d = dr - dw \qquad (2.8)$$

in which:

d = Waterdepth relative to the chosen ripple top [m]

dr = Reading of the gauging rod when the foot is placed on the chosen ripple top [m]

dw = Reading of the gauging rod when the foot is placed on the water level [m]

Because of the fluctuations of the water level caused by the current and because of adhesion of the water to the foot of the gauging rod, the parameter dw could not be measured more accurate than 2 [mm]. The compression of the ripple top by the foot of the gauging rod caused an inaccuracy in dr of 2 [mm]. The parameters dr and dw are independent, so:

$$\Delta d = \sqrt{2^2 + 2^2} = 2.8 \text{ [mm]}$$

When the value of the parameter d is known, the value of the parameter r (distance chosen ripple top to mean bed level) can be computed from:

$$r = h - d = a - \delta - d \qquad (2.9)$$

in which:

h = Water depth relative to mean bed level [m]

d = Water depth relative to chosen ripple top [m]

a = Water depth relative to flume bottom [m]

$\delta$ = Mean bed level (relative to the flume bottom) [m]

From the known errors in h ($\Delta h$ = 1.3 [mm]) and d ($\Delta d$ = 2.8 [mm]), the error in r can be computed:

$$\Delta r = \sqrt{1.3^2 + 2.8^2} = 3.1 \text{ [mm]}$$

With the known value of the parameter r, the heights above mean bed level of the measuring points follow from:

$$zn = r + \nabla + \sum_{i=1}^{n} Li-1 \quad ; \text{ for } n = 1 \text{ to } 10 \qquad (2.10)$$

in which:

zn = Height above mean bed level of the nth measuring point [m]

$\nabla$ = Distance between the selected ripple top and the lowest intake tube (= 0.01 [m]) [m]

Li-1 = Distance between the i-1 th and the ith measuring point (see Fig. 2.5) [m]

For example: $z1 = r + \nabla$

$z4 = r + \nabla + L1 + L2 + L3$

The error in $\nabla$ is estimated to be 1 [mm]. Because the intake tubes were accurately installed at fixed distances, the errors in Li are negligible. The parameters r and $\nabla$ are independent so the error in heights can be computed as:

$$\Delta zn = \sqrt{3.1^2 + 1^2} = 3.3 \text{ [mm]}$$

When the heights are averaged over three tests (see measuring procedure, paragraph 2.4), the error in (averaged) heights becomes:

$$\Delta zn = \frac{1}{3}\sqrt{3*3.3^2} = 1.9 \text{ [mm]}$$

The error in water depth averaged over three tests becomes:

$$\Delta h = \frac{1}{3}\sqrt{3*1.3^2} = 0.8 \text{ [mm]}$$

The errors in relative heights, z/h, can be determined, as follows:

$$r(z/h)^2 = r(z)^2 + r(h)^2 \tag{2.11}$$

in which:

r(z/h) = Relative error in z/h, $\Delta(z/h)/(z/h)$

r(z) = Relative error in z, $\Delta z/z$

r(h) = Relative error in water depth, $\Delta h/h$

With $\Delta z$ = 3.3 [mm] and $\Delta h$ = 1.3 [mm] for one test, or $\Delta z$ = 1.9 [mm] and $\Delta h$ = 0.8 [mm] when all three tests of an experiment are averaged, the relative errors in relative heights can be computed. When the relative error in relative height is known, the error in relative height can be determined as follows:

$$\Delta(z/h) = (z/h)*r(z/h) \tag{2.12}$$

## 2.3.9 Ripple parameters

In each experiment bed profile registrations were made before the first and after the last test to determine the ripple dimensions, see Fig. 2.10. These registrations were made in the three longitudinal sections to average out possible differences in transverse direction. From each registration the mean ripple height, mean ripple length and their standard deviations were determined. These results were averaged over all the registrations to obtain the values of the ripple height and the ripple length that are characteristic for the hydraulical conditions of the experiment.
To get an impression of the bed regime, the parameter $\lambda 1/\lambda 2$ was determined from the registrations. In this ratio $\lambda 1$ is the upstream length of the ripples and $\lambda 2$ the downstream length of the ripples, see Fig H.

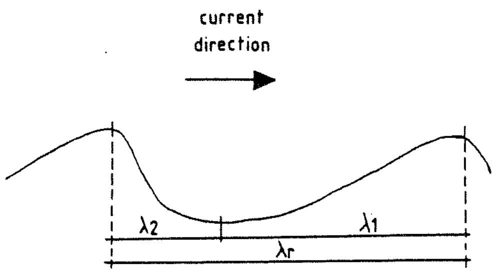



Fig. H: Upstream and downstream ripple length

The ripple registrations were made using the profo (see paragraph 2.3.2) and a pen recorder. The calibration was done with the use of the calibration block. The height difference of this block (0.1 [m]) must correspond (on the desired scale) with 0.1 [m] on the pen recorder. Because the ripple height is a height difference parameter (distance ripple top to ripple trough), again the "keel clearance" of the profo is automatically taken into account. The length scale of the registration was determined by the ratio of the velocities of the pen recorder and the moving carriage.

In order to estimate the bed load transport, the ripple migration velocity of 10 ripples was determined at different points on the sand bed. This migration velocity was determined at the flume window by measuring the distance covered by a ripple top during a certain time period. The measurements were carried out using a stopwatch and a measuring tape. Considering the large observed variation in ripple migration velocity, possible inaccuracies as a result of the measuring procedure are negligible.

### 2.3.10 Particle diameters of bed material

At the end of each experiment a sample of the bed material was taken at the measuring section. This sampling was done using a small grab sampler. The sample was dried after which it was split up until a representative sample of 30 [gr] was left. The particle size distribution of this sample was determined using a series of sieves. From this particle size distribution, the particle parameters D10, D50 and D90 were determined.

### 2.3.11 Fall velocity

The suspended sediment samples, collected at different heights above the bed, and the bedsamples were analysed in a Visual Accumulation Tube (VAT) at the Delft Hydraulics. This tube is made of perspex and has a length of approximately 2 [m]. At the bottom of the tube a calibrated cylinder is constructed and at the top of the tube a compression lock is installed (see Fig. 2.11). A calibration of the VAT was carried out with the use of calibration samples of which the median fall velocity was already determined with a sophicated settling tube of the Delft University (DUST).

It appeared that the median fall velocities of the calibration samples determined with the VAT, calculated from the fall length of the VAT and the median fall time, differed slightly from the median fall velocities determined with the DUST. Therefore it was decided not to use the actual fall length of the VAT but a fictitious fall length. This fictitious fall length of the VAT appeared to be dependent on the particle diameters of the sample and, hence, on the median fall time. Based on the calibration samples, a relation between the median fall time and the fictitious fall length of the settling tube was determined. The median fall velocities of the calibration samples determined with the VAT showed a variation of 10% relative to the median fall velocities determined with the DUST.

The procedure of determining the fall velocities using the VAT was as follows. A sample bottle was taken and, after stirring, a teaspoon of sand was put in the tube. The test started after opening of the compression lock. Each time the sand level in the cylinder at the bottom of the VAT passed a certain level, the elapsed time was stored into the memory of a calculator with a stopwatch function. The median fall time could be calculated from the height of the sample in the calibrated cylinder and the stored times. The median fall velocity could be computed as the ratio of the fictitious fall length and the median fall time. To check the accuracy of the of the procedure, the fall velocity of one sample was determined four times. A variation of less than 1% occured as a result of the measuring procedure.

Because the water temperature in the VAT differed from the water temperature in the flume, the measured fall velocities had to be corrected because the fall velocity depends on the viscosity which depends on the water temperature. Based on the measured water temperatures in the flume and the VAT, the fall velocity in the flume was computed from the measured fall velocity in the VAT, as follows:

$$W50,flume = W50,meas. * \left[\frac{\nu_{vat}}{\nu_{flume}}\right]^{\beta} \qquad (2.13)$$

in which:

| | | |
|---|---|---|
| W50,flume | = Median fall velocity in the flume | [m/s] |
| W50,meas. | = Measured median fall velocity in the VAT | [m/s] |
| $\nu_{flume}$ | = Viscosity in the flume | [m2/s] |
| $\nu_{vat}$ | = Viscosity in the VAT | [m2/s] |
| $\beta$ | = Correction coefficient (= 0.7 for 100 < D50 < 300 [$\mu$m]) | [-] |

The viscosities were computed from:

$$\nu = [1.143 - 0.031*(T-15) + 0.00068*(T-15)^2]*10^{-6} \qquad (2.14)$$

in which:

T = Water temperature [oC]

The median fall velocity was determined for the bed material samples and the suspended sediment samples collected at the different heights. After that a mixture was composed of all suspended sediment samples in proportion to their sample volumes. The fall velocity of this mixture is a kind of weighed average of the fall velocities of all suspended sediment samples.

As a check, the median fall velocities of 15 suspended sediment samples were also determined with the DUST. The overall relative difference between the fall velocities measured with the DUST and the VAT was 4.7%, The variation in relative difference was 4.2%.

## 2.4 Measuring procedure

The point by point measuring procedure of each experiment was, as follows:

1) Generation of the desired discharge and water depth.
2) Generation of the desired significant wave height.
3) Wait until the characteristic ripple pattern has been generated (approximately one hour).
4) Measure water temperature.
5) Make a wave registration at the measuring section.
6) Make ripple registrations in three longitudinal sections at the measuring section.
7) Switch off the wave generator.
8) Read the discharge.
9) Determine mean bed level in three longitudinal sections at the measuring location.
10) Measure distance still water level to flume bottom.
11) Measure distance still water level to ripple top at the measuring section using the gauging rod of the concentration sampler.
12) Installation of the concentration sampler and the velocity meter at the correct height above the bed.
13) Start the wave generator.
14) Determine wave parameters at the measuring location.

15) Pump out water-sediment samples and measure fluid velocities at 10 heights above the bed at the measuring location using a oscillating carriage.

16) Determine sediment concentrations with the volume meter (put the samples in sample bottles).

17) Switch off the wave generator.

18) Read the discharge.

19) Make ripple registrations in three longitudinal sections at the measuring location.

20) Determine mean bed level in three longitudinal sections at the measuring section.

21) Measure fluid velocities at the measuring section at 10 heights above the bed using an oscillating carriage (current without waves).

22) Turn off the flow.

23) Take a bedsample at the measuring location and put it in a sample bottle.

Items 8 to 18 have been carried out three times (three tests). During one of these three tests, the ripple migration velocity was measured at 10 locations.

## 2.5 Test program

In the following table a summary of the performed experiments is given.

| Um [m/s] \ Hs [m] | 0 | 0.075 | 0.090 | 0.100 | 0.120 | 0.150 | max. |
|---|---|---|---|---|---|---|---|
| 0 | | T 7.5 0 | T 9 0 | T 10 0 | T 12 0 | T 15 0 | |
| 0.1 | | T 7.5 10 | | T 10 10 | T 12 10 | T 15 10 | |
| -0.1 | | | | T 10 -10 | T 12 -10 | T 15 -10 | |
| 0.2 | | T 7.5 20 | | T 10 20 | T 12 20 | T 15 20 | |
| -0.2 | | | | T 10 -20 | T 12 -20 | T 15 -20 | T 17.5 -20 |
| 0.4 | T 0 40 | T 7.5 40 | | T 10 40 | T 12 40 | | |
| -0.4 | | | | T 10 -40 | T 12 -40 | T 15 -40 | T 18.5 -40 |

The first number in the code of the experiment is the value of the desired significant wave height (in [cm]) and the second number is the value of the desired depth-averaged fluid velocity (in [cm/s]). For example, T 10 -40 stands for an experiment with waves of an approximate significant wave height of 0.1 [m], propagating against (negative sign) a current with an approximate depth-averaged fluid velocity of 0.4 [m/s]. In general the actual measured values differ slightly from the desired values. In table 2.4 the true measured values are given.

In case of a weak current (Um $\leq$ 0.2 [m/s]) alone, there is no movement of bed material and no sediment brought into suspension (below initiation of motion). Because of this, experiments T 0 10 and T 0 20 were not carried out. The opposing current experiments with a significant wave height of 0.075 [m] were not carried out because of the extremely low concentrations found in the following current experiments. Experiment T 15 40 could not be carried out because it was not possible to adjust a significant wave height of 0.15 [m] in case of a strong following current. The experiments T 17.5 -20 and T 18.5 -40 were done with the highest achievable significant wave height.

All experiments were conducted with a water depth of approximately 0.5 [m]. The bed material consisted of sand with a median size diameter of approximately 205 [$\mu$m].

This series of experiments is the first of a set of series. The follow up experiments will be conducted with a sand bed consisting of finer sediment whereas the other boundary conditions (significant wave height, depth-averaged fluid velocity and water depth) will be kept constant.

# 3 Experimental results

## 3.1 General

In this chapter the results of the experiments are presented. The basic data are given in tables 3.1A - 3.1β. Applying the basic data the following parameters have been computed:

- Depth-averaged fluid velocity
- Mean, maximum and minimum sediment loads
- Mean, maximum and minimum transport rates

These data are also given in tables 3.1A - 3.1β.

The following parameters will be discussed successively in this chapter:

- Wave characteristics (paragraph 3.2)
- Time- and bed-averaged sediment concentrations (paragraph 3.3)
- Time- and bed-averaged fluid velocities (paragraph 3.4)
- Depth-integrated sediment loads (paragraph 3.5)
- Depth-integrated transport rates (paragraph 3.6)
- Total sediment transport according to sand balance computations (paragraph 3.7)
- The ripple parameters (paragraph 3.8)
- Size and fall velocity of suspended sediment (paragraph 3.9)

## 3.2 Wave characteristics

### 3.2.1 General

The wave profile is changed by a current superimposed on the waves. Compared with the wave lengths when no current is superimposed on the waves, the length of waves travelling with the current is large whereas small wave lengths occur when waves travel against a current. As a result of this, the steepness of waves travelling against a current is large compared with the steepness of waves travelling with a current.

The current-induced changes in wave profile are reflected in the measured wave spectra. Generally, the spectra measured when waves travel with a current were less narrow than spectra measured when waves travel against a current. As an example, the measured wave spectra of experiments T 10 40 and T 10 -40 are shown in Fig. 3.1. The (small) differences in spectrum shape indicate differences in wave height distribution. *In general, the ratio H1%/Hs is relatively* large when waves oppose a current and relatively small when waves follow a current (see tables 3.1A - 3.1B). With exception of experiments where waves oppose a strong current, the ratio H1%/Hs is small compared with the value of this ratio when the wave heights are Rayleigh-distributed (H1%/Hs = 1.517). The assumption of Rayleigh-distributed wave heights leads to an overestimation of the number of large waves.

### 3.2.2 Characteristic parameters

To characterize the wave action just above the bed, two parameters are introduced here:

1) $\hat{U}b$ - A characteristic orbital horizontal velocity amplitude.

2) $\hat{A}b$ - A characteristic orbital horizontal displacement amplitude.

These two parameters are computed using the significant wave height as characteristic wave height and the wave spectrum peak period as characteristic wave period. To account for the presence of the current, the relative wave spectrum peak period and corresponding wave length should be used in the wave formulae, so:

$$\hat{U}b = \frac{\pi * Hs}{Tp,rel} * \frac{1}{\sinh(2*\pi*h/L)} \qquad (3.1)$$

$$\hat{A}b = \frac{Hs}{2} * \frac{1}{\sinh(2*\pi*h/L)} \qquad (3.2)$$

in which:

| | | |
|---|---|---|
| Hs | = Significant wave height | [m] |
| Tp,rel | = Wave spectrum peak period relative to the current | [s] |
| h | = Waterdepth | [m] |
| L | = Characteristic wave length | [m] |

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

$$L = c_a * Tp \qquad (3.3)$$

$$L = c_r * Tp,rel \qquad (3.4)$$

$$c_a = c_r + Um \qquad (3.5)$$

$$c_r = \sqrt{\frac{g*L}{2*\pi} \tanh(2*\pi*h/L)} \qquad (3.6)$$

in which:

| | | |
|---|---|---|
| Tp | = Absolute wave spectrum peak period | [s] |
| Um | = Depth-averaged fluid velocity | [m/s] |
| $c_a$ | = Absolute wave celerity | [m/s] |
| $c_r$ | = Relative wave celerity | [m/s] |

Using a bit of algebra, the following implicite equation can be derived:

$$\sqrt{\frac{h}{L} \tanh(2*\pi*h/L)} = \sqrt{\frac{2*\pi*h}{g*Tp}} * \left[1 - \frac{Um*Tp}{h} * \frac{h}{L}\right] \qquad (3.7)$$

With the known waterdepth, h, and absolute wave spectrum peak period, Tp, the wave length, L, and relative peak period, Tp,rel, can be computed numerically. The results of these computations are given in table 3.2.

## 3.3 Time- and bed-averaged concentrations

### 3.3.1 General

The measured (time- and bed-averaged) concentration profiles are all shown in Figs. 3.2A - 3.2G. Since three tests are available, not only the mean (averaged over three tests), but also the measured maximum and minimum concentrations are stated in this figures. As explained in paragraph 2.3.6, the velocity and concentration measurements of the different tests were often executed at different heights above mean bed level. In Fig. I the situation for the nth measuring point is presented (for simplicity only two tests are considered).

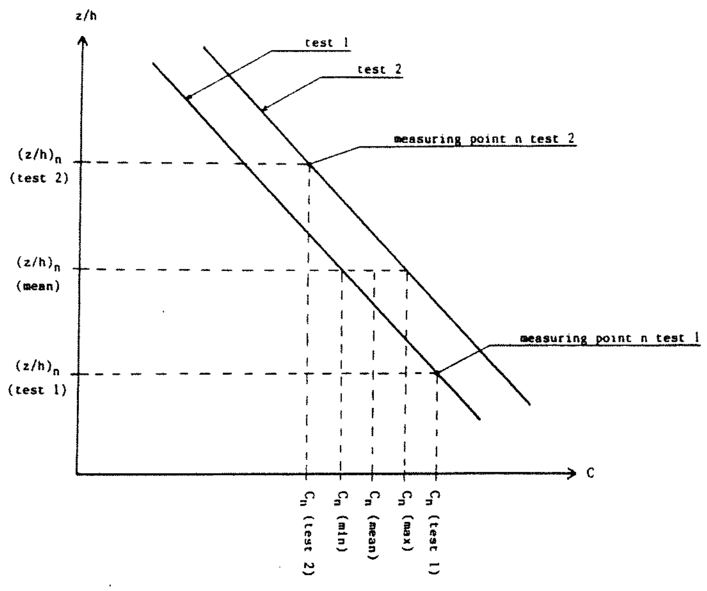



Fig. I: Mean, maximum and minimum concentration

In order to determine the mean, maximum and minimum concentration for the nth measuring point, the concentrations at the mean relative height (averaged over all three tests), of the nth measuring point are determined via lineair interpolation (see Fig. I).
As can be seen in Fig. I, Cn(min) clearly differs from Cn(test 2) and Cn(max) clearly differs from Cn(test 2). Via interpolation the relevant variation in concentration is determined.

## 3.3.2 Influence of wave height

The (significant) wave height influences the concentration profile in two ways, see Fig. 3.3:

1) Increasing the significant wave height leads, probably as a result of an increased wave-induced mixing, to a somewhat steeper concentration profile. This phenomenon becomes less pronounced with increasing current strength.

2) Increasing the significant wave height leads to an increase in concentrations. The magnitude of this increase depends on the strength of the current superimposed on the waves. Compared with a weak current superimposed on the waves, a strong current causes the increase in concentrations with increasing wave height to be less pronounced.

Although it may seem logical that an increase in wave height causes an increase in concentrations, this statement may not be true in general. The bed forms largely determine the suspension generation, in case of flat bed condition (not observed during these experiments) there may be a decrease in concentrations.

### 3.3.3 Influence of current velocity.

To examine the current influence on the concentrations, Fig. 3.4 is presented. As can be observed, a very weak current ($|Um| \simeq 0.1$ [m/s]) superimposed on the waves hardly effects the magnitude of the concentrations. A stronger ($|Um| \simeq 0.2$, $0.4$ [m/s]) current superimposed on the waves causes an increase in concentrations, especially in the upper layers. This increase becomes more pronounced with increasing current strength.

*When only a very weak current ($|Um| \simeq 0.1$ [m/s]) or no current is superimposed on the waves, the measured concentration profiles can be represented by the following distribution, which is often used for regular waves (Nielsen, 1985):*

$$\overline{\overline{C}}(z) = Cb*\exp(-z/Lc) \qquad (3.8)$$

in which:

| | | |
|---|---|---|
| $\overline{\overline{C}}(z)$ | = Time- and bed-averaged concentration at height z | [Kg/m3] |
| Cb | = Reference concentration, concentration at z=0 | [Kg/m3] |
| Lc | = Vertical length scale (order ripple height) | [m] |

Eq. (3.8) can not be used when a stronger current ($|Um| \simeq 0.2, 0.4$ [m/s]) is superimposed on the waves. The current causes a deviation of this theoretical distribution in the upper layers. For increasing current velocities the current-induced mixing becomes more important, resulting in an increased vertical transport of sediment particles to the upper layers.

### 3.3.4 Influence of current direction

Compared with waves following a current, waves opposing a current cause a somewhat steeper concentration profile. This may be caused by the relatively large velocity gradient and hence relatively large mixing coefficient ($\varepsilon_f$) in case of waves combined with an opposing current. A relatively large $\varepsilon_f$-value leads to a relatively steep concentration profile.
The magnitude of the concentrations in the near bed zone ($z/h < 0.1, 0.2$) is hardly influenced by the current direction in case of a relatively weak current ($|Um| \simeq 0.1, 0.2$ [m/s]) superimposed on the waves. The relative concentration differences between a following and an opposing current are less than 30% in the near bed zone. When a strong current ($|Um| \simeq 0.4$ [m/s]) is superimposed on the waves,

the concentrations in the near bed zone are, as a result of the relatively large ratio H1%/Hs in case of an opposing current, relatively large in case of an opposing current (see also paragraph 3.5.4).

### 3.3.5 Reproducibility of the time-averaged concentrations

To examine how well the time-averaged concentrations reproduce, four experiments were repeated. The basic data of the repeated experiments are given in tables 3.3A - 3.3D. These tables also contain the parameters computed from the basic data.
The measured concentration profiles of the original and repeated experiments are shown in Fig. 3.5. As can be observed, the time-averaged concentrations reproduce rather well with the chosen bed-averaging distance (0.6 [m]) and time-averaging period (15 min.). The maximum relative concentration difference near the bed is about 20% in case of relatively large concentrations. In case of relatively small concentrations (Hs $\simeq$ 0.075 [m] and Um $\simeq$ 0.1 [m/s]) the relative concentration diffence near the bed is about 50%. The reproducibility of relatively large concentrations seems to be somewhat better than the reproducibility of relatively small concentrations.

## 3.4 Time- and bed-averaged fluid velocities

### 3.4.1 General

The time-averaged velocities could only be measured when a current was superimposed on the waves. In case of waves alone the time-averaged velocities are too small (< 0.02 [m/s]) to measure with the E.M.S..

In order to compare the velocity profiles measured in different experiments, the measured velocities are made dimensionless by dividing them by the depth-averaged fluid velocity. To compute the depth-averaged velocity from the measured velocities, two assumptions have been made (see Fig. J):

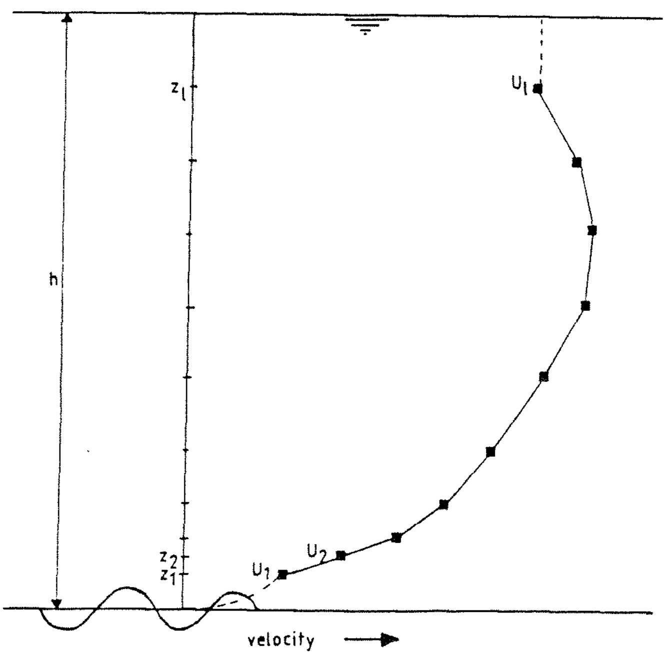



Fig. J: Extrapolation of velocity profile

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):

$$\bar{\bar{U}}(z) = \bar{\bar{U}}1*(z/z1)^{0.25} \qquad (3.9)$$

in which:

$\overline{\overline{U}}_1$ = Measured velocity in the lowest measuring point [m/s]

$z_1$ = Height above mean bed level of the the lowest measuring point [m]

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

Based on these two assumptions, the depth-averaged fluid velocity is computed as:

$$U_m = 1/h \sum_{i=1}^{N} 0.5*(\overline{\overline{U}}_i + \overline{\overline{U}}_{i-1})*(z_i - z_{i-1}) \qquad (3.10)$$

in which:

$U_m$ = Depth-averaged fluid velocity [m/s]

$\overline{\overline{U}}_i$ = (time- and bed-averaged) Velocity at height $z_i$ above mean bed level [m/s]

N = Total number of points (including extrapolated points) [-]

The measured velocity profiles are all shown in Figs. 3.6A - 3.6N. The mean, maximum and minimum velocities are computed in the same way as the mean, maximum and minimum concentrations are computed (see paragraph 3.3.1).

<u>3.4.2 Current alone</u>

In each experiment current velocities were also measured in absence of waves (Hs = 0, experiments T 0 10, T 0 20 and T 0 40). In case of relatively weak currents ($|Um| \lesssim 0.2$ [m/s]) there was no movement of bed material particles in absence of waves (below initiation of motion). Hence, the bed forms were those generated earlier in the presence of waves. In case of a strong current ($|Um| \simeq 0.4$ [m/s]), bed form migration did occur, thereby changing the bed forms to those for a current. To reduce this current influence, the velocities were measured just after the wave generator was stopped, beginning with the lowest point and working upward.

First it was investigated whether the current velocities in the absence of waves show a logarithmic distribution or not. This was done by curve fitting, using:

$$U(z) = (U*/\kappa)*Ln(z/z0) \qquad (3.11)$$

in which:

| | | | |
|---|---|---|---|
| U(z) | = | Current velocity at height z | [m/s] |
| U* | = | Bed-shear velocity | [m/s] |
| z | = | Height above mean bed level | [m] |
| z0 | = | Roughness length scale (zero-velocity level) | [m] |
| $\kappa$ | = | The Von Karman constant (= 0.4) | [-] |

The bed roughness is computed from z0 as:

$$Ks = 33*z0 \qquad (3.12)$$

Because surface friction causes a deviation of this logarithmic profile, only the lowest eight measuring points ($z/h < 0.6$) were used in the fitting procedure. The results of the fitting procedure are given in table 3.4. The maximum and minimum bed roughness values stated in this table follow from the error in heights (see paragraph 2.3.8).

As can be observed the regression coefficients are between 0.95 and 1, indicating that, although the bed forms were generated by waves and a current, a logarithmic velocity distribution is valid for $z/h < 0.6$.

To examine wheter a relation between the ripple characteristics and the bed roughness excists, Fig. 3.7 is presented. No real systematic tendency can be observed. To examine how the strength of the current superimposed on the waves influences the bed roughness, Fig. 3.8 is presented. In this figure, the ratio of the bed roughness and the mean ripple height (the relative bed roughness) is plotted aginst the dimensionless current parameter $Um^2/\Delta gD50$ (with $\Delta$ = relative sediment density = 1.65). The parameter $\Delta gD50$ is used in the denominator because this parameter also occurs in the denominator of the Shields parameter. As can be observed, it is not clear how the strength of the superimposed current influences the bed roughness.

Compared with steady flow conditions, where the bed roughness is approximately equal to to the ripple height (van Rijn, 1982), the bed forms generated by both waves and a current cause extremely large bed roughness values of approximately five times the ripple height.

The lack of systematic tendencies may be explained by the method used to determine the bed roughness. Relatively small errors in measured velocities in the lowest measuring points lead to a large error in the bed roughness calculated from the measured velocities. To gain more insight into the bed roughness it is recommended here to measure during the follow-up experiments also the water surface slope.

### 3.4.3 Following current

Compared with the velocities measured when waves are absent, the velocities measured when waves follow a current are:

- Relatively small in the near bed region (z/h < 0.1, 0.2)
- Relatively small in the upper layers (z/h > 0.6, 0.7)
- Relatively large in the layer between the two aforementioned layers

These wave-induced changes in velocity distribution become less pronounced with increasing current strength (see Fig. 3.9A). They become more important with increasing significant wave height, especially when a weak current ($Um \simeq 0.1$ [m/s]) is superimposed on the waves. A stronger current ($Um \simeq 0.2, 0.4$ [m/s]) superimposed on the waves causes a less pronounced wave height influence (see Figs. 3.6A - 3.6N and Fig. 3.9A).

In case of regular waves, the same phenomena are observed. For comparison, Fig. 3.10A shows velocity profiles measured Bakker and van Doorn (1980).

### 3.4.4 Opposing current

Compared with the velocities measured when waves are absent, the velocities measured when waves oppose a current are:

- Relatively small in the near bed region (z/h < 0.1, 0.2). Compared with a following current, the wave-induced velocity reduction in this layer is larger.

- Relatively large in the upper layers ($z/h$ 0.6, 0.7).
- Relatively small in the middle layers (0.1, 0.2 < $z/h$ < 0.6, 0.7).

With increasing current strength these wave-induced changes in velocity distribution become less important, see Fig. 3.9B. They become more important with increasing wave height, especially in case of a weak current ($Um \simeq -0.1$ [m/s]) superimposed on the waves (see Figs 3.6A - 3.6N and Fig. 3.9B).
As can be seen in Fig. 3.10B, Kemp and Simons (1983) observed the same phenomena in case of regular waves.

## 3.5 Sediment loads

### 3.5.1 General

The sediment load is defined here as the total amount of sediment in supension per unit bed surface area, so:

$$Lt = \int_{z=0}^{h} \bar{\bar{C}}(z)\, dz \qquad (3.13)$$

in which:

Lt = Total load [Kg/m2]

$\bar{\bar{C}}(z)$ = Time- and bed-averaged concentration at height z [Kg/m3]

h = Water depth [m]

The total load is divided in two parts, the bed load and the suspended load:

$$Lb = \int_{z=0}^{\frac{1}{2}\overline{\Delta r}} \bar{\bar{C}}(z)\ dz \tag{3.14}$$

$$Ls = \int_{z=\frac{1}{2}\overline{\Delta r}}^{h} \bar{\bar{C}}(z)\ dz \tag{3.15}$$

in which:

| | | |
|---|---|---|
| Lb | = Bed load | [Kg/m2] |
| Ls | = Suspended load | [Kg/m2] |
| $\overline{\Delta r}$ | = Mean ripple height | [m] |

To compute the loads from the measured concentrations, several approximations have been made (see Fig. K):

- The concentrations in the zone between the bed and the lowest measuring point (height z1) are approximated by:

  $$C(z) = \exp(A*z+B);\ \text{for } 0 < z < z1 \tag{3.16}$$

  The coefficients A and B are computed by a linear regression method using the lowest three measuring points.

- The concentrations between the water surface and the highest measuring point are represented by a linear function giving a concentration equal to zero at the water surface, so:

$$\bar{\bar{C}}(z) = \left[\frac{h - z}{h - z1}\right] * \bar{\bar{C}}1; \text{ for } z1 < z < h \qquad (3.17)$$

in which:

$\bar{\bar{C}}1$ = Measured concentration in the highest measuring point [Kg/m3]

z1 = Height above the bed of the highest measuring point [m]

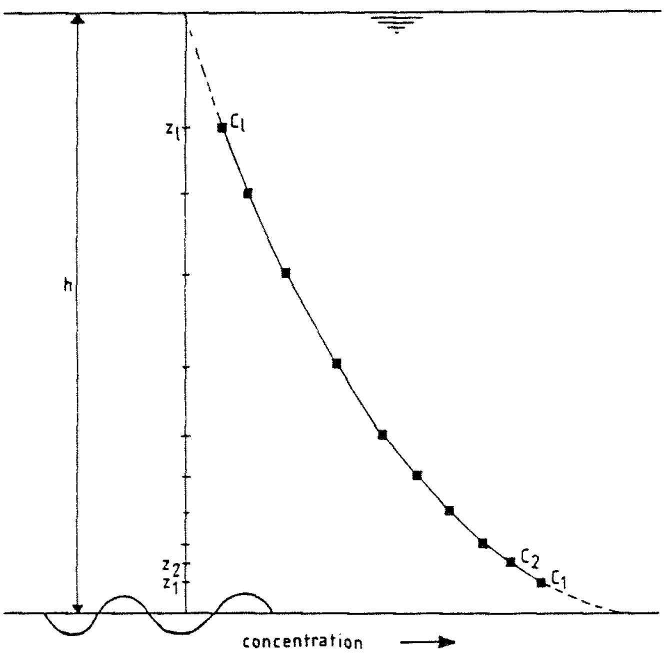



Fig. K: Extrapolation of concentration profile

Using these two approximations, the bed load and the suspended load can be computed numerically. Since three tests are available for each experiment, this computation was carried out three times, leading to mean, maximum and minimum loads. The loads, computed as just described, are given in tables 3.1A - 3.1β.

### 3.5.2 Influence of wave height

A larger significant wave height leads, as a result of the larger concentrations, to a larger load, see Figs. 3.11A and 3.11B. The magnitude of the increase in loads with increasing wave height depends on the strength of the current superimposed on the waves. Increasing the significant wave height from 0.075 [m] to 0.15 [m] (a factor 2) leads to:

- An increase of a factor 30 in total load for Um = 0 and $|Um| \simeq 0.1$ [m/s].
- An increase of a factor 20 in total load for $|Um| \simeq 0.2$ [m/s].
- An increase of a factor 4 in total load for $|Um| \simeq 0.4$ [m/s].

### 3.5.3 Influence of current velocity

A weak current ($|Um| \simeq 0.1$ [m/s]) superimposed on the waves hardly effects the loads. When the current becomes stronger the loads increase. The magnitude of this increase depends on the significant wave height. Increasing the depth-averaged fluid velocity from 0.2 [m/s] to 0.4 [m/s] (a factor 2) causes:

- An increase of a factor 20 in total load for $Hs \simeq 0.075$ [m].
- An increase of a factor 8 in total load for $Hs \simeq 0.100$ [m].
- An increase of a factor 6 in total load for $Hs \simeq 0.120$ [m].
- An increase of a factor 4 in total load for $Hs \simeq 0.150$ [m].

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

### 3.5.4 Influence of current direction

The current direction (whether waves are following or opposing a current), hardly effects the loads when the current superimposed on the waves is a weak one ( $|Um| \lesssim 0.2$ [m/s]). When a strong current is superimposed on the waves, the loads are significantly influenced by the current direction (see table below).

| Hs [m] | Um [m/s] | H1%/Hs [-] | Lt [Kg/m2] |
|---|---|---|---|
| 0.098 | 0.450 | 1.26 | 0.0666 |
| 0.101 | -0.453 | 1.71 | 0.0987 |
| 0.119 | 0.439 | 1.26 | 0.0874 |
| 0.118 | -0.442 | 1.57 | 0.1182 |

The relatively large loads when waves oppose a strong current may be explained by the relatively large ratio H1%/Hs caused by the opposing current (see paragraph 3.2.1). Since the larger waves seem to dominate the sediment pick-up proces, a larger ratio H1%/Hs should lead to an increased sediment pick-up of bed material, larger concentrations and hence a larger load. The ratio H1%/Hs is hardly influenced by a weak current so the current direction does not influence the loads when a weak current is superimposed on the waves.

## 3.6 Sediment transports

### 3.6.1 General

The sediment transport rates are computed here from the measured (time- and bed-averaged) concentrations and velocities. This (convective) sediment transport is devided in two parts:

- The bed load transport.
- The suspended load transport.

### 3.6.2 Bed load transport

The bed load layer, where the bed load transport is assumed to take place, is defined here as the layer between z = 0 (mean bed level) and $z = \frac{1}{2}\overline{\Delta r}$. Although this layer is rather small, the transport in this layer can not be neglected, as will be shown.
Two fundementally different methods are used to compute the bed load transport:

1) The bed load transport is computed as:

$$Sbl = \int_{z=0}^{\frac{1}{2}\overline{\Delta r}} \overline{\overline{C}}(z) * \overline{\overline{U}}(z)\, dz \qquad (3.18)$$

in which:

| | | | |
|---|---|---|---|
| Sbl | = | Bed load transport | [Kg/ms] |
| $\overline{\Delta r}$ | = | Mean ripple height | [m] |
| $\overline{\overline{C}}(z)$ | = | Time- and bed-averaged concentration at height z | [Kg/m3] |
| $\overline{\overline{U}}(z)$ | = | Time- and bed-averaged fluid velocity at height z | [m/s] |

Because the velocities and concentrations could not be measured in the bed load layer due to the presence of ripples, they have been estimated from the measured velocities and concentrations.

The velocities in the bed load layer are approximated by Eq. (3.9). The concentrations in this layer are approximated by the same exponential function used to compute the loads, Eq. (3.16). These two approximations make it possible to compute the bed load transport numerically. The computation is carried out for all three test of an experiment, giving a mean, maximum and minimum bed load transport. The bed load transport rates, computed as just described, are given in table 3.5.

2) The bed load transport is computed as (van Rijn, 1985):

$$Sb2 = \alpha * (1-p) * \rho_s * \overline{Ur} * \overline{\Delta r} \qquad (3.19)$$

in which:

| | | | |
|---|---|---|---|
| Sb2 | = | Bed load transport | [Kg/ms] |
| $\alpha$ | = | Shape factor (= 0.6 (van Rijn, 1985)) | [-] |
| p | = | Porosity (= 0.4) | [-] |
| $\rho_s$ | = | Density of sediment (= 2650) | [Kg/m3] |
| $\overline{\Delta r}$ | = | Mean ripple height | [m] |
| $\overline{Ur}$ | = | Mean migration velocity of the ripples | [m/s] |

Since the standard deviations of the ripple height and the ripple migration velocity are known, the standard deviation of the bed load transport according to Eq. (3.19) can be computed:

$$\sigma_{Sb2} = Sb2 * \sqrt{\left(\frac{\sigma_{\Delta r}}{\overline{\Delta r}}\right)^2 + \left(\frac{\sigma_{Ur}}{\overline{Ur}}\right)^2} \qquad (3.20)$$

Maximum and minimum transports are computed as:

$$Sb2\ max,min = Sb2 \pm \sigma_{Sb2} \tag{3.21}$$

The mean, maximum and minimum bed load transports, computed as just described, are also given in table 3.5.

The first method used to compute the bed load transport uses extrapolated velocities and concentrations in the bed load layer. The direction of the bed load transport is determined by the extrapolated velocities. A following current always causes a positive bed load transport whereas an opposing current always causes a negative bed load transport. With the second method, the direction of the bed load transport is determined by the direction of the ripple migration which only depends upon the strength and the direction of the current.

| Current strength and direction | Direction of bed load transport | |
|---|---|---|
| | Sb1 | Sb2 |
| Um = 0 [m/s] | *** | + |
| Um 0.1 [m/s] | + | + |
| Um -0.1 [m/s] | - | + |
| Um 0.2 [m/s] | + | + |
| Um -0.2 [m/s] | - | - |
| Um 0.4 [m/s] | + | + |
| Um -0.4 [m/s] | - | - |

Direction of wave propagation chosen positive

With exception of experiments in which a very weak current opposes the waves (Um $\simeq$ -0.1 [m/s]), both methods lead to the same direction of the bed load transport. To compare both methods Figs. 3.12A and 3.12B are presented. As can be observed, the outcome of both methods is in reasonable agreement (except for experiments in which a very weak opposed the waves). Based on this, it may be concluded that the concentrations in the bed load layer can be adequately described by an exponential function (Eq. (3.16)).

### 3.6.3 Suspended load transport

The suspended load transport is computed as:

$$Ss = \int_{z=\frac{1}{2}\overline{\Delta r}}^{h} \overline{\overline{C}}(z)*\overline{\overline{U}}(z)\, dz \qquad (3.22)$$

In the zone between $z = \frac{1}{2}\Delta r$ and the lowest measuring point, the velocities and concentrations are approximated by Eqs. (3.9) and (3.16). Between the measuring points, both the concentrations and velocities are approximated by a linear function. Above the highest measuring point, the velocities are assumed to be equal to the velocity measured in the highest measuring point. The concentrations in this zone are approximated by Eq. (3.17).
Using these approximations, the suspended load transports can be computed numerically. The results of this computation are given in table 3.6.

### 3.6.4 Total transport

The total convective sediment transport is the sum of the bed load transport and the suspended load transport. Since two methods are used to compute the bed load transport:

$$St1 = Sb1 + Ss \quad (3.23)$$

$$St2 = Sb2 + Ss \quad (3.24)$$

Total transports computed according to Eqs. (3.23) and (3.24) are given in table 3.7.

As can be seen in Figs 3.13A and 3.13B, the method used to compute the bed load transport hardly influences the total transport. The transport rates used in the remainder of this report and reported in the overall tables 3.1A - 3.1β are those computed by the second method (Sb2 and St2). The second method is prefered because the bed load transport is based on the actually measured migration velocity of the ripples while the first method uses the extrapolated (less certain) velocities and concentrations in the bed load layer.

The computer program used to compute the depth-averaged velocities, the bed, suspended and total loads and the bed suspended and total load transports, is included in Appendix I.

To investigate the relation between the total transport and the significant wave height, Fig. 3.14 is presented. As can be observed, the magnitude of the total transport is hardly influenced by the current direction, therefore no distinction is made between waves following and waves opposing a current.

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

$$|St| \approx Hs^{\alpha} \quad (3.25)$$

in which $\alpha$ still depends on the depth-averaged fluid velocity. The parameter $\alpha$ is computed from the measured significant wave heights and the computed total transports by linear regression, resulting in:

| $\|Um\|$ [m/s] | $\alpha$ [-] |
|---|---|
| 0.1 | 5.4 |
| 0.2 | 3.2 |
| 0.4 | 2.0 |

The $\alpha$-coefficient has been realated to the dimensionless current parameter $Um^2/\Delta gD50$ as shown in Fig. 3.15. An increase in $Um^2/\Delta gD50$ (an increase in depth-averaged fluid velocity) leads to a decrease in $\alpha$. This decrease in $\alpha$ means a less pronounced increase in total transport with increasing current velocity.
To investigate the relation between the total transport and the depth-averaged fluid velocity, Fig. 3.16 is presented. From this figure it follows that:

$$|St| \approx |Um|^{\beta} \tag{3.26}$$

The $\beta$-coefficient still depends on the depth-averaged fluid velocity. This coefficient is computed from the depth-averaged velocities and the total transports by linear regression.

| Hs [m] | β [-] |
|---|---|
| 0.075 | 4.5 |
| 0.100 | 4.1 |
| 0.120 | 3.6 |
| 0.150 | 2.9 |

The β-coefficient has been related to the parameter $\hat{U}b^2/\Delta gD50$ as shown in Fig. 3.17. An increase in $\hat{U}b^2/\Delta gD50$ (increase in wave height) leads to a decrease in β, meaning a less pronounced increase in total transport with increasing wave height.

## 3.7 Sand balance computations

### 3.7.1 General

The sediment transport based upon the time- and bed-averaged concentrations and velocities only represents the convective part of the total sediment transport (see paragraph 1.2). The diffusive part of the sediment transport, which may be rather important in case of waves alone or in combination with a weak current, is totally neglected. In order to get insight into the importance of the diffusive transport, three sand balance experiments were carried out (experiments S 12 10, S 12 20 and S 12 40). During these experiments not only time- and bed-averaged concentrations and velocities (to compute the convective sediment transport as described in paragraphs 3.6.2, 3.6.3 and 3.6.4) were measured, but the total sediment transport, including the diffusive part, was also determined from a sand balance consideration. In this way, the diffusive part of the sediment transport can be determined from:

Sdiffusive = Stot - Sconvective (1.5)

## 3.7.2 Computational technique

The principle of the sandbalance computations is shown schematically in Fig. L. To compute the sand balance sediment transport, the mean bed level, $\delta_s$, of the sand bed over a fixed length, L, was measured with the profo (see paragraph 2.3.2) before (t=0) and after (t=T) the concentration and velocity measurements.

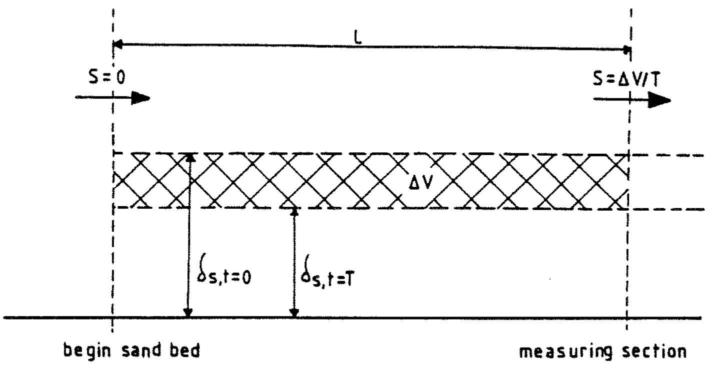



Fig. L: Principle of sand balance computations

To average out variations in tranverse direction, this was done in three longitudinal sections. The sand volume difference, ΔV, is computed from the measured mean bed levels as:

$$\Delta V = ( \overline{\delta_{s,t=o}} - \overline{\delta_{s,t=T}} )*L \qquad (3.27)$$

in which:

ΔV = Volume difference per unit width [m3/m]

$\overline{\delta_{s,t=o}}$ = Mean bed level, averaged over three longitudinal sections, before concentration and velocity measurements [m]

$\overline{d_{s,t+T}}$ = Mean bed level, averaged over three longitudinal sections, after concentration and velocity measurements [m]

T = Time period between the two soundings [s]

L = Distance between the begin of the sand bed and the measuring section [m]

Since there is no initial sediment load at the beginning of the bed, the total sediment transport at the measuring section can be computed as:

$$Sbalance = \Delta V/T \tag{3.28}$$

in which:

Sbalance = Sand balance sediment transport [m3/ms]

The sediment transport according to Eq. (3.28) includes the voids and is expressed in [m3/ms]. The (convective) sediment transport computed from the measured concentrations does not include the voids and is expressed in [Kg/ms]. To be able to compare these two transports, the sand balance sediment transport is converted as follows:

$$Sbalance = (1 - p)*\rho_s*\Delta V/T \tag{3.29}$$

in which:

Sbalance = Sand balance sediment transport not including the voids [Kg/ms]

p = Porosity (= 0.4) [-]

$\rho_s$ = Sediment density (= 2650) [Kg/m3]

The sand balance sediment transport is computed from the height differences in measured mean bed level over the length L. Relatively small errors in measured mean bed level cause a relatively large error in height difference. By determining the mean bed level several times in one longitudinal section, the error in measured mean bed level appeared to be 0.0003 [m], causing an error in measured height difference equal to:

$$\Delta( \delta_{s,t=o} - \delta_{s,t=T} ) = \sqrt{0.0003^2 + 0.0003^2} = 0.00042 \text{ [m]}$$

Averaging over three longitudinal sections reduces this error to:

$$\Delta( \overline{\delta_{s,t=o} - \delta_{s,t=T}} ) = \Delta( \overline{\delta_{s,t=o}} - \overline{\delta_{s,t=T}} ) = \tfrac{1}{3}\sqrt{3*0.00042^2} = 0.00024 \text{ [m]}$$

As a result of this, the measuring error in sand balance sediment transport is equal to:

$$\Delta(\text{Sbalance}) = (1 - p)*\rho_s*L*0.00024/T = 0.382*L/T \text{ [Kg/ms]}$$

## 3.7.3 Sand balance results

The sediment transports computed from the sand balance and the transports computed from the measured concentrations, velocities and migration velocity of the ripples (see paragraphs 3.6.2, 3.6.3 and 3.6.4) are presented in tables 3.8A - 3.8C. In the S 12 10 experiment (very weak current), the transport based upon the sand balance is a factor 2 larger than that based upon the measured concentrations and velocities. In the S 12 40 experiment (strong current) the sediment transport based upon the sand balance computation is a factor 3 smaller. In the S 12 20 experiment, the transport based upon the sand balance has a negative sign (against direction of wave propagation), while that based upon the measured concentrations and velocities has a positive sign.

The strange results of the S 12 10 and S 12 20 experiment may be explained by the method used to compute the sand balance transport. Sand balance transports are computed from a volume difference which is estimated from three measured height differences in mean bed level. Although these height differences are measured quite accurate (see paragraph 3.7.2), the large observed differences in measured height difference between the three longitudinal sections in the S 12 10 and S 12 20 experiment indicate that the (small) volume difference $\Delta V$ can not be estimated accurately based upon only three longitudinal sections. In the S 12 40 experiment the differences in measured height difference between the three longitudinal sections are much smaller and therefore this experiment seems more reliable. Although it is dangerous to draw conclusions based on one reliable experiment, the large difference between the sand balance transport and the (convective) transport computed from the measured velocities and concentrations in the S 12 40 experiment indicates that the diffusive part of the total sediment transport is extremely important and not negligible when waves are present. In order to gain more insight into the diffusive part of the total transport further tests are necessary applying more longitudinal sections and a larger time period between the soundings.

## 3.8 Bed geometry

### 3.8.1 General

The water movement above a sand bed generates the bed forms. Which bed form will occur depends on the intensity of the water movement and the characteristics of the sediment. With increasing intensity of the water movement the following bed forms will occur:

- 2-Dimensional ripples : A regular ripple-shaped bed. Looking from above, ripple crests are parallel (normal to current direction).

- 3-Dimensional ripples : A less regular ripple-shaped bed. Ripple crests do not excist, only individual bumps.

- Dunes : Large bumps with a large distance between the individual bumps.

- Flat bed : A small layer with relatively large concentration moves over a flat bed. This state is also called sheetflow.

When the intensity of the water movement is small, the forces acting on the grains are too small to cause motion of the grains. This state is often called the no-motion state.

During these experiments, only 2- and 3-dimensional ripples were observed. To describe these ripples the following parameters are used:

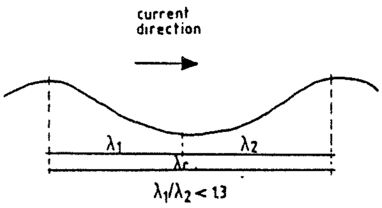
- Ripple height
- Ripple length
- Ripple steepness

These parameters and the bed forms will be discussed in the following paragraphs.

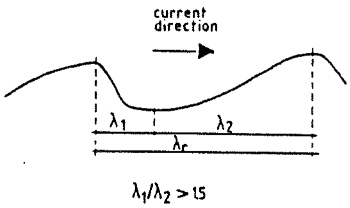
### 3.8.2 Bed forms

In the preceding paragraph a distinction in ripple types based upon the irregularity (2- or 3-dimensional ripples) of the ripples was presented. When a current is superimposed on the waves, it is also possible to make a distinction between wave-dominated (symmetrical) and current-dominated (asymmetrical) ripples. Whether ripples are called wave-dominated or current-dominated depends on the value of the parameter $\lambda 1/\lambda 2$ (see paragraph 2.3.9).

Wave-dominated ripples




Current-dominated ripples




In case of a current alone (experiment T 0 40, Hs = 0 [m] and Um $\simeq$ 0.45 [m/s]), the parameter $\lambda 1/\lambda 2$ has a value of approximately 1.7.

To describe the water movement just above the bed, the following dimensionless parameters are used:

- $\hat{U}b^2/\Delta gD50$, this parameter is assumed to describe the wave influence.
- $Um^2/\Delta gD50$, this parameter is assumed to describe the current infuence.
- $|Um|/\hat{U}b$, the value of this parameter indicates the importance of the current with regard to the waves.

The parameters concerning the bed forms are given in table 3.9.
Fig. 3.18A shows the value of the parameter $\lambda1/\lambda2$ as a function of the parameter $|Um|/\hat{U}b$. From this figure it follows that ripples generated by a current opposing the waves are more symmetrical than ripples generated by a following current. This may be explained by the relatively large reduction of the near bed velocities in case of an opposing current (see paragraph 3.4.4). In general, wave-dominated ripples ($\lambda1/\lambda2 < 1.3$) seem to occur for $|Um|/\hat{U}b < 0.75$, current-dominated ripples ($\lambda1/\lambda2 > 1.5$) seem to occur for $|Um|/\hat{U}b > 1.5$.
As can be observed in Figs. 3.18B and 3.18C, the mean ripple height and the mean ripple length of current-dominated ripples are large with regard to the mean ripple height and the mean ripple length for waves alone ($\Delta0$ and $\lambda0$). In case of wave-dominated ripples, the values of the mean ripple height and the mean ripple length are approximately equal to those for waves alone.
To identify the relation between 2D/3D ripples and wave/current dominated ripples, a global regime figure is presented, Fig. 3.19. The boundaries between the different ripple types are, due to the

limited amount of data, estimated. From this figure it follows that:

- Ripples are approximately 2-dimensional when waves are dominating.
- Ripples are approximately 3-dimensional when the current is dominating.

### 3.8.3 Ripple height

During these experiments mean ripple heights between 0.01 and 0.03 [m] were observed. In general, the mean ripple height of 2-dimensional (wave-dominated) ripples is small compared with the mean ripple height of 3-dimensional (current-dominated) ripples. As a result of the irregularity of 3-dimensional ripples, the standard deviation of the ripple height of 3-dimensional ripples is large compared with 2-dimensional ripples.

Figs. 3.20A and 3.20B show the relation between the parameter $\Delta r/\hat{A}b$, the relative ripple height, and the parameter $\hat{U}b^2/\Delta gD50$. Increasing values of this parameter always lead to a decrease in the relative ripple height when the current conditions are comparable. Waves following a current or waves opposing a weak current ($Um \simeq -0.1$, $-0.2$ [m/s]) cause the value of the parameter $\Delta r/\hat{A}b$ to decrease from 0.25 for $\hat{U}b^2/\Delta gD50 \simeq 5$ to 0.12 for $\hat{U}b^2/\Delta gD50 \simeq 30$. A strong current opposing the waves ($Um \simeq -0.4$ [m/s]) causes a a decrease in $\Delta r/\hat{A}b$ from 0.35 for $\hat{U}b^2/\Delta gd50 \simeq 10$ to 0.28 for $\hat{U}b^2/\Delta gD50 \simeq 30$.

### 3.8.4 Ripple length

During these experiments mean ripple lengths between 0.08 and 0.20 [m] were observed. Just as with the mean ripple heights, the mean ripple lengths of 2-dimensional ripples are small compared with the mean ripple lengths of 3-dimensional ripples. The standard deviation of the ripple length of 2-dimensional ripples is small compared with that of 3-dimensional ripples.

Just as was done with the ripple heights, the relative ripple length, $\lambda r/\hat{A}b$, is related to the parameter $\hat{U}b^2/\Delta gD50$, see Figs. 3.21A and 3.21B. When no current, or only a weak current ($|Um| \simeq$ 0.1, 0.2 [m/s]), is superimposed on the waves the relative ripple length decreases from 1.5 for $\hat{U}b^2/\Delta gD50 \simeq 5$ to 1.0 for $\hat{U}b^2/\Delta gD50 \simeq 30$. In case of a strong following current ($Um \simeq 0.4$ [m/s]) the relative ripple length decreases from 2.0 for $\hat{U}b^2/\Delta gD50 \simeq 5$ to 1.5 for $\hat{U}b^2/\Delta gD50 \simeq 20$. A strong current opposing the waves causes a decrease from 2.5 for $\hat{U}b^2/\Delta gD50 \simeq 10$ to 2.0 for $\hat{U}b^2/\Delta gD50 \simeq 30$.

### 3.8.5 Ripple steepness

The ripple steepness is defined as the ratio $\Delta r/\lambda r$. This ratio seems only to depend on the strength of the current superimposed on the waves, see Figs. 3.22A and 3.22B.

$|Um| \simeq 0, 0.1, 0.2$ [m/s] (mostly 2-dimensional ripples), $\Delta r/\lambda r \simeq 0.16$

$Um \simeq 0.4$ [m/s] (mostly 3-dimensional ripples), $\Delta r/\lambda r \simeq 0.11$

$Um \simeq -0.4$ [m/s] (mostly 3-dimensional ripples), $\Delta r/\lambda r \simeq 0.13$

## 3.9 Size and fall velocity of the suspended sediment

### 3.9.1 General

The bed material consisted of a non-uniform sediment. As a result of the relatively large mass of the coarser sediment particles, these particles will have more difficulties to be lifted to a certain height above mean bed level than the finer sediment particles in the same hydraulic conditions. Therefore, the sediment transported in the higher regions will be relatively fine compared with sediment transported in the lower regions. To examine this segregation over the water depth, the suspended sediment samples were analysed in the VAT (see paragraph 2.3.11)

### 3.9.2 Fall velocity of suspended sediment

In tables 3.10A - 3.10C the median fall velocity distribution over the water depth of the performed experiments is given. The median fall velocities of the suspended sediment samples have been made dimensionless by deviding them by the median fall velocity of the bed material. It appears that, for a constant significant wave height, the median fall velocity at a constant height above mean bed level decreases with increasing depth-averaged velocity. Apparently the suspended sediment becomes finer when the strength of the current imposed on the waves increases. For a constant depth-averaged velocity and an increasing significant wave height such a general tendency can not be detected.

### 3.9.3 Size and fall velocity of suspended sediment mixture

When non-uniform sediment is involved, the distribution of the size and fall velocity can only be represented by deviding the bed material in a number of size fractions (Einstein, 1950), which makes sediment transport calculations rather complicated.

To examine whether the suspended sediment can be characterised by one characteristic size, the median fall velocity of the suspended sediment mixture (composed as described in paragraph 2.3.11) was determined. This median fall velocity was converted to a median suspended sediment size using the Slot (1983) formula:

$$D50,sus = \frac{9*Ko}{\Delta*g}*W50^2,sus*\left\{1 + \sqrt{1 + \frac{2*\Delta*g}{9*K0^2*W50^2,sus}*\left[\frac{\nu}{W50,sus} + K1*Q\right]}\right\} \quad (3.30)$$

in which:

| | | | |
|---|---|---|---|
| D50,sus | = | Median size diameter of the suspended sediment | [m] |
| W50,sus | = | Median fall velocity of the mixture | [m/s] |
| $\Delta$ | = | Relative sediment density (= 1.65) | [-] |
| g | = | acceleration of gravity (= 9.81) | [m/s2] |
| $\nu$ | = | Viscosity determined with Eq. (2.14) | [m2/s] |
| K0 | = | 0.0125 | |
| K1 | = | 0.0348 | |
| Q | = | $\left[\frac{6*\nu^2}{\pi*\Delta*g}\right]^{1/3}$ | |

The characteristic median size diameter of the suspended sediment, computed with Eq. (3.30), was made dimensionless by deviding by the median sieve diameter of the bed material. Because all values of this ratio are in the range 0.8 to 1 it is difficult to discover significant tendencies. Best results are obtained when the ratio D50,sus./D50,bed is related to the parameter $|Um|/\hat{U}b$, see table 3.11 and Fig. 3.23. Increasing values of this parameter (increasing depth averaged velocity or decreasing significant wave height) lead to a decrease of the characteristic median size diameter. Fitting a relation through the deduced data leads to:

$$\frac{D50,sus}{D50,bed} = 0.0037*\left|\frac{Um}{\hat{U}b}\right|^2 - 0.0558*\left|\frac{Um}{\hat{U}b}\right| + 0.9755 \; ; \text{ for } |Um|/\hat{U}b < 4 \quad (3.31)$$

The mean of the absolute value of the relative differences between the ratio D50,sus/D50,bed measured and the same ratio computed with to Eq. (3.31) is 2.39%, see table 3.11.

# 4 Comparison of experimental results with existing transport models

## 4.1 Applied transport models

Three sediment transport models were used to be compared with the experimental results. These models are:

- The Bijker formula (van de Graaff and van Overeem, 1979)
- The adapted Engelund-Hansen formula (van de Graaff and van Overeem, 1979)
- The Nielsen formula (Nielsen, 1985)

The Bijker formula and the adapted Engelund-Hansen formula are usually applied to calculate the longshore transport in the breaker zone. Due to refraction, the direction of wave propagation is nearly perpendicular to the longshore current direction. Therefore, these formula do not make an estimation of the diffusive tranport rate. The Nielsen formula, which is partly based on the results of flume experiments, does give an estimation of the diffusive transport rate.

In this paragraph only a brief outline of the framework of the formulae will be given, details are presented in the various appendices.

The Bijker method computes the convective transport. Firstly the bed load transport is computed with the use of the Kalinske- Frijlink formula. The wave influence is accounted for by an increase of the bed shear stress. With the known bed load transport, the concentration in the bed load layer, assumed to have a thickness equal to the bed roughness, is computed. The suspended load

transport follows from multiplication of a concentration profile with a velocity profile and integration over the depth. The concentrations are approximated by an Einstein-Rouse concentration distribution in which the bed layer concentration calculated with the Kalinske-Frijlink formula is used as reference concentration. The velocities are approximated by a logarithmic velocity distribution. The total transport is calculated as the sum of the bed load and suspended load transport. The Kalinske-Frijlink formula, used to compute the bed load transport, contains a dimensionless parameter B (see appendix II). There is much discussion about the proper value of this parameter. Values between 1 and 5 have been suggested. When the Bijker method is applied to compute the longshore transport in the breaker zone, this parameter is usually taken equal to 5. Because we are dealing with non-breaking waves in this study, B is taken equal to 1. Details of the Bijker formula and a computer program are given in appendix II and III.
The adapted Engelund-Hansen formula is a total (convective) load transport formula in which, according to the Bijker principle, the bed shear stress is increased to account for the presence of waves. Details of the adapted Engelund-Hansen formula and a computer program are given in appendix IV.
In the Nielsen method, a distinction between convective and diffusive transport is made. The convective transport is computed by multiplication of a velocity profile with a concentration profile. The concentrations are approximated by an exponential concentration distribution and the velocities are approximated by a modified logarithmic distribution. The diffusive transport is calculated via an expression for the time dependent load. Details of the Nielsen

method and a computer program are given in appendix V, VI, VII and VIII.

Two roughness predictors are used in combination with the Bijker method and the Engelund-Hansen method; the Swart roughness predictor and the van Rijn roughness predictor (see paragraph 4.8 and appendix II). Both predictors use the ripple height and the ripple length. The measured mean ripple height and mean ripple length have been used to calculate the bed roughness. The Swart predictor predicts Ks values in the range Ks = 3 to 5 $\overline{\Delta r}$ (with $\overline{\Delta r}$ the mean ripple height). The van Rijn predictor predicts Ks values in the range Ks = 0.5 to 1 $\overline{\Delta r}$. In the Nielsen method, the use of the Grant and Madsen roughness predictor (see paragraph 4.8 and appendix V) is prescribed.

Both the Bijker method and the Nielsen method use the sediment particle fall velocity. It seems logical to use the median fall velocity of the suspended sediment mixture, which is a kind of weighted average (see paragraph 2.3.11), as a characteristic particle fall velocity in the computations. However, the median fall velocity of the suspended sediment mixture was not available for all experiments and therefore the median fall velocity of the bed material (available for all experiments) was used in the computations.

In all computation the following parameters were kept constant:

mass density of water : $\rho$ = 1000 [Kg/m3]

mass density of sediment : $\rho_s$ = 2650 [Kg/m3] porosity : p = 0.4 [-]

acceleration of gravity : g = 9.81 [m/s2]

The computer programs included in appendix I, II, IV and V are all written in BASIC. All programs may be copied freely, provided that reference is made to this report.

## 4.2 Choice of wave parameters in the computations

The sediment transport formulae mentioned in the preceding paragraph assume regular waves. No information is given about the wave parameters to be used when applying these formulae to irregular waves.

### Wave period

For the wave period, possibilities are:

- The (relative) zero crossing period Tz
- The (relative) wave spectrum peak period Tp

Preliminary calculations showed that the influence of the wave period parameter was rather small. It was decided to choose the peak period Tp as the characteristic parameter because most of the wave energy is concentrated around this period. To account for the presence of the current, the relative peak period and corresponding wave length (see paragraph 3.2.2) were used in the computations.

Wave height

For the wave height to be used in the calculations, possibilities are:

- The average wave height H
- The significant wave height Hs
- The root mean square wave height Hrms
- The wave height with 1% chance of being exceeded H1%

From preliminary calculations it appeared that the influence of the wave height parameter was large. To calculate the concentration profiles, the velocity profiles, the loads and the transports as objective as possible, it was decided to use the wave height distribution in the calculations. As mentioned in paragraph 2.3.4, the wave height distribution can be described by a Rayleigh distribution because the measured wave spectra were single topped. Assuming Rayleigh distributed wave heights, the probability that a wave height H is exceeded is:

$$P(H) = Pr\left\{\underline{H} > H \mid Hs\right\} = \exp(-2*(H/Hs)^2) \qquad (4.1)$$

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

$$p(H) = P(H - \Delta H) - P(H + \Delta H) \qquad (4.2)$$

in which p(H) is the probability that H falls in the interval

$$(H + \Delta H) > H > (H - \Delta H)$$

This interval, having a width of $2\Delta H$, is characterised by its mid value.

The sediment loads and transports are computed step by step, starting with $H = \Delta H$, continuing with $H = 3\Delta H, 5\Delta H$, until $p(H)$ is smaller than $10^{-4}$. The results of the computations per step are weighted with the probability of occurrence of the wave height used, so:

$$Pa = \frac{\sum_{H=\Delta H}^{N*\Delta H} Pa(H)*p(H)}{\sum_{H=\Delta H}^{N*\Delta H} p(H)} \qquad (4.3)$$

in which:

Pa = Probability-weighted value of a parameter

Pa(H) = Parameter value calculated with wave height H

p(H) = Chance of occurrence of wave height H [-]

N = Total number of steps [-]

Applying the Bijker method, the following probability-weighted parameters were calculated:

- The bed load transport Sb
- The suspended load transport Ss
- The total load transport St (sum of bed load and suspended load transport)
- The bed load Lb
- The suspended load Ls

- The total load Lt (sum of bed and suspended load)
- The bed load layer concentration Cb (used to predict the concentration profile)
- The parameter Z* (also used to predict the concentration profile)

Applying the Engelund-Hansen method, only the probability-weighted total load transport could be calculated.

Applying the Nielsen method, the following probability-weighted parameters were calculated:

- The convective transport Scon.
- The diffusive transport Sdiff.
- The total transport (sum of convective and diffusive transport) Stot
- The total load Lt (with a normal and an adapted concentration profile)
- The bed concentration Cb (used to predict the concentration profile)
- The mixing length scale for waves alone Lc (also used to predict the concentration profile)
- The zero-intercepts z0 and z1 (used to predict the velocity profile)
- The shear velocities $\overline{U*}$ and $\widetilde{U*}$ (used to predict the velocity profile)
- The parameter F (used to predict the velocity profile)

From preliminary calculations it appeared that the probability weighted parameters did not change noticeably when applying steps smaller than $\Delta H$ = Hs/20. Therefore, the probability-weighted parameters were computed with $\Delta H$ = Hs/20.

The results of the calculations are given in tables 4.1A - 4.1β.

### Influence of wave height representation on the computed sediment transport rates

Based upon calculations for prototype conditions, Van de Graaff and Van Overeem (1979) argue that the average wave height $\overline{H}$ should be taken as a characteristic wave height for determining the mean bed shear stress due to an irregular wave field. Because of this, it was decided to calculate also the transport rates with the average wave height $\overline{H}$ (= 0.625*Hs in case of Rayleigh distributed wave heights) as characteristic wave height parameter. The results of these calculations are given in tables 4.2A - 4.2β. The ratios of the probability-weighted transport rate and the transport rate calculated with the average wave height $\overline{H}$ as a characteristic parameter, are given in table 4.3.

The ratio of the probability-weighted transport rate and the transport rate based on $\overline{H}$, strongly depends on the method used. It appears that the Bijker and Engelund-Hansen formulae, if used with $\overline{H}$ as characteristic parameter, underestimate the probability-weighted transport rate roughly with a factor 1.5. The Nielsen formula, if used with $\overline{H}$ as a characteristic parameter, underestimates the probability-weighted transport rate roughly with a factor 5 to 25, strongly dependent on the depth-averaged velocity.

In the following paragraphs, only computations based on the wave height distribution are presented.

### 4.3 Concentration profiles

### 4.3.1 Profiles based on the Bijker method.

#### 4.3.1.1 General

To predict the concentration profiles, the probability-weighted bed layer concentration $\bar{C}b$ and the probability-weighted value of the parameter Z* (see appendix II) were calculated. The predicted and measured concentration profiles are shown in Figs. 4.1A - 4.1F.

#### 4.3.1.2 Influence of bed roughness

As explained earlier, two roughness predictors are used with the Bijker method; the Swart roughness predictor and the van Rijn roughness predictor. Compared with the van Rijn roughness, the Swart roughness causes:

- Relatively small bed load layer concentrations
- Relatively large thicknesses of the bed load layer
- A relatively large "steepness" of the concentration profiles

In general, application of the van Rijn roughness leads to better prediction results, especially when the depth-averaged velocity is smaller than or equal to 0.2 [m/s]. The assumption of a constant concentration in the bed load layer clearly disagrees with the experimental results when the Swart roughness is used.

#### 4.3.1.3 Influence of significant wave height

For a small significant wave height (Hs $\simeq$ 0.075 [m]) the calculated concentrations at height z = Ks (the bed layer concentration Cb) are large compared with the measured concentrations at this height. This is true for the bed roughness Ks calculated via both Swart and van Rijn. With increasing significant wave height both the calculated and the measured concentrations at height z = Ks increase. However, the increase in calculated concentrations at height z = Ks is small compared with the increase in measured concentrations.
For a small significant wave height (Hs $\simeq$ 0.075 [m]) the "steepness" of the calculated profiles is too small compared with the "steepness" of the measured profiles if the van Rijn bed roughness is used and too large if the Swart bed roughness is used. With increasing significant wave height the "steepness" of both the calculated and the measured profiles increases. However, the increase in "steepness" of the calculated profiles is large compared with the increase in "steepness" of the measured profiles.
Apparently, the wave height influence on the concentration distribution is not reflected correct by the Bijker method. The increase of the calculated concentrations in relation to the increase in significant wave height is too small.

#### 4.3.1.4 Influence of depth-averaged velocity

For a small depth-averaged velocity (|Um| $\simeq$ 0.1 [m/s]) the calculated concentrations at height z = Ks are large compared with the measured concentrations at this height. This is true for the bed roughness Ks calculated via both Swart and van Rijn. With increasing depth-averaged velocity both the calculated and measured concentrations at height z = Ks increase. However, the increase in calculated concentrations is small compared with the increase in measured concentrations.

For a small depth-averaged velocity ( $|Um| \simeq 0.1$ [m/s]) the "steepness" of the calculated profiles is too small compared with the "steepness" of the measured profiles if the van Rijn bed roughness is used and too large if the Swart bed roughness is used.

With increasing depth-averaged velocity the "steepness" of both the calculated and the measured profiles increases. However, the increase in "steepness" of the calculated profiles is small compared with the increase in "steepness" of the measured profiles.

Apparently, the infuence of the depth-averaged velocity on the concentration distribution is not reflected correct by the Bijker method. The increase of the calculated concentrations in relation to the increase in depth-averaged velocity is too small.

#### 4.3.1.5 Influence of current direction

For the measured concentration profiles it appeared that an opposing current caused a somewhat steeper concentration profile (see paragraph 3.3.4) than a following current. For the calculated profiles there seems to be no clear difference between a following and an opposing current, so the influence of the current direction on the concentration distribution is not reflected correct by the Bijker method.

#### 4.3.1.6 General remarks concerning the concentration profiles calculated with the Bijker method

In general, the van Rijn bed roughness seems to lead to better results than the Swart bed roughness, especially when the depth-averaged velocity is smaller than or equal to 0.2 [m/s]. The assumption of a constant concentration over the entire bed load layer thickness clearly disagrees with the experimental results when the Swart roughness is used. In his original work Bijker sugested to take the bed roughness equal to half the ripple height. The more recent study of Swart indicated that the bed roughness has a value of three to five times the ripple height. With this increased bed roughness, the bed load layer thickness increases and the assumption of a constant concentration over the entire bed load layer thickness seems not to be correct according to the results of the present experiments. A solution might be to compute the bed load transport with the bed roughness Ks and to take the bed load layer thickness equal to half the ripple height, see appendix IX. The choice of half the ripple height as bed load layer thickness seems physically more realistic.

### 4.3.2 Profiles based on the Nielsen method

#### 4.3.2.1 General

With the Nielsen method two concentration profiles have been calculated (see appendix V):

- A concentration profile based on a mixing length scale for waves alone. No account has been taken for extra mixing and resulting upward stretching of the concentration profile due to the current. This profile will be called a normal concentration profile.

- A concentration profile based on a rather speculative mixing length scale for waves and currents (see appendix VII). This profile will be called an adapted concentration profile.

To predict the normal concentration profiles, the probability weighted value of the bed concentration Cb and the probability weighted value of the mixing length scale for waves alone Lc were calculated. To predict the adapted concentration profile, the probability-weighted value of the parameter $\overline{U*}$ was also calculated. The calculated and measured concentration profiles are shown in Figs. 4.2A - 4.2H

### 4.3.2.2 Influence of significant wave height

For a small significant wave height the calculated bed concentrations are large compared with the measured (extrapolated) bed concentrations. With increasing significant wave height both the calculated and measured bed concentrations increase. Until the depth-averaged velocity is smaller than or equal to 0.2 [m/s], the increase in measured and calculated bed concentrations is of the same order. In case of a depth-averaged velocity equal to 0.4 [m/s], the increase in calculated bed concentration with increasing significant wave height is large compared with the increase in measured bed concentration.

For a small significant wave height the "steepness" of the calculated normal concentration profiles is much too small compared with the "steepness" of the measured concentration profiles. With increasing significant wave height the "steepness" of the calculated and measured normal concentration profiles increases. This increase in "steepness" for the measured and calculated normal concentration profiles is of the same order of magnitude.

### 4.3.2.3 Influence of depth-averaged velocity

For a small depth-averaged velocity the calculated bed concentrations are large compared with the measured (extrapolated) bed concentrations. With increasing depth-averaged velocity the calculated bed concentrations stay nearly constant whereas the measured (extrapolated) bed concentrations increase.
For a small depth-averaged velocity the "steepness" of the calculated normal concentration profiles is small compared with the "steepness" of the measured concentration profiles. With increasing depth-averaged velocity the "steepness" of both the calculated normal concentration profiles and the measured concentration profiles increases. The (small) increase in "steepness" of the calculated normal concentration profiles is extremely small compared with the increase in "steepness" of the measured profiles.
Apparently, the influence of the depth-averaged velocity on the concentration distribution is not reflected correct by the Nielsen method.

### 4.3.2.4 Influence of current direction

For the measured concentration profiles it appeared that an opposing current caused a somewhat steeper concentration profile (see paragraph 3.3.4) than a following current. With the Nielsen method, the calculated normal concentration profiles are less steep in case of an opposing current than in case of a following current, so the influence of the current direction is not reflected correct by the Nielsen method.

#### 4.3.2.5 General remarks concerning the concentration profiles calculated with the Nielsen method

In all cases considered the "steepness" of the calculated normal concentration profile is much too small compared with the "steepness" of the measured concentration profiles. Application of the adapted concentration profile leads to better results.
It appears that as long as the depth-averaged velocity is smaller than or equal to 0.2 [m/s] the bed concentration is mainly dominated by the significant wave height and therefore by the amplitude of the orbital velocities. The Nielsen method reflects the dependence of the bed concentration on the orbital velocity rather well. Nielsen only estimates the bed concentration a nearly constant factor too large.
When the depth-averaged velocity is equal to 0.4 [m/s] (beyond initiation of motion for a steady current) the influence of the significant wave height on the bed concentrations appears to be less great. The Nielsen method no longer reflects the dependence of the bed concentration on the orbital velocity well.

## 4.4 Velocity profiles

### 4.4.1 Velocity profiles based on the Bijker method

In the Bijker method, a logarithmic velocity distribution is used. No adaptions to account for the presence of waves are made.

The calculated and measured velocity profiles are shown in Figs. 4.3A - 4.3F. The influence of the applied bed roughness on the velocity profiles is relatively small. Compared with the van Rijn roughness, the Swart roughness causes relatively small velocities near the bed. Near the water level, the Swart roughness causes relatively large velocities.

Both the van Rijn roughness and the Swart roughness cause large velocities near the bed compared with the measured velocities. At higher elevations, the predicted velocities are small compared with the measured velocities.

With increasing significant wave height the deviations between the measured and the predicted velocity profiles are increasing. In case of a large significant wave height, the measured velocity profiles clearly differ from the assumed logarithmic velocity profile.

With increasing depth-averaged velocity the agreement between the measured and the predicted profiles is getting better. In case of a strong current ($|Um| \simeq 0.4$ [m/s]) superimposed on the waves, the predicted velocity profiles agree rather well with the assumed logarithmic velocity profile.

### 4.4.2 Velocity profiles based on the Nielsen method.

In the Nielsen method, a modified logarithmic velocity distribution is used (see appendix V). The velocity profiles are determined with the probability-weighted values of the parameters z0, z1, F, $\overline{U*}$. The calculated and measured velocity profiles are shown in Figs. 4.4A - 4.4F. As can be observed, the Nielsen method gives a reasonable prediction of the velocities near the bed, especially in case of a following current. Generally, the predicted velocities near the bed are somewhat too large. With increasing wave height, the difference between the measured velocities and the predicted velocities at higher elevations becomes larger. An increase in depth-averaged velocity causes a better agreement between the measured and the predicted velocities at higher elevations

### 4.4.3 General remarks concerning the velocity profiles

The assumption of a logarithmic velocity distribution does not hold when waves are superimposed on a current, especially in case of an opposing current. The presence of waves causes a large velocity reduction near the bed. When the Nielsen method is used, the velocities near the bed are predicted reasonably well, especially in case of a folowing current. In case of an opposing current the predicted velocities are somewhat too large. Because the Bijker method takes no account for the presence of waves, the velocities near the bed are largely overestimated.

## 4.5 Total loads

### 4.5.1 General

In table 4.4 an overview of the measured total loads and calculated probability-weighted total loads is given. Figs. 4.5A - 4.5D show the measured total loads plotted against the calculated probability-weighted total loads. The loads computed with the Bijker method are overestimating the measured loads when the measured loads are relatively small and underestimating the measured loads when the measured loads are relatively large. The van Rijn roughness usually gives better results, especially when the measured loads are small. With the Nielsen method, the measured loads are overestimated when the depth-averaged fluid velocity is smaller than or equal to 0.2 [m/s]. A depth-averaged fluid velocity of 0.4 [m/s] causes an underestimation of the measured loads with the Nielsen method. Using the adapted Nielsen concentration profile hardly seems to improve the results.

With the use of table 4.5, in which the ratios of the calculated probability-weighted total load and the measured total load are given for the different experiments and the different methods, the following score table has been composed.

| Method | 0.5 < fL < 2 | 0.33 < fL < 3 | 0.2 < fL < 5 |
|---|---|---|---|
| Bijker (Swart) | 65% | 74% | 96% |
| Bijker (van Rijn) | 61% | 91% | 100% |
| Nielsen (normal) | 30% | 74% | 93% |
| Nielsen (adapted) | 33% | 59% | 89% |

fL = Lcalc./Lmeas.

Apparently, the Bijker method with the use of the van Rijn roughness leads to the best results.

### 4.5.2 Influence of significant wave height

To examine whether the wave height influence on the calculated total loads is reflected correctly by the different methods, Figs. 4.6A - 4.6D are presented. The Bijker method causes a decrease of the ratio Lcalc./Lmeas. with increasing significant wave height, this decrease is relatively large in case of a relatively small depth-averaged fluid velocity. Apparently, the Bijker method underestimates the wave height influence on the total loads. The Nielsen method causes increasing values of the ratio Lcalc./Lmeas. with increasing significant wave height. This increase is relatively large in case of a relatively large depth-averaged velocity. Apparently, the Nielsen method overestimates the wave height influence.

### 4.5.3 Influence of depth-averaged velocity

To examine whether the infuence of the depth-averaged velocity on the calculated total loads is reflected correctly by the different methods, Figs 4.7A - 4.7D are presented. Both for the Bijker method and the Nielsen method it appears that an increase in depth-averaged velocity causes a decrease in the ratio Lcalc./Lmeas. This decrease is relatively large in case of a relatively small significant wave height and relatively small in case of a relatively large significant wave height. Apparently, both methods underestimate the influence of the depth-averaged fluid velocity on the total loads.

## 4.6 Transport rates

In paragraph 1.2 it was explained that the total transport consists of a convective and a diffusive part, which will be treated respectively in paragraphs 4.6.1 and 4.6.2.

### 4.6.1 Convective transport rate

#### 4.6.1.1 General

In table 4.6 an overview is given of the measured and calculated probability-weighted transport rates. Figs. 4.8A - 4.8E show the measured transport rate plotted against the calculated transport rate. Especially for the Bijker method, but also for the Engelund-Hansen method, it holds that an almost straight line can be drawn through the plotted points. This might indicate that the principle of these two methods of using the combined bottom shear stress for waves and currents to account for the wave and current influence, is a good priciple. Unfortunately, the influence of the combined bottom shear stress is not reflected correctly by these two methods, meaning that the slope of the line drawn through the plotted points is incorrect.

As can be observed, the Bijker method overestimates the measured transport rates when the measured transport rates are relatively small, and underestimates the measured transport rates when the measured transport rates are relatively large. The van Rijn roughness generally gives better results, especially in case of relatively small measured transport rates.

For the adapted Engelund-Hansen method it holds that in all cases the measured transport rates are largely overestimated by the calculated ones. Relatively large transport rates are estimated better by this method than the relatively small ones. The van Rijn roughness gives better results with this method.

The convective transport rates calculated with the Nielsen method are, in general, large compared with the measured transport rates.

With the use of table 4.7, in which the ratios of the calculated transport rate and the measured transport rate are given, the following score table has been composed.

| Method | 0.5 < fS < 2 | 0.33 < fS < 3 | 0.2 < fS < 5 |
|---|---|---|---|
| Bijker (Swart) | 26% | 57% | 83% |
| Bijker (van Rijn) | 48% | 83% | 87% |
| Engelund-H (Swart) | 0% | 0% | 13% |
| Engelund-H (van Rijn) | 4% | 26% | 39% |
| Nielsen | 32% | 50% | 64% |

fS = Scalc./Smeas.

As can be observed, the Bijker method with the use of the van Rijn roughness leads to the best results.

4.6.1.2 Influence of significant wave height

To examine whether wave height influence on the convective transports is reflected correctly by the different methods, Figs. 4.9A - 4.9E are presented.
For the Bijker method it appears that an increase in significant wave height leads to a decrease in the ratio Scalc./Smeas.. This decrease is relatively large in case of a relatively small depth-averaged fluid velocity. Apparently, the Bijker method underestimates the wave height influence, especially in case of a relatively small depth-averaged velocity.
For the adapted Engelund-Hansen method it appears that with increasing significant wave height the ratio Scalc./Smeas. decreases slightly or stays nearly constant (depending on the depth-averaged velocity). The Engelund-Hansen method underestimates the wave height influence, especially in case of a relatively small depth-averaged velocity.

For the Nielsen method it appears that with increasing significant wave height the ratio Scalc./Smeas. increases. This increase is relatively large in case of a relatively large depth-averaged velocity. The wave height influence is overestimated by the Nielsen method, especially in case of a relatively large depth-averaged velocity.

#### 4.6.1.3 Influence of depth-averaged velocity

To examine whether the influence of the depth-averaged velocity on the transports is reflected correctly by the different methods, Figs. 4.10A - 4.10E are presented. As can be observed, all methods cause a decrease in the ratio Scalc./Smeas. with an increase in depth-averaged fluid velocity. This decrease is relatively large in case of a relatively large significant wave height and relatively small in case of a relatively small significant wave height. Apparently, all methods underestimate the influence of the depth-averaged velocity on the transport. The Nielsen method gives the least underestimation of the velocity effect.

### 4.6.2 Diffusive transport rate

As explained in paragraph 3.7, attempts to determine the diffusive transport rates via sand balance computations were not succesfull. Therefore it is not possible to compare the diffusive transport rates calculated with the Nielsen method with measured diffusive transports.
In table 4.8 an overview is given of the convective and diffusive transport rates computed with the Nielsen method. As can be

observed, the diffusive transport is only important when a very weak current is superimposed on the waves. In case of a strong current superimposed on the waves, the diffusive transport is negligible compared with the convective transport according to the Nielsen method. It appears that an increase in depth-averaged velocity causes a small increase in diffusive transport, however, relative to the convective transport the diffusive transport is becoming less important. An increase in significant wave height also causes an increase in diffusive transport. Relative to the convective transport, the diffusive transport is becoming less important with increasing significant wave height.
For the experiments without a current, the calculated diffusive transport rates give zero as result. This is caused by the fact that only the first order component of the orbital velocity was used in the calculations, as explained in appendix V.

## 4.7 Ripple parameters

In this paragraph the measured ripple heights, ripple lengths and ripple steepnesses are compared with the relations given by Nielsen (1985). As explained in appendix V, the ripple parameters were calculated using the significant wave height as characteristic wave height parameter.

### 4.7.1 Ripple height

In Fig. 4.11 the ratio of the measured ripple height and the amplitude of the orbital displacement at the bed is plotted against the parameter $\hat{U}b^2/\Delta gD50$. According to Nielsen the ripple height can be computed as:

$$(\Delta r/\hat{A}b) = 0.275 - 0.022*(\hat{U}b^2/\Delta g D50)^{1/2} \qquad (V-11) \qquad (4.4)$$

This approximation of Nielsen does not contain a current influence. With exception of a strong opposing current ($Um \simeq -0.4$ [m/s]), the current influence on the ripple height appears to be small and the ripple heights are predicted rather well by Nielsen. In case of a strong opposing current ($Um \simeq -0.4$ [m/s]) superimposed on the waves, the predicted ripple heights are small compared with the measured ripple heights.

### 4.7.2 Ripple length

In Fig. 4.12 the ratio of the measured ripple length and the amplitude of the orbital displacement at the bed are plotted against the parameter $\hat{U}b/\Delta g D50$. According to Nielsen the ripple length can be computed as:

$$(\lambda r/\hat{A}b) = 2.2 - 0.345*(\hat{U}b^2/\Delta g D50)^{0.34} \qquad (V-12) \qquad (4.5)$$

This approximation of Nielsen does not contain a current influence. With exception of a strong opposing current ($Um \simeq -0.4$ [m/s]), the current influence on the ripple length appears to be small and the ripple lengths are predicted rather well by Nielsen. In case of a strong opposing current ($Um \simeq -0.4$ [m/s]) superimposed on the waves, the predicted ripple lengths are small compared with the measured ripple lengths.

4.7.3 Ripple steepness

In Fig. 4.13 the measured ripple steepnesses, determined by deviding the measured mean ripple height by the measured mean ripple length, are plotted against the the skin friction parameter $\theta'$ (see appendix V). According to Nielsen the ripple steepness can be computed as:

$$RS = (\Delta r/\lambda r) = 0.182 - 0.24*(\theta')^{3/2} \qquad \text{(V-13)} \qquad (4.6)$$

With a dashed line the approximation of Nielsen is included in Fig. 4.13. It appears that the approximation of Nielsen predicts the ripple steepness rather well in case of a weak current superimposed on the waves. When a strong current ( $|Um| \simeq 0.4$ [m/s]) is superimposed on the waves, the approximation of Nielsen largely overestimates the measured ripple steepnesses.

Apparently, the relations of Nielsen rather well predict the ripple characteristics when no current or only a weak current (a depth-averaged velocity smaller than or equal to 0.2 [m/s], mostly wave-dominated ripples) is superimposed on the waves. When a strong current ( $|Um| \simeq 0.4$ [m/s]) is superimposed on the waves these relations become less good.

## 4.8 Bed roughness

Three different relations were used to determine the bed roughness. The Swart bed roughness (1976), the van Rijn bed roughness (1982), which are used in the Bijker method and the Engelund-Hansen method, and the Grant and Madsen bed roughness (1982), used in the Nielsen method.

Swart : $Ks = 25*(\Delta r^2/\lambda r)$ (II-4)

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

Madsen and Grant : $Ks = 8*\Delta r*RS + 190*D50*\sqrt{(\theta' - 0.05)}$ (V-8)

In table 4.9 an overview is given of the bed roughnesses calculated with these relations. In addition, the mean, maximum and minimum bed roughness values, derived by fitting a logarithmic velocity distribution through the velocities measured in absence of waves (see paragraph 3.4.2), are also given in this table. As can be observed, the Swart roughness is always large compared with the Madsen and Grant roughness and the van Rijn roughness. The van Rijn roughness is small compared with the Madsen and Grant roughness.
In general, the van Rijn and the Madsen and Grant roughnesses are small compared with the fitted values. The Swart roughness agrees reasonably well with the fitted roughnesses.
Although the Swart roughness predictor seems to be the best roughness predictor, use of the (incorrect) van Rijn roughness in the Bijker method and Engelund-Hansen method leads to better results. Further research is necessary.

# 5 Conclusions and recommendations

## 5.1 Conclusions

The main findings of this study can be summarized in the following conclusions:

1) The significant wave height influences the concentration profile in two ways (see Fig. 3.3):
   - Increasing the significant wave height leads to a steeper concentration profile. This phenomenon becomes less important with increasing current strength.
   - Increasing the significant wave height leads to an increase in concentrations.

2) When a weak current ($|Um| \simeq 0.1$ [m/s]) or no current is superimposed on the waves, the concentration profile can be represented by an exponential distribution (Eq. 3.8):

   $$\bar{\bar{C}}(z) = Cb*\exp(-z/Lc)$$

   The presence of a stronger current causes a deviation of this theoretical distribution in the upper layers (see Fig. 3.4). For increasing current velocities the current-induced mixing becomes more important, resulting in an increased vertical transport of sediment particles to the upper layers.

3) An opposing current causes a somewhat steeper concentration profile than a following current. The magnitude of the

concentrations in the near bed zone ($z/h < 0.2$) is hardly influenced by the current direction.

4) The waves cause a reduction of the time-averaged velocities in the near bed zone ($z/h < 0.2$). This effect is larger for a larger significant wave height. This effect is largest in case of an opposing current (see Figs. 3.9A and 3.9B).
The waves cause a reduction of the near-surface velocities in case of a following current (see Fig. 3.9A) and an enlargement of the near-surface velocities in case of an opposing current (see Fig. 3.9B).

5) The effective bed roughness of ripples generated by waves in combination with a current is about 3 to 8 times the average ripple height (see Fig. 3.7).

6) The total load transport is hardly influenced by the current direction (see Figs. 3.14 and 3.16)

7) The relationship between the (significant) wave height and the total load transport is reflected rather well by $|St| \approx Hs^{\alpha}$, with $\alpha = 5.4$ for $|Um| \simeq 0.1$ [m/s], $\alpha = 3.2$ for $|Um| \simeq 0.2$ [m/s] and $\alpha = 2.0$ for $|Um| \simeq 0.4$ [m/s]. Thus $\alpha$ is strongly reduced for increasing depth-averaged velocity (see Figs. 3.14 and 3.15).

8) The relationship between the depth-averaged velocity and the total load transport is reflected rather well by $|St| \approx |Um|^{\beta}$, with $\beta = 4.5$ for $Hs \simeq 0.075$ [m], $\beta = 4.1$ for $Hs \simeq 0.100$ [m], $\beta = 3.6$ for $Hs \simeq 0.120$ [m] and $\beta = 2.9$ for $Hs \simeq 0.150$ [m]. Thus $\beta$ is

reduced with increasing significant wave height (see Figs. 3.16 and 3.17).

9) Wave-dominated (mostly 2-dimensional) ripples generally occur for $|Um|/\hat{U}b < 0.75$ (see paragraph 3.8.2).
Current-dominated (mostly 3-dimensional) ripples generally occur for $|Um|/\hat{U}b > 1.5$ (see paragraph 3.8.2).

10) The median size of the suspended sediment is equal to about 0.85 to 1 times the median size of the bed material for all conditions. No clear influence of the wave height and depth-averaged velocity has been found (see paragraph 3.9.2).

11) The concept of relating the sediment transport to the combined bottom shear stress for waves and currents might be a good concept (see paragraph 4.6.1.1).

12) The Bijker method predicts sediment transport rates which are much too large in case of a depth-averaged velocity smaller than or equal to 0.2 [m/s] and too small in case of a depth-averaged velocity of approximately 0.4 [m/s]. Use of the van Rijn roughness in combination with the Bijker method leads to better prediction results than the Swart roughness. Applying the van Rijn roughness, about 48% of the predicted transport rates are within a factor 2 of the measured transport rates (see paragraph 4.6.1.1).

13) The Engelund-Hansen method predicts sediment transport rates which are much too large for all conditions. Only 4% of the predicted transport rates are within a factor 2 of the measured transport rates (see paragraph 4.6.1.1).

14) The Nielsen method predicts convective sediment transport rates which are generally much too large, particularly when the depth-averaged velocity is smaller than or equal to 0.2 [m/s]. About 32% of the predicted transport rates are within a factor 2 of the measured transport rates (see paragraph 4.6.1.1).

15) The effective bed roughness predictor of Swart yields the best agreement with the measured bed roughness values. The method of van Rijn and Madsen-Grant yields values which are too small, especially the van Rijn roughness (see paragraph 4.8).

It proved that the sediment transport rate can not be predicted accurately by the formulae used. None of the formulae correctly reflects the wave height influence and the influence of the depth-averaged velocity on the concentration distribution, the total load and the (convective) sediment transport. The best results are obtained with the Bijker formula in combination with the van Rijn bed roughness predictor. This latter effect is not very consistent (see conclusion 15).
Although the Engelund-Hansen formula predicts the sediment transport rate rather well in case of a current alone, adaption and application in case of waves in combination with a current causes extremely high transport rates and can not be recommended.
The incorrect results of the Bijker method and the Nielsen method can be explained by the fact that the predicted concentration profiles disagree with the measured profiles. Until a better describtion of the concentration distribution is available, no large improvements have to be expected.

## 5.2 Recommendations

During the follow-up experiments, which will be carried out with a sand bed consisting of finer sediment than the sediment used in the present investigation, special attention should be paid to:

- The bed roughness
- The diffusive transport

More insight into the bed roughness can be obtained by measuring not only velocities in the absence of waves (bed forms generated by waves and the current), but also the water surface slope.
To gain more insight into the importance of the diffusive transport, sand balance experiments have to be carried out. In order to determine properly the volume difference of which the sand balance sediment transport can be computed, it is necessary to apply more than three longitudinal sections (ten longitudinal sections) and to use a sufficiently large experimental time period.

Symbols

| | | |
|---|---|---|
| A | - dimensionless roughness | [-] |
| Ab | - dimensionless enhancement factor in the Nielsen formula | [-] |
| $\hat{A}b$ | - horizontal orbital dispacement amplitude at the bed | [m] |
| A1 | - coefficient in the Nielsen formula | [m] |
| Af | - dimensionless enhancement factor in the Nielsen formula | [-] |
| a | - water depth relative to the flume bottom | [m] |
| B | - coefficient in the Bijker formula | [-] |
| C | - Chezy friction coefficient | [m /s] |
| $\bar{\bar{C}}$ | - time- and bed-averaged concentration | [Kg/m3] |
| $C'$ | - concentration fluctuation | [Kg/m3] |
| | - Chezy friction coefficient | [m /s] |
| Cb | - bed concentration | [Kg/m3] |
| $c_a$ | - absolute wave celerity | [m/s] |
| $c_r$ | - relative wave celerity | [m/s] |
| Dx | - grain diameter exceeded by x% (by weight) | [m] |
| d | - water depth relative to chosen ripple top | [m] |
| F | - coefficient in the Nielsen formula | [-] |
| f | - frequency | [1/s] |
| fNyq. | - Nyquist frequency | [1/s] |
| fp | - peak frequency | [1/s] |
| fw | - friction factor | [-] |
| $f_w'$ | - skin friction factor | [-] |
| g | - acceleration of gravity | [m/s2] |
| H | - wave height | [m] |
| $\bar{H}$ | - average wave height | [m] |

| | | |
|---|---|---|
| Hrms | - root-mean-square wave height | [m] |
| Hs | - significant wave height | [m] |
| H1% | - wave height with 1% probability of being exceeded | [m] |
| h | - water depth | [m] |
| I1 | - Einstein integral | [-] |
| I2 | - Einstein integral | [-] |
| Ks | - equivalent roughness of NiKuradse | [m] |
| K1 | - dry weight / wet volume correction factor | [Kg/m3] |
| K2 | - trapping correction factor | [-] |
| L | - wave length | [m] |
| Lb | - bed load | [Kg/m2] |
| Lc | - vertical concentration length scale | [m] |
| Lcf | - concentration length scale in the Nielsen formula | [m] |
| Lcb | - concentration length scale in the Nielsen formula | [m] |
| Ls | - suspended load | [Kg/m2] |
| Lt | - total load | [Kg/m2] |
| P(..) | - probability of exceedance of (..) | [-] |
| p(..) | - probability of occurance of (..) | [-] |
| p | - porosity | [-] |
| RS | - ripple steepness | [-] |
| Sb | - bed load transport | [Kg/ms] |
| Scon. | - convective sediment transport | [Kg/ms] |
| Sdiff. | - diffusive sediment transport | [Kg/ms] |
| Ss | - suspended load transport | [Kg/ms] |
| St | - total load transport (sum of bed load and supended load transport) | [Kg/ms] |
| Stot | - total transport (sum of convective and diffusive sediment transport) | [Kg/ms] |
| T | - water temperature | [oC] |

| | | |
|---|---|---|
| | - 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] |
| $\bar{\bar{U}}$ | - time- and bed-averaged velocity | [m/s] |
| $U'$ | - velocity fluctuation | [m/s] |
| $\hat{U}b$ | - horizontal orbital velocity amplitude | [m/s] |
| Um | - depth-averaged velocity | [m/s] |
| U* | - shear velocity | [m/s] |
| $\overline{U*}$ | - shear velocity due to the current | [m/s] |
| $\tilde{U}*$ | - wave shear velocity | [m/s] |
| W50 | - median fall velocity | [m/s] |
| W50,bed | - median fall velocity of the bed material | [m/s] |
| W50,sus. | - median fall velocity of the suspended sediment | [m/s] |
| x | - coordinate in the direction of wave propagation | [m] |
| Z* | - dimensionless parameter | [-] |
| z | - vertical coordinate | [m] |
| z0 | - zero velocity level | [m] |
| z1 | - adapted zero velocity level | [m] |
| | | |
| $\alpha$ | - shape factor | [-] |
| | - power coefficient | [-] |
| $\beta$ | - power coefficient | [-] |
| $\Delta$ | - relative sediment density | [-] |
| $\Delta$(..) | - inaccuracy in (..) | |
| $\Delta$r | - ripple height | [m] |
| $\overline{\Delta r}$ | - mean ripple height | [m] |
| $\Delta$0 | - mean ripple height in case of waves alone | [m] |

| | | | |
|---|---|---|---|
| $\delta$ | - mean bed level | | [m] |
| $\theta'$ | - skin friction Shields parameter | | [-] |
| $\theta_r$ | - Shields parameter corrected for flow contraction near the ripple crests | | [-] |
| $\kappa$ | - constant of Von Karman | | [-] |
| $\lambda_r$ | - ripple length | | [m] |
| $\overline{\lambda_r}$ | - 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] |
| $\eta$ | - water surface elevation | | [m] |
| $\mu$ | - ripple factor | | [-] |
| $\nu$ | - kinematic viscosity | | [m2/s] |
| $\xi$ | - parameter | | [-] |
| $\rho$ | - density of fluid | | [Kg/m3] |
| $\rho_s$ | - density of sediment | | [Kg/m3] |
| $\sigma(..)$ | - standard deviation of (..) | | |

$\simeq$ stands for approximately equal to

$\approx$ stands for proportional to

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Appendix I: Application program for measuring results

List of \FIT.BAS

```
10   REM **************************
20   REM THIS PROGRAM CALCULATES THE MEAN. MINIMUM AND MAXIMUM
30   REM CONCENTRATION AND VELOCITY PROFILES . THE DEPTH
40   REM AVERAGED VELOCITIES , THE BEDCONCENTRATIONS ,
50   REM THE LOADS AND THE TRANSPORTS
60   REM **************************
70   FULLW 2: CLEARW 2
80   PRINT " CALCULATION OF THE MEAN, MINIMUM AND MAXIMUM"
90   PRINT " CONCENTRATION AND VELOCITY PROFILES ,"
100  PRINT " THE DEPTH AVERAGED VELOCITIES , THE BEDCONCENTRATIONS,"
110  PRINT " THE LOADS AND THE TRANSPORTS."
120  PRINT: PRINT
130  PRINT " ";CHR$(189);" BY T. VAN DER KAAIJ AND M.W.C. NIEUWJAAR"
140  PRINT " FEBRUARY 1987"
150  PRINT: PRINT: PRINT: PRINT: PRINT: PRINT: PRINT
160  PRINT " PRESS [Return] IF YOU WANT THE NEXT PAGE"
170  PAGE$=CHR$(INP(2))
180  IF ASC(PAGE$)=13 THEN GOTO 220 ELSE GOTO 170
190  REM *************************
200  REM INPUT
210  REM *************************
220  CLEARW 2
230  INPUT " NUMBER OF CONCENTRATION TESTS";M
240  INPUT " NUMBER OF VELOCITY TESTS      ";N
250  IF M=0 AND N=0 THEN GOTO 260 ELSE GOTO 280
260  PRINT: PRINT " THIS IS AN IMPOSSIBLE INPUT."
270  PRINT " PLEASE CORRECT IT.": GOTO 220
280  IF M >= N THEN MAX=M: MIN=N ELSE MAX=N: MIN=M
290  OPTION BASE 1
300  DIM Z(MAX,10),ZMEAN(10),ZH(MAX+3,10),ZHSOM(10),ZHMEAN(10),H(MAX+3),
    R(MAX),C(MAX+3,10),U(MAX+3,10),UM(MAX+3),X(MAX,10),X1(MAX,10)
310  DIM XSOM(10),XMEAN(10),XMIN(10),XMAX(10),A(MAX+3),B(MAX+3),
    CB(MAX+3),LB(M),LS(M),LT(M),SB(MIN),SS(MIN),ST(MIN)
320  CLEARW 2
330  REM *WATERDEPTHS*
340  FOR T=1 TO MAX
350  PRINT " TEST ";T;: INPUT "      WATERDEPTH (M) = ";H(T)
360  NEXT T
370  PRINT: PRINT
380  REM *DISTANCE RIPPLETOP GAUGING-ROD TO MEAN BED*
390  FOR T=1 TO MAX
400  PRINT " TEST ";T;:
    INPUT "      DISTANCE RIPPLETOP GAUGING-ROD TO MEAN BED (M) = ";R(T)
410  NEXT T
420  PRINT: PRINT
430  IF M=0 THEN GOTO 500
440  REM *RIPPLE PARAMETERS*
450  INPUT " MEAN RIPPLE HEIGHT (M)           = ";MDR
460  INPUT " DEVIATION RIPPLE HEIGHT (M)      = ";DDR
470  INPUT " MEAN RIPPLE VELOCITY (M/S)       = ";MUR
480  INPUT " DEVIATION RIPPLE VELOCITY (M/S) = ";DUR
490  PRINT: PRINT
500  REM *CONCENTRATIONS*
510  FOR T=1 TO MAX
520  PRINT " TEST ";T
530  PRINT
540  FOR I=1 TO 10
550  IF T<=M THEN GOTO 560 ELSE GOTO 580
560  PRINT " LEVEL ";I;: INPUT "      CONCENTRATION (KG/M3) = ";C(T,I)
570  REM *VELOCITIES*
580  IF T<=N THEN GOTO 590 ELSE GOTO 600
```

```
590   PRINT " LEVEL ";I;: INPUT "      VELOCITY (M/S)          = ";U(T,I)
600   PRINT
610   NEXT I
620   PRINT: PRINT
630   NEXT T
640   PRINT: PRINT
650   IF M=0 THEN GOTO 660 ELSE GOTO 710
660   FOR T=1 TO MAX+3
670   FOR I=1 TO 10
680   C(T,I)=0
690   NEXT I
700   NEXT T
710   IF N=0 THEN GOTO 720 ELSE GOTO 770
720   FOR T=1 TO MAX+3
730   FOR I=1 TO 10
740   U(T,I)=0
750   NEXT I
760   NEXT T
770   CLEARW 2
780   PRINT TAB(10);"PATIENCE PLEASE, I'M CALCULATING..."
790   PRINT: PRINT: PRINT: PRINT: PRINT: PRINT
800   REM *************************
810   REM CALCULATION OF MEAN, MINIMUM AND MAXIMUM
820   REM CONCENTRATION AND VELOCITY PROFILES
830   REM *************************
840   B1=0.5*MDR
850   REM *HEIGHT AND RELATIVE HEIGHT*
860   FOR T=1 TO MAX
870   FOR I=1 TO 10
880   READ Z
890   Z(T,I)=Z/100+R(T)
900   ZH(T,I)=Z(T,I)/H(T)
910   NEXT I
920   RESTORE
930   NEXT T
940   REM *MEAN WATERDEPTH AND MEAN DISTANCE RIPPLETOP
950   REM GAUGING-ROD TO MEAN BED*
960   HSOM=0: RSOM=0
970   FOR T=1 TO MAX
980   HSOM=HSOM+H(T)
990   RSOM=RSOM+R(T)
1000  NEXT T
1010  HMEAN=HSOM/MAX
1020  RMEAN=RSOM/MAX
1030  FOR T=MAX+1 TO MAX+3
1040  H(T)=HMEAN
1050  NEXT T
1060  REM *MEAN HEIGHT AND MEAN RELATIVE HEIGHT*
1070  FOR I=1 TO 10
1080  J=I
1090  READ Z
1100  ZMEAN(I)=Z/100+RMEAN
1110  ZHMEAN(J)=ZMEAN(I)/HMEAN
1120  NEXT I
1130  RESTORE
1140  FOR T=MAX+1 TO MAX+3
1150  FOR I=1 TO 10
1160  J=I
1170  ZH(T,I)=ZHMEAN(J)
1180  NEXT I
1190  NEXT T
1200  IF M=0 THEN GOTO 1340 ELSE GOTO 1210
1210  REM *CONCENTRATION PROFILES*
```

```
1220  FOR T=1 TO M
1230  FOR I=1 TO 10
1240  X(T,I)=C(T,I)
1250  NEXT I
1260  NEXT T
1270  P=M
1280  GOSUB 5290
1290  FOR I=1 TO 10
1300  C(MAX+1,I)=XMEAN(I)
1310  C(MAX+2,I)=XMIN(I)
1320  C(MAX+3,I)=XMAX(I)
1330  NEXT I
1340  IF N=0 THEN GOTO 1740 ELSE GOTO 1350
1350  REM *VELOCITY PROFILES*
1360  SG=SGN(U(1,1))
1370  FOR T=1 TO N
1380  FOR I=1 TO 10
1390  X(T,I)=U(T,I)*SG
1400  NEXT I
1410  NEXT T
1420  P=N
1430  GOSUB 5290
1440  FOR I=1 TO 10
1450  U(MAX+1,I)=XMEAN(I)*SG
1460  U(MAX+2,I)=XMIN(I)*SG
1470  U(MAX+3,I)=XMAX(I)*SG
1480  NEXT I
1490  REM *************************
1500  REM CALCULATION OF DEPTH AVERAGED VELOCITY
1510  REM *************************
1520  FOR T=1 TO MAX+3
1530  SP=ZH(T,1)/100
1540  UM(T)=0
1550  FOR ZH=0 TO (ZH(T,1)-SP) STEP SP
1560  U1=U(T,1)*(ZH/ZH(T,1))^0.25
1570  U2=U(T,1)*((ZH+SP)/ZH(T,1))^0.25
1580  UM(T)=UM(T)+0.5*SP*(U1+U2)
1590  NEXT ZH
1600  FOR I=1 TO 9
1610  J=I
1620  UM(T)=UM(T)+0.5*(U(T,I)+U(T,I+1))*(ZH(T,J+1)-ZH(T,J))
1630  NEXT I
1640  UM(T)=UM(T)+U(T,10)*(1-ZH(T,10))
1650  NEXT T
1660  REM ***MEAN, MINIMUM AND MAXIMUM OF TESTS***
1670  SG=SGN(UM(1))
1680  FOR T=1 TO N
1690  Y(T)=UM(T)*SG
1700  NEXT T
1710  Q=N
1720  GOSUB 5490
1730  UMMEAN=YMEAN*SG: UMMIN=YMIN*SG: UMMAX=YMAX*SG
1740  IF M=0 THEN GOTO 3360 ELSE GOTO 1750
1750  REM **************************
1760  REM CALCULATION OF LOADS AND BEDCONCENTRATIONS
1770  REM **************************
1780  FOR T=1 TO MAX+3
1790  REM ***CONCENTRATION FIT***
1800  LNC=0: ZHLNC=0: ZH=0: ZH2=0
1810  FOR I=1 TO 3
1820  LNC=LNC+LOG(C(T,I))
1830  ZHLNC=ZHLNC+ZH(T,I)*LOG(C(T,I))
1840  ZH=ZH+ZH(T,I)
```

```
1850  ZH2=ZH2+ZH(T,I)*ZH(T,I)
1860  NEXT I
1870  A(T)=(3*ZHLNC-ZH*LNC)/(3*ZH2-ZH*ZH)
1880  B(T)=(ZH2*LNC-ZH*ZHLNC)/(3*ZH2-ZH*ZH)
1890  REM ***BED CONCENTRATIONS***
1900  CB(T)=EXP(B(T))
1910  IF CB(T) > 1600 THEN CB(T)=1600
1920  NEXT T
1930  REM ***LOADS***
1940  REM *BED LOAD*
1950  FOR T=1 TO M
1960  SP1=(B1/H(T))/50
1970  LB(T)=0
1980  FOR ZH=0 TO ((B1/H(T))-SP1) STEP SP1
1990  C1=EXP(A(T)*ZH+B(T))
2000  C2=EXP(A(T)*(ZH+SP1)+B(T))
2010  IF C1 > 1600 THEN C1=1600
2020  IF C2 > 1600 THEN C2=1600
2030  LB(T)=LB(T)+0.5*SP1*(C1+C2)
2040  NEXT ZH
2050  LB(T)=LB(T)*H(T)
2060  REM *SUSPENDED LOAD*
2070  SP2=(ZH(T,1)-B1/H(T))/50
2080  LS(T)=0
2090  FOR ZH=(B1/H(T)) TO (ZH(T,1)-SP2) STEP SP2
2100  C1=EXP(A(T)*ZH+B(T))
2110  C2=EXP(A(T)*(ZH+SP2)+B(T))
2120  IF C1 > 1600 THEN C1=1600
2130  IF C2 > 1600 THEN C2=1600
2140  LS(T)=LS(T)+0.5*SP2*(C1+C2)
2150  NEXT ZH
2160  FOR I=1 TO 9
2170  LS(T)=LS(T)+0.5*(C(T,I)+C(T,I+1))*(ZH(T,I+1)-ZH(T,I))
2180  NEXT I
2190  LS(T)=LS(T)+0.5*C(T,10)*(1-ZH(T,10))
2200  LS(T)=LS(T)*H(T)
2210  REM *TOTAL LOAD*
2220  LT(T)=LB(T)+LS(T)
2230  NEXT T
2240  REM ***MEAN, MINIMUM AND MAXIMUM OF TESTS***
2250  FOR T=1 TO M
2260  Y(T)=CB(T)
2270  NEXT T
2280  Q=M
2290  GOSUB 5490
2300  CBMEAN=YMEAN: CBMIN=YMIN: CBMAX=YMAX
2310  FOR T=1 TO M
2320  Y(T)=LB(T)
2330  NEXT T
2340  Q=M
2350  GOSUB 5490
2360  LBMEAN=YMEAN: LBMIN=YMIN: LBMAX=YMAX
2370  FOR T=1 TO M
2380  Y(T)=LS(T)
2390  NEXT T
2400  Q=M
2410  GOSUB 5490
2420  LSMEAN=YMEAN: LSMIN=YMIN: LSMAX=YMAX
2430  FOR T=1 TO M
2440  Y(T)=LT(T)
2450  NEXT T
2460  Q=M
2470  GOSUB 5490
```

```
2480  LTMEAN=YMEAN: LTMIN=YMIN: LTMAX=YMAX
2490  IF N=0 THEN GOTO 3360 ELSE GOTO 2500
2500  REM ************************
2510  REM CALCULATION OF TRANSPORTS
2520  REM ************************
2530  FOR T=1 TO MIN
2540  REM *** TRANSPORTS***
2550  REM *BED LOAD TRANSPORT*
2560  SP1=(B1/H(T))/50
2570  SB1(T)=0
2580  FOR ZH=0 TO ((B1/H(T))-SP1) STEP SP1
2590  U1=U(T,1)*(ZH/ZH(T,1))^0.25
2600  U2=U(T,1)*((ZH+SP1)/ZH(T,1))^0.25
2610  C1=EXP(A(T)*ZH+B(T))
2620  C2=EXP(A(T)*(ZH+SP1)+B(T))
2630  IF C1 > 1600 THEN C1=1600
2640  IF C2 > 1600 THEN C2=1600
2650  SB1(T)=SB1(T)+0.5*SP1*(U1*C1+U2*C2)
2660  NEXT ZH
2670  SB1(T)=SB1(T)*H(T)
2680  REM *SUSPENDED LOAD TRANSPORT*
2690  SP2=(ZH(T,1)-B1/H(T))/50
2700  SS(T)=0
2710  FOR ZH=(B1/H(T)) TO (ZH(T,1)-SP2) STEP SP2
2720  U1=U(T,1)*(ZH/ZH(T,1))^0.25
2730  U2=U(T,1)*((ZH+SP2)/ZH(T,1))^0.25
2740  C1=EXP(A(T)*ZH+B(T))
2750  C2=EXP(A(T)*(ZH+SP2)+B(T))
2760  IF C1 > 1600 THEN C1=1600
2770  IF C2 > 1600 THEN C2=1600
2780  SS(T)=SS(T)+0.5*SP2*(U1*C1+U2*C2)
2790  NEXT ZH
2800  FOR I=1 TO 9
2810  SP3=(ZH(T,I+1)-ZH(T,I))/50
2820  FOR ZH=ZH(T,I) TO (ZH(T,I+1)-SP3) STEP SP3
2830  C1=C(T,I)+(ZH-ZH(T,I))*(C(T,I+1)-C(T,I))/
     (ZH(T,I+1)-ZH(T,I))
2840  C2=C(T,I)+(ZH+SP3-ZH(T,I))*(C(T,I+1)-C(T,I))/
     (ZH(T,I+1)-ZH(T,I))
2850  U1=U(T,I)+(ZH-ZH(T,I))*(U(T,I+1)-U(T,I))/
     (ZH(T,I+1)-ZH(T,I))
2860  U2=U(T,I)+(ZH+SP3-ZH(T,I))*(U(T,I+1)-U(T,I))/
     (ZH(T,I+1)-ZH(T,I))
2870  SS(T)=SS(T)+0.5*SP3*(U1*C1+U2*C2)
2880  NEXT ZH
2890  NEXT I
2900  SP3=(1-ZH(T,10))/50
2910  U1=U(T,10)
2920  U2=U(T,10)
2930  FOR ZH=ZH(T,10) TO (1-SP3) STEP SP3
2940  C1=C(T,10)+(ZH-ZH(T,10))*(-C(T,10))/(1-ZH(T,10))
2950  C2=C(T,10)+(ZH+SP3-ZH(T,10))*(-C(T,10))/(1-ZH(T,10))
2960  SS(T)=SS(T)+0.5*SP3*(U1*C1+U2*C2)
2970  NEXT ZH
2980  SS(T)=SS(T)*H(T)
2990  REM *TOTAL LOAD TRANSPORTS*
3000  ST1(T)=SB1(T)+SS(T)
3010  NEXT T
3020  REM ***MEAN, MINIMUM AND MAXIMUM OF TESTS***
3030  SG=SGN(SB1(1))
3040  FOR T=1 TO MIN
3050  Y(T)=SB1(T)*SG
3060  NEXT T
```

```
3070  Q=MIN
3080  GOSUB 5490
3090  SB1MEAN=YMEAN*SG: SB1MIN=YMIN*SG: SB1MAX=YMAX*SG
3100  SG=SGN(SS(1))
3110  FOR T=1 TO MIN
3120  Y(T)=SS(T)*SG
3130  NEXT T
3140  Q=MIN
3150  GOSUB 5490
3160  SSMEAN=YMEAN*SG: SSMIN=YMIN*SG: SSMAX=YMAX*SG
3170  SG=SGN(ST1(1))
3180  FOR T=1 TO MIN
3190  Y(T)=ST1(T)*SG
3200  NEXT T
3210  Q=MIN
3220  GOSUB 5490
3230  ST1MEAN=YMEAN*SG: ST1MIN=YMIN*SG: ST1MAX=YMAX*SG
3240  REM ***CALCULATION OF TRANSPORT VIA RIPPLEPARAMETERS***
3250  SB2MEAN=0.6*(1-0.4)*2650*MUR*MDR
3260  DSB=SB2MEAN*SQR(((DDR/MDR)^2)+((DUR/MUR)^2))
3270  SB2MIN=SB2MEAN-DSB
3280  SB2MAX=SB2MEAN+DSB
3290  ST2MEAN=SB2MEAN+SSMEAN
3300  IF SB2MEAN/SSMEAN > 0 THEN ST2MIN=SB2MIN+SSMIN ELSE
     ST2MIN=SB2MAX+SSMIN
3310  IF SB2MEAN/SSMEAN > 0 THEN ST2MAX=SB2MAX+SSMAX ELSE
     ST2MAX=SB2MIN+SSMAX
3320  ST2MAX=SB2MAX+SSMAX
3330  REM *************************
3340  REM OUTPUT
3350  REM *************************
3360  PRINT CHR$(7)
3370  REM *MEAN, MINIMUM AND MAXIMUM CONCENTRATION
3380  REM AND VELOCITY PROFILES*
3390  CLEARW 2
3400  PRINT "MEAN, MINIMUM AND MAXIMUM CONCENTRATION";
3410  PRINT " AND VELOCITY PROFILES"
3420  PRINT
3430  PRINT " I";TAB(7);"Z/H";TAB(16);"Z";TAB(22);
3440  PRINT "C MEAN";TAB(31);"C MIN";TAB(40);"C MAX";TAB(49);
3450  PRINT "U MEAN";TAB(57);"U MIN";TAB(65);"U MAX"
3460  PRINT "(-)";TAB(7);"(-)";TAB(15);"(M)";TAB(21);
3470  PRINT "(KG/M";CHR$(254);")";TAB(29);"(KG/M";CHR$(254);
3480  PRINT ")";TAB(37);"(KG/M";CHR$(254);")";TAB(46);
3490  PRINT "(M/S)";TAB(54);"(M/S)";TAB(62);"(M/S)"
3500  PRINT
3510  FOR I=1 TO 10
3520  J=I
3530  PRINT USING"##";I;: PRINT TAB(6);
3540  PRINT USING"#.###";ZHMEAN(J);: PRINT TAB(14);
3550  PRINT USING"#.###";ZMEAN(I);: PRINT TAB(22);
3560  PRINT USING"#.####";C(MAX+1,I);: PRINT TAB(31);
3570  PRINT USING"#.####";C(MAX+2,I);: PRINT TAB(40);
3580  PRINT USING"#.####";C(MAX+3,I);: PRINT TAB(49);
3590  PRINT USING"#.###";U(MAX+1,I);: PRINT TAB(57);
3600  PRINT USING"#.###";U(MAX+2,I);: PRINT TAB(65);
3610  PRINT USING"#.###";U(MAX+3,I)
3620  NEXT I
3630  PRINT
3640  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
3650  PAGE$=CHR$(INP(2))
3660  IF ASC(PAGE$)=13 THEN GOTO 3670 ELSE GOTO 3650
3670  IF N=0 THEN GOTO 3920 ELSE GOTO 3680
```

```
3680  REM *DEPTH AVERAGED VELOCITIES*
3690  CLEARW 2
3700  PRINT "DEPTH AVERAGED VELOCITIES (M/S)"
3710  PRINT
3720  FOR T=1 TO N
3730  PRINT "TEST ";T;TAB(25);: PRINT USING"#.###";UM(T)
3740  NEXT T
3750  PRINT
3760  PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"#.###";UMMEAN
3770  PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"#.###";UMMIN
3780  PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"#.###";UMMAX
3790  PRINT
3800  PRINT "**********************************************"
3810  PRINT
3820  FOR T=MAX+1 TO MAX+3
3830  IF T=MAX+1 THEN T$="MEAN" ELSE IF T=MAX+2 THEN T$="MIN."
     ELSE IF T=MAX+3 THEN T$="MAX."
3840  PRINT T$;" PROFILE";TAB(25);: PRINT USING"#.###";UM(T)
3850  NEXT T
3860  PRINT
3870  IF M=0 THEN GOTO 5170 ELSE GOTO 3880
3880  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
3890  PAGE$=CHR$(INP(2))
3900  IF ASC(PAGE$)=13 THEN GOTO 3910 ELSE GOTO 3890
3910  REM *BEDCONCENTRATIONS*
3920  CLEARW 2
3930  PRINT "BEDCONCENTRATIONS (KG/M";CHR$(254);")"
3940  PRINT
3950  FOR T=1 TO M
3960  PRINT "TEST ";T;TAB(25);: PRINT USING"##.####";CB(T)
3970  NEXT T
3980  PRINT
3990  PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.####";CBMEAN
4000  PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.####";CBMIN
4010  PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.####";CBMAX
4020  PRINT
4030  PRINT "**********************************************"
4040  PRINT
4050  FOR T=MAX+1 TO MAX+3
4060  IF T=MAX+1 THEN T$="MEAN" ELSE IF T=MAX+2 THEN T$="MIN."
     ELSE IF T=MAX+3 THEN T$="MAX."
4070  PRINT T$;" PROFILE";TAB(25);: PRINT USING"##.####";CB(T)
4080  NEXT T
4090  PRINT
4100  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
4110  PAGE$=CHR$(INP(2))
4120  IF ASC(PAGE$)=13 THEN GOTO 4130 ELSE GOTO 4110
4130  REM *BED LOADS*
4140  CLEARW 2
4150  PRINT "BED LOADS (KG/M";CHR$(253);")"
4160  PRINT
4170  FOR T=1 TO M
4180  PRINT "TEST ";T;TAB(25);: PRINT USING"##.##^^";LB(T)
4190  NEXT T
4200  PRINT
4210  PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";LBMEAN
4220  PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";LBMIN
4230  PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";LBMAX
4240  PRINT
4250  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
4260  PAGE$=CHR$(INP(2))
4270  IF ASC(PAGE$)=13 THEN GOTO 4280 ELSE GOTO 4260
4280  REM *SUSPENDED LOADS*
```

```
4290 CLEARW 2
4300 PRINT "SUSPENDED LOADS (KG/M";CHR$(253);")"
4310 PRINT
4320 FOR T=1 TO M
4330 PRINT "TEST ";T;TAB(25);: PRINT USING"##.##^^";LS(T)
4340 NEXT T
4350 PRINT
4360 PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";LSMEAN
4370 PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";LSMIN
4380 PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";LSMAX
4390 PRINT
4400 PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
4410 PAGE$=CHR$(INP(2))
4420 IF ASC(PAGE$)=13 THEN GOTO 4430 ELSE GOTO 4410
4430 REM *TOTAL LOADS*
4440 CLEARW 2
4450 PRINT "TOTAL LOADS (KG/M";CHR$(253);")"
4460 PRINT
4470 FOR T=1 TO M
4480 PRINT "TEST ";T;TAB(25);: PRINT USING"##.##^^";LT(T)
4490 NEXT T
4500 PRINT
4510 PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";LTMEAN
4520 PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";LTMIN
4530 PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";LTMAX
4540 PRINT
4550 IF N=0 THEN GOTO 5170 ELSE GOTO 4560
4560 PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
4570 PAGE$=CHR$(INP(2))
4580 IF ASC(PAGE$)=13 THEN GOTO 4590 ELSE GOTO 4570
4590 REM *BED LOAD TRANSPORTS*
4600 CLEARW 2
4610 PRINT "BED LOAD TRANSPORTS (KG/S.M)"
4620 PRINT
4630 PRINT "** CALCULATION VIA PROFILES **"
4640 PRINT
4650 FOR T=1 TO MIN
4660 PRINT "TEST ";T;TAB(25);: PRINT USING"##.##^^";SB1(T)
4670 NEXT T
4680 PRINT
4690 PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";SB1MEAN
4700 PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";SB1MIN
4710 PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";SB1MAX
4720 PRINT
4730 PRINT "** CALCULATION VIA RIPPLE PARAMETERS **"
4740 PRINT
4750 PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";SB2MEAN
4760 PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";SB2MIN
4770 PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";SB2MAX
4780 PRINT
4790 PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
4800 PAGE$=CHR$(INP(2))
4810 IF ASC(PAGE$)=13 THEN GOTO 4820 ELSE GOTO 4800
4820 REM *SUSPENDED LOAD TRANSPORTS*
4830 CLEARW 2
4840 PRINT "SUSPENDED LOAD TRANSPORTS (KG/S.M)"
4850 PRINT
4860 FOR T=1 TO MIN
4870 PRINT "TEST ";T;TAB(25);: PRINT USING"##.##^^";SS(T)
4880 NEXT T
4890 PRINT
4900 PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";SSMEAN
4910 PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";SSMIN
```

```
4920  PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";SSMAX
4930  PRINT
4940  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
4950  PAGE$=CHR$(INP(2))
4960  IF ASC(PAGE$)=13 THEN GOTO 4970 ELSE GOTO 4950
4970  REM *TOTAL LOAD TRANSPORTS*
4980  CLEARW 2
4990  PRINT "TOTAL LOAD TRANSPORTS (KG/S.M)"
5000  PRINT
5010  PRINT "** CALCULATION VIA PROFILES **"
5020  PRINT
5030  FOR T=1 TO MIN
5040  PRINT "TEST ";T;TAB(25);: PRINT USING"##.##^^";ST1(T)
5050  NEXT T
5060  PRINT
5070  PRINT "MEAN OF- TESTS";TAB(25);:PRINT USING"##.##^^";ST1MEAN
5080  PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";ST1MIN
5090  PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";ST1MAX
5100  PRINT
5110  PRINT "** CALCULATION VIA RIPPLE PARAMETERS **"
5120  PRINT
5130  PRINT "MEAN OF TESTS";TAB(25);:PRINT USING"##.##^^";ST2MEAN
5140  PRINT "MINIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";ST2MIN
5150  PRINT "MAXIMUM OF TESTS";TAB(25);:PRINT USING"##.##^^";ST2MAX
5160  PRINT
5170  PRINT "CALCULATIONS FINISHED !"
5180  INPUT "DO YOU WANT TO RUN AGAIN (Y/N)";RUN$
5190  PRINT: PRINT
5200  IF RUN$ <> "Y" AND RUN$ <> "N" THEN GOTO 5180
5210  IF RUN$ = "N" THEN GOTO 5260
5220  IF RUN$ = "Y" THEN GOTO 5230
5230  ERASE Z,ZMEAN,ZH,ZHSOM,ZHMEAN,H,R,C,U,UM,X,X1,XSOM,XMEAN,
     XMIN,XMAX,A,B,CB,LB,LS,LT,SB,SS,ST
5240  GOTO 220
5250  DATA 1,2,3,4.5,7,11,17,23,29,36
5260  END
5270  REM ***INTERPOLATION AND MINIMUM-MAXIMUM SUBROUTINE***
5280  REM INTERPOLATION PART
5290  FOR T=1 TO P
5300  FOR J=1 TO 10
5310  I=0
5320  IF ZHMEAN(J)<ZH(T,I+1) THEN GOTO 5340 ELSE
     IF I=9 THEN GOTO 5350 ELSE GOTO 5330
5330  I=I+1: GOTO 5320
5340  IF I=0 THEN I=1
5350  X1(T,J)=X(T,I)+(ZHMEAN(J)-ZH(T,I))*
     (X(T,I+1)-X(T,I))/(ZH(T,I+1)-ZH(T,I))
5360  NEXT J
5370  NEXT T
5380  REM MINIMUM-MAXIMUM PART
5390  FOR I=1 TO 10
5400  J=I
5410  XMIN(I)=X1(1,J): XMAX(I)=XMIN(I): XSOM(I)=XMAX(I)
5420  FOR T=2 TO P
5430  IF X1(T,J)>XMAX(I) THEN XMAX(I)=X1(T,J) ELSE
     IF X1(T,J)<XMIN(I) THEN XMIN(I)=X1(T,J)
5440  XSOM(I)=XSOM(I)+X1(T,J)
5450  NEXT T
5460  XMEAN(I)=XSOM(I)/P
5470  NEXT I
5480  RETURN
5490  REM ***MINIMUM-MAXIMUM SUBROUTINE***
5500  YMIN=Y(1): YMAX=YMIN: YSOM=YMAX
```

```
5510  FOR T=2 TO Q
5520  IF Y(T)>YMAX THEN YMAX=Y(T) ELSE
     IF Y(T)<YMIN THEN YMIN=Y(T)
5530  YSOM=YSOM+Y(T)
5540  NEXT T
5550  YMEAN=YSOM/Q
5560  RETURN
```

## Appendix II: The Bijker formula

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:

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

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.(II-1) with a factor $(1 - p)*\rho_s$ (with p = porosity [-]; $\rho_s$ = 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):

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

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

$\Delta r$ = Ripple height [m]

$\lambda r$ = Ripple length [m]

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

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

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]

$\Delta$ = Relative sediment density [-]

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

$\mu$ = Ripple factor [-]

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

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

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

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

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

$\xi$ = Dimensionless parameter [-]

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

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

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

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

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

where: H = Wave height [m]

L = Wave length [m]

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

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

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:

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

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

The suspended load transport is calculated as:

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

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:

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

in which:

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

U* = Shear velocity [m/s]

$\kappa$ = Von Karman coefficient (= 0.4) [-]

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

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

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

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

in which:

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

Z* = Dimensionless parameter [-]

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

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

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

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

in which I1 and I2 are Einstein's integrals.

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

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

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.(II-19) after which the total load transport can be computed as:

$$St = Sb + Ss \qquad (II-22)$$

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:

$$Lb = Cb*Ks \qquad (II-23)$$

The suspended load is calculated as:

$$Ls = \int_{z=Ks}^{h} C(z)\ dz \qquad (II-24)$$

Substituting(II-17) and solving (see appendix III), leads to:

$$Ls = 4.63*Lb*I1 \qquad (II-25)$$

Knowing the bed load and the suspended load, the total load can be computed as:

$$Lt = Lb + Ls \qquad (II-26)$$

List of \BIJKER.BAS

```
10    REM **********
20    REM THIS PROGRAM CALCULATES THE SANDTRANSPORT
30    REM VIA THE BIJKER FORMULA
40    REM **********
50    FULLW 2: CLEARW 2
60    PRINT " CALCULATION OF THE BED LOAD AND THE";
70    PRINT " BED LOAD TRANSPORT,"
80    PRINT " THE SUSPENDED LOAD AND THE SUSPENDED";
90    PRINT " LOAD TRANSPORT,"
100   PRINT " THE TOTAL LOAD AND THE TOTAL LOAD TRANSPORT"
110   PRINT " WITH THE BIJKER FORMULA."
120   PRINT:PRINT
130   PRINT " ";CHR$(189);" BY M.W.C. NIEUWJAAR"
140   PRINT " NOVEMBER 1986"
150   PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
160   PRINT " PRESS [Return] IF YOU WANT THE NEXT PAGE"
170   PAGE$=CHR$(INP(2))
180   IF ASC(PAGE$)=13 THEN GOTO 190 ELSE GOTO 170
190   DEF FNTANH(X)=(EXP(2*X)-1)/(EXP(2*X)+1)
200   DEF FNSINH(X)=(EXP(X)-EXP(-X))/2
210   PI=3.141592654
220   E=2.718281828
230   REM **********
240   REM INPUT
250   REM **********
260   CLEARW 2
270   PRINT "DO YOU WANT TO CALCULATE :"
280   PRINT "1) VIA THE RAYLEIGH DISTRIBUTION"
290   PRINT "2) VIA A CHARACTERISTIC WAVE HEIGHT"
300   PRINT
310   INPUT "PLEASE CHOOSE 1 OR 2";TELLER1
320   PRINT:PRINT
330   IF TELLER1=1 THEN GOTO 380
340   IF TELLER1=2 THEN GOTO 360
350   IF TELLER1<>1 AND TELLER1<>2 THEN GOTO 310
360   INPUT "WAVE HEIGHT (M)                              = ";H
370   IF H=0 THEN GOTO 410 ELSE 400
380   INPUT "SIGNIFICANT WAVE HEIGHT (M)                  = ";HS
390   IF HS=0 THEN GOTO 410
400   INPUT "PEAK PERIOD (S)                              = ";TP
410   INPUT "DEPTH-AVERAGED VELOCITY (M/S)                = ";UM
420   IF UM=0 THEN PRINT "THIS INPUT IS NOT ALLOWED, ";
     "PLEASE CORRECT IT !": GOTO 410
430   INPUT "WATER DEPTH TO MEAN BED (M)                  = ";H1
440   INPUT "DISTANCE RIPPLETOP TO MEAN BED (M)           = ";R
450   INPUT "W50 FALL VELOCITY OF BED MATERIAL (M/S) = ";W50
460   INPUT "D50 DIAMETER OF BED MATERIAL (M)             = ";D50
470   INPUT "D90 DIAMETER OF BED MATERIAL (M)             = ";D90
480   PRINT:PRINT
490   PRINT "DO YOU WANT TO :"
500   PRINT "1) INPUT YOUR OWN APPROXIMATION OF THE BED ROUGHNESS"
510   PRINT "2) USE THE BED ROUGHNESS APPROXIMATION OF VAN RIJN"
520   PRINT "3) USE THE BED ROUGHNESS APPROXIMATION OF SWART"
530   PRINT
540   INPUT "PLEASE CHOOSE 1, 2 OR 3";TELLER2
550   PRINT
560   IF TELLER2=1 THEN GOTO 590
570   IF TELLER2=2 OR TELLER2=3 THEN GOTO 620
580   IF TELLER2<>1 AND TELLER2<>2 AND TELLER2<>3 THEN GOTO 540
590   INPUT "BED ROUGHNESS (M)                            = ";KS
600   PRINT:PRINT
```

```
610   GOTO 640
620   INPUT "RIPPLE HEIGHT (M)                          = ";DR
630   INPUT "RIPPLE LENGTH (M)                          = ";LR
640   REM **********
650   REM CALCULATION
660   REM **********
670   CLEARW 2
680   PRINT "  PATIENCE PLEASE, I'M CALCULATING....."
690   PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
700   IF TELLER1=2 THEN HS=0
710   FOR I=1 TO 10
720   READ N
730   Z(I)=N/100+R
740   NEXT I
750   RESTORE
760   SB1=0: SS1=0: ST1=0: CB1=0: Z1=0: LB1=0: LS1=0: LT1=0
770   PH1=0: SB=0: SS=0: ST=0: CB=0: Z=0: LB=0: LS=0: LT=0
780   DH=HS/20
790   RW=1000
800   RS=2650
810   P=0.4
820   B=1
830   IF TELLER2=2 THEN KS=3*D90+1.1*DR*(1-EXP(-25*DR/LR))
840   IF TELLER2=3 THEN KS=25*(DR^2)/LR
850   C=18*LOG10(12*H1/KS)
860   C1=18*LOG10(12*H1/D90)
870   MU=(C/C1)^1.5
880   TC=RW*9.81*(UM^2)/(C^2)
890   D=(RS-RW)/RW
900   IF TELLER1=1 AND HS=0 THEN PH=1: H=0: GOTO 1080
910   IF TELLER1=2 AND H=0 THEN PH=1: GOTO 1080
920   LO=(9.81/(2*PI))*TP^2
930   HL1=0
940   HL1=HL1+0.01
950   IF SQR(HL1*FNTANH(2*PI*HL1))-SQR(H1/LO)*(1-UM*TP*HL1/H1)
     < 0 THEN GOTO 940
960   HL2=0
970   HL3=0.5*(HL1+HL2)
980   IF SQR(HL3*FNTANH(2*PI*HL3))-SQR(H1/LO)*(1-UM*TP*HL3/H1)
     < 0 THEN HL2=HL3: GOTO 1000
990   HL1=HL3
1000  IF ABS(SQR(HL3*FNTANH(2*PI*HL3))-SQR(H1/LO)*(1-UM*TP*HL3/H1))
     < 1E-5 THEN GOTO 1010 ELSE GOTO 970
1010  L=H1/HL3
1020  CR=SQR((9.81*L/(2*PI))*FNTANH(2*PI*H1/L))
1030  TPREL=L/CR
1040  IF TELLER1=2 THEN PH=1: GOTO 1080
1050  DEF FNP(H)=EXP(-2*((H/HS)^2))
1060  H=DH
1070  PH=FNP(0)-FNP(2*DH)
1080  WHILE PH > 1E-4
1090  IF H=0 THEN GOTO 1100 ELSE GOTO 1110
1100  FW=0.32: UB=0: GOTO 1150
1110  AB=H/(2*FNSINH(2*PI*H1/L))
1120  UB=2*PI*AB/TPREL
1130  IF 1.47<AB/KS AND AB/KS<3000 THEN
     FW=EXP(-5.977+5.213*((AB/KS)^-0.194))
1140  IF AB/KS<=1.47 THEN FW=0.32
1150  XI=C*SQR(FW)/SQR(2*9.81)
1160  SB=(B*D50*UM*SQR(9.81)/C)*EXP(-0.27*D*D50
     *RW*9.81/(MU*TC*(1+0.5*(XI*UB/UM)^2)))
1170  SB=SB*(1-P)*RS
1180  Z=W50*SQR(RW)/(0.4*SQR(TC*(1+0.5*(XI*UB/UM)^2)))
```

```
1190  A=KS/H1
1200  K=0.216*((A^(Z-1))/((1-A)^Z))
1210  G=1
1220  IF Z <> 1 THEN Z2=Z ELSE Z2=1.001
1230  W1=(1/(-Z2+1))*(1-A^(-Z2+1))
1240  W2=(1/(-Z2+1))*((-1/(-Z2+1))-(A^(-Z2+1))*(LOG(A)-(1/(-Z2+1))))
1250  FOR I=2 TO 5
1260  IF Z <> I THEN Z2=Z ELSE Z2=I+0.001
1270  G=-G*(Z2-I+2)/(I-1)
1280  W1=W1+(G/(-Z2+I))*(1-A^(-Z2+I))
1290  W2=W2+(G/(-Z2+I))*((-1/(-Z2+I))-(A^(-Z2+I))*(LOG(A)-(1/(-Z2+I))))
1300  NEXT I
1310  I1=K*W1
1320  I2=K*W2
1330  Q=I1*LOG(33/A)+I2
1340  SS=1.83*Q*SB
1350  ST=SB+SS
1360  CB=ABS(SB)/(6.34*SQR(TC/RW)*KS)
1370  LB=CB*KS
1380  LS=4.63*I1*LB
1390  LT=LB+LS
1400  SB1=SB1+SB*PH: SS1=SS1+SS*PH: ST1=ST1+ST*PH
1410  LB1=LB1+LB*PH: LS1=LS1+LS*PH: LT1=LT1+LT*PH
1420  CB1=CB1+CB*PH: Z1=Z1+Z*PH
1430  PH1=PH1+PH
1440  H=H+2*DH
1450  IF HS=0 THEN PH=0: GOTO 1470
1460  PH=FNP(H-DH)-FNP(H+DH)
1470  WEND
1480  SB=SB1/PH1: SS=SS1/PH1: ST=ST1/PH1: CB=CB1/PH1
1490  LB=LB1/PH1: LS=LS1/PH1: LT=LT1/PH1: Z=Z1/PH1
1500  DEF FNC1(I)=CB*(KS*(H1-Z(I))/(Z(I)*(H1-KS)))^Z
1510  Z0=KS/33
1520  DEF FNU(I)=UM*LOG(Z(I)/Z0)/LOG(H1/(E*Z0))
1530  REM **********
1540  REM OUTPUT
1550  REM **********
1560  PRINT CHR$(7): REM BELL SIGNAL
1570  CLEARW 2
1580  PRINT "BED ROUGNESS (M)";TAB(44);"= ";:
     PRINT USING"##.##^^";KS
1590  PRINT "CH";CHR$(144);"ZY COEFFICIENT (M";CHR$(171);"/S)";
     TAB(42);"=  ";:PRINT USING"##.#";C
1600  PRINT
1610  PRINT "BED LOAD (KG/M";CHR$(253);")";TAB(43);"= ";:
     PRINT USING"##.##^^";LB
1620  PRINT "SUSPENDED LOAD (KG/M";CHR$(253);")";TAB(43);"= ";:
     PRINT USING"##.##^^";LS
1630  PRINT "TOTAL LOAD (KG/M";CHR$(253);")";TAB(43);"= ";:
     PRINT USING"##.##^^";LT
1640  PRINT
1650  PRINT "BED LOAD TRANSPORT (KG/S.M)";TAB(44);"= ";:
     PRINT USING"##.##^^";SB
1660  PRINT "SUSPENDED LOAD TRANSPORT (KG/S.M)";TAB(44);"= ";:
     PRINT USING"##.##^^";SS
1670  PRINT "TOTAL LOAD TRANSPORT (KG/S.M)";TAB(44);"= ";:
     PRINT USING"##.##^^";ST
1680  PRINT
1690  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
1700  PAGE$=CHR$(INP(2))
1710  IF ASC(PAGE$)=13 THEN GOTO 1720 ELSE GOTO 1700
1720  CLEARW 2
1730  PRINT "REL. BOTTOM ROUGHNESS (-)";TAB(44);"= ";:
```

```
     PRINT USING"##.###";KS/H1
1740  PRINT "BOTTOM CONCENTRATION (KG/M";
     CHR$(254);")";TAB(43);"= ";:PRINT USING"##.####";CB
1750  PRINT "PARAMETER Z* (-)";TAB(44);"= ";:
     PRINT USING"##.##";Z
1760  PRINT
1770  PRINT " NO.";SPC(7);"REL. HEIGHT";SPC(7);"HEIGHT";
     SPC(7);"CONCENTRATION";SPC(6);"VELOCITY"
1780  PRINT "  (-)";SPC(11);"(-)";SPC(13);"(M)";SPC(11);
     "(KG/M";CHR$(254);")";SPC(11);"(M/S)"
1790  PRINT
1800  FOR I=1 TO 10
1810  PRINT TAB(2);:PRINT USING"##";I;:PRINT SPC(10);:
     PRINT USING"##.###";Z(I)/H1;:PRINT SPC(10);:
    PRINT USING"##.###";Z(I);
1820  C(I)=FNC1(I)
1830  IF Z(I) <= KS THEN C(I)=CB
1840  PRINT SPC(10);:PRINT USING"##.####";C(I);:
     PRINT SPC(10);:PRINT USING"##.###";FNU(I)
1850  NEXT I
1860  PRINT
1870  PRINT "CALCULATIONS FINISHED !"
1880  INPUT "DO YOU WANT TO RUN AGAIN (Y/N)"; RUN$
1890  PRINT:PRINT
1900  IF RUN$ <> "Y" AND RUN$ <> "N" THEN GOTO 1880
1910  IF RUN$ = "Y" THEN GOTO 260
1920  IF RUN$ = "N" THEN GOTO 1940
1930  DATA 1,2,3,4.5,7,11,17.23,29,36
1940  END
```

## Appendix III: Suspended load with the Bijker method

The suspended load is calculated as:

$$Ls = \int_{z=Ks}^{h} C(z)\, dz \qquad \text{(II-24)}$$

Substitution of the Einstein concentration distribution leads to:

$$Ls = \int_{z=Ks}^{h} Cb*\left[\frac{h - z}{z}*\frac{Ks}{h - Ks}\right]^{Z*} dz = Cb*\left[\frac{Ks}{h - Ks}\right]^{Z*}*\int_{z=Ks}^{h}\left[\frac{h - z}{z}\right]^{Z*} dz$$

Substitution of z = h*x and Ks = h*A leads to:

$$Ls = Cb*\left[\frac{h*A}{h - h*A}\right]^{Z*}*\int_{x=A}^{1}\left[\frac{h - h*x}{h*x}\right]^{Z*}*h\, dx$$

$$= Cb*\left[\frac{A}{1 - A}\right]^{Z*}*h*\int_{x=A}^{1}\left[\frac{1 - x}{x}\right]^{Z*} dx$$

$$= Cb*\frac{A^{Z*}}{(1 - A)^{Z*}}*\frac{Ks}{A}*\int_{x=A}^{1}\left[\frac{1 - x}{x}\right]^{Z*} dx$$

$$= Cb*Ks*\frac{A^{Z*-1}}{(1 - A)^{Z*}}*\int_{x=A}^{1}\left[\frac{1 - x}{x}\right]^{Z*} dx = 4.63*Cb*Ks*I1 = 4.63*Lb*I1 \qquad \text{(II-25)}$$

## Appendix IV: The adapted 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:

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

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. (IV-1) was multiplied by $\rho_s$, after which the transport is expressed in [Kg/ms].

Um = Depth-averaged velocity [m/s]

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

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

$\xi$ = Parameter; see Eq. (II-9) [-]

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

$\rho$ = Mass density of water (= 1000) [Kg/m3]

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

$\Delta$ = 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. (II-2). For the roughness Ks again a minimum and a maximum approximation was used, the van Rijn bed roughness and the Swart bed roughness.

List of \ENGELUND.BAS

```
10     REM **********
20     REM THIS PROGRAM CALCULATES THE SANDTRANSPORT
30     REM VIA THE ADAPTED ENGELUND-HANSEN FORMULA
40     REM **********
50     FULLW 2: CLEARW 2
60     PRINT " CALCULATION OF THE TOTAL TRANSPORT RATE"
70     PRINT " WITH THE ADAPTED ENGELUND-HANSEN FORMULA."
80     PRINT:PRINT
90     PRINT " ";CHR$(189);" BY M.W.C. NIEUWJAAR"
100    PRINT " APRIL 1987"
110    PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
120    PRINT " PRESS [Return] IF YOU WANT THE NEXT PAGE "
130    PAGE$=CHR$(INP(2))
140    IF ASC(PAGE$)=13 THEN GOTO 150 ELSE GOTO 130
150    DEF FNTANH(X)=(EXP(2*X)-1)/(EXP(2*X)+1)
160    DEF FNSINH(X)=(EXP(X)-EXP(-X))/2
170    PI=3.141592654
180    REM **********
190    REM INPUT
200    REM **********
210    CLEARW 2
220    PRINT "DO YOU WANT TO CALCULATE :"
230    PRINT "1) VIA THE RAYLEIGH DISTRIBUTION "
240    PRINT "2) VIA A CHARACTERISTIC WAVE HEIGHT "
250    PRINT
260    INPUT "PLEASE CHOOSE 1 OR 2";TELLER1
270    PRINT:PRINT
280    IF TELLER1=1 THEN GOTO 330
290    IF TELLER1=2 THEN GOTO 310
300    IF TELLER1<>1 AND TELLER1<>2 THEN GOTO 260
310    INPUT "WAVE HEIGHT (M)                       = ";H
320    IF H=0 THEN GOTO 360 ELSE GOTO 350
330    INPUT "SIGNIFICANT WAVE HEIGHT (M)           = ";HS
340    IF HS=0 THEN GOTO 360
350    INPUT "PEAK PERIOD (S)                       = ";TP
360    INPUT "DEPTH-AVERAGED VELOCITY (M/S)         = ";UM
370    IF UM=0 THEN PRINT "THIS INPUT IS NOT ALLOWED, ";
      "PLEASE CORRECT IT !": GOTO 360
380    INPUT "WATER DEPTH TO MEAN BED (M)           = ";H1
390    INPUT "D50 DIAMETER OF BED MATERIAL (M) = ";D50
400    INPUT "D90 DIAMETER OF BED MATERIAL (M) = ";D90
410    PRINT:PRINT
420    PRINT "DO YOU WANT TO :"
430    PRINT "1) INPUT YOUR OWN APPROXIMATION OF THE BED ROUGHNESS"
440    PRINT "2) USE THE BED ROUGHNESS APPROXIMATION OF VAN RIJN"
450    PRINT "3) USE THE BED ROUGHNESS APPROXIMATION OF SWART"
460    PRINT
470    INPUT "PLEASE CHOOSE 1, 2 OR 3";TELLER2
480    PRINT
490    IF TELLER2=1 THEN GOTO 520
500    IF TELLER2=2 OR TELLER2=3 THEN GOTO 550
510    IF TELLER2<>1 AND TELLER2<>2 AND TELLER2<>3 THEN GOTO 470
520    INPUT "BED ROUGHNESS (M)                     = ";KS
530    PRINT:PRINT
540    GOTO 570
550    INPUT "RIPPLE HEIGHT (M)                     = ";DR
560    INPUT "RIPPLE LENGTH (M)                     = ";LR
570    REM **********
580    REM CALCULATION
590    REM **********
600    CLEARW 2
```

```
610   PRINT "  PATIENCE PLEASE, I'M CALCULATING....."
620   PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
630   IF TELLER1=2 THEN HS=0
640   ST1=0: PH1=0: ST=0
650   DH=HS/20
660   RW=1000
670   RS=2650
680   IF TELLER2=2 THEN KS=3*D90+1.1*DR*(1-EXP(-25*DR/LR))
690   IF TELLER2=3 THEN KS=25*(DR^2)/LR
700   C=18*LOG10(12*H1/KS)
710   TC=RW*9.81*(UM^2)/(C^2)
720   D=(RS-RW)/RW
730   IF TELLER1=1 AND HS=0 THEN PH=1: H=0: GOTO 910
740   IF TELLER1=2 AND H=0 THEN PH=1: GOTO 910
750   LO=(9.81/(2*PI))*TP^2
760   HL1=0
770   HL1=HL1+0.01
780   IF SQR(HL1*FNTANH(2*PI*HL1))-SQR(H1/LO)*(1-UM*TP*HL1/H1)
     < 0 THEN GOTO 770
790   HL2=0
800   HL3=0.5*(HL1+HL2)
810   IF SQR(HL3*FNTANH(2*PI*HL3))-SQR(H1/LO)*(1-UM*TP*HL3/H1)
     < 0 THEN HL2=HL3: GOTO 830
820   HL1=HL3
830   IF ABS(SQR(HL3*FNTANH(2*PI*HL3))-SQR(H1/LO)*(1-UM*TP*HL3/H1))
     < 1E-5 THEN GOTO 840 ELSE GOTO 800
840   L=H1/HL3
850   CR=SQR((9.81*L/(2*PI))*FNTANH(2*PI*H1/L))
860   TPREL=L/CR
870   IF TELLER1=2 THEN PH=1: GOTO 910
880   DEF FNP(H)=EXP(-2*((H/HS)^2))
890   H=DH
900   PH=FNP(0)-FNP(2*DH)
910   WHILE PH > 1E-4
920   IF H=0 THEN GOTO 930 ELSE GOTO 940
930   FW=0.32: UB=0:GOTO 980
940   AB=H/(2*FNSINH(2*PI*H1/L))
950   UB=2*PI*AB/TPREL
960   IF 1.47<AB/KS AND AB/KS<3000 THEN
     FW=EXP(-5.977+5.213*((AB/KS)^-0.194))
970   IF AB/KS<=1.47 THEN FW=0.32
980   XI=C*SQR(FW)/SQR(2*9.81)
990   ST=UM*0.05*C*(TC^2)*((1+0.5*(XI*UB/UM)^2)^2)/
     ((RW^2)*(9.81^2.5)*(D^2)*D50)
1000  ST=ST*RS
1010  ST1=ST1+ST*PH
1020  PH1=PH1+PH
1030  H=H+2*DH
1040  IF HS=0 THEN PH=0: GOTO 1060
1050  PH=FNP(H-DH)-FNP(H+DH)
1060  WEND
1070  ST=ST1/PH1
1080  REM **********
1090  REM OUTPUT
1100  REM **********
1110  PRINT CHR$(7): REM BELL SIGNAL
1120  CLEARW 2
1130  PRINT "BED ROUGNESS (M)";TAB(37);"= ";:
     PRINT USING"##.##^^";KS
1140  PRINT "CH";CHR$(144);"ZY COEFFICIENT (M";CHR$(171);"/S)";
     TAB(35);"=  ";:PRINT USING"##.#";C
1150  PRINT
1160  PRINT "TOTAL TRANSPORT RATE (KG/S.M)";TAB(37);"= ";:
```

```
     PRINT USING"##.##^^^";ST
1170  PRINT
1180  PRINT "CALCULATIONS FINISHED !"
1190  INPUT "DO YOU WANT TO RUN AGAIN (Y/N)": RUN$
1200  PRINT:PRINT
1210  IF RUN$ <> "Y" AND RUN$ <> "N" THEN GOTO 1190
1220  IF RUN$ = "Y" THEN GOTO 210
1230  IF RUN$ = "N" THEN GOTO 1240
1240  END
```

## Appendix V: The Nielsen formula

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

### Convective sediment transport

The convective sediment transport is computed as:

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

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:

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

in which:

$\overline{U*}$ = Current shear velocity [m/s]

$\kappa$ = Von Karman constant (= 0.4) [-]

$z0$ = Zero-velocity level [m]

$$z0 = Ks/30 \qquad (V-3)$$

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

$F$ = Dimensionless factor [-]

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

$$A1 = z0*F \qquad (V-4)$$

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

$$z1/z0 = F*\exp(1/F - 1) \qquad (V-5)$$

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

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

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

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

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:

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

in which:

| | | |
|---|---|---|
| $\Delta r$ | = Ripple height | [m] |
| RS | = Ripple steepness | [-] |
| D50 | = Grain diameter exceeded by 50% (by weight) of the bed material | [m] |
| $\theta'$ | = Skin friction shields parameter | [-] |

$$\theta' = 0.5*f_w'*(\hat{U}b^2/\Delta g D50) \qquad \text{(V-9)}$$

where: $f_w'$ = Skin friction coefficient [-]

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

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

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

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

in which:

$\bar{C}(z)$ = 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:

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

in which:

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

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

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 $\rho_s$.

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.

$$Umax = \overline{U*}/\sqrt{0.5*fw} + \hat{U}b \quad \text{(V-17)}$$

$$Umin = \overline{U*}/\sqrt{0.5*fw} - \hat{U}b \quad \text{(V-18)}$$

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

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

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

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

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):

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

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:

$$Scon = \left\{ \frac{Lcf^2*Cb*Af*\overline{U*}}{\kappa * Al} * (1 - \exp(-1.9*(Al/Lcf)^{0,79})) + \right.$$

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

(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.

Diffusive sediment transport
----------------------------

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:

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

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

$$Sdiff = Sf + Sb \qquad (V\text{-}32)$$

with: T = Wave period [s]

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

$$Stot = Scon + Sdiff \qquad (V\text{-}33)$$

List of \NIELSEN.BAS

```
10    REM **********
20    REM THIS PROGRAM CALCULATES THE SANDTRANSPORT
30    REM VIA THE NIELSEN METHOD
40    REM **********
50    FULLW 2: CLEARW 2
60    PRINT " CALCULATION OF THE BED LOAD TRANSPORT,"
70    PRINT " THE SUSPENDED LOAD TRANSPORT."
80    PRINT " AND THE TOTAL LOAD TRANSPORT"
90    PRINT " WITH THE NIELSEN METHOD."
100   PRINT:PRINT
110   PRINT " ";CHR$(189);" BY M.W.C. NIEUWJAAR"
120   PRINT " APRIL 1987"
130   PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
140   PRINT " PRESS [Return] IF YOU WANT THE NEXT PAGE"
150   PAGE$=CHR$(INP(2))
160   IF ASC(PAGE$)=13 THEN GOTO 170 ELSE GOTO 150
170   DEF FNTANH(X)=(EXP(2*X)-1)/(EXP(2*X)+1)
180   DEF FNSINH(X)=(EXP(X)-EXP(-X))/2
190   DEF FNCOSH(X)=(EXP(X)+EXP(-X))/2
200   PI=3.141592654
210   E=2.718281828
220   REM **********
230   REM INPUT
240   REM **********
250   CLEARW 2
260   PRINT "DO YOU WANT TO CALCULATE :"
270   PRINT "1) VIA THE RAYLEIGH DISTRIBUTION "
280   PRINT "2) VIA A CHARACTERISTIC WAVE HEIGHT "
290   PRINT
300   INPUT "PLEASE CHOOSE 1 OR 2 ";TELLER1
310   PRINT:PRINT
320   IF TELLER1=1 THEN GOTO 370
330   IF TELLER1=2 THEN GOTO 350
340   IF TELLER1<> 1 AND TELLER1<> 2 THEN GOTO 300
350   INPUT "WAVE HEIGHT (M)                              = ";H
360   IF H=0 THEN PRINT "THIS INPUT IS NOT ALLOWED, ";:
     PRINT "PLEASE CORRECT IT!": GOTO 350
370   INPUT "SIGNIFICANT WAVE HEIGHT (M)                  = ";HS
380   IF HS=0 THEN PRINT "THIS INPUT IS NOT ALLOWED, ";:
     PRINT "PLEASE CORRECT IT!": GOTO 370
390   INPUT "PEAK PERIOD (S)                              = ";TP
400   INPUT "DEPTH AVERAGED VELOCITY (M/S)                = ";UM
410   INPUT "WATER DEPTH TO MEAN BED (M)                  = ";H1
420   INPUT "DISTANCE RIPPLETOP TO MEAN BED (M)           = ";R
430   INPUT "W50 FALL VELOCITY OF BED MATERIAL (M/S) = ";W50
440   INPUT "D50 DIAMETER OF BED MATERIAL (M)             = ";D50
450   REM **********
460   REM CALCULATION
470   REM **********
480   CLEARW 2
490   PRINT "  PATIENCE PLEASE, I'M CALCULATING....."
500   PRINT:PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
510   FOR I=1 TO 10
520   READ N
530   Z(I)=N/100+R
540   NEXT I
550   RESTORE
560   SCON1=0: SDIFF1=0: STOT1=0: LT11=0: LT21=0
570   CB1=0: LC1=0: Z11=0: F1=0: UFW1=0: UFC1=0: PH1=0
580   SCON=0: SDIFF=0: STOT=0: LT1=0: LT2=0
590   CB=0: LC=0: Z1=0: F=0: UFW=0: UFC=0
```

```
600   DH=HS/20
610   RW=1000
620   RS=2650
630   LO=(9.81/(2*PI))*TP^2
640   HL1=0
650   HL1=HL1+0.01
660   IF SQR(HL1*FNTANH(2*PI*HL1))-SQR(H1/LO)*(1-UM*TP*HL1/H1)
     < 0 THEN GOTO 650
670   HL2=0
680   HL3=0.5*(HL1+HL2)
690   IF SQR(HL3*FNTANH(2*PI*HL3))-SQR(H1/LO)*(1-UM*TP*HL3/H1)
     < 0 THEN HL2=HL3: GOTO 710
700   HL1=HL3
710   IF ABS(SQR(HL3*FNTANH(2*PI*HL3))-SQR(H1/LO)*(1-UM*TP*HL3/H1))
     < 1E-5 THEN GOTO 720 ELSE GOTO 680
720   L=H1/HL3
730   CR=SQR((9.81*L/(2*PI))*FNTANH(2*PI*H1/L))
740   TPREL=L/CR
750   UBSIG=(PI*HS/TPREL)*(1/FNSINH(2*PI*H1/L))
760   OMEGA=2*PI/TPREL
770   ABSIG=UBSIG/OMEGA
780   FWSIG=EXP(5.213*((2.5*D50/ABSIG)^0.194)-5.977)
790   D=(RS-RW)/RW
800   PSISIG=(UBSIG^2)/(D*9.81*D50)
810   TETASIG=0.5*FWSIG*PSISIG
820   LR=ABSIG*(2.2-0.345*(PSISIG^0.34))
830   DR=ABSIG*(0.275-0.022*SQR(PSISIG))
840   RST=0.182-0.24*(TETASIG^1.5)
850   KS=8*RST*DR+190*D50*SQR(TETASIG-0.05)
860   Z0=KS/30
870   Z1=2*Z0
880   IF TELLER=2 THEN PH=1: GOTO 920
890   DEF FNP(H)=EXP(-2*((H/HS)^2))
900   H=DH
910   PH=FNP(0)-FNP(2*DH)
920   WHILE PH > 1E-4
930   UB=(PI*H/TPREL)*(1/FNSINH(2*PI*H1/L))
940   AB1=UB/OMEGA
950   FW1=EXP(5.213*((2.5*D50/AB1)^0.194)-5.977)
960   PSI=(UB^2)/(D*9.81*D50)
970   TETA1=0.5*FW1*PSI
980   IF KS/AB1 > 0.63 THEN FW=0.30 ELSE
     FW=EXP(5.213*((KS/AB1)^0.194)-5.977)
990   CB=0.005*(TETA1/(1-PI*RST)^2)^3
1000  CB=CB*RS
1010  UFW=SQR(0.5*FW)*UB
1020  IF UM=0 THEN Z1=Z0: UFC=0: F=1: GOTO 1110
1030  Z2=0
1040  WHILE ABS((Z2-Z1)/Z1) > 0.01
1050  Z2=(2*Z1+Z2)/3
1060  UFC=0.4*UM/LOG(H1/(E*Z2))
1070  F=1+((UFW/ABS(UFC))^3)/6
1080  Z1=Z0*F*EXP(1/F-1)
1090  WEND
1100  AL=F*Z0
1110  UMAX=(UFC/SQR(F/2))+UB
1120  UMIN=(UFC/SQR(F/2))-UB
1130  IF UMAX < 0 OR UMIN > 0 THEN REVERSAL$="N"
1140  AF=0.5*(UMAX/UB)^6
1150  AB=0.5*(UMIN/UB)^6
1160  RVF=UMAX/W50
1170  RVB=UMIN/W50
1180  LCF=DR*(0.2+1.24*EXP(-40/RVF^2))
```

```
1190  LCB=DR*(0.2+1.24*EXP(-40/RVB^2))
1200  LC=(LCF+LCB)/2
1210  IF UM=0 THEN SCON=0: GOTO 1250
1220  SCON=2.5*UFC*CB*AF*(LCF^2)*(1-EXP(-1.9*(AL/LCF)^0.79))/AL
1230  SCON=SCON+2.5*UFC*CB*AB*(LCB^2)*(1-EXP(-1.9*(AL/LCB)^0.79))/AL
1240  SCON=SCON*EXP(1.1*ABS(UFC)/W50)
1250  IF REVERSAL$="N" THEN SDIFF=0: GOTO 1310
1260  TSRF=OMEGA*LCF/W50
1270  TSRB=OMEGA*LCB/W50
1280  SF=-AF*CB*UB*LCF*TSRF/(1+TSRF^2)
1290  SB=AB*CB*UB*LCB*TSRB/(1+TSRB^2)
1300  SDIFF=SF+SB
1310  STOT=SCON+SDIFF
1320  LT1=CB*LC*(1-EXP(-H1/LC))
1330  IF UM=0 THEN GOTO 1350
1340  LT2=(CB*LC/(1-0.4*ABS(UFC)/W50))*
     (1-((LC/(LC+0.4*ABS(UFC)*H1/W50))^((W50/(0.4*ABS(UFC)))-1)))
1350  SCON1=SCON1+SCON*PH: SDIFF1=SDIFF1+SDIFF*PH: STOT1=STOT1+STOT*PH
1360  LT11=LT11+LT1*PH: LT21=LT21+LT2*PH: CB1=CB1+CB*PH
1370  LC1=LC1+LC*PH: Z11=Z11+Z1*PH: F1=F1+F*PH
1380  UFW1=UFW1+UFW*PH: UFC1=UFC1+UFC*PH: PH1=PH1+PH
1390  H=H+2*DH
1400  IF TELLER=2 THEN PH=0: GOTO 1430
1410  PH=FNP(H-DH)-FNP(H+DH)
1420  REVERSAL$="Y"
1430  WEND
1440  SCON=SCON1/PH1: SDIFF=SDIFF1/PH1: STOT=STOT1/PH1: LT1=LT11/PH1
1450  LT2=LT21/PH1: CB=CB1/PH1: LC=LC1/PH1: Z1=Z11/PH1
1460  F=F1/PH1: UFW=UFW1/PH1: UFC=UFC1/PH1
1470  DEF FNC1(I)=CB*EXP(-Z(I)/LC)
1480  IF UM=0 THEN F=1: GOTO 1500
1490  DEF FNC2(I)=CB*(LC/(LC+0.4*ABS(UFC)*Z(I)/W50))^(W50/(0.4*ABS(UFC)))
1500  DEF FNU1(I)=(2.5*UFC/F)*(Z(I)/Z0-1)
1510  DEF FNU2(I)=2.5*UFC*LOG(Z(I)/Z1)
1520  AL=F*Z0
1530  REM **********
1540  REM OUTPUT
1550  REM **********
1560  PRINT CHR$(7): REM BELL SIGNAL
1570  CLEARW 2
1580  PRINT "RIPPLE HEIGHT (M)";TAB(43);"= ";:
     PRINT USING"##.##^^";DR
1590  PRINT "RIPPLE LENGTH (M)";TAB(43);"= ";:
     PRINT USING"##.##^^";LR
1600  PRINT "RIPPLE STEEPNESS (-)";TAB(43);"= ";:
     PRINT USING"##.##";RST
1610  PRINT "BED ROUGNESS (M)";TAB(43);"= ";:
     PRINT USING"##.##^^";KS
1620  PRINT "WAVE FRICTION VELOCITY (M/S)";TAB(43);"= ";:
     PRINT USING"##.###";UFW
1630  PRINT "CURRENT FRICTION VELOCITY (M/S)";TAB(43);"= ";:
     PRINT USING"##.###";UFC
1640  PRINT "ZERO INTERCEPT Z0 (M)";TAB(43);"= ";:
     PRINT USING"##.##^^";Z0
1650  PRINT "ZERO INTERCEPT Z1 (M)";TAB(43);"= ";:
     PRINT USING"##.##^^";Z1
1660  PRINT
1670  PRINT "TOTAL LOAD (KG/M";CHR$(253);")";TAB(42);"= ";:
     PRINT USING"##.##^^";LT1
1680  IF UM=0 THEN GOTO 1700
1690  PRINT "TOTAL LOAD ADAPTED CONCENTRATION (KG/M";CHR$(253);")";
     TAB(42);"= ";: PRINT USING"##.##^^";LT2
1700  PRINT
```

```
1710  PRINT "CONVECTIVE TOTAL TRANSPORT RATE (KG/S.M)";TAB(43);"= "::
     PRINT USING"##.##^^^";SCON
1720  PRINT "DIFFUSIVE TOTAL TRANSPORT RATE (KG/S.M)";TAB(43);"= ";:
     PRINT USING"##.##^^^";SDIFF
1730  PRINT "TOTAL TRANSPORT RATE (KG/S.M)";TAB(43);"= ";:
     PRINT USING"##.##^^^";STOT
1740  PRINT
1750  PRINT "PRESS [Return] IF YOU WANT THE NEXT PAGE"
1760  PAGE$=CHR$(INP(2))
1770  IF ASC(PAGE$)=13 THEN GOTO 1780 ELSE GOTO 1760
1780  CLEARW 2
1790  PRINT "BOTTOM CONCENTRATION (KG/M";CHR$(254);")";
     TAB(42);"= ";: PRINT USING"##.####";CB
1800  PRINT "LENGTH SCALE CONCENTRATION (M)";TAB(43);"= ";:
     PRINT USING"##.##^^^";LC
1810  PRINT
1820  PRINT " NO.";SPC(4);"REL. HEIGHT";SPC(4);"HEIGHT";SPC(4);
     "CONCENTRATION";
1830  IF UM=0 THEN PRINT " "; ELSE PRINT SPC(5);"ADAPTED";
1840  PRINT SPC(5);"VELOCITY"
1850  IF UM <> 0 THEN PRINT SPC(48);"CONCENTRATION"
1860  PRINT "  (-)";SPC(8);"(-)";SPC(10);"(M)";SPC(8);
     "(KG/M";CHR$(254);")";
1870  IF UM=0 THEN PRINT SPC(3); ELSE PRINT SPC(7);
     "(KG/M";CHR$(254);")";
1880  PRINT SPC(8);"(M/S)"
1890  PRINT
1900  FOR I=1 TO 10
1910  PRINT TAB(2);:PRINT USING"##";I;:PRINT SPC(7);:
     PRINT USING"##.###";Z(I)/H1;:PRINT SPC(7);:PRINT USING"##.###";Z(I);:
    PRINT SPC(7);:PRINT USING"##.####";FNC1(I);
1920  IF UM=0 THEN PRINT SPC(3);: GOTO 1940
1930  PRINT SPC(7);:PRINT USING"##.####";FNC2(I);
1940  PRINT SPC(7);
1950  IF Z(I) <= AL THEN PRINT USING"##.###";FNU1(I) ELSE
     PRINT USING"##.###";FNU2(I)
1960  NEXT I
1970  PRINT
1980  PRINT "CALCULATIONS FINISHED !"
1990  INPUT "DO YOU WANT TO RUN AGAIN (Y/N)"; RUN$
2000  PRINT:PRINT
2010  IF RUN$ <> "Y" AND RUN$ <> "N" THEN GOTO 1990
2020  IF RUN$ = "Y" THEN GOTO 250
2030  IF RUN$ = "N" THEN GOTO 2050
2040  DATA 1,2,3,4.5,7,11,17,23,29,36
2050  END
```

## Appendix VI: Determination of $\overline{U*}$ in the Nielsen method

Nielsen uses a modified logarithmic velocty distribution:

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

The depth-averaged velocity can be computed from this distribution as:

$$Um = \frac{1}{h} \int_{z=z0}^{z0*F} \frac{\overline{U*}}{\kappa*F}*\left[\frac{z}{z0} - 1\right] dz + \int_{z=z0*F}^{h} \frac{\overline{U*}}{\kappa}*Ln\left[\frac{z}{z1}\right] dz$$

$$= \frac{\overline{U*}}{h*\kappa*F} \left| \frac{z}{2*z0} - z \right|_{z0}^{z0*F} + \frac{\overline{U*}}{\kappa*h} \left| z*Ln\left[\frac{z}{z1}\right] - z \right|_{z0*F}^{h}$$

$$= \frac{\overline{U*}}{\kappa*h}*\left[\frac{z0*F}{2} - z0 + \frac{z0}{2*F} + h*Ln\left[\frac{h}{z1}\right] - h - z0*F*Ln\left[\frac{z0*F}{z1}\right] + z0*F\right] \quad (VI-1)$$

Using Eq. (V-5): $(z1/z0) = F*exp(1/F - 1)$

$\Rightarrow Ln(zo*F/z1) = 1 - 1/F$

$\Rightarrow z0*F*Ln(z0*F/z1) = z0*F - z0$

Substituting this last expression into Eq. (V-1) leads to:

$$Um = \frac{\overline{U*}}{\kappa*h}*\left[\frac{z0*F}{2} - z0 + \frac{z0}{2*F} + h*Ln\left[\frac{h}{z1}\right] - h - z0*F + z0 + z0*F\right]$$

$$= \frac{\overline{U*}}{h*\kappa}*\left[\frac{z0}{2}*(F + 1/F) - h + h*Ln\left[\frac{h}{z1}\right]\right]$$

Because F is of magnitude 10, z0 is of magnitude $10^{-3}$ [m] and h is of magnitude 0.5 [m], the term 0.5*z0*(F + 1/F) can be neglected compared with h, therefore:

$$Um \simeq \frac{\overline{U*}}{h*\kappa}*\left[h*Ln\left[\frac{h}{z1}\right] - h\right]$$

$$= \frac{\overline{U*}}{h*\kappa}*h*Ln\left[\frac{h}{e*z1}\right]$$

$$= \frac{\overline{U*}}{\kappa}*Ln\left[\frac{h}{e*z1}\right] \qquad \text{(VI-2)}$$

In this last equation, $\overline{U*}$ and z1 are unknown. These parameters can be calculated as follows:

1) Estimate z1

2) Calculate $\overline{U*}$ from Eq. (VI-2) : $\overline{U*} = \kappa*Um/Ln(h/(e*z1))$

3) Calculate the factor F from Eq. (V-6) : $F = 1 + (\tilde{U*}/|\overline{U*}|)^3/6$

4) Calculate z1 from Eq. (V-5) : $(z1/z0) = F*exp(1/F - 1)$

Repeat items 2 to 4 until z1 and $\overline{U*}$ have the required accuracy.

## Appendix VII: Adapted Nielsen concentration profile

In case of waves in combination with a current, Nielsen suggested to use an adapted mixing length scale:

$$Lc(z') = Lc + \frac{X*|\overline{U*}|*z'}{W50} = Lc + X*z' \qquad (VII-1)$$

in which Lc is the mixing length scale for waves alone (see appendix V). With this adapted vertical length scale, the concentration at height z can be calculated from:

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

$$= Cb*exp\left\{-\int_{z'=0}^{z} \frac{1}{Lc + X*z'} dz'\right\} \qquad (VII-2)$$

The integral in Eq. (VII-2) can be solved by substituting t = Lc + X*z'. This substitution leads to:

$$\int_{z'=0}^{z} \frac{1}{Lc + X*z'} dz' = \int_{t=Lc}^{Lc + X*z} \frac{1}{t*X} dt$$

$$= \frac{1}{X}*Ln\left[\frac{Lc + X*z}{Lc}\right] \qquad (VII-3)$$

Substitution of Eq. (VII-3) in Eq. (VII-2) leads to:

$$\overline{C}(z) = Cb*\exp\left\{\frac{-1}{X}*Ln\left[\frac{Lc + X*z}{Lc}\right]\right\}$$

$$= Cb*\left[\frac{Lc}{Lc + X*z}\right]^{1/X} \qquad (VII-4)$$

## Appendix VIII: Loads with the Nielsen method

The total loads are computed from:

$$Lt = \int_{z=0}^{h} \bar{C}(z)\, dz$$

Substitution of the normal concentration profile Eq. (V-14) leads to:

$$Lt = \int_{z=0}^{h} Cb*\exp(-z/Lc)\, dz$$

$$= \Big| -Cb*Lc.\exp(-z/Lc) \Big|_{0}^{h}$$

$$= -Cb*Lc*\exp(-h/Lc) + Cb*Lc$$

$$= Cb*Lc*(1 - \exp(-h/Lc) \qquad \text{(VIII-1)}$$

Substitution of the adapted concentration profile Eq. (V-24) leads to:

$$Lt = \int_{z=0}^{h} Cb*\left[\frac{Lc}{Lc + X*z}\right]^{1/X} dz$$

This integral can be solved by substitution of t = Lc + X*z:

$$Lt = \int_{t=Lc}^{Lc + X*h} \frac{Cb}{X} * \left[\frac{Lc}{t}\right]^{1/X} dt$$

$$= Lc^{1/X} * \frac{Cb}{X} * \left|\frac{t^{-1/X - 1}}{1 - 1/X}\right|_{Lc}^{Lc + X*h}$$

$$= \frac{Cb*Lc}{1 - X} * \left[1 - \left[\frac{Lc}{Lc + X*h}\right]^{1/X - 1}\right] \qquad \text{(VIII-2)}$$

## Appendix IX: Modification of the bed load layer thickness in the Bijker method

The bed layer concentration Cb is assumed to be constant over the bed load layer thickness b $(=\frac{1}{2}\overline{\Delta r})$:

$$Cb = \frac{Sb}{\int_{z=0}^{b} U(z)\, dz} \qquad (IX-1)$$

The velocities in the bed load layer are approximated by a logarithmic velocity distribution:

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

Below the elevation z0 this distribution leads to negative and therefore unrealistic velocities. The velocities near the bed are described by a lineair velocity profile from the origin (z = 0, U(z) = 0) tangent to the profile described by Eq. (II-15). For the point of tangency it holds:

$$zt = e*z0 = e*Ks/33 \qquad (IX-2)$$

For the velocity at this elevation it holds:

$$Ut = (1/\kappa)*\sqrt{(Tc/\rho)} \qquad (IX-3)$$

Using Eqs. (IX-2) and (IX-3), the integral in Eq. (IX-1) can be solved:

$$\int_{z=0}^{b} U(z)\,dz = \int_{z=0}^{zt} \frac{Ut*z}{zt}\,dz + \int_{z=zt}^{b} \frac{U*}{\kappa}*Ln\left[\frac{z}{z0}\right] dz$$

$$= \left|\frac{Ut*z}{2\ zt}\right|_{0}^{zt} + \frac{U*}{\kappa}*\left|z*Ln\left[\frac{z}{z0}\right] - z\right|_{zt}^{b}$$

$$= \frac{zt*Ut}{2} + \frac{U*}{\kappa}*\left[b*Ln\left[\frac{b}{z0}\right] - b - zt*Ln\left[\frac{zt}{z0}\right] + zt\right]$$

$$= \frac{zt*Ut}{2} + \frac{U*}{\kappa}*\left[b*Ln\left[\frac{b}{z0}\right] - b - zt*Ln(e) + zt\right]$$

$$= \frac{zt*Ut}{2} + \frac{U*}{\kappa}*b*\left[Ln\left[\frac{33b}{Ks}\right] - 1\right]$$

$$= \frac{e*Ks}{66\,\kappa}*\sqrt{\frac{Tc}{\rho}} + \frac{b}{\kappa}*\sqrt{\frac{Tc}{\rho}}*\left[Ln\left[\frac{33b}{Ks}\right] - 1\right]$$

$$= 0.10*Ks*\sqrt{\frac{Tc}{\rho}} + 2.5*b*\sqrt{\frac{Tc}{\rho}}*\left[Ln\left[\frac{33b}{Ks}\right] - 1\right] \qquad (IX-4)$$

Substitution of Eq. (IX-4) in Eq. (IX-1) leads to:

$$Cb = \frac{Sb}{\sqrt{(Tc/\rho)}*\{0.10*Ks + 2.5*b*(Ln(33b/Ks) - 1)\}} \qquad (IX-5)$$

Substitution of b = Ks leads to Eq. (II-13)

The suspended transport is computed via Eq. (II-14). Substitution of velocity profile Eq. (II-15) and the concentration profile Eq. (II-17), with bed load layer b instead of Ks, leads to:

$$Ss = 11.6*\sqrt{(Tc/\rho)}*b*Cb*(I1*Ln(33h/Ks) + I2) \quad (IX-6)$$

Substitution Eq. (IX-5) leads to:

$$Ss = \frac{11.6*b}{0.10*Ks + 2.5*b*(Ln(33b/Ks) - 1)}*(I1*Ln(33h/Ks) + I2)*Sb \quad (IX-7)$$

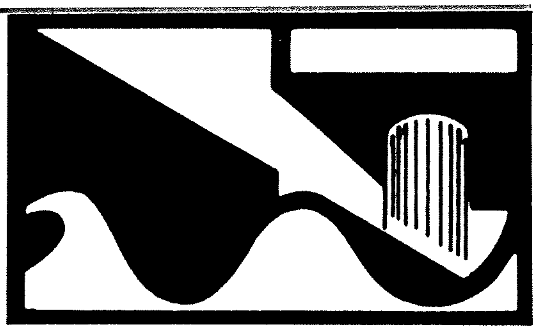
Substitution of b = Ks leads to Eq. (II-19)

# Sediment concentrations and sediment transport in case of irregular non-breaking waves with a current

Part B: Tables and Figures

October 1987

Th. van der Kaaij / M.W.C. Nieuwjaar



delft hydraulics

TU Delft

Delft University of Technology

**Faculty of Civil Engineering**
Hydraulic and Geotechnical Engineering Group
Coastal Engineering Division

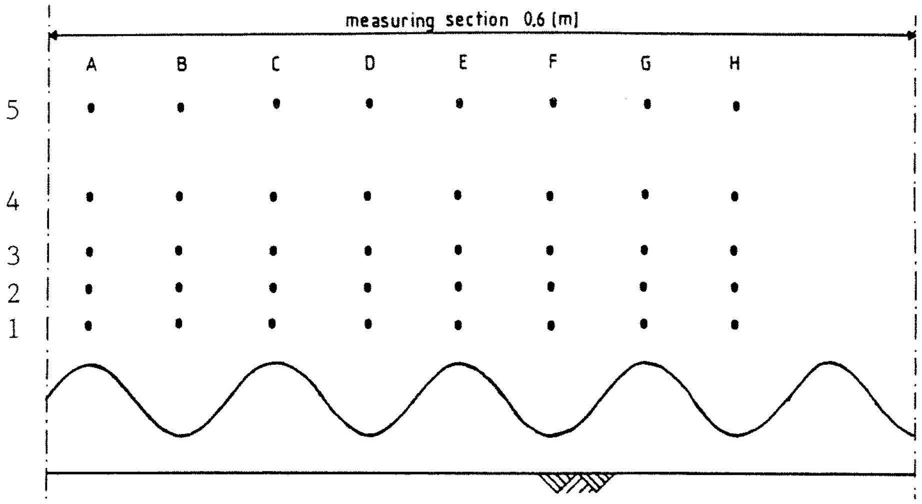
# SEDIMENT CONCENTRATIONS AND SEDIMENT TRANSPORT IN CASE OF IRREGULAR NON-BREAKING WAVES WITH A CURRENT

## Part B: Tables and Figures

Delft University of Technology - Delft Hydraulics

| time [min.] | At 0.015 [m] above mean bed level: conc. [mg/l] | averaged conc. [mg/l] | (C60-Ct)/C60 * 100% | At 0.035 [m] above mean bed level: conc. [mg/l] | averaged conc. [mg/l] | (C60-Ct)/C60 * 100% |
|---|---|---|---|---|---|---|
| 0-3 | 204.27 | 204.27 | 7.4 % | 88.62 | 88.62 | 4.4 % |
| 3-6 | 306.41 | 255.34 | 15.8 % | 93.28 | 90.95 | 7.1 % |
| 6-9 | 233.45 | 248.04 | 12.4 % | 88.62 | 90.17 | 6.2 % |
| 12-15 | 226.16 | 239.29 | 8.5 % | 79.29 | 84.89 | 0 % |
| 15-18 | 262.64 | 243.18 | 10.2 % | 130.60 | 92.51 | 9.0 % |
| 18-21 | 145.91 | 229.29 | 3.9 % | 74.63 | 89.95 | 6.0 % |
| 21-24 | 313.70 | 239.84 | 8.7 % | 130.60 | 95.03 | 11.9 % |
| 24-27 | 153.20 | 230.21 | 4.4 % | 51.31 | 90.18 | 6.2 % |
| 27-30 | 218.86 | 229.08 | 3.9 % | 65.30 | 87.69 | 3.3 % |
| 30-33 | 87.55 | 216.21 | 2.0 % | 27.99 | 82.26 | 3.1 % |
| 33-36 | 306.41 | 223.73 | 1.4 % | 121.27 | 85.51 | 0.7 % |
| 36-39 | 306.41 | 230.09 | 4.3 % | 116.60 | 87.90 | 3.6 % |
| 39-42 | 204.27 | 228.24 | 3.5 % | 88.62 | 87.95 | 3.6 % |
| 42-45 | 124.02 | 221.29 | 0.3 % | 46.64 | 85.20 | 0.4 % |
| 45-48 | 240.75 | 222.51 | 0.9 % | 93.28 | 85.71 | 1.0 % |
| 48-51 | 136.61 | 217.46 | 1.4 % | 23.32 | 82.04 | 3.4 % |
| 51-54 | 306.41 | 222.40 | 0.8 % | 139.93 | 85.25 | 0.4 % |
| 54-57 | 248.05 | 223.75 | 1.4 % | 102.61 | 86.17 | 1.5 % |
| 57-60 | 160.50 | 220.59 | 0 % | 60.63 | 84.89 | 0 % |

Table 2.1: Suction time dependence of time-averaged concentrations




| suction level [-] | conc. top A [mg/l] | conc. trough B [mg/l] | conc. top C [mg/l] | conc. trough D [mg/l] | conc. top E [mg/l] | conc. trough F [mg/l] | conc. top G [mg/l] | conc. trough H [mg/l] |
|---|---|---|---|---|---|---|---|---|
| 1 | 365 | 286 | 321 | 278 | 443 | 365 | 408 | 304 |
| 2 | 203 | 177 | 164 | 164 | 259 | 236 | 190 | 203 |
| 3 | 128 | 132 | 87 | 114 | 153 | 178 | 96 | 153 |
| 4 | 54 | 70 | 38 | 53 | 54 | 88 | 44 | 79 |
| 5 | 13 | 22 | 9 | 9 | 11 | 28 | 11 | 28 |

Table 2.2 A: Concentrations measured with a non-moving carriage.

| suction level | oscillating carriage | averaged over locations A to G | | | relative conc. difference |
|---|---|---|---|---|---|
| | bed-averaged concentration [mg/l] | mean conc. [mg/l] | standard deviation [mg/l] | relative standard deviation | |
| 1 | 352 | 346 | 59 | 17 % | 1.7 % |
| 2 | 197 | 200 | 34 | 17 % | -1.5 % |
| 3 | 132 | 130 | 31 | 24 % | 1.5 % |
| 4 | 66 | 60 | 17 | 29 % | 8.8 % |
| 5 | 20 | 17 | 8 | 49 % | 19.0 % |

Table 2.2 B: Comparison of concentrations measured with an oscillating carriage and concentrations measured with a non moving carriage, averaged over different locations.

| Sample | volume meter | | | under water balance | $\frac{Mv - Mu}{Mv} * 100\%$ |
|---|---|---|---|---|---|
| | calibrated cilinder | reading [mm] | dry mass Mv [mg] | dry mass Mu [mg] | |
| 1 | 10 | 2 | 25 | 22 | 12.0 % |
| 2 | 10 | 2.5 | 31 | 31 | 0 % |
| 3 | 10 | 6 | 74 | 77 | -4.1 % |
| 4 | 10 | 8 | 99 | 106 | -7.1 % |
| 5 | 10 | 31 | 383 | 384 | -0.2 % |
| 6 | 10 | 47 | 582 | 568 | 2.4 % |
| 7 | 10 | 67 | 831 | 802 | 3.5 % |
| 8 | 10 | 86 | 1066 | 1066 | 0 % |
| 9 | 8 | 45 | 1255 | 1262 | -0.6 % |
| 10 | 10 | 125 | 1551 | 1626 | -4.8 % |
| 11 | 9 | 145 | 2808 | 3057 | -8.8 % |
| 12 | 7 | 97 | 4220 | 4407 | -4.4 % |
| 13 | 6 | 97 | 5588 | 5410 | 3.2 % |

Table 2.3 : Comparison of volume meter with under water balance.

| Experiment no. | Water depth to mean bed h [m] | Significant wave height Hs [m] | Peak period Tp [s] | Depth-averaged velocity Um [m/s] | Median size diameter D50 [μm] |
|---|---|---|---|---|---|
| T 7.5 0 | 0.509 | 0.077 | 2.49 | ***** | 201 |
| T 7.5 10 | 0.512 | 0.076 | 2.63 | 0.117 | 201 |
| T 7.5 20 | 0.510 | 0.074 | 2.40 | 0.226 | 203 |
| T 7.5 40 | 0.502 | 0.076 | 2.44 | 0.449 | 203 |
| T 9 0 | 0.510 | 0.090 | 2.43 | ***** | 201 |
| T 10 0 | 0.504 | 0.101 | 2.48 | ***** | 201 |
| T 10 10 | 0.515 | 0.106 | 2.62 | 0.118 | 205 |
| T 10 -10 | 0.494 | 0.098 | 2.48 | -0.128 | 209 |
| T 10 20 | 0.509 | 0.099 | 2.48 | 0.219 | 212 |
| T 10 -20 | 0.494 | 0.096 | 2.46 | -0.228 | 209 |
| T 10 40 | 0.511 | 0.098 | 2.60 | 0.449 | 205 |
| T 10 -40 | 0.495 | 0.101 | 2.51 | -0.453 | 206 |
| T 12 0 | 0.524 | 0.122 | 2.42 | ***** | 208 |
| T 12 10 | 0.519 | 0.121 | 2.50 | 0.093 | 208 |
| T 12 -10 | 0.497 | 0.115 | 2.49 | -0.116 | 212 |
| T 12 20 | 0.509 | 0.123 | 2.59 | 0.220 | 203 |
| T 12 -20 | 0.490 | 0.116 | 2.51 | -0.233 | 206 |
| T 12 40 | 0.509 | 0.119 | 2.45 | 0.443 | 204 |
| T 12 -40 | 0.497 | 0.118 | 2.62 | -0.442 | 200 |
| T 15 0 | 0.503 | 0.153 | 2.45 | ***** | 205 |
| T 15 10 | 0.503 | 0.146 | 2.37 | 0.107 | 218 |
| T 15 -10 | 0.498 | 0.149 | 2.49 | -0.132 | 223 |
| T 15 20 | 0.511 | 0.151 | 2.41 | 0.222 | 211 |
| T 15 -20 | 0.491 | 0.147 | 2.52 | -0.232 | 205 |
| T 15 -40 | 0.509 | 0.146 | 2.47 | -0.437 | 200 |
| T 17.5 -20 | 0.498 | 0.177 | 2.53 | -0.227 | 205 |
| T 18.5 -40 | 0.515 | 0.186 | 2.39 | -0.429 | 211 |

Table 2.4 : Summary of experimental data

EXPERIMENT NO. : T0,40
WATERTEMPERATURE T (°C) : 22

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | — | — | — |
| ZERO-CROSS PERIOD Tz (s) | — | — | — |
| PEAK PERIOD Tp (s) | — | — | — |
| RATIO $H_{1\%}$/Hs (-) | — | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.507 | — | — |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.445 | — | — |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.019 | 0.010 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.108 | 0.028 |
| RIPPLE VELOCITY $u_r$ (m/s) | $1.09\times10^{-4}$ (IN CURRENT DIRECTION) | $3.83\times10^{-5}$ |
| RIPPLE SHAPE | 3 DIMENSIONAL CURRENT DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.507) | | | TEST 2 (h (m) = — ) | | | TEST 3 (h (m) = — ) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.041 | 0.1730 | 0.265 | — | — | — | — | — | — | — | — |
| 2 | 0.061 | 0.1080 | 0.293 | — | — | — | — | — | — | — | — |
| 3 | 0.081 | 0.0861 | 0.324 | — | — | — | — | — | — | — | — |
| 4 | 0.110 | 0.0522 | 0.339 | — | — | — | — | — | — | — | — |
| 5 | 0.160 | 0.0315 | 0.378 | — | — | — | — | — | — | — | — |
| 6 | 0.239 | 0.0148 | 0.404 | — | — | — | — | — | — | — | — |
| 7 | 0.357 | 0.0084 | 0.452 | — | — | — | — | — | — | — | — |
| 8 | 0.475 | 0.0030 | 0.489 | — | — | — | — | — | — | — | — |
| 9 | 0.591 | 0.0014 | 0.497 | — | — | — | — | — | — | — | — |
| 10 | 0.792 | 0.0007 | 0.496 | — | — | — | — | — | — | — | — |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.041 | 0.021 | 0.1730 | 0.1730 | 0.1730 | 0.265 | 0.265 | 0.265 |
| 2 | 0.061 | 0.031 | 0.1080 | 0.1080 | 0.1080 | 0.293 | 0.293 | 0.293 |
| 3 | 0.081 | 0.041 | 0.0861 | 0.0861 | 0.0861 | 0.324 | 0.324 | 0.324 |
| 4 | 0.110 | 0.056 | 0.0522 | 0.0522 | 0.0522 | 0.339 | 0.339 | 0.339 |
| 5 | 0.160 | 0.081 | 0.0315 | 0.0315 | 0.0315 | 0.378 | 0.378 | 0.378 |
| 6 | 0.239 | 0.121 | 0.0148 | 0.0148 | 0.0148 | 0.404 | 0.404 | 0.404 |
| 7 | 0.357 | 0.181 | 0.0084 | 0.0084 | 0.0084 | 0.452 | 0.452 | 0.452 |
| 8 | 0.475 | 0.241 | 0.0030 | 0.0030 | 0.0030 | 0.489 | 0.489 | 0.489 |
| 9 | 0.591 | 0.301 | 0.0014 | 0.0014 | 0.0014 | 0.497 | 0.497 | 0.497 |
| 10 | 0.792 | 0.401 | 0.0007 | 0.0007 | 0.0007 | 0.496 | 0.496 | 0.496 |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.8\times10^{-3}$ |
| 1 | $22.7\times10^{-3}$ |
| 2 | $17.9\times10^{-3}$ |
| 3 | $17.0\times10^{-3}$ |
| 4 | $16.4\times10^{-3}$ |
| 5 | $15.0\times10^{-3}$ |
| 6 TO 10 | $14.0\times10^{-3}$ |
| MIXTURE | $19.1\times10^{-3}$ |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $149\times10^{-6}$ |
| $D_{50}$ | $204\times10^{-6}$ |
| $D_{90}$ | $311\times10^{-6}$ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $2.75\times10^{-3}$ | $2.75\times10^{-3}$ | $2.75\times10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $8.96\times10^{-3}$ | $8.96\times10^{-3}$ | $8.96\times10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $1.17\times10^{-2}$ | $1.17\times10^{-2}$ | $1.17\times10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $1.97\times10^{-3}$ | $7.25\times10^{-4}$ | $3.22\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.90\times10^{-3}$ | $2.90\times10^{-3}$ | $2.90\times10^{-3}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $4.87\times10^{-3}$ | $3.63\times10^{-3}$ | $6.12\times10^{-3}$ |

} IN CURRENT DIRECTION

Table 3.1 A : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T7½,0 |
| WATERTEMPERATURE T (°C) | : 21.5 |

**WAVE AND CURRENT PARAMETERS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.077 | 0.075 | 0.079 |
| ZERO-CROSS PERIOD Tz (s) | 2.06 | 2.04 | 2.09 |
| PEAK PERIOD Tp (s) | 2.49 | 2.44 | 2.57 |
| RATIO $H_{1\%}/Hs$ (-) | 1.48 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.509 | 0.505 | 0.513 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | — | — | — |

**RIPPLE PARAMETERS**

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.015 | 0.004 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.090 | 0.016 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+1.66\times10^{-6}$ | $1.11\times10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL<br>WAVE DOMINATED | |

**CONCENTRATIONS AND VELOCITIES**

| | TEST 1 (h (m) = 0.513) | | | TEST 2 (h (m) = 0.509) | | | TEST 3 (h (m) = 0.505) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.033 | 0.0261 | — | 0.031 | 0.0392 | — | 0.034 | 0.0271 | — | — | — |
| 2 | 0.053 | 0.0112 | — | 0.051 | 0.0168 | — | 0.053 | 0.0112 | — | — | — |
| 3 | 0.072 | 0.0047 | — | 0.071 | 0.0075 | — | 0.073 | 0.0047 | — | — | — |
| 4 | 0.101 | 0.0009 | — | 0.100 | 0.0028 | — | 0.103 | 0.0009 | — | — | — |
| 5 | 0.150 | 0 | — | 0.149 | 0 | — | 0.152 | 0 | — | — | — |
| 6 | 0.228 | 0 | — | 0.228 | 0 | — | 0.232 | 0 | — | — | — |
| 7 | 0.345 | 0 | — | 0.346 | 0 | — | 0.350 | 0 | — | — | — |
| 8 | 0.462 | 0 | — | 0.464 | 0 | — | 0.469 | 0 | — | — | — |
| 9 | 0.579 | 0 | — | 0.582 | 0 | — | 0.588 | 0 | — | — | — |
| 10 | 0.715 | 0 | — | 0.719 | 0 | — | 0.727 | 0 | — | — | — |

**COMBINATION OF TEST 1, 2 AND 3**

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.017 | 0.0306 | 0.0263 | 0.0373 | — | — | — |
| 2 | 0.052 | 0.027 | 0.0132 | 0.0117 | 0.0162 | — | — | — |
| 3 | 0.072 | 0.037 | 0.0057 | 0.0047 | 0.0073 | — | — | — |
| 4 | 0.101 | 0.052 | 0.0016 | 0.0009 | 0.0027 | — | — | — |
| 5 | 0.150 | 0.077 | 0 | 0 | 0 | — | — | — |
| 6 | 0.229 | 0.117 | 0 | 0 | 0 | — | — | — |
| 7 | 0.347 | 0.177 | 0 | 0 | 0 | — | — | — |
| 8 | 0.465 | 0.237 | 0 | 0 | 0 | — | — | — |
| 9 | 0.583 | 0.297 | 0 | 0 | 0 | — | — | — |
| 10 | 0.720 | 0.367 | 0 | 0 | 0 | — | — | — |

**FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL**

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.0\times10^{-3}$ |
| 1 | $(25.8\times10^{-3})$ |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | $24.4\times10^{-3}$ |

**PARTICLE DIAMETER BED MATERIAL (m)**

| | |
|---|---|
| $D_{10}$ | $151\times10^{-6}$ |
| $D_{50}$ | $201\times10^{-6}$ |
| $D_{90}$ | $279\times10^{-6}$ |

**LOADS AND TRANSPORTS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $6.89\times10^{-4}$ | $6.14\times10^{-4}$ | $7.76\times10^{-4}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $7.99\times10^{-4}$ | $7.00\times10^{-4}$ | $9.73\times10^{-4}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $1.49\times10^{-3}$ | $1.31\times10^{-3}$ | $1.75\times10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $2.37\times10^{-5}$ | $6.65\times10^{-6}$ | $4.08\times10^{-5}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | — | — | — |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | — | — | — |

Table 3.1 B : Basic measuring data

EXPERIMENT NO. : T7½,10
WATERTEMPERATURE T (°C) : 22

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.076 | 0.075 | 0.077 |
| ZERO-CROSS PERIOD Tz (s) | 2.08 | 2.02 | 2.14 |
| PEAK PERIOD Tp (s) | 2.63 | 2.61 | 2.64 |
| RATIO $H_{1\%}/H_s$ (-) | 1.50 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.512 | 0.512 | 0.512 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.113 | 0.109 | 0.116 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.016 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.093 | 0.014 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+2.69\times10^{-7}$ | $3.31\times10^{-7}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.512) | | | TEST 2 (h (m) = 0.512) | | | TEST 3 (h (m) = 0.512) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.033 | 0.0233 | 0.029 | 0.027 | 0.0299 | 0.035 | 0.027 | 0.0299 | 0.033 | 0.014 | 0.043 |
| 2 | 0.053 | 0.0112 | 0.040 | 0.047 | 0.0112 | 0.047 | 0.047 | 0.0112 | 0.047 | 0.024 | 0.044 |
| 3 | 0.072 | 0.0037 | 0.058 | 0.066 | 0.0047 | 0.056 | 0.066 | 0.0047 | 0.063 | 0.034 | 0.051 |
| 4 | 0.102 | 0.0009 | 0.067 | 0.096 | 0.0009 | 0.065 | 0.096 | 0.0009 | 0.074 | 0.049 | 0.054 |
| 5 | 0.150 | 0 | 0.074 | 0.145 | 0 | 0.094 | 0.145 | 0 | 0.075 | 0.074 | 0.104 |
| 6 | 0.229 | 0 | 0.111 | 0.223 | 0 | 0.105 | 0.223 | 0 | 0.111 | 0.114 | 0.105 |
| 7 | 0.346 | 0 | 0.119 | 0.340 | 0 | 0.120 | 0.340 | 0 | 0.102 | 0.174 | 0.119 |
| 8 | 0.463 | 0 | 0.124 | 0.457 | 0 | 0.124 | 0.457 | 0 | 0.138 | 0.234 | 0.173 |
| 9 | 0.580 | 0 | 0.130 | 0.574 | 0 | 0.132 | 0.574 | 0 | 0.141 | 0.294 | 0.130 |
| 10 | 0.717 | 0 | 0.122 | 0.711 | 0 | 0.130 | 0.711 | 0 | 0.133 | 0.364 | 0.124 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.029 | 0.015 | 0.0273 | 0.0257 | 0.0280 | 0.032 | 0.027 | 0.036 |
| 2 | 0.049 | 0.025 | 0.0116 | 0.0105 | 0.0136 | 0.045 | 0.038 | 0.049 |
| 3 | 0.068 | 0.035 | 0.0047 | 0.0044 | 0.0053 | 0.058 | 0.054 | 0.064 |
| 4 | 0.098 | 0.050 | 0.0010 | 0.0009 | 0.0013 | 0.069 | 0.066 | 0.074 |
| 5 | 0.147 | 0.075 | 0 | 0 | 0.0001 | 0.081 | 0.074 | 0.094 |
| 6 | 0.225 | 0.115 | 0 | 0 | 0 | 0.108 | 0.105 | 0.111 |
| 7 | 0.342 | 0.175 | 0 | 0 | 0 | 0.114 | 0.103 | 0.120 |
| 8 | 0.459 | 0.235 | 0 | 0 | 0 | 0.129 | 0.124 | 0.138 |
| 9 | 0.576 | 0.295 | 0 | 0 | 0 | 0.134 | 0.130 | 0.141 |
| 10 | 0.713 | 0.365 | 0 | 0 | 0 | 0.128 | 0.122 | 0.133 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.2\times10^{-3}$ |
| 1 | — |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | $24.5\times10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $148\times10^{-6}$ |
| $D_{50}$ | $201\times10^{-6}$ |
| $D_{90}$ | $269\times10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $6.24\times10^{-4}$ | $6.02\times10^{-4}$ | $6.68\times10^{-4}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $5.92\times10^{-4}$ | $5.30\times10^{-4}$ | $6.35\times10^{-4}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $1.22\times10^{-3}$ | $1.12\times10^{-3}$ | $1.30\times10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $4.10\times10^{-6}$ | $-1.00\times10^{-6}$ | $7.21\times10^{-6}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.26\times10^{-5}$ | $2.13\times10^{-5}$ | $2.33\times10^{-5}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $2.67\times10^{-5}$ | $2.03\times10^{-5}$ | $3.25\times10^{-5}$ |

Table 3.1 C : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| WATERTEMPERATURE T (°C) | : 21.5 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.074 | 0.073 | 0.075 |
| ZERO-CROSS PERIOD Tz (s) | 2.03 | 1.97 | 2.09 |
| PEAK PERIOD Tp (s) | 2.40 | 2.35 | 2.51 |
| RATIO $H_{1\%}/Hs$ (-) | 1.55 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.510 | 0.509 | 0.510 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.226 | 0.216 | 0.231 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.015 | 0.006 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.099 | 0.020 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+1.33\times10^{-5}$ | $5.10\times10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL CURRENT DOMINATED | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.510) | | | TEST 2 (h (m) = 0.510) | | | TEST 3 (h (m) = 0.509) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.049 | 0.0394 | 0.133 | 0.035 | 0.0394 | 0.098 | 0.045 | 0.0459 | 0.076 | 0.023 | 0.107 |
| 2 | 0.069 | 0.0205 | 0.126 | 0.055 | 0.0182 | 0.110 | 0.065 | 0.0228 | 0.095 | 0.033 | 0.122 |
| 3 | [illegible] | 0.0117 | 0.149 | 0.073 | 0.0146 | 0.132 | 0.084 | 0.0117 | 0.116 | 0.043 | 0.142 |
| 4 | 0.118 | 0.0075 | 0.158 | 0.102 | 0.0075 | 0.142 | 0.114 | 0.0084 | 0.131 | 0.058 | 0.169 |
| 5 | 0.167 | 0.0047 | 0.186 | 0.151 | 0.0037 | 0.176 | 0.165 | 0.0047 | 0.183 | 0.083 | 0.178 |
| 6 | 0.215 | 0.0009 | 0.207 | 0.229 | 0.0009 | 0.199 | 0.242 | 0.0009 | 0.196 | 0.123 | 0.199 |
| 7 | 0.343 | 0 | 0.225 | 0.347 | 0 | 0.218 | 0.360 | 0 | 0.213 | 0.183 | 0.215 |
| 8 | 0.480 | 0 | 0.269 | 0.465 | 0 | 0.259 | 0.477 | 0 | 0.241 | 0.243 | 0.234 |
| 9 | 0.598 | 0 | 0.264 | 0.582 | 0 | 0.269 | 0.595 | 0 | 0.254 | 0.303 | 0.266 |
| 10 | 0.735 | 0 | 0.262 | 0.720 | 0 | 0.273 | 0.733 | 0 | 0.255 | 0.373 | 0.265 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.042 | 0.022 | 0.0414 | 0.0295 | 0.0490 | 0.103 | 0.073 | 0.132 |
| 2 | 0.062 | 0.032 | 0.0231 | 0.0165 | 0.0268 | 0.116 | 0.092 | 0.135 |
| 3 | 0.082 | 0.042 | 0.0134 | 0.0125 | 0.0146 | 0.131 | 0.113 | 0.145 |
| 4 | 0.111 | 0.057 | 0.0080 | 0.0068 | 0.0087 | 0.145 | 0.130 | 0.156 |
| 5 | 0.161 | 0.082 | 0.0045 | 0.0033 | 0.0050 | 0.180 | 0.179 | 0.183 |
| 6 | 0.239 | 0.122 | 0.0010 | 0.0008 | 0.0012 | 0.200 | 0.195 | 0.205 |
| 7 | 0.357 | 0.182 | 0 | 0 | 0 | 0.219 | 0.213 | 0.224 |
| 8 | 0.474 | 0.242 | 0 | 0 | 0 | 0.256 | 0.240 | 0.267 |
| 9 | 0.592 | 0.302 | 0 | 0 | 0 | 0.264 | 0.254 | 0.269 |
| 10 | 0.729 | 0.372 | 0 | 0 | 0 | 0.263 | 0.235 | 0.273 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.4\times10^{-3}$ |
| 1 | — |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | $22.5\times10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $148\times10^{-6}$ |
| $D_{50}$ | $203\times10^{-6}$ |
| $D_{90}$ | $293\times10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $9.58\times10^{-4}$ | $5.12\times10^{-4}$ | $1.28\times10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $1.89\times10^{-3}$ | $1.30\times10^{-3}$ | $2.24\times10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $2.85\times10^{-3}$ | $1.81\times10^{-3}$ | $3.52\times10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $1.90\times10^{-4}$ | $8.48\times10^{-5}$ | $2.95\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.12\times10^{-4}$ | $1.54\times10^{-4}$ | $2.79\times10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $4.02\times10^{-4}$ | $2.30\times10^{-4}$ | $5.34\times10^{-4}$ |

Table 3.1 D : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T3/4,40 |
| WATERTEMPERATURE T (°C) | : 21.5 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.076 | 0.075 | 0.077 |
| ZERO-CROSS PERIOD Tz (s) | 1.97 | 1.94 | 2.01 |
| PEAK PERIOD Tp (s) | 2.41 | 2.39 | 2.42 |
| RATIO $H_{1\%}/Hs$ (-) | 1.41 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.502 | 0.501 | 0.503 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.449 | 0.441 | 0.455 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.014 | 0.009 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.134 | 0.048 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+1.23 \times 10^{-4}$ | $3.30 \times 10^{-5}$ |
| RIPPLE SHAPE | 3 DIMENSIONAL CURRENT DOMINATED | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.501) | | | TEST 2 (h (m) = 0.501) | | | TEST 3 (h (m) = 0.503) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.036 | 0.7700 | 0.248 | 0.030 | 0.7810 | 0.235 | 0.046 | 0.7720 | 0.268 | 0.023 | 0.278 |
| 2 | 0.056 | 0.4430 | 0.267 | 0.050 | 0.4430 | 0.266 | 0.066 | 0.4090 | 0.286 | 0.033 | 0.293 |
| 3 | 0.076 | 0.3170 | 0.308 | 0.070 | 0.3210 | 0.310 | 0.085 | 0.3040 | 0.318 | 0.043 | 0.313 |
| 4 | 0.106 | 0.2130 | 0.338 | 0.100 | 0.2260 | 0.321 | 0.115 | 0.2170 | 0.348 | 0.058 | 0.336 |
| 5 | 0.156 | 0.1300 | 0.378 | 0.150 | 0.1370 | 0.356 | 0.165 | 0.1350 | 0.364 | 0.083 | 0.360 |
| 6 | 0.236 | 0.0554 | 0.417 | 0.230 | 0.0613 | 0.420 | 0.245 | 0.0525 | 0.408 | 0.123 | 0.388 |
| 7 | 0.355 | 0.0196 | 0.460 | 0.349 | 0.0215 | 0.456 | 0.364 | 0.0215 | 0.442 | 0.183 | 0.421 |
| 8 | 0.475 | 0.0075 | 0.497 | 0.469 | 0.0073 | 0.489 | 0.483 | 0.0093 | 0.489 | 0.243 | 0.470 |
| 9 | 0.595 | 0.0037 | 0.500 | 0.589 | 0.0037 | 0.513 | 0.602 | 0.0028 | 0.508 | 0.303 | 0.495 |
| 10 | 0.735 | 0.0019 | 0.446 | 0.729 | 0.0019 | 0.518 | 0.742 | 0.0009 | 0.499 | 0.373 | 0.495 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.037 | 0.019 | 0.7782 | 0.6571 | 0.8293 | 0.252 | 0.246 | 0.260 |
| 2 | 0.057 | 0.029 | 0.4663 | 0.3983 | 0.5663 | 0.272 | 0.270 | 0.282 |
| 3 | 0.077 | 0.039 | 0.3186 | 0.2988 | 0.3482 | [illegible] | 0.305 | 0.313 |
| 4 | 0.107 | 0.054 | 0.2217 | 0.2113 | 0.2402 | 0.334 | 0.326 | 0.340 |
| 5 | 0.157 | 0.079 | 0.1359 | 0.1231 | 0.1471 | 0.362 | 0.341 | 0.378 |
| 6 | 0.237 | 0.119 | 0.0583 | 0.0551 | 0.0606 | 0.414 | 0.404 | 0.422 |
| 7 | 0.356 | 0.179 | 0.0213 | 0.0195 | [illegible] | 0.453 | 0.440 | 0.460 |
| 8 | 0.476 | 0.239 | 0.0085 | 0.0035 | 0.0101 | 0.483 | 0.482 | 0.497 |
| 9 | 0.595 | 0.299 | 0.0035 | 0.0032 | 0.0034 | 0.507 | 0.500 | 0.513 |
| 10 | 0.735 | 0.369 | 0.0016 | 0.0010 | 0.0019 | 0.505 | 0.494 | 0.518 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.1 \times 10^{-3}$ |
| 1 | $22.5 \times 10^{-3}$ |
| 2 | $21.5 \times 10^{-3}$ |
| 3 | $20.6 \times 10^{-3}$ |
| 4 | $20.3 \times 10^{-3}$ |
| 5 | $18.4 \times 10^{-3}$ |
| 6 TO 10 | $17.5 \times 10^{-3}$ |
| MIXTURE | $21.4 \times 10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $148 \times 10^{-6}$ |
| $D_{50}$ | $203 \times 10^{-6}$ |
| $D_{90}$ | $293 \times 10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.05 \times 10^{-2}$ | $8.64 \times 10^{-3}$ | $1.29 \times 10^{-2}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $3.76 \times 10^{-2}$ | $3.38 \times 10^{-2}$ | $4.27 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $4.81 \times 10^{-2}$ | $4.24 \times 10^{-2}$ | $5.56 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $1.64 \times 10^{-3}$ | $1.08 \times 10^{-4}$ | $2.78 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $1.13 \times 10^{-2}$ | $1.03 \times 10^{-2}$ | $1.27 \times 10^{-2}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $1.29 \times 10^{-2}$ | $1.08 \times 10^{-2}$ | [illegible] |

Table 3.1 E : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T9,0 |
| WATERTEMPERATURE T (°C) | : 21 |

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.090 | 0.088 | 0.092 |
| ZERO-CROSS PERIOD Tz (s) | 2.03 | 1.99 | 2.06 |
| PEAK PERIOD Tp (s) | 2.43 | 2.34 | 2.59 |
| RATIO $H_{1\%}/Hs$ (-) | 1.40 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.510 | 0.507 | 0.513 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | — | — | — |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.011 | 0.004 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.093 | 0.028 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+4.38 \times 10^{-5}$ | $2.22 \times 10^{-5}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL WAVE DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| LEVEL NO. | TEST 1 (h (m) = 0.513) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 2 (h (m) = 0.510) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 3 (h (m) = 0.507) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | ONLY CURRENT HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.0788 | — | 0.039 | 0.0686 | — | 0.034 | 0.0744 | — | — | — |
| 2 | 0.053 | 0.0401 | — | 0.059 | 0.0336 | — | 0.053 | 0.0395 | — | — | — |
| 3 | 0.077 | 0.0187 | — | 0.078 | 0.0159 | — | 0.073 | 0.0143 | — | — | — |
| 4 | 0.101 | 0.0035 | — | 0.108 | 0.0056 | — | 0.103 | 0.0047 | — | — | — |
| 5 | 0.150 | 0.0004 | — | 0.157 | 0.0009 | — | 0.152 | 0 | — | — | — |
| 6 | 0.228 | 0 | — | 0.235 | 0 | — | 0.231 | 0 | — | — | — |
| 7 | 0.345 | 0 | — | 0.353 | 0 | — | 0.349 | 0 | — | — | — |
| 8 | 0.462 | 0 | — | 0.471 | 0 | — | 0.462 | 0 | — | — | — |
| 9 | 0.579 | 0 | — | 0.588 | 0 | — | 0.586 | 0 | — | — | — |
| 10 | 0.715 | 0 | | 0.725 | 0 | — | 0.724 | 0 | — | — | — |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.035 | 0.018 | 0.0737 | 0.0712 | 0.0750 | — | — | — |
| 2 | 0.055 | 0.028 | 0.0373 | 0.0334 | 0.0406 | — | — | — |
| 3 | 0.074 | 0.038 | 0.0172 | 0.0144 | 0.0193 | — | — | — |
| 4 | 0.104 | 0.053 | 0.0062 | 0.0046 | 0.0081 | — | — | — |
| 5 | 0.153 | 0.078 | 0.0007 | 0 | 0.0013 | — | — | — |
| 6 | 0.231 | 0.118 | 0 | 0 | 0 | — | — | — |
| 7 | 0.346 | 0.178 | 0 | 0 | 0 | — | — | — |
| 8 | 0.462 | 0.238 | 0 | 0 | 0 | — | — | — |
| 9 | 0.581 | 0.298 | 0 | 0 | 0 | — | — | — |
| 10 | 0.721 | 0.368 | 0 | 0 | 0 | — | — | — |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $24.8 \times 10^{-3}$ |
| 1 | $24.1 \times 10^{-3}$ |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | $23.9 \times 10^{-3}$ |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $151 \times 10^{-6}$ |
| $D_{50}$ | $201 \times 10^{-6}$ |
| $D_{90}$ | $279 \times 10^{-6}$ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.32 \times 10^{-3}$ | $1.28 \times 10^{-3}$ | $1.36 \times 10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $2.63 \times 10^{-3}$ | $2.48 \times 10^{-3}$ | $2.78 \times 10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $3.95 \times 10^{-3}$ | $3.91 \times 10^{-3}$ | $4.11 \times 10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $4.59 \times 10^{-5}$ | $1.74 \times 10^{-5}$ | $7.91 \times 10^{-5}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | — | — | — |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | — | — | — |

Table 3.1 F : Basic measuring data

EXPERIMENT NO. : T10,0
WATERTEMPERATURE T (°C) : [illegible]

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.101 | 0.098 | 0.102 |
| ZERO-CROSS PERIOD Tz (s) | 2.01 | 1.96 | 2.05 |
| PEAK PERIOD Tp (s) | 2.48 | 2.34 | 2.63 |
| RATIO $H_{1\%}/H_s$ (-) | 1.23 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.504 | 0.500 | 0.509 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | — | — | — |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.015 | 0.004 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.091 | 0.013 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+2.81 \times 10^{-6}$ | $1.25 \times 10^{-5}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL<br>WAVE DOMINATED | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.509) | | | TEST 2 (h (m) = 0.504) | | | TEST 3 (h (m) = 0.500) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | [illegible] | 0.0845 | · | 0.032 | 0.1030 | — | 0.032 | 0.1210 | — | — | — |
| 2 | 0.053 | 0.0328 | — | [illegible] | [illegible] | — | 0.052 | 0.0613 | — | — | — |
| 3 | 0.073 | 0.0111 | — | 0.071 | [illegible] | — | 0.072 | 0.0299 | — | — | — |
| 4 | 0.102 | 0.0029 | — | 0.101 | [illegible] | — | 0.107 | 0.0131 | — | — | — |
| 5 | 0.151 | 0 | — | 0.151 | 0.0000 | — | 0.152 | 0.0037 | — | — | — |
| 6 | 0.230 | 0 | — | 0.230 | 0 | — | 0.232 | 0 | — | — | — |
| 7 | 0.344 | 0 | — | 0.349 | 0 | — | 0.352 | 0 | — | — | — |
| 8 | 0.466 | 0 | — | [illegible] | 0 | — | [illegible] | 0 | — | — | — |
| 9 | 0.583 | 0 | — | 0.583 | 0 | — | [illegible] | 0 | — | — | — |
| 10 | 0.721 | 0 | — | 0.728 | 0 | — | [illegible] | 0 | — | — | — |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.032 | 0.016 | 0.1021 | 0.0842 | 0.1200 | — | — | — |
| 2 | 0.052 | 0.026 | 0.0471 | 0.0345 | 0.0606 | — | — | — |
| 3 | 0.072 | 0.036 | 0.0202 | 0.0125 | 0.0299 | — | — | — |
| 4 | 0.102 | 0.051 | 0.0079 | 0.0030 | 0.0133 | — | — | — |
| 5 | 0.151 | 0.076 | 0.0016 | 0 | 0.0038 | — | — | — |
| 6 | 0.231 | 0.116 | 0 | 0 | 0.0001 | — | — | — |
| 7 | 0.350 | 0.176 | 0 | 0 | 0 | — | — | — |
| 8 | 0.469 | 0.236 | 0 | 0 | 0 | — | — | — |
| 9 | 0.587 | 0.296 | 0 | 0 | 0 | — | — | — |
| 10 | 0.726 | 0.366 | 0 | 0 | 0 | — | — | — |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $24.8 \times 10^{-3}$ |
| 1 | $24.1 \times 10^{-3}$ |
| 2 | $24.0 \times 10^{-3}$ |
| 3 | $(23.2 \times 10^{-3})$ |
| 4 | |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | $24.0 \times 10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $148 \times 10^{-6}$ |
| $D_{50}$ | $201 \times 10^{-6}$ |
| $D_{90}$ | $269 \times 10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $2.26 \times 10^{-3}$ | $2.14 \times 10^{-3}$ | $2.3? \times 10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $2.79 \times 10^{-3}$ | $2.2? \times 10^{-3}$ | $3.39 \times 10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $5.05 \times 10^{-3}$ | $4.34 \times 10^{-3}$ | $5.75 \times 10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $4.02 \times 10^{-5}$ | $1.9? \times 10^{-5}$ | $6.08 \times 10^{-5}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | — | — | — |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | — | — | — |

Table 3.1 G : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : $T_{10,10}$ |
| WATERTEMPERATURE T (°C) | : 22 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.106 | 0.105 | 0.107 |
| ZERO-CROSS PERIOD Tz (s) | 1.95 | 1.92 | 1.96 |
| PEAK PERIOD Tp (s) | 2.67 | 2.61 | 2.67 |
| RATIO $H_{1\%}/Hs$ (-) | 1.35 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.515 | 0.515 | 0.515 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.118 | 0.117 | 0.120 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.017 | 0.002 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.092 | 0.011 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+2.80\times10^{-6}$ | $2.20\times10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.515) | | | TEST 2 (h (m) = 0.515) | | | TEST 3 (h (m) = 0.515) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.023 | 0.1050 | 0.018 | 0.023 | 0.1330 | 0.025 | 0.027 | 0.1050 | 0.015 | 0.014 | 0.053 |
| 2 | 0.046 | 0.0510 | 0.032 | 0.048 | 0.0503 | 0.033 | 0.047 | 0.0467 | 0.037 | 0.024 | 0.063 |
| 3 | 0.068 | 0.0280 | 0.045 | 0.068 | 0.0280 | 0.051 | 0.066 | 0.0243 | 0.046 | 0.034 | 0.075 |
| 4 | 0.097 | 0.0103 | 0.071 | 0.097 | 0.0112 | 0.060 | 0.095 | 0.0084 | 0.068 | 0.049 | 0.080 |
| 5 | 0.146 | 0.0028 | 0.083 | 0.146 | 0.0028 | 0.082 | 0.144 | 0.0019 | 0.080 | 0.074 | 0.093 |
| 6 | 0.222 | 0 | 0.096 | 0.223 | 0 | 0.102 | 0.221 | 0 | 0.107 | 0.114 | 0.099 |
| 7 | 0.340 | 0 | 0.131 | 0.340 | 0 | 0.126 | 0.338 | 0 | 0.122 | 0.174 | 0.114 |
| 8 | 0.456 | 0 | 0.134 | 0.456 | 0 | 0.131 | 0.454 | 0 | 0.127 | 0.234 | 0.123 |
| 9 | 0.593 | 0 | 0.138 | 0.573 | 0 | 0.136 | 0.571 | 0 | 0.136 | 0.294 | 0.125 |
| 10 | 0.709 | 0 | 0.145 | 0.709 | 0 | 0.143 | 0.707 | 0 | 0.139 | 0.364 | 0.132 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.025 | 0.015 | 0.1159 | 0.1011 | 0.1398 | 0.019 | 0.016 | 0.025 |
| 2 | 0.048 | 0.025 | 0.0525 | 0.0459 | 0.0597 | 0.036 | 0.034 | 0.038 |
| 3 | 0.067 | 0.035 | 0.0274 | 0.0236 | 0.0296 | 0.047 | 0.045 | 0.050 |
| 4 | 0.096 | 0.050 | 0.0102 | 0.0082 | 0.0116 | 0.066 | 0.060 | 0.070 |
| 5 | 0.145 | 0.075 | 0.0026 | 0.0019 | 0.0029 | 0.081 | 0.080 | 0.083 |
| 6 | 0.222 | 0.115 | 0 | 0 | 0 | 0.107 | 0.096 | 0.109 |
| 7 | 0.339 | 0.175 | 0 | 0 | 0 | 0.126 | 0.122 | 0.131 |
| 8 | 0.455 | 0.235 | 0 | 0 | 0 | 0.131 | 0.127 | 0.134 |
| 9 | 0.572 | 0.295 | 0 | 0 | 0 | 0.137 | 0.136 | 0.138 |
| 10 | 0.708 | 0.365 | 0 | 0 | 0 | 0.142 | 0.139 | 0.145 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.9\times10^{-3}$ |
| 1 | $25.3\times10^{-3}$ |
| 2 | $25.1\times10^{-3}$ |
| 3 | – |
| 4 | – |
| 5 | – |
| 6 TO 10 | – |
| MIXTURE | $24.9\times10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $147\times10^{-6}$ |
| $D_{50}$ | $205\times10^{-6}$ |
| $D_{90}$ | $307\times10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $2.07\times10^{-3}$ | $1.74\times10^{-3}$ | $2.68\times10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $2.57\times10^{-3}$ | $2.21\times10^{-3}$ | $3.03\times10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $4.64\times10^{-3}$ | $3.95\times10^{-3}$ | $5.71\times10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $6.16\times10^{-5}$ | $2.52\times10^{-5}$ | $9.80\times10^{-5}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $8.61\times10^{-5}$ | $6.34\times10^{-5}$ | $1.04\times10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $1.48\times10^{-4}$ | $1.16\times10^{-4}$ | $2.07\times10^{-4}$ |

Table 3.1 H : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T10-6 |
| WATERTEMPERATURE T (°C) | : 21 |

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.098 | 0.097 | 0.099 |
| ZERO-CROSS PERIOD Tz (s) | 1.95 | 1.90 | 1.98 |
| PEAK PERIOD Tp (s) | 2.48 | 2.47 | 2.49 |
| RATIO $H_{1\%}$/Hs (-) | 1.35 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.494 | 0.494 | 0.495 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.128 | -0.125 | -0.131 |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.013 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.089 | 0.012 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+2.50\times10^{-6}$ | $1.90\times10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL WAVE DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| LEVEL NO. | TEST 1 (h (m) = 0.495) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 2 (h (m) = 0.494) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 3 (h (m) = 0.494) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | ONLY CURRENT HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.1210 | -0.021 | 0.034 | 0.1210 | -0.018 | 0.034 | 0.1050 | -0.023 | 0.018 | -0.065 |
| 2 | 0.055 | 0.0454 | -0.034 | 0.055 | 0.0617 | -0.037 | 0.057 | 0.0565 | -0.039 | 0.028 | -0.081 |
| 3 | 0.075 | 0.0317 | -0.045 | 0.073 | 0.0392 | -0.041 | 0.077 | 0.0317 | -0.051 | 0.038 | -0.085 |
| 4 | 0.105 | 0.0168 | -0.079 | 0.103 | 0.0205 | -0.069 | 0.107 | 0.0168 | -0.072 | 0.053 | -0.096 |
| 5 | 0.156 | 0.0037 | -0.090 | 0.151 | 0.0041 | -0.085 | 0.158 | 0.0037 | -0.084 | 0.078 | -0.104 |
| 6 | 0.236 | 0.0013 | -0.111 | [illegible] | 0.0013 | -0.107 | 0.239 | 0 | -0.114 | 0.118 | -0.117 |
| 7 | 0.356 | 0 | -0.120 | [illegible] | 0 | -0.119 | 0.360 | 0 | -0.115 | 0.178 | -0.126 |
| 8 | 0.479 | 0 | [illegible] | [illegible] | 0 | -0.128 | 0.482 | 0 | -0.135 | 0.238 | -0.146 |
| 9 | 0.600 | 0 | [illegible] | 0.600 | 0 | -0.151 | 0.603 | 0 | -0.150 | 0.298 | -0.151 |
| 10 | 0.744 | 0 | -0.166 | 0.744 | 0 | -0.164 | 0.745 | 0 | -0.164 | 0.368 | -0.164 |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.017 | 0.1154 | 0.1006 | 0.1210 | -0.026 | -0.020 | -0.031 |
| 2 | 0.055 | [illegible] | 0.0535 | 0.0454 | 0.0617 | -0.036 | -0.034 | -0.038 |
| 3 | 0.075 | [illegible] | 0.0346 | 0.0317 | 0.0380 | -0.046 | -0.042 | -0.050 |
| 4 | 0.105 | [illegible] | 0.0187 | 0.0168 | 0.0200 | -0.073 | -0.076 | -0.079 |
| 5 | 0.156 | [illegible] | 0.0034 | 0.0032 | 0.0037 | -0.086 | -0.084 | [illegible] |
| 6 | [illegible] | [illegible] | 0.0013 | 0.0001 | 0.0019 | -0.109 | -0.107 | -0.113 |
| 7 | [illegible] | [illegible] | 0 | 0 | 0 | -0.120 | -0.115 | [illegible] |
| 8 | [illegible] | [illegible] | 0 | 0 | 0 | -0.136 | -0.128 | [illegible] |
| 9 | [illegible] | [illegible] | 0 | 0 | 0 | -0.153 | -0.151 | [illegible] |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | -0.165 | -0.164 | [illegible] |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $26.3\times10^{-3}$ |
| 1 | $25.2\times10^{-3}$ |
| 2 | $24.9\times10^{-3}$ |
| 3 | – |
| 4 | – |
| 5 | – |
| 6 TO 10 | – |
| MIXTURE | $24.3\times10^{-3}$ |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $152\times10^{-6}$ |
| $D_{50}$ | $209\times10^{-6}$ |
| $D_{90}$ | $291\times10^{-6}$ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.66\times10^{-3}$ | $1.54\times10^{-3}$ | $1.85\times10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $3.82\times10^{-3}$ | $3.65\times10^{-3}$ | $3.93\times10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $5.48\times10^{-3}$ | [illegible] | $5.82\times10^{-3}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $3.10\times10^{-5}$ | [illegible] | $5.56\times10^{-5}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $-1.45\times10^{-4}$ | [illegible] | $-1.54\times10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $-1.14\times10^{-4}$ | [illegible] | $-1.48\times10^{-4}$ |

Table 3.1 I : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T10,20 |
| WATERTEMPERATURE T (°C) | : 20 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.099 | 0.097 | 0.100 |
| ZERO-CROSS PERIOD Tz (s) | 1.95 | 1.92 | 1.99 |
| PEAK PERIOD Tp (s) | 2.48 | 2.47 | 2.49 |
| RATIO $H_{1\%}$/Hs (-) | 1.48 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.509 | 0.507 | 0.510 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.219 | 0.217 | 0.221 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.017 | 0.005 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.099 | 0.006 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+1.48\times10^{-5}$ | $2.60\times10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.510) | | | TEST 2 (h (m) = 0.509) | | | TEST 3 (h (m) = 0.507) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.037 | 0.2260 | 0.060 | 0.029 | 0.2240 | 0.060 | 0.036 | 0.2270 | 0.066 | 0.018 | 0.109 |
| 2 | 0.057 | 0.1540 | [illegible] | 0.049 | [illegible] | 0.080 | 0.055 | 0.1510 | 0.083 | 0.028 | 0.114 |
| 3 | 0.078 | 0.1120 | 0.116 | 0.069 | 0.1050 | 0.107 | 0.075 | 0.1000 | 0.096 | 0.038 | 0.138 |
| 4 | 0.106 | 0.0583 | 0.131 | 0.098 | [illegible] | 0.120 | 0.105 | 0.0621 | 0.125 | 0.053 | 0.149 |
| 5 | 0.155 | 0.0280 | 0.162 | 0.142 | [illegible] | 0.150 | 0.154 | 0.0299 | 0.148 | 0.078 | 0.159 |
| 6 | 0.233 | 0.0093 | 0.191 | 0.226 | 0.0093 | 0.188 | 0.232 | 0.0112 | 0.191 | 0.118 | 0.200 |
| 7 | 0.351 | 0.0037 | [illegible] | [illegible] | 0.0037 | 0.227 | 0.351 | 0.0037 | 0.222 | 0.178 | 0.227 |
| 8 | 0.469 | 0.0012 | [illegible] | [illegible] | 0.0012 | 0.239 | 0.469 | 0.0012 | 0.246 | 0.238 | 0.248 |
| 9 | 0.586 | 0.0006 | 0.230 | [illegible] | 0.0006 | 0.267 | 0.588 | 0.0006 | 0.260 | 0.298 | 0.251 |
| 10 | 0.724 | 0 | 0.240 | 0.712 | 0 | 0.253 | 0.726 | 0 | 0.267 | 0.368 | 0.258 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.017 | 0.2241 | 0.2115 | 0.2368 | 0.062 | 0.057 | 0.065 |
| 2 | 0.054 | 0.027 | 0.1522 | 0.1349 | 0.1660 | 0.082 | 0.079 | 0.086 |
| 3 | 0.073 | 0.037 | 0.1091 | 0.0909 | 0.1179 | 0.105 | 0.095 | 0.111 |
| 4 | 0.103 | 0.052 | 0.0608 | 0.0482 | 0.0699 | 0.125 | 0.123 | 0.130 |
| 5 | 0.152 | 0.077 | 0.0296 | 0.0273 | 0.0314 | 0.155 | 0.147 | 0.165 |
| 6 | 0.231 | 0.117 | 0.0102 | 0.0091 | 0.0118 | 0.190 | 0.190 | 0.190 |
| 7 | 0.349 | [illegible] | 0.0037 | 0.0036 | 0.0038 | 0.224 | 0.221 | 0.229 |
| 8 | 0.467 | [illegible] | 0.0012 | 0.0012 | 0.0012 | 0.245 | 0.240 | 0.250 |
| 9 | 0.585 | 0.297 | 0.0006 | 0.0006 | 0.0006 | 0.265 | 0.260 | 0.270 |
| 10 | 0.722 | 0.367 | 0 | 0 | 0 | 0.260 | 0.252 | 0.262 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $26.4\times10^{-3}$ |
| 1 | $23.9\times10^{-3}$ |
| 2 | $23.5\times10^{-3}$ |
| 3 | $21.8\times10^{-3}$ |
| 4 | $21.6\times10^{-3}$ |
| 5 | – |
| 6 TO 10 | – |
| MIXTURE | [illegible] |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $158\times10^{-6}$ |
| $D_{50}$ | $217\times10^{-6}$ |
| $D_{90}$ | $289\times10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $3.03\times10^{-3}$ | $2.93\times10^{-3}$ | $3.21\times10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $9.20\times10^{-3}$ | $8.31\times10^{-3}$ | $9.73\times10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $1.22\times10^{-2}$ | $1.12\times10^{-2}$ | $1.29\times10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $2.40\times10^{-4}$ | $1.57\times10^{-4}$ | $3.22\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $9.43\times10^{-4}$ | $8.45\times10^{-4}$ | $9.93\times10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $1.19\times10^{-3}$ | $1.07\times10^{-3}$ | $1.32\times10^{-3}$ |

Table 3.1 J : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T10,-20 |
| WATERTEMPERATURE T (°C) | : 21 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.096 | 0.096 | 0.097 |
| ZERO-CROSS PERIOD Tz (s) | 1.91 | 1.88 | 1.94 |
| PEAK PERIOD Tp (s) | 2.46 | 2.36 | 2.51 |
| RATIO $H_{1\%}$/Hs (-) | 1.55 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.494 | 0.494 | 0.495 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.228 | -0.221 | -0.233 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.019 | 0.007 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.114 | 0.013 |
| RIPPLE VELOCITY $u_r$ (m/s) | $-7.10\times10^{-6}$ | $4.30\times10^{-6}$ |
| RIPPLE SHAPE | 2½ DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.495) | | | TEST 2 (h (m) = 0.494) | | | TEST 3 (h (m) = 0.494) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.053 | 0.1610 | -0.055 | 0.053 | 0.1300 | -0.083 | 0.049 | 0.1120 | -0.025 | 0.024 | -0.113 |
| 2 | 0.073 | 0.1120 | -0.086 | 0.073 | 0.0952 | -0.096 | 0.069 | 0.0853 | [illegible] | 0.034 | -0.135 |
| 3 | 0.093 | 0.0866 | -0.090 | 0.093 | 0.0684 | -0.115 | 0.089 | 0.0638 | -0.110 | 0.044 | -0.154 |
| 4 | 0.123 | 0.0554 | -0.115 | 0.123 | 0.0448 | -0.133 | 0.119 | 0.0379 | -0.120 | 0.059 | -0.178 |
| 5 | 0.174 | 0.0290 | -0.150 | 0.174 | 0.0271 | -0.161 | 0.170 | 0.0183 | -0.160 | 0.084 | -0.204 |
| 6 | 0.255 | 0.0117 | -0.182 | 0.255 | 0.0045 | -0.190 | 0.251 | 0.0035 | -0.185 | 0.124 | -0.236 |
| 7 | 0.334 | 0.0037 | -0.217 | 0.333 | 0.0019 | -0.233 | 0.372 | 0.0013 | -0.225 | 0.184 | -0.254 |
| 8 | 0.463 | 0.0009 | -0.253 | 0.468 | 0.0006 | -0.251 | 0.494 | 0.0000 | -0.253 | 0.244 | -0.267 |
| 9 | 0.618 | 0 | -0.263 | 0.616 | 0 | -0.277 | 0.615 | 0 | [illegible] | 0.304 | -0.272 |
| 10 | [illegible] | 0 | -0.288 | 0.761 | 0 | -0.282 | 0.757 | 0 | [illegible] | 0.334 | -0.266 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.052 | 0.025 | 0.1365 | 0.1128 | 0.1663 | -0.021 | -0.053 | -0.082 |
| 2 | 0.072 | 0.035 | 0.0984 | 0.0824 | 0.1153 | -0.092 | -0.084 | -0.097 |
| 3 | 0.092 | 0.045 | 0.0733 | 0.0615 | 0.0853 | -0.105 | -0.090 | -0.114 |
| 4 | 0.122 | 0.060 | 0.0462 | 0.0367 | 0.0548 | -0.125 | -0.114 | -0.132 |
| 5 | 0.173 | [illegible] | 0.0237 | 0.0183 | 0.0293 | -0.157 | -0.140 | -0.161 |
| 6 | 0.254 | [illegible] | 0.0089 | 0.0035 | 0.0115 | -0.186 | -0.181 | -0.190 |
| 7 | [illegible] | [illegible] | 0.0023 | 0.0010 | 0.0037 | -0.225 | -0.212 | [illegible] |
| 8 | 0.464 | [illegible] | 0.0009 | 0.0005 | 0.0009 | -0.254 | -0.251 | -0.255 |
| 9 | 0.615 | [illegible] | 0 | 0 | 0 | -0.275 | -0.263 | [illegible] |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | -0.292 | -0.282 | [illegible] |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $26.3\times10^{-3}$ |
| 1 | $24.8\times10^{-3}$ |
| 2 | $23.7\times10^{-3}$ |
| 3 | $24.1\times10^{-3}$ |
| 4 | – |
| 5 | – |
| 6 TO 10 | – |
| MIXTURE | $24.1\times10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $152\times10^{-6}$ |
| $D_{50}$ | $209\times10^{-6}$ |
| $D_{90}$ | $291\times10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $2.46\times10^{-3}$ | [illegible] | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | $9.30\times10^{-3}$ |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | $1.23\times10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.1 K : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T10,40 |
| WATERTEMPERATURE T (°C) | : 20 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.098 | 0.096 | 0.100 |
| ZERO-CROSS PERIOD Tz (s) | 2.03 | 2.01 | 2.05 |
| PEAK PERIOD Tp (s) | 2.60 | 2.59 | 2.67 |
| RATIO $H_{1\%}/Hs$ (-) | 1.26 | - | - |
| WATERDEPTH TO MEAN BED h (m) | 0.511 | 0.506 | 0.515 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.449 | 0.449 | 0.449 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.017 | 0.010 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.155 | 0.041 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+1.02 \times 10^{-4}$ | [illegible] |
| RIPPLE SHAPE | 3 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = [illegible]) | | | TEST 2 (h (m) = 0.511) | | | TEST 3 (h (m) = 0.515) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | [illegible] | 0.7840 | 0.289 | 0.055 | 0.6630 | - | 0.068 | 0.6030 | - | - | - |
| 2 | [illegible] | 0.6230 | [illegible] | 0.074 | 0.5100 | - | 0.087 | 0.5100 | - | - | - |
| 3 | [illegible] | 0.5570 | [illegible] | 0.094 | 0.4640 | - | 0.107 | 0.4410 | - | - | - |
| 4 | [illegible] | 0.4250 | [illegible] | 0.123 | 0.3510 | - | 0.136 | 0.3240 | - | - | - |
| 5 | [illegible] | [illegible] | 0.383 | 0.172 | 0.2260 | - | 0.184 | 0.2030 | - | - | - |
| 6 | [illegible] | [illegible] | [illegible] | 0.250 | [illegible] | - | 0.262 | 0.0906 | - | - | - |
| 7 | [illegible] | [illegible] | [illegible] | 0.368 | [illegible] | - | 0.377 | 0.0424 | - | - | - |
| 8 | [illegible] | 0.0260 | [illegible] | 0.485 | [illegible] | - | 0.495 | 0.0216 | - | - | - |
| 9 | [illegible] | 0.0122 | [illegible] | 0.603 | [illegible] | - | 0.612 | 0.0103 | - | - | - |
| 10 | [illegible] | [illegible] | [illegible] | 0.740 | [illegible] | - | 0.748 | 0.0048 | - | - | - |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.055 | 0.028 | 0.6792 | 0.6630 | 0.7081 | 0.306 | 0.306 | 0.306 |
| 2 | 0.074 | 0.038 | 0.5604 | 0.5100 | 0.5976 | 0.335 | 0.335 | 0.335 |
| 3 | 0.094 | 0.048 | 0.4832 | 0.4640 | 0.4998 | 0.355 | 0.355 | 0.355 |
| 4 | 0.123 | 0.063 | 0.3702 | 0.3601 | [illegible] | 0.371 | 0.371 | 0.371 |
| 5 | 0.172 | 0.088 | 0.2356 | 0.2260 | [illegible] | 0.386 | 0.386 | 0.386 |
| 6 | 0.250 | 0.128 | 0.1170 | 0.1024 | 0.1317 | 0.408 | 0.408 | 0.408 |
| 7 | 0.368 | 0.188 | 0.0534 | [illegible] | 0.0678 | 0.434 | 0.434 | 0.434 |
| 8 | 0.485 | 0.248 | 0.0240 | [illegible] | 0.0249 | 0.467 | 0.467 | 0.467 |
| 9 | 0.603 | 0.308 | 0.0114 | 0.0111 | 0.0116 | 0.521 | 0.521 | 0.521 |
| 10 | 0.740 | 0.378 | 0.0051 | 0.0051 | 0.0051 | 0.506 | 0.506 | 0.506 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.2 \times 10^{-3}$ |
| 1 | $19.2 \times 10^{-3}$ |
| 2 | $19.0 \times 10^{-3}$ |
| 3 | $18.8 \times 10^{-3}$ |
| 4 | $19.0 \times 10^{-3}$ |
| 5 | $18.3 \times 10^{-3}$ |
| 6 TO 10 | $16.1 \times 10^{-3}$ |
| MIXTURE | $18.9 \times 10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $147 \times 10^{-6}$ |
| $D_{50}$ | $205 \times 10^{-6}$ |
| $D_{90}$ | $307 \times 10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.77 \times 10^{-2}$ | $8.97 \times 10^{-3}$ | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | $5.37 \times 10^{-2}$ | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | $6.72 \times 10^{-2}$ | $6.86 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | $1.11 \times 10^{-3}$ | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.08 \times 10^{-2}$ | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $2.36 \times 10^{-2}$ | [illegible] | [illegible] |

Table 3.1 L : Basic measuring data

EXPERIMENT NO. : T10-40
WATERTEMPERATURE T (°C) : 21

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.101 | 0.100 | 0.102 |
| ZERO-CROSS PERIOD Tz (s) | 2.10 | 2.06 | 2.15 |
| PEAK PERIOD Tp (s) | 2.51 | 2.34 | 2.60 |
| RATIO $H_{1\%}$/Hs (-) | [illegible] | - | - |
| WATERDEPTH TO MEAN BED h (m) | 0.495 | 0.493 | 0.499 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.453 | -0.452 | -0.454 |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.021 | 0.006 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.156 | 0.078 |
| RIPPLE VELOCITY $u_r$ (m/s) | -1.[illegible] ×10^[illegible] | 4.30 ×10^[illegible] |
| RIPPLE SHAPE | 3 DIMENSIONAL<br>CURRENT DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = [illegible]) | | | TEST 2 (h (m) = 0.494) | | | TEST 3 (h (m) = 0.499) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | [illegible] | 0.8630 | -0.287 | 0.071 | 0.9340 | -0.277 | 0.066 | 0.9800 | -0.279 | 0.033 | -0.263 |
| 2 | 0.087 | 0.6640 | -0.302 | 0.091 | 0.7000 | -0.277 | 0.086 | 0.7240 | -0.296 | 0.043 | -0.296 |
| 3 | 0.108 | 0.5110 | -0.309 | 0.111 | 0.5580 | -0.297 | 0.106 | 0.6140 | -0.317 | 0.053 | -0.315 |
| 4 | 0.138 | 0.3910 | -0.331 | 0.142 | 0.4080 | -0.323 | 0.136 | 0.4430 | -0.336 | 0.068 | -0.337 |
| 5 | 0.189 | 0.2610 | -0.373 | 0.192 | 0.2740 | -0.368 | 0.186 | 0.3040 | -0.346 | 0.093 | -0.375 |
| 6 | 0.230 | 0.1440 | -0.404 | 0.233 | 0.1520 | -0.407 | 0.267 | 0.1580 | -0.394 | 0.133 | -0.417 |
| 7 | 0.391 | 0.0684 | -0.456 | 0.395 | 0.0706 | -0.463 | 0.387 | 0.0770 | -0.453 | 0.193 | -0.465 |
| 8 | 0.510 | 0.0292 | -0.493 | 0.516 | 0.0292 | -0.492 | 0.507 | 0.0292 | -0.483 | 0.253 | -0.501 |
| 9 | 0.635 | 0.0140 | -0.515 | 0.638 | 0.0149 | -0.512 | 0.677 | 0.0140 | -0.516 | 0.313 | -0.577 |
| 10 | 0.777 | 0.0065 | -0.542 | [illegible] | 0.0065 | -0.545 | 0.768 | 0.0065 | -0.547 | 0.383 | -0.523 |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.068 | [illegible] | 0.9254 | 0.8526 | 0.9691 | -0.282 | -0.277 | -0.288 |
| 2 | 0.088 | [illegible] | 0.6984 | 0.6492 | [illegible] | -0.293 | -0.277 | -0.302 |
| 3 | 0.108 | [illegible] | 0.5624 | 0.5093 | [illegible] | -0.307 | -0.294 | -0.317 |
| 4 | 0.139 | [illegible] | 0.4163 | [illegible] | [illegible] | -0.329 | -0.320 | -0.337 |
| 5 | 0.189 | [illegible] | 0.2805 | 0.2610 | [illegible] | -0.364 | -0.348 | -0.373 |
| 6 | 0.240 | [illegible] | 0.1521 | [illegible] | [illegible] | -0.402 | -0.395 | -0.406 |
| 7 | [illegible] | [illegible] | 0.0710 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | 0.0276 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | 0.0142 | 0.0132 | [illegible] | -0.514 | -0.511 | -0.517 |
| 10 | [illegible] | [illegible] | 0.0065 | 0.0061 | [illegible] | -0.545 | [illegible] | [illegible] |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | 25.8 ×10⁻³ |
| 1 | 20.8 ×10⁻³ |
| 2 | 20.5 ×10⁻³ |
| 3 | 19.8 ×10⁻³ |
| 4 | 19.5 ×10⁻³ |
| 5 | 18.1 ×10⁻³ |
| 6 TO 10 | 16.7 ×10⁻³ |
| MIXTURE | 20.0 ×10⁻³ |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | 148 ×10⁻⁶ |
| $D_{50}$ | 206 ×10⁻⁶ |
| $D_{90}$ | 306 ×10⁻⁶ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | 1.96 ×10^[illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | 8.26 ×10^[illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | 9.25 ×10^[illegible] | 1.04 ×10^[illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.1 M : Basic measuring data

EXPERIMENT NO. : T12,0
WATERTEMPERATURE T (°C) : 23.5

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.122 | 0.120 | 0.124 |
| ZERO-CROSS PERIOD Tz (s) | 2.02 | 2.00 | 2.04 |
| PEAK PERIOD Tp (s) | 2.42 | 2.40 | 2.44 |
| RATIO $H_{1\%}/Hs$ (-) | 1.28 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.524 | 0.521 | 0.528 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | – | – | – |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.018 | 0.002 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.110 | 0.011 |
| RIPPLE VELOCITY $u_r$ (m/s) | ±5.50 x $10^{-6}$ | 3.50 x $10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL<br>WAVE DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.528) | | | TEST 2 (h (m) = 0.524) | | | TEST 3 (h (m) = 0.521) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.034 | 0.3560 | – | 0.034 | 0.3730 | – | 0.038 | 0.3650 | – | – | – |
| 2 | 0.054 | 0.1500 | – | 0.053 | 0.2100 | – | 0.058 | 0.1900 | – | – | – |
| 3 | 0.077 | 0.1190 | – | 0.073 | 0.1190 | – | 0.077 | 0.1230 | – | – | – |
| 4 | 0.100 | 0.0529 | – | 0.101 | 0.0525 | – | 0.106 | 0.0525 | – | – | – |
| 5 | 0.145 | 0.0103 | – | 0.149 | 0.0112 | – | 0.154 | 0.0168 | – | – | – |
| 6 | [illegible] | 0.0009 | – | 0.225 | 0.0019 | – | 0.230 | 0.0028 | – | – | – |
| 7 | [illegible] | 0 | – | 0.340 | 0 | – | 0.345 | 0 | – | – | – |
| 8 | 0.451 | 0 | – | 0.454 | 0 | – | 0.461 | 0 | – | – | – |
| 9 | 0.566 | 0 | – | 0.569 | 0 | – | 0.576 | 0 | – | – | – |
| 10 | 0.692 | 0 | – | 0.702 | 0 | – | 0.710 | 0 | – | – | – |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.035 | 0.019 | 0.3645 | 0.3426 | 0.3883 | – | – | – |
| 2 | 0.055 | 0.029 | 0.1987 | 0.1264 | 0.2192 | – | – | – |
| 3 | 0.074 | 0.039 | 0.1211 | 0.1132 | 0.1356 | – | – | – |
| 4 | 0.102 | 0.054 | 0.0498 | 0.0366 | 0.0614 | – | – | – |
| 5 | 0.150 | 0.079 | 0.0135 | 0.0100 | 0.0195 | – | – | – |
| 6 | 0.226 | 0.119 | 0.0021 | 0.0009 | 0.0035 | – | – | – |
| 7 | 0.341 | 0.179 | 0 | 0 | 0.0001 | – | – | – |
| 8 | 0.455 | 0.239 | 0 | 0 | 0 | – | – | – |
| 9 | 0.570 | 0.299 | 0 | 0 | 0 | – | – | – |
| 10 | 0.704 | 0.369 | 0 | 0 | 0 | – | – | – |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | 27.0 x $10^{-3}$ |
| 1 | 26.7 x $10^{-3}$ |
| 2 | 26.4 x $10^{-3}$ |
| 3 | 24.5 x $10^{-3}$ |
| 4 | 24.1 x $10^{-3}$ |
| 5 | – |
| 6 TO 10 | – |
| MIXTURE | 26.0 x $10^{-3}$ |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | 151 x $10^{-6}$ |
| $D_{50}$ | 208 x $10^{-6}$ |
| $D_{90}$ | 323 x $10^{-6}$ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | 6.91 x $10^{-3}$ | 6.45 x $10^{-3}$ | 7.30 x $10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | 1.12 x $10^{-2}$ | 1.01 x $10^{-2}$ | 1.23 x $10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | 1.81 x $10^{-2}$ | 1.66 x $10^{-2}$ | 1.96 x $10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | 0.78 x $10^{-5}$ | -3.13 x $10^{-5}$ | 2.77 x $10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | – | – | – |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | – | – | – |

Table 3.1 N : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : T12,60 |
| WATERTEMPERATURE T (°C) | : 23 |

**WAVE AND CURRENT PARAMETERS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.121 | 0.120 | 0.122 |
| ZERO-CROSS PERIOD Tz (s) | 1.92 | 1.94 | 1.93 |
| PEAK PERIOD Tp (s) | 2.50 | 2.44 | 2.61 |
| RATIO $H_{1\%}/Hs$ (-) | 1.25 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.519 | 0.518 | 0.520 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.093 | 0.092 | 0.093 |

**RIPPLE PARAMETERS**

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.016 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.100 | 0.015 |
| RIPPLE VELOCITY $u_r$ (m/s) | $\pm 1.23 \times 10^{-5}$ | $1.02 \times 10^{-5}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL TRANSITION | |

**CONCENTRATIONS AND VELOCITIES**

| | TEST 1 (h (m) = 0.520) | | | TEST 2 (h (m) = 0.518) | | | TEST 3 (h (m) = 0.520) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.035 | 0.2620 | 0.027 | 0.031 | 0.3710 | 0.018 | 0.033 | 0.3030 | [illegible] | 0.012 | 0.056 |
| 2 | 0.054 | 0.1330 | 0.038 | 0.050 | 0.2000 | 0.036 | 0.052 | 0.2100 | [illegible] | 0.022 | 0.057 |
| 3 | 0.073 | 0.0839 | 0.060 | 0.069 | 0.1130 | 0.054 | 0.071 | 0.1130 | [illegible] | 0.032 | 0.068 |
| 4 | 0.102 | 0.0362 | 0.066 | 0.098 | 0.0522 | 0.058 | 0.100 | 0.0493 | 0.064 | 0.052 | 0.075 |
| 5 | 0.150 | 0.0093 | 0.090 | 0.147 | 0.0148 | 0.081 | 0.148 | 0.0102 | 0.091 | 0.077 | 0.075 |
| 6 | 0.227 | 0 | 0.102 | 0.224 | 0.0017 | 0.094 | 0.225 | 0.0019 | 0.111 | 0.117 | 0.088 |
| 7 | 0.342 | 0 | 0.111 | 0.340 | 0 | 0.111 | 0.340 | 0 | 0.113 | 0.177 | 0.104 |
| 8 | 0.458 | 0 | 0.104 | 0.456 | 0 | 0.114 | 0.456 | 0 | 0.102 | 0.237 | 0.108 |
| 9 | [illegible] | 0 | 0.107 | 0.531 | 0 | 0.103 | 0.531 | 0 | 0.105 | 0.292 | 0.111 |
| 10 | [illegible] | 0 | 0.098 | 0.702 | 0 | 0.096 | 0.706 | 0 | [illegible] | 0.367 | 0.115 |

**COMBINATION OF TEST 1, 2 AND 3**

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.012 | 0.3439 | 0.2802 | 0.3930 | 0.024 | 0.020 | 0.026 |
| 2 | 0.052 | 0.022 | 0.1895 | 0.1502 | 0.2190 | 0.032 | 0.036 | 0.038 |
| 3 | 0.071 | 0.037 | 0.1037 | 0.0824 | 0.1130 | 0.055 | 0.053 | 0.058 |
| 4 | 0.100 | 0.052 | 0.0465 | 0.0365 | 0.0522 | 0.063 | 0.059 | 0.066 |
| 5 | 0.148 | 0.077 | 0.0112 | 0.0102 | 0.0146 | 0.084 | 0.081 | 0.093 |
| 6 | 0.225 | 0.117 | 0.0012 | 0.0007 | 0.0019 | 0.101 | 0.094 | 0.111 |
| 7 | 0.341 | 0.177 | 0 | 0 | 0 | 0.111 | 0.111 | 0.113 |
| 8 | 0.457 | 0.237 | 0 | 0 | 0 | 0.108 | 0.104 | 0.116 |
| 9 | 0.528 | 0.292 | 0 | 0 | 0 | 0.105 | 0.102 | 0.105 |
| 10 | 0.702 | 0.367 | 0 | 0 | 0 | 0.094 | 0.092 | 0.096 |

**FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL**

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $26.9 \times 10^{-3}$ |
| 1 | $26.3 \times 10^{-3}$ |
| 2 | $25.6 \times 10^{-3}$ |
| 3 | $24.0 \times 10^{-3}$ |
| 4 | $23.9 \times 10^{-3}$ |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | $25.5 \times 10^{-3}$ |

**LOADS AND TRANSPORTS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $6.19 \times 10^{-3}$ | $4.81 \times 10^{-3}$ | $7.50 \times 10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $1.03 \times 10^{-2}$ | $8.31 \times 10^{-3}$ | $1.19 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $1.65 \times 10^{-2}$ | $1.31 \times 10^{-2}$ | $1.94 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $1.87 \times 10^{-4}$ | $2.81 \times 10^{-5}$ | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $3.74 \times 10^{-4}$ | $3.20 \times 10^{-4}$ | $4.35 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $5.61 \times 10^{-4}$ | $3.48 \times 10^{-4}$ | $7.82 \times 10^{-4}$ |

**PARTICLE DIAMETER BED MATERIAL (m)**

| | |
|---|---|
| $D_{10}$ | $151 \times 10^{-6}$ |
| $D_{50}$ | $208 \times 10^{-6}$ |
| $D_{90}$ | $323 \times 10^{-6}$ |

Table 3.10 : Basic measuring data

EXPERIMENT NO. : T12-10
WATERTEMPERATURE T (°C) : 21

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.115 | 0.114 | 0.116 |
| ZERO-CROSS PERIOD Tz (s) | 1.94 | 1.89 | 2.00 |
| PEAK PERIOD Tp (s) | 2.49 | 2.15 | 2.51 |
| RATIO $H_{1\%}$/Hs (-) | 1.40 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.497 | 0.493 | 0.501 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.118 | -0.115 | -0.120 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.016 | 0.002 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.102 | 0.010 |
| RIPPLE VELOCITY $u_r$ (m/s) | 12.20×10⁻⁶ | 2.60×10⁻⁶ |
| RIPPLE SHAPE | 2 DIMENSIONAL WAVE DOMINATED | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.493) | | | TEST 2 (h (m) = 0.496) | | | TEST 3 (h (m) = 0.501) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.041 | 0.2260 | -0.014 | 0.036 | 0.2410 | -0.017 | [illegible] | 0.2200 | -0.025 | 0.019 | -0.049 |
| 2 | 0.061 | 0.1540 | -0.035 | 0.056 | 0.1480 | -0.032 | [illegible] | 0.1300 | -0.033 | 0.029 | -0.063 |
| 3 | 0.081 | 0.0561 | -0.045 | 0.077 | 0.0812 | -0.038 | 0.038 | 0.0816 | -0.055 | 0.039 | -0.077 |
| 4 | 0.117 | 0.0406 | -0.057 | 0.107 | 0.0429 | -0.040 | 0.109 | 0.0365 | -0.063 | 0.054 | -0.086 |
| 5 | 0.162 | 0.0130 | -0.074 | 0.157 | 0.0111 | -0.071 | 0.158 | 0.0093 | -0.086 | 0.079 | -0.094 |
| 6 | 0.243 | 0.0028 | -0.086 | 0.238 | 0.0019 | -0.103 | 0.238 | 0.0009 | -0.093 | 0.119 | -0.100 |
| 7 | 0.361 | 0 | -0.108 | 0.359 | 0 | -0.119 | 0.357 | 0 | -0.124 | 0.179 | -0.105 |
| 8 | 0.487 | 0 | -0.122 | 0.480 | 0 | -0.120 | 0.477 | 0 | -0.130 | 0.239 | -0.120 |
| 9 | 0.600 | 0 | [illegible] | 0.601 | 0 | -0.142 | 0.593 | 0 | [illegible] | 0.299 | -0.113 |
| 10 | 0.751 | 0 | [illegible] | 0.742 | 0 | -0.158 | 0.733 | 0 | [illegible] | 0.369 | -0.120 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 0.019 | 0.2281 | 0.2195 | 0.2356 | -0.017 | -0.011 | -0.025 |
| 2 | [illegible] | 0.029 | 0.1505 | 0.1427 | 0.1646 | -0.034 | -0.032 | -0.037 |
| 3 | [illegible] | 0.039 | 0.0839 | 0.0791 | 0.0920 | -0.046 | -0.039 | -0.055 |
| 4 | 0.109 | 0.054 | 0.0424 | [illegible] | 0.0450 | -0.055 | -0.050 | -0.064 |
| 5 | 0.159 | 0.079 | 0.011 | [illegible] | 0.0155 | -0.074 | -0.072 | -0.089 |
| 6 | 0.240 | 0.119 | 0.0020 | 0.0009 | 0.0028 | -0.094 | -0.086 | -0.103 |
| 7 | 0.360 | 0.179 | - | 0 | 0.0001 | -0.117 | -0.107 | -0.124 |
| 8 | 0.481 | 0.239 | 0 | 0 | 0 | [illegible] | -0.127 | -0.140 |
| 9 | 0.602 | 0.299 | 0 | 0 | 0 | [illegible] | -0.136 | -0.142 |
| 10 | 0.742 | 0.369 | - | - | 0 | -0.15 | -0.152 | -0.158 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | 27.0×10⁻³ |
| 1 | 26.6×10⁻³ |
| 2 | 26.3×10⁻³ |
| 3 | 25.2×10⁻³ |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | 26.0×10⁻³ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | 158×10⁻⁶ |
| $D_{50}$ | 212×10⁻⁶ |
| $D_{90}$ | 289×10⁻⁶ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | 3.90×10⁻³ | 3.68×10⁻³ | 4.11×10⁻³ |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible]×10⁻³ | 7.35×10⁻³ | 8.65×10⁻³ |
| TOTAL LOAD $L_t$ (kg/m²) | 1.21×10⁻² | 1.13×10⁻² | 1.28×10⁻² |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | 3.25×10⁻⁵ | -6.32×10⁻⁶ | 7.31×10⁻⁵ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | -2.57×10⁻⁴ | -2.23×10⁻⁴ | -2.86×10⁻⁴ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | -2.25×10⁻⁴ | -1.50×10⁻⁴ | -2.91×10⁻⁴ |

Table 3.1 P : Basic measuring data

EXPERIMENT NO. : T12,20
WATERTEMPERATURE T (°C) : 22

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.123 | 0.121 | 0.125 |
| ZERO-CROSS PERIOD Tz (s) | 1.91 | 1.88 | 1.97 |
| PEAK PERIOD Tp (s) | 2.59 | 2.50 | 2.64 |
| RATIO $H_{1\%}/Hs$ (-) | 1.22 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.509 | 0.508 | 0.509 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.220 | 0.215 | 0.226 |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.017 | 0.005 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.108 | 0.016 |
| RIPPLE VELOCITY $u_r$ (m/s) | +2.18×10^-5? | 1.00×10^[illegible] |
| RIPPLE SHAPE | 2 DIMENSIONAL CURRENT DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = [illegible]) | | | TEST 2 (h (m) = 0.509?) | | | TEST 3 (h (m) = 0.509) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.030? | 0.3690 | 0.076? | 0.047 | 0.2950 | 0.095 | 0.033? | 0.3990? | 0.071 | 0.017 | 0.087 |
| 2 | 0.049? | 0.2360 | 0.103? | 0.067 | 0.1800 | 0.100 | 0.053? | 0.2760 | 0.095 | 0.027 | 0.116 |
| 3 | 0.069 | 0.1600 | 0.105? | 0.086 | 0.1250 | 0.120 | 0.073? | 0.2050 | 0.110 | 0.037 | 0.131 |
| 4 | 0.098? | 0.0967? | 0.129 | 0.116 | 0.0656 | 0.143? | 0.102 | 0.1140 | 0.137 | 0.052 | 0.139 |
| 5 | 0.148 | 0.0420 | 0.156? | 0.165 | 0.0317 | 0.184 | 0.151 | 0.0560 | 0.166 | 0.077 | 0.172 |
| 6 | 0.226 | 0.0140? | 0.186 | 0.244 | 0.0131 | 0.217 | 0.230 | 0.0168 | 0.189 | 0.117 | 0.204 |
| 7 | 0.344? | 0.0050? | [illegible] | 0.363 | 0.0037 | 0.232? | 0.348 | 0.0047 | 0.236 | 0.177 | 0.228 |
| 8 | 0.463? | 0.0013? | [illegible] | 0.479 | 0.0009 | 0.262 | 0.466 | 0.0009 | 0.248 | 0.237 | 0.239 |
| 9 | 0.581? | 0 | [illegible] | 0.597 | 0 | 0.261 | 0.583 | 0 | 0.245 | 0.297 | 0.256 |
| 10 | 0.719 | 0 | 0.255 | 0.735 | 0 | 0.257 | 0.721 | 0 | 0.244 | 0.367 | 0.260 |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 0.016? | 0.3511? | [illegible] | [illegible] | 0.084 | 0.075 | [illegible] |
| 2 | [illegible] | 0.026? | 0.2330? | 0.2114? | [illegible] | 0.101 | 0.098? | [illegible] |
| 3 | [illegible] | [illegible] | 0.1633? | 0.1515? | [illegible] | 0.116 | 0.111 | [illegible] |
| 4 | [illegible] | [illegible] | 0.0948? | 0.0656? | 0.1101? | 0.138 | 0.131? | 0.147 |
| 5 | [illegible] | 0.090? | [illegible] | [illegible] | 0.0562? | 0.170 | 0.162? | 0.175 |
| 6 | [illegible] | 0.119? | [illegible] | [illegible] | 0.0156 | 0.197? | 0.184? | 0.214? |
| 7 | [illegible] | 0.180? | [illegible] | [illegible] | 0.0054? | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | 0.240? | 0.0013 | 0.0009? | 0.0018 | 0.25? | 0.248 | 0.260? |
| 9 | [illegible] | 0.299? | 0 | 0 | 0.0001 | 0.252? | 0.245? | 0.261 |
| 10 | [illegible] | 0.369? | 0 | 0 | 0 | 0.252? | 0.244 | 0.257 |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | 25.6×10^-3 |
| 1 | 23.5×10^-3 |
| 2 | 23.6×10^-3 |
| 3 | 22.0×10^-3? |
| 4 | 22.3×10^-3 |
| 5 | 21.8×10^-3 |
| 6 TO 10 | — |
| MIXTURE | 23.2×10^-3 |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | 148×10^-6 |
| $D_{50}$ | 203×10^-6 |
| $D_{90}$ | 293×10^-6 |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible] | 4.25×10^-3? | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | 1.5?×10^-2 | 1.64×10^-2 |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | 1.83×10^-2 | 2.23×10^-2 |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | 5.16×10^-4 |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.1 Q : Basic measuring data

EXPERIMENT NO. : T12-20
WATERTEMPERATURE T (°C) : 21

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.116 | 0.116 | 0.116 |
| ZERO-CROSS PERIOD Tz (s) | 1.97 | 1.96 | 1.99 |
| PEAK PERIOD Tp (s) | 2.51 | 2.51 | 2.52 |
| RATIO $H_{1\%}$/Hs (-) | 1.45 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.490 | 0.490 | 0.491 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.233 | -0.232 | -0.235 |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.018 | 0.008 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.111 | 0.026 |
| RIPPLE VELOCITY $u_r$ (m/s) | -0.80×10⁻⁴ [illegible] | 2.40×10⁻⁵ [illegible] |
| RIPPLE SHAPE | 2 DIMENSIONAL CURRENT DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.491) | | | TEST 2 (h (m) = 0.490) | | | TEST 3 (h (m) = 0.490) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.043 | 0.2930 | -0.093 | 0.035 | 0.2590 | -0.064 | 0.037 | 0.2620 | -0.076 | 0.018 | -0.128 |
| 2 | 0.063 | 0.2020 | -0.107 | 0.055 | 0.1790 | -0.088 | 0.057 | 0.1890 | -0.096 | 0.028 | -0.147 |
| 3 | 0.084 | 0.1610 | -0.122 | 0.076 | 0.1380 | -0.108 | 0.078 | 0.1520 | -0.124 | 0.038 | -0.167 |
| 4 | 0.114 | 0.1000 | -0.137 | 0.106 | 0.0841 | -0.138 | 0.108 | 0.0886 | -0.142 | 0.053 | -0.175 |
| 5 | 0.165 | 0.0510 | -0.161 | 0.157 | 0.0473 | -0.158 | 0.159 | 0.0501 | -0.170 | 0.078 | -0.201 |
| 6 | 0.246 | 0.0176 | -0.191 | 0.239 | 0.0176 | -0.196 | 0.241 | 0.0204 | -0.190 | 0.118 | -0.240 |
| 7 | 0.369 | 0.0056 | -0.231 | 0.361 | 0.0056 | -0.229 | 0.363 | 0.0024 | -0.229 | 0.178 | -0.258 |
| 8 | 0.491 | 0.0028 | -0.262 | 0.484 | 0.0019 | -0.251 | 0.486 | 0.0028 | -0.265 | 0.238 | -0.271 |
| 9 | 0.613 | 0.0009 | -0.274 | 0.606 | 0.0009 | -0.280 | 0.608 | 0.0009 | -0.280 | 0.298 | -0.275 |
| 10 | 0.756 | 0.0003 | -0.290 | 0.749 | 0.0003 | -0.290 | 0.751 | 0.0003 | -0.292 | 0.368 | -0.256 |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.038 | 0.019 | 0.2739 | [illegible] | 0.3147 | -0.077 | -0.068 | -0.090 |
| 2 | 0.058 | 0.029 | 0.1941 | 0.1239 | 0.2432 | -0.098 | -0.091 | -0.104 |
| 3 | 0.079 | 0.039 | 0.1506 | 0.1366 | 0.1701 | -0.119 | -0.111 | -0.128 |
| 4 | 0.109 | 0.054 | 0.0927 | [illegible] | 0.1095 | -0.150 | -0.135 | -0.144 |
| 5 | 0.160 | 0.079 | 0.0504 | 0.0461 | 0.0505 | -0.161 | -0.150 | -0.172 |
| 6 | 0.242 | [illegible] | 0.0180 | 0.0173 | 0.0202 | -0.192 | -0.190 | -0.193 |
| 7 | 0.364 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.229 | -0.230 |
| 8 | 0.485 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.261 |
| 9 | 0.609 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.289 |
| 10 | 0.752 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.292 |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | 25.8×10⁻³ |
| 1 | 24.9×10⁻³ |
| 2 | 23.9×10⁻³ |
| 3 | 23.3×10⁻³ |
| 4 | 22.5×10⁻³ |
| 5 | 21.8×10⁻³ |
| 6 TO 10 | – |
| MIXTURE | 22.8×10⁻³ |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | 118×10⁻⁶ |
| $D_{50}$ | 206×10⁻⁶ |
| $D_{90}$ | 306×10⁻⁶ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible]×10⁻³ | 3.54×10⁻³ | 4.21×10⁻³ |
| SUSPENDED LOAD $L_s$ (kg/m²) | 1.32×10⁻² | 1.17×10⁻² | 1.48×10⁻² |
| TOTAL LOAD $L_t$ (kg/m²) | 1.69×10⁻² | 1.50×10⁻² | 1.90×10⁻² |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | -1.70×10⁻⁴ | -2.21×10⁻⁵ | -3.17×10⁻⁴ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | -1.61×10⁻³ | -1.36×10⁻³ | -1.87×10⁻³ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | -1.78×10⁻³ | -1.38×10⁻³ | -2.14×10⁻³ |

Table 3.1 R : Basic measuring data

EXPERIMENT NO. : T12,40
WATERTEMPERATURE T (°C) : 22

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.119 | 0.117 | 0.121 |
| ZERO-CROSS PERIOD Tz (s) | 1.80 | 1.77 | 1.84 |
| PEAK PERIOD Tp (s) | 2.45 | 2.43 | 2.49 |
| RATIO $H_{1\%}$/Hs (-) | 1.26 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.509 | 0.507 | 0.511 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.443 | 0.442 | 0.443 |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.018 | 0.008 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.174 | 0.049 |
| RIPPLE VELOCITY $u_r$ (m/s) | $3.04 \times 10^{-4}$ | $6.50 \times 10^{-5}$ |
| RIPPLE SHAPE | 2½ DIMENSIONAL CURRENT DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.507) | | | TEST 2 (h (m) = 0.508) | | | TEST 3 (h (m) = 0.511) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.039 | 1.2060 | 0.255 | 0.031 | 1.0880? | 0.271 | 0.031 | 1.1460 | — | — | — |
| 2 | 0.050 | 0.8810 | 0.281 | 0.051 | [illegible] | 0.289 | 0.051 | 0.8010? | — | — | — |
| 3 | 0.079 | 0.6060 | 0.322 | 0.071 | 0.6900? | 0.295 | 0.070 | 0.6900? | — | — | — |
| 4 | 0.108 | 0.5360 | 0.340 | 0.100 | 0.5180? | 0.319 | 0.100 | 0.4990? | — | — | — |
| 5 | 0.158 | 0.3360 | 0.389 | 0.150 | 0.3180? | 0.361 | 0.149? | 0.3250 | — | — | — |
| 6 | 0.237 | 0.1530? | 0.417 | 0.228 | 0.1730? | 0.398 | 0.234? | 0.1600 | — | — | — |
| 7 | 0.355 | [illegible] | 0.467? | 0.343 | 0.0383? | 0.468 | 0.344 | 0.0383 | — | — | — |
| 8 | 0.470? | [illegible] | 0.493? | 0.465 | 0.0243? | 0.493 | 0.462 | 0.0344? | — | — | — |
| 9 | 0.592? | 0.0158? | [illegible] | 0.585 | 0.0166 | 0.494 | 0.579 | 0.0166 | — | — | — |
| 10 | 0.730? | [illegible] | [illegible] | 0.720? | 0.0080 | 0.485 | 0.716 | 0.0080 | — | — | — |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.017 | 1.1540 | [illegible] | [illegible] | 0.261 | 0.248 | 0.273? |
| 2 | [illegible] | 0.027 | 0.8930 | [illegible] | [illegible] | 0.282 | 0.274 | [illegible] |
| 3 | 0.073 | 0.037 | 0.7014 | [illegible] | [illegible] | 0.304 | 0.297 | 0.310 |
| 4 | 0.103 | 0.052 | [illegible] | [illegible] | [illegible] | 0.329 | 0.321 | [illegible] |
| 5 | 0.152 | 0.077 | [illegible] | [illegible] | 0.3527? | 0.373 | 0.362 | [illegible] |
| 6 | 0.231 | 0.117 | [illegible] | 0.1534? | [illegible] | 0.405 | 0.400 | [illegible] |
| 7 | 0.349 | 0.173 | [illegible] | [illegible] | [illegible] | 0.466 | 0.464 | [illegible] |
| 8 | 0.467 | 0.237 | [illegible] | [illegible] | [illegible] | 0.492 | 0.491 | [illegible] |
| 9 | 0.585 | 0.297 | [illegible] | [illegible] | 0.0168? | 0.495 | 0.494 | 0.496 |
| 10 | 0.722 | 0.367 | [illegible] | 0.0076? | 0.0082? | 0.482 | 0.479 | 0.485 |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.8 \times 10^{-3}$? |
| 1 | $21.2 \times 10^{-3}$? |
| 2 | $20.0 \times 10^{-3}$? |
| 3 | $19.1 \times 10^{-3}$? |
| 4 | [illegible] |
| 5 | $19.2 \times 10^{-3}$? |
| 6 TO 10 | $18.3 \times 10^{-3}$? |
| MIXTURE | [illegible] |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $119 \times 10^{-6}$? |
| $D_{50}$ | $204 \times 10^{-6}$ |
| $D_{90}$ | $311 \times 10^{-6}$ |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.41 \times 10^{-2}$? | $1.24 \times 10^{-2}$? | $1.62 \times 10^{-2}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | $6.90 \times 10^{-2}$ | $7.76 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | $8.14 \times 10^{-2}$ | $9.38 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $5.22 \times 10^{-3}$ | $2.64 \times 10^{-3}$? | $7.79 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.49 \times 10^{-2}$? | $2.37 \times 10^{-2}$ | $2.61 \times 10^{-2}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $3.01 \times 10^{-2}$ | $2.63 \times 10^{-2}$? | $3.39 \times 10^{-2}$ |

Table 3.1 S : Basic measuring data

EXPERIMENT NO. : T12,-40
WATERTEMPERATURE T (°C) : 21

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.116 | 0.117 | 0.118 |
| ZERO-CROSS PERIOD Tz (s) | 2.11 | 2.05 | 2.16 |
| PEAK PERIOD Tp (s) | 2.62 | 2.59 | 2.68 |
| RATIO $H_{1\%}$/Hs (-) | 1.56 | – | – |
| WATERDEPTH TO MEAN BED h (m) | 0.497 | 0.496 | 0.499 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.442 | -0.438 | -0.445 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.020 | 0.007 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.155 | 0.051 |
| RIPPLE VELOCITY $u_r$ (m/s) | $-1.89 \times 10^{-7}$ | $1.08 \times 10^{-7}$ |
| RIPPLE SHAPE | 3 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.496) | | | TEST 2 (h (m) = 0.497) | | | TEST 3 (h (m) = 0.499) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.046 | 1.3770 | -0.231 | 0.060 | 1.2130 | -0.240 | 0.050 | — | -0.223 | 0.025 | -0.292 |
| 2 | 0.062 | 1.0270 | -0.271 | 0.080 | 0.9340 | -0.263 | 0.070 | — | -0.241 | 0.035 | -0.305 |
| 3 | 0.087 | 0.8180 | -0.288 | 0.101 | 0.7250 | -0.292 | 0.090 | — | -0.270 | 0.045 | -0.320 |
| 4 | 0.113 | 0.6300 | -0.297 | 0.131 | 0.5600 | -0.307 | 0.120 | — | -0.308 | 0.060 | -0.328 |
| 5 | 0.167 | 0.4560 | -0.341 | 0.181 | 0.3640 | -0.335 | 0.170 | — | -0.320 | 0.085 | -0.360 |
| 6 | 0.248 | 0.2130 | -0.376 | 0.262 | 0.1900 | -0.385 | 0.251 | — | -0.301 | 0.125 | -0.391 |
| 7 | 0.360 | 0.0935 | -0.430 | 0.382 | 0.0275 | -0.433 | 0.321 | — | -0.447 | 0.185 | -0.435 |
| 8 | 0.490 | 0.0364 | -0.475 | 0.503 | 0.0306 | -0.484 | 0.491 | — | -0.470 | 0.245 | -0.466 |
| 9 | 0.611 | 0.0177 | -0.515 | 0.624 | 0.0149 | -0.513 | 0.611 | — | -0.512 | 0.305 | -0.507 |
| 10 | 0.752 | 0.0066 | -0.541 | 0.765 | 0.0056 | -0.525 | 0.757 | — | -0.539 | 0.375 | -0.533 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 0.026 | 1.3008 | 1.2770 | [illegible] | [illegible] | -0.225 | -0.247 |
| 2 | [illegible] | 0.036 | 1.0061 | 0.9712 | [illegible] | [illegible] | [illegible] | -0.276 |
| 3 | [illegible] | 0.046 | 0.7952 | [illegible] | [illegible] | [illegible] | [illegible] | -0.290 |
| 4 | [illegible] | 0.061 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.309 |
| 5 | [illegible] | 0.086 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.343 |
| 6 | [illegible] | 0.126 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | 0.186 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | 0.246 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.480 |
| 9 | [illegible] | 0.306 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.516 |
| 10 | [illegible] | 0.376 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.542 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | [illegible] |
| 1 | [illegible] |
| 2 | [illegible] |
| 3 | [illegible] |
| 4 | [illegible] |
| 5 | [illegible] |
| 6 TO 10 | [illegible] |
| MIXTURE | [illegible] |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | [illegible] |
| $D_{50}$ | [illegible] |
| $D_{90}$ | [illegible] |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | $1.19 \times 10^{-1}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.1 T : Basic measuring data

| EXPERIMENT NO. : [illegible] |
|---|
| WATERTEMPERATURE T (°C) : [illegible] |

**WAVE AND CURRENT PARAMETERS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | [illegible] | 0.151 | 0.155 |
| ZERO-CROSS PERIOD Tz (s) | [illegible] | 1.50 | 1.54 |
| PEAK PERIOD Tp (s) | [illegible] | [illegible] | [illegible] |
| RATIO $H_{1\%}/Hs$ (-) | [illegible] | — | — |
| WATERDEPTH TO MEAN BED h (m) | [illegible] | 0.498 | 0.508 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | — | — | — |

**RIPPLE PARAMETERS**

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.018 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.115 | 0.017 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+9.70 \times 10^{-6}$ | $2.00 \times 10^{-6}$ |
| RIPPLE SHAPE | 2-DIMENSIONAL WAVE DOMINATED | |

**CONCENTRATIONS AND VELOCITIES**

| | TEST 1 (h (m) = 0.50[illegible]) | | | TEST 2 (h (m) = 0.503) | | | TEST 3 (h (m) = [illegible]) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.043 | 0.8110 | — | 0.036 | 0.8200 | — | 0.038 | 0.9920 | — | — | — |
| 2 | 0.063 | 0.4760 | — | 0.056 | 0.5070 | — | 0.058 | 0.6200 | — | — | — |
| 3 | 0.083 | 0.3080 | — | 0.026 | 0.3400 | — | 0.078 | 0.4030 | — | — | — |
| 4 | 0.112 | 0.1420 | — | 0.105 | 0.1680 | — | 0.108 | 0.1970 | — | — | — |
| 5 | 0.161 | 0.0371 | — | 0.155 | 0.0408 | — | 0.159 | 0.0594 | — | — | — |
| 6 | 0.240 | 0.0032 | — | 0.235 | 0.0037 | — | 0.239 | 0.0093 | — | — | — |
| 7 | 0.358 | 0 | | 0.354 | 0 | — | 0.359 | 0 | — | — | — |
| 8 | 0.476 | 0 | — | 0.472 | 0 | — | 0.480 | 0 | — | — | — |
| 9 | 0.594 | 0 | — | 0.592 | 0 | — | 0.600 | 0 | — | — | — |
| 10 | 0.732 | 0 | — | 0.737 | 0 | — | 0.741 | 0 | — | — | — |

**COMBINATION OF TEST 1, 2 AND 3**

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.039 | 0.020 | 0.8746 | 0.7723 | 0.9734 | — | — | — |
| 2 | 0.059 | 0.030 | 0.5433 | 0.4733 | 0.6007 | — | — | — |
| 3 | 0.079 | 0.040 | 0.3573 | 0.3222 | 0.3961 | — | — | — |
| 4 | 0.108 | 0.055 | 0.1729 | [illegible] | 0.1961 | — | — | — |
| 5 | 0.158 | 0.080 | 0.0492 | [illegible] | 0.0612 | — | — | — |
| 6 | 0.238 | 0.120 | 0.0060 | [illegible] | 0.0093 | — | — | — |
| 7 | 0.357 | 0.180 | [illegible] | 0 | 0.0007 | — | — | — |
| 8 | 0.476 | 0.240 | 0 | 0 | 0 | — | — | — |
| 9 | 0.595 | 0.300 | 0 | 0 | 0 | — | — | — |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | — | — | — |

**FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL**

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $26.7 \times 10^{-3}$ |
| 1 | $24.8 \times 10^{-3}$ |
| 2 | $24.9 \times 10^{-3}$ |
| 3 | $24.8 \times 10^{-3}$ |
| 4 | $23.3 \times 10^{-3}$ |
| 5 | $21.9 \times 10^{-3}$ |
| 6 TO 10 | — |
| MIXTURE | $24.6 \times 10^{-3}$ |

**PARTICLE DIAMETER BED MATERIAL (m)**

| | |
|---|---|
| $D_{10}$ | $1?? \times 10^{-6}$ |
| $D_{50}$ | $2?? \times 10^{-6}$ |
| $D_{90}$ | $311 \times 10^{-6}$ |

**LOADS AND TRANSPORTS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible] | [illegible] | $1.31 \times 10^{-1}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | $3.49 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | $5.20 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | $2.39 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | — | — | — |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | — | — | — |

Table 3.1 U : Basic measuring data

EXPERIMENT NO. : [illegible]
WATERTEMPERATURE T (°C) : [illegible]

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.146 | 0.146 | 0.146 |
| ZERO-CROSS PERIOD Tz (s) | 1.95 | 1.94 | 1.95 |
| PEAK PERIOD Tp (s) | 2.37 | 2.32 | 2.46 |
| RATIO $H_{1\%}/Hs$ (-) | 1.30 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.503 | 0.502 | 0.503 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.107 | 0.105 | 0.108 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.018 | 0.002 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.090 | 0.003 |
| RIPPLE VELOCITY $u_r$ (m/s) | +6.75×10⁻⁶ | 1.30×10⁻⁶ |
| RIPPLE SHAPE | 2 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| LEVEL NO. | TEST 1 (h (m) = 0.503) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 2 (h (m) = 0.503) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 3 (h (m) = 0.502) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | ONLY CURRENT HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.038 | 0.5970 | 0.026 | 0.038 | 0.5920 | 0.015 | 0.036 | [illegible] | 0.020 | [illegible] | 0.058 |
| 2 | 0.058 | 0.3450 | 0.030 | 0.058 | 0.3750 | 0.027 | 0.056 | 0.3030 | 0.033 | [illegible] | 0.030 |
| 3 | 0.078 | 0.1960 | 0.049 | 0.078 | 0.2150 | 0.050 | 0.076 | 0.2640 | 0.043 | [illegible] | 0.022 |
| 4 | 0.107 | 0.1060 | 0.068 | 0.107 | 0.1130 | 0.062 | 0.106 | 0.1270 | 0.067 | 0.053 | 0.038 |
| 5 | 0.157 | 0.0290 | 0.090 | 0.157 | 0.0261 | 0.083 | [illegible] | 0.0377 | 0.081 | 0.078 | 0.085 |
| 6 | 0.237 | 0.0037 | 0.112 | 0.237 | 0.0037 | 0.105 | [illegible] | [illegible] | 0.114 | 0.118 | 0.103 |
| 7 | 0.356 | 0.0019 | 0.120 | 0.356 | 0.0019 | 0.124 | [illegible] | [illegible] | 0.121 | 0.178 | 0.116 |
| 8 | 0.475 | 0.0003 | 0.129 | 0.475 | 0.0003 | 0.131 | [illegible] | [illegible] | 0.127 | 0.238 | 0.130 |
| 9 | 0.594 | 0 | 0.130 | 0.594 | 0 | 0.143 | [illegible] | 0 | 0.117 | 0.298 | 0.153 |
| 10 | 0.734 | 0 | 0.111 | 0.734 | 0 | 0.127 | [illegible] | 0 | 0.127 | 0.368 | 0.144 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 0.019 | 0.5926 | 0.5731 | 0.6054 | 0.020 | 0.015 | 0.026 |
| 2 | [illegible] | 0.029 | 0.3733 | 0.3534 | 0.3844 | 0.030 | 0.027 | 0.034 |
| 3 | [illegible] | [illegible] | 0.2264 | 0.2010 | 0.2599 | 0.048 | 0.048 | 0.049 |
| 4 | [illegible] | [illegible] | 0.1153 | 0.1070 | [illegible] | 0.064 | 0.062 | 0.068 |
| 5 | [illegible] | [illegible] | 0.0315 | [illegible] | [illegible] | 0.085 | 0.082 | 0.090 |
| 6 | [illegible] | [illegible] | 0.0035 | [illegible] | [illegible] | 0.110 | 0.105 | 0.116 |
| 7 | [illegible] | [illegible] | 0.0016 | [illegible] | [illegible] | 0.122 | 0.120 | [illegible] |
| 8 | 0.475 | [illegible] | 0.0003 | [illegible] | [illegible] | 0.129 | 0.127 | 0.131 |
| 9 | [illegible] | [illegible] | 0 | 0 | 0 | 0.120 | 0.113 | [illegible] |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | [illegible] | 0.111 | 0.127 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | [illegible] |
| 1 | [illegible] |
| 2 | [illegible] |
| 3 | [illegible] |
| 4 | [illegible] |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | [illegible] |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | [illegible] |
| $D_{50}$ | [illegible] |
| $D_{90}$ | [illegible] |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible] | 8.93 [illegible] | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.1 V : Basic measuring data

EXPERIMENT NO. : [illegible]
WATERTEMPERATURE T (°C) : [illegible]

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | [illegible] | 0.145 | 0.149 |
| ZERO-CROSS PERIOD Tz (s) | [illegible] | 1.77 | 1.83 |
| PEAK PERIOD Tp (s) | [illegible] | 2.47 | 2.50 |
| RATIO $H_{1\%}/Hs$ (-) | [illegible] | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.498 | 0.497 | 0.498 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.132 | -0.130 | -0.134 |

RIPPLE PARAMETERS

| - | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.012 | 0.004 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.100 | 0.014 |
| RIPPLE VELOCITY $u_r$ (m/s) | [illegible] | [illegible] |
| RIPPLE SHAPE | 2DIMENSIONAL WAVE DOMINATED | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.498) | | | TEST 2 (h (m) = 0.498) | | | TEST 3 (h (m) = 0.497) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.044 | 0.7120 | -0.016 | 0.038 | 0.6930 | -0.019 | 0.048 | 0.6930 | -0.025 | 0.024 | -0.064 |
| 2 | 0.064 | 0.4060 | -0.034 | 0.058 | 0.4410 | -0.029 | 0.068 | 0.4520 | -0.041 | 0.034 | -0.071 |
| 3 | 0.084 | 0.2850 | -0.042 | 0.078 | 0.3020 | -0.046 | 0.089 | 0.3150 | -0.040 | 0.044 | -0.081 |
| 4 | 0.114 | 0.1600 | -0.063 | 0.108 | 0.1700 | -0.064 | 0.119 | 0.1890 | -0.049 | 0.059 | -0.088 |
| 5 | 0.165 | 0.0566 | -0.085 | 0.159 | 0.0589 | -0.071 | 0.169 | 0.0725 | -0.079 | 0.084 | -0.102 |
| 6 | 0.245 | 0.0045 | [illegible] | 0.239 | 0.0058 | -0.095 | 0.249 | 0.0084 | -0.103 | 0.124 | -0.116 |
| 7 | 0.365 | 0 | -0.131 | 0.359 | 0.0009 | -0.123 | 0.370 | 0.0009 | -0.131 | 0.184 | -0.129 |
| 8 | 0.486 | 0 | -0.145 | 0.480 | 0 | -0.143 | 0.491 | 0 | -0.116 | 0.244 | -0.131 |
| 9 | 0.606 | 0 | -0.161 | 0.600 | 0 | -0.159 | 0.612 | 0 | -0.159 | 0.304 | -0.137 |
| 10 | 0.747 | 0 | -0.173 | 0.741 | 0 | -0.180 | 0.753 | 0 | -0.187 | 0.374 | -0.134 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.043 | 0.022 | 0.6991 | 0.6255 | 0.7492 | -0.019 | -0.015 | -0.022 |
| 2 | 0.063 | 0.032 | 0.4428 | 0.4039 | 0.5082 | -0.038 | -0.034 | -0.042 |
| 3 | 0.084 | 0.047 | 0.3046 | 0.2771 | 0.3498 | -0.044 | -0.040 | -0.049 |
| 4 | 0.114 | 0.057 | 0.1768 | 0.1577 | 0.2114 | -0.058 | -0.047 | -0.065 |
| 5 | 0.164 | 0.082 | 0.0606 | 0.0554 | 0.0834 | -0.075 | -0.073 | -0.096 |
| 6 | 0.244 | 0.122 | 0.0075 | 0.0018 | 0.0121 | -0.098 | -0.086 | -0.107 |
| 7 | 0.365 | 0.182 | 0.0002 | - | 0.0012 | -0.128 | -0.124 | -0.131 |
| 8 | 0.486 | 0.242 | 0 | - | 0 | -0.145 | -0.114 | -0.115 |
| 9 | 0.606 | 0.302 | 0 | - | 0 | -0.160 | -0.158 | -0.161 |
| 10 | 0.747 | 0.372 | 0 | - | 0 | -0.180 | -0.173 | -0.186 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $28.9 \times 10^{-3}$ |
| 1 | $26.7 \times 10^{-3}$ |
| 2 | $25.8 \times 10^{-3}$ |
| 3 | $26.3 \times 10^{-3}$ |
| 4 | $24.0 \times 10^{-3}$ |
| 5 | $22.8 \times 10^{-3}$ |
| 6 TO 10 | — |
| MIXTURE | $26.1 \times 10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $170 \times 10^{-6}$ |
| $D_{50}$ | $223 \times 10^{-6}$ |
| $D_{90}$ | $309 \times 10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.21 \times 10^{-2}$ | $1.08 \times 10^{-2}$ | $1.32 \times 10^{-2}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | $2.62 \times 10^{-2}$ | $3.29 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | $3.30 \times 10^{-2}$ | $4.61 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | $1.01 \times 10^{-5}$ | $1.21 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $-1.03 \times 10^{-3}$ | [illegible] | $-1.21 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $-9.49 \times 10^{-4}$ | [illegible] | $-1.13 \times 10^{-3}$ |

Table 3.1 W : Basic measuring data

EXPERIMENT NO. : T15,20
WATERTEMPERATURE T (°C) : 21

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.151 | 0.149 | 0.153 |
| ZERO-CROSS PERIOD Tz (s) | 1.78 | 1.76 | 1.79 |
| PEAK PERIOD Tp (s) | 2.41 | 2.38 | 2.47 |
| RATIO $H_{1\%}$/Hs (-) | 1.27 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.511 | 0.511 | 0.512 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.222 | 0.218 | 0.227 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.016 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.111 | 0.011 |
| RIPPLE VELOCITY $u_r$ (m/s) | $1.42 \times 10^{-5}$ | $1.21 \times 10^{-5}$ |
| RIPPLE SHAPE | 2½ DIMENSIONAL CURRENT DOMINATED | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.511) | | | TEST 2 (h (m) = 0.512) | | | TEST 3 (h (m) = 0.511) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.041 | 0.6060 | 0.081 | 0.043 | 0.7890 | 0.072 | 0.042 | 0.9430 | 0.095 | 0.022 | 0.121 |
| 2 | 0.061 | 0.4400 | 0.100 | 0.063 | 0.5360 | 0.093 | 0.063 | 0.5920 | 0.117 | 0.032 | 0.140 |
| 3 | 0.080 | 0.3180 | 0.104 | 0.082 | 0.3710 | 0.119 | 0.082 | 0.4660 | 0.129 | 0.042 | 0.150 |
| 4 | 0.110 | 0.2420 | 0.133 | 0.111 | 0.2460 | 0.138 | 0.112 | 0.3070 | 0.143 | 0.057 | 0.163 |
| 5 | 0.159 | 0.1140 | 0.146 | 0.160 | 0.1110 | 0.165 | 0.160 | 0.1570 | 0.177 | 0.082 | 0.201 |
| 6 | 0.237 | 0.0362 | 0.193 | 0.238 | 0.0362 | 0.192 | 0.239 | 0.0406 | 0.201 | 0.122 | 0.201 |
| 7 | 0.354 | 0.0087 | 0.233 | 0.355 | 0.0093 | 0.228 | 0.356 | 0.0093 | 0.248 | 0.182 | 0.229 |
| 8 | 0.437 | 0.0037 | 0.251 | 0.473 | 0.0037 | 0.256 | 0.474 | 0.0028 | 0.256 | 0.242 | 0.259 |
| 9 | 0.589 | 0.0008 | 0.258 | 0.590 | 0.0009 | 0.254 | 0.591 | 0.0009 | 0.260 | 0.302 | 0.271 |
| 10 | 0.726 | – | 0.262 | 0.727 | 0 | 0.253 | 0.728 | 0 | 0.261 | 0.372 | 0.272 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.042 | 0.022 | 0.8097 | 0.6857 | 0.9430 | 0.082 | 0.071 | 0.095 |
| 2 | 0.067 | 0.032 | 0.5512 | 0.4800 | 0.6031 | 0.100 | 0.091 | 0.116 |
| 3 | 0.081 | 0.042 | 0.3971 | 0.3433 | 0.4704 | 0.117 | 0.105 | 0.129 |
| 4 | 0.111 | 0.057 | 0.2659 | 0.2394 | 0.3123 | 0.138 | 0.133 | 0.143 |
| 5 | 0.160 | 0.082 | 0.1278 | 0.1119 | 0.1580 | 0.163 | 0.146 | 0.177 |
| 6 | 0.238 | 0.122 | 0.0371 | 0.0360 | 0.0421 | 0.192 | 0.193 | 0.201 |
| 7 | 0.355 | 0.182 | 0.0092 | 0.0087 | 0.0096 | 0.236 | 0.228 | 0.248 |
| 8 | 0.444 | 0.242 | 0.0034 | 0.0030 | 0.0037 | 0.254 | 0.251 | 0.256 |
| 9 | 0.590 | 0.302 | 0.0009 | 0.0007 | 0.0009 | 0.257 | 0.254 | 0.260 |
| 10 | 0.727 | 0.372 | 0 | 0 | 0 | 0.259 | 0.253 | 0.262 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $26.6 \times 10^{-3}$ |
| 1 | $25.4 \times 10^{-3}$ |
| 2 | $23.9 \times 10^{-3}$ |
| 3 | $24.2 \times 10^{-3}$ |
| 4 | $23.6 \times 10^{-3}$ |
| 5 | $22.9 \times 10^{-3}$ |
| 6 TO 10 | $21.2 \times 10^{-3}$ |
| MIXTURE | $24.4 \times 10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $165 \times 10^{-6}$ |
| $D_{50}$ | $211 \times 10^{-6}$ |
| $D_{90}$ | $284 \times 10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.20 \times 10^{-2}$ | $1.01 \times 10^{-2}$ | $1.34 \times 10^{-2}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $4.04 \times 10^{-2}$ | $3.52 \times 10^{-2}$ | $4.64 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $5.24 \times 10^{-2}$ | $4.53 \times 10^{-2}$ | $5.98 \times 10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $6.74 \times 10^{-4}$ | $4.50 \times 10^{-4}$ | $8.98 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $4.53 \times 10^{-3}$ | $3.76 \times 10^{-3}$ | $5.67 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $5.20 \times 10^{-3}$ | $4.21 \times 10^{-3}$ | $6.57 \times 10^{-3}$ |

Table 3.1 X : Basic measuring data

EXPERIMENT NO. : T15-20
WATERTEMPERATURE T (°C) : [illegible]

**WAVE AND CURRENT PARAMETERS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.147 | 0.147 | 0.147 |
| ZERO-CROSS PERIOD Tz (s) | 1.92 | 1.88 | 1.95 |
| PEAK PERIOD Tp (s) | 2.52 | 2.51 | 2.52 |
| RATIO $H_{1\%}/Hs$ (-) | 1.29 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.491 | 0.491 | 0.492 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.232 | -0.231 | -0.232 |

**RIPPLE PARAMETERS**

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.013 | 0.007 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.092 | 0.035 |
| RIPPLE VELOCITY $u_r$ (m/s) | $-7.50\times10^{-6}$ | $8.90\times10^{-6}$ |
| RIPPLE SHAPE | 3 DIMENSIONAL TRANSITION | |

**CONCENTRATIONS AND VELOCITIES**

| | TEST 1 (h (m) =0.491) | | | TEST 2 (h (m) =0.491) | | | TEST 3 (h (m) =0.492) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.045 | [illegible] | [illegible] | 0.047 | 0.5310 | -0.070 | 0.047 | 0.5190 | -0.065 | 0.023 | -0.133 |
| 2 | 0.065 | [illegible] | [illegible] | 0.067 | 0.3610 | -0.097 | 0.067 | 0.3650 | -0.088 | 0.033 | -0.142 |
| 3 | 0.086 | 0.2430 | -0.110 | 0.088 | 0.2660 | -0.120 | 0.087 | 0.2630 | -0.106 | 0.043 | -0.159 |
| 4 | 0.116 | 0.1850 | -0.130 | 0.118 | 0.1960 | -0.137 | 0.118 | 0.1830 | -0.140 | 0.058 | -0.178 |
| 5 | 0.167 | 0.0948 | -0.157 | 0.169 | 0.0978 | -0.161 | 0.169 | 0.0846 | -0.161 | 0.083 | -0.193 |
| 6 | 0.248 | 0.0355 | -0.182 | 0.251 | 0.0402 | -0.196 | 0.250 | 0.0392 | -0.189 | 0.123 | -0.201 |
| 7 | 0.371 | 0.0084 | -0.219 | 0.373 | 0.0131 | -0.227 | 0.372 | 0.0112 | -0.218 | 0.183 | -0.238 |
| 8 | 0.494 | 0.0037 | -0.262 | 0.495 | 0.0037 | -0.255 | 0.494 | 0.0037 | -0.253 | 0.243 | -0.261 |
| 9 | 0.615 | 0.0012 | -0.274 | 0.617 | 0.0012 | -0.275 | 0.616 | 0.0012 | -0.280 | 0.303 | -0.264 |
| 10 | 0.758 | 0.0003 | -0.299 | 0.760 | 0.0003 | -0.304 | 0.758 | 0.0003 | -0.302 | 0.373 | -0.261 |

**COMBINATION OF TEST 1, 2 AND 3**

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.046 | 0.023 | 0.5173 | 0.4911 | 0.5367 | -0.066 | -0.064 | -0.069 |
| 2 | 0.066 | 0.033 | 0.3566 | 0.3329 | 0.3701 | -0.089 | -0.082 | -0.091 |
| 3 | 0.087 | 0.043 | 0.2582 | 0.2411 | 0.2705 | -0.112 | -0.106 | -0.119 |
| 4 | 0.117 | 0.058 | 0.1896 | 0.1826 | 0.1976 | -0.138 | -0.137 | -0.139 |
| 5 | 0.168 | 0.083 | 0.0920 | 0.0859 | 0.0991 | -0.160 | -0.157 | -0.161 |
| 6 | 0.250 | 0.123 | 0.0386 | 0.0351 | 0.0411 | -0.189 | -0.182 | -0.195 |
| 7 | [illegible] | 0.183 | 0.0110 | 0.0084 | 0.0133 | -0.221 | -0.218 | [illegible] |
| 8 | [illegible] | 0.243 | 0.0037 | 0.0037 | 0.0038 | -0.255 | -0.252 | -0.258 |
| 9 | 0.616 | 0.303 | 0.0012 | 0.0017 | 0.0012 | [illegible] | -0.275 | -0.284 |
| 10 | 0.759 | 0.373 | 0.0003 | 0.0003 | 0.0003 | -0.300 | -0.293 | -0.307 |

**FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL**

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $25.6\times10^{-3}$ |
| 1 | $22.5\times10^{-3}$ |
| 2 | $20.7\times10^{-3}$ |
| 3 | $20.7\times10^{-3}$ |
| 4 | $20.0\times10^{-3}$ |
| 5 | $18.9\times10^{-3}$ |
| 6 TO 10 | $16.7\times10^{-3}$ |
| MIXTURE | $21.1\times10^{-3}$ |

**PARTICLE DIAMETER BED MATERIAL (m)**

| | |
|---|---|
| $D_{10}$ | $146\times10^{-6}$ |
| $D_{50}$ | $205\times10^{-6}$ |
| $D_{90}$ | $294\times10^{-6}$ |

**LOADS AND TRANSPORTS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $6.59\times10^{-3}$ | $6.26\times10^{-3}$ | $6.71\times10^{-3}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | $2.86\times10^{-2}$ | $3.13\times10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $3.68\times10^{-2}$ | [illegible] | $3.80\times10^{-2}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $-1.05\times10^{-4}$ | [illegible] | $-7.79\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $-3.12\times10^{-3}$ | $-2.96\times10^{-3}$ | $-3.36\times10^{-3}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $-3.23\times10^{-3}$ | $-2.88\times10^{-3}$ | $-3.59\times10^{-3}$ |

Table 3.1 Y : Basic measuring data

EXPERIMENT NO. : 15,-40
WATERTEMPERATURE T (°C) : 21

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.146 | 0.144 | 0.147 |
| ZERO-CROSS PERIOD Tz (s) | 2.11 | 2.07 | 2.18 |
| PEAK PERIOD Tp (s) | 2.47 | 2.37 | 2.55 |
| RATIO $H_{1\%}/Hs$ (-) | 1.47 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.509 | 0.508 | 0.509 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.432 | -0.431 | -0.441 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.024 | 0.008 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.188 | 0.051 |
| RIPPLE VELOCITY $u_r$ (m/s) | $-3.64\times10^{-4}$ | $1.18\times10^{-4}$ |
| RIPPLE SHAPE | 3 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.508) | | | TEST 2 (h (m) = 0.509) | | | TEST 3 (h (m) = 0.509) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.065 | 1.5870 | -0.232 | 0.061 | 1.4900 | -0.243 | 0.059 | 1.6100 | -0.239 | 0.053 | -0.254 |
| 2 | 0.085 | 1.3300 | -0.255 | 0.081 | 1.2600 | -0.253 | 0.073 | 1.3540 | -0.259 | 0.073 | -0.280 |
| 3 | 0.104 | 1.0320 | -0.281 | 0.100 | 1.0410 | -0.274 | 0.092 | 1.0790 | -0.275 | 0.092 | -0.297 |
| 4 | 0.134 | 0.8630 | -0.305 | 0.130 | 0.8460 | -0.304 | 0.122 | 0.8750 | -0.292 | 0.122 | -0.328 |
| 5 | 0.183 | 0.5880 | -0.338 | 0.179 | 0.5870 | -0.322 | 0.171 | 0.6080 | -0.324 | 0.171 | -0.364 |
| 6 | 0.262 | 0.2990 | -0.377 | 0.257 | 0.3180 | -0.380 | 0.250 | 0.3410 | -0.372 | 0.250 | -0.404 |
| 7 | 0.380 | 0.1370 | -0.433 | 0.375 | 0.1370 | -0.421 | 0.367 | 0.1550 | -0.470 | 0.367 | -0.433 |
| 8 | 0.498 | 0.0462 | -0.476 | 0.493 | 0.0481 | -0.471 | 0.485 | 0.0496 | -0.482 | 0.485 | -0.475 |
| 9 | 0.616 | 0.0187 | -0.494 | 0.611 | 0.0187 | -0.507 | 0.603 | 0.0205 | -0.506 | 0.603 | -0.492 |
| 10 | 0.754 | 0.0065 | -0.520 | 0.749 | 0.0056 | -0.537 | 0.741 | 0.0065 | -0.530 | 0.741 | -0.504 |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.060 | 0.030 | 1.5633 | 1.5096 | 1.6595 | -0.238 | -0.226 | -0.246 |
| 2 | 0.080 | 0.040 | 1.3105 | 1.2575 | 1.3985 | -0.255 | -0.249 | -0.265 |
| 3 | 0.099 | 0.050 | 1.0686 | 1.0337 | 1.1156 | -0.275 | -0.273 | -0.279 |
| 4 | 0.129 | 0.065 | 0.8621 | 0.8382 | 0.8930 | -0.300 | -0.296 | -0.303 |
| 5 | 0.178 | 0.090 | 0.5827 | 0.5734 | 0.5892 | -0.328 | -0.322 | -0.334 |
| 6 | 0.256 | 0.130 | 0.3224 | 0.3141 | 0.3309 | -0.376 | -0.374 | -0.380 |
| 7 | 0.374 | 0.190 | 0.1426 | 0.1385 | 0.1487 | -0.425 | -0.421 | -0.430 |
| 8 | 0.492 | 0.250 | 0.0493 | 0.0479 | 0.0510 | -0.477 | -0.474 | -0.483 |
| 9 | 0.610 | 0.310 | 0.0186 | 0.0169 | 0.0201 | -0.502 | -0.493 | -0.508 |
| 10 | 0.748 | 0.380 | 0.0067 | 0.0057 | 0.0070 | -0.532 | -0.519 | -0.541 |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | $24.7\times10^{-3}$ |
| 1 | $21.9\times10^{-3}$ |
| 2 | $21.9\times10^{-3}$ |
| 3 | $21.9\times10^{-3}$ |
| 4 | $21.3\times10^{-3}$ |
| 5 | $20.9\times10^{-3}$ |
| 6 TO 10 | $19.6\times10^{-3}$ |
| MIXTURE | $21.7\times10^{-3}$ |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $149\times10^{-6}$ |
| $D_{50}$ | $200\times10^{-6}$ |
| $D_{90}$ | $278\times10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $3.05\times10^{-2}$ | $2.80\times10^{-2}$ | $3.42\times10^{-2}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $1.34\times10^{-1}$ | $1.31\times10^{-1}$ | $1.39\times10^{-1}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $1.65\times10^{-1}$ | $1.59\times10^{-1}$ | $1.73\times10^{-1}$ |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $-[illegible].33\times10^{-3}$ | $-4.45\times10^{-3}$ | $-1.22\times10^{-2}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $-3.96\times10^{-2}$ | $-3.89\times10^{-2}$ | $-4.04\times10^{-2}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $-4.29\times10^{-2}$ | $-4.31\times10^{-2}$ | $-5.26\times10^{-2}$ |

Table 3.1 Z : Basic measuring data

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| WATERTEMPERATURE T (°C) | : [illegible] |

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.177 | [illegible] | [illegible] |
| ZERO-CROSS PERIOD Tz (s) | 1.8[illegible] | [illegible] | [illegible] |
| PEAK PERIOD Tp (s) | [illegible] | [illegible] | [illegible] |
| RATIO $H_{1\%}/Hs$ (-) | [illegible] | — | — |
| WATERDEPTH TO MEAN BED h (m) | [illegible] | [illegible] | [illegible] |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | [illegible] | [illegible] | -0.2[illegible] |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | [illegible] | [illegible] |
| RIPPLE LENGTH $\lambda_r$ (m) | [illegible] | [illegible] |
| RIPPLE VELOCITY $u_r$ (m/s) | [illegible] | [illegible] |
| RIPPLE SHAPE | [illegible]DIMENSIONAL WAVE DOMINATED | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = [illegible]) | | | TEST 2 (h (m) = 0.499) | | | TEST 3 (h (m) = 0.499) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | [illegible] | [illegible] | [illegible] | 0.042 | [illegible] | -0.069 | [illegible] | [illegible] | [illegible] | 0.021 | -0.143 |
| 2 | 0.060 | [illegible] | [illegible] | 0.061 | 0.5130 | -0.085 | [illegible] | [illegible] | [illegible] | 0.031 | -0.149 |
| 3 | 0.080 | [illegible] | [illegible] | 0.082 | 0.3650 | -0.098 | [illegible] | [illegible] | [illegible] | 0.041 | -0.154 |
| 4 | 0.111 | [illegible] | [illegible] | 0.112 | 0.2460 | -0.125 | [illegible] | [illegible] | -0.123 | 0.056 | -0.174 |
| 5 | 0.161 | [illegible] | [illegible] | 0.162 | 0.1140 | -0.157 | [illegible] | [illegible] | [illegible] | 0.081 | -0.194 |
| 6 | 0.241 | [illegible] | [illegible] | 0.242 | 0.0335 | -0.187 | [illegible] | [illegible] | [illegible] | 0.121 | -0.210 |
| 7 | 0.362 | [illegible] | [illegible] | 0.363 | 0.0093 | -0.224 | 0.363 | 0.0093 | [illegible] | 0.181 | -0.230 |
| 8 | [illegible] | [illegible] | [illegible] | 0.483 | 0.0028 | -0.245 | [illegible] | [illegible] | [illegible] | 0.241 | -0.251 |
| 9 | 0.604 | [illegible] | [illegible] | 0.603 | 0.0006 | -0.263 | 0.603 | 0.0006 | [illegible] | 0.301 | -0.262 |
| 10 | [illegible] | 0 | [illegible] | 0.742 | 0 | [illegible] | 0.742 | 0 | -0.206 | 0.371 | -0.258 |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.041 | 0.021 | 0.7742 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | 0.061 | [illegible] | 0.5136 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.096 | [illegible] | -0.106 |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.121 | -0.114 | [illegible] |
| 5 | [illegible] | [illegible] | 0.1186 | [illegible] | [illegible] | [illegible] | -0.150 | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.180 | -0.176 | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.216 | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0037 | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0006 | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | [illegible] |
| 1 | [illegible] |
| 2 | [illegible] |
| 3 | [illegible] |
| 4 | [illegible] |
| 5 | [illegible] |
| 6 TO 10 | [illegible] |
| MIXTURE | [illegible] |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | [illegible] |
| $D_{50}$ | [illegible] |
| $D_{90}$ | [illegible] |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.1 α : Basic measuring data

EXPERIMENT NO. : [illegible]
WATERTEMPERATURE T (°C) : [illegible]

## WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.166 | 0.164 | 0.187 |
| ZERO-CROSS PERIOD Tz (s) | 2.13 | 2.08 | 2.20 |
| PEAK PERIOD Tp (s) | 2.39 | 2.30 | 2.56 |
| RATIO $H_{1\%}/Hs$ (-) | 1.33 | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.515 | 0.513 | 0.517 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.427 | -0.422 | -0.433 |

## RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.029 | 0.008 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.200 | 0.047 |
| RIPPLE VELOCITY $u_r$ (m/s) | -3.06x10^-4 | [illegible] |
| RIPPLE SHAPE | 3 DIMENSIONAL TRANSITION | |

## CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = [illegible]) | | | TEST 2 (h (m) = 0.515) | | | TEST 3 (h (m) = 0.517) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.066 | 2.4040 | -0.234 | 0.076 | 2.0020 | -0.238 | 0.075 | 2.3520 | -0.244 | 0.039 | -0.277 |
| 2 | 0.086 | 1.8170 | -0.259 | 0.095 | 1.7770 | -0.245 | 0.095 | 1.7070 | -0.250 | 0.049 | -0.291 |
| 3 | 0.105 | 1.5250 | -0.268 | 0.115 | 1.4790 | -0.240 | 0.114 | 1.5810 | -0.264 | 0.059 | -0.302 |
| 4 | 0.135 | 1.2130 | -0.309 | 0.144 | 1.1960 | -0.271 | 0.143 | 1.2250 | -0.291 | 0.074 | -0.330 |
| 5 | 0.184 | 0.8550 | -0.320 | 0.192 | 0.8720 | -0.301 | 0.191 | 0.8420 | -0.334 | 0.099 | -0.351 |
| 6 | 0.262 | 0.4730 | -0.357 | 0.270 | 0.4660 | -0.357 | 0.263 | 0.4730 | -0.367 | 0.139 | -0.402 |
| 7 | 0.379 | 0.2330 | -0.419 | 0.386 | 0.2160 | -0.410 | 0.385 | 0.2280 | -0.424 | 0.199 | -0.425 |
| 8 | 0.496 | 0.0763 | -0.473 | 0.503 | 0.0773 | -0.470 | 0.501 | 0.0846 | -0.458 | 0.259 | -0.438 |
| 9 | 0.613 | 0.0420 | -0.505 | 0.619 | 0.0317 | -0.506 | 0.617 | 0.0392 | -0.501 | 0.319 | -0.495 |
| 10 | 0.750 | 0.0131 | -0.536 | 0.755 | 0.0121 | -0.541 | 0.752 | 0.0112 | -0.522 | 0.389 | -0.497 |

## COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.072 | 0.037 | 2.2527 | 2.0610 | 2.4313 | -0.241 | -0.239 | -0.247 |
| 2 | 0.092 | 0.047 | 1.8037 | 1.7590 | 1.8810 | -0.251 | -0.235 | -0.262 |
| 3 | 0.111 | 0.057 | 1.5316 | 1.4591 | 1.6113 | -0.262 | -0.246 | -0.277 |
| 4 | 0.141 | 0.072 | 1.2179 | 1.1716 | 1.2536 | -0.289 | -0.268 | -0.310 |
| 5 | 0.189 | 0.097 | 0.8602 | 0.8305 | 0.9027 | -0.318 | -0.299 | -0.332 |
| 6 | 0.263 | 0.135 | 0.4757 | 0.4670 | 0.4825 | -0.359 | -0.355 | -0.361 |
| 7 | 0.383 | 0.197 | 0.2284 | 0.2217 | 0.2318 | -0.418 | -0.400 | -0.423 |
| 8 | 0.500 | 0.257 | 0.0830 | 0.0800 | 0.0944 | -0.473 | -0.468 | -0.438 |
| 9 | 0.616 | 0.317 | 0.0378 | 0.0325 | 0.0413 | -0.504 | -0.501 | -0.506 |
| 10 | 0.752 | 0.387 | 0.0121 | 0.0111 | 0.0126 | -0.533 | -0.522 | -0.540 |

## FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | 26.7 x10^-3 |
| 1 | 22.7 x10^-3 |
| 2 | 23.8 x10^-3 |
| 3 | 22.6 x10^-3 |
| 4 | 22.8 x10^-3 |
| 5 | 21.4 x10^-3 |
| 6 TO 10 | 21.6 x10^-3 |
| MIXTURE | [illegible] x10^-3 |

## PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | 156x10^-6 |
| $D_{50}$ | 211x10^-6 |
| $D_{90}$ | 293x10^-6 |

## LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | 5.43x10^-2 | 4.65x10^-2 | 6.38x10^-2 |
| SUSPENDED LOAD $L_s$ (kg/m²) | 3.10x10^-1 | 3.02x10^-1 | 3.20x10^-1 |
| TOTAL LOAD $L_t$ (kg/m²) | 3.64x10^-1 | 3.49x10^-1 | 3.84x10^-1 |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | -8.46x10^-3 | -6.13x10^-3 | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | -6.03x10^-2 | -5.65x10^-2 | -6.36x10^-2 |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | -6.88x10^-2 | -6.26x10^-2 | -7.64x10^-2 |

Table 3.1 β : Basic measuring data

| Experiment no. | Hs [m] | Um [m/s] | Tp [s] | Tp,rel [s] | L [m] | Ûb [m/s] | Âb [m] |
|---|---|---|---|---|---|---|---|
| T 7.5 0 | 0.077 | **** | 2.49 | 2.49 | 5.26 | 0.1496 | 0.0593 |
| T 9 0 | 0.090 | **** | 2.43 | 2.43 | 5.12 | 0.1743 | 0.0674 |
| T 10 0 | 0.101 | **** | 2.48 | 2.48 | 5.21 | 0.2059 | 0.0813 |
| T 12 0 | 0.122 | **** | 2.42 | 2.42 | 5.16 | 0.2319 | 0.0893 |
| T 15 0 | 0.153 | **** | 2.45 | 2.45 | 5.13 | 0.2995 | 0.1167 |
| T 7.5 10 | 0.076 | 0.117 | 2.63 | 2.77 | 5.93 | 0.1517 | 0.0668 |
| T 10 10 | 0.106 | 0.118 | 2.62 | 2.76 | 5.93 | 0.2102 | 0.0925 |
| T 10 -10 | 0.098 | -0.128 | 2.48 | 2.33 | 4.81 | 0.1913 | 0.0708 |
| T 12 10 | 0.121 | 0.093 | 2.50 | 2.61 | 5.58 | 0.2359 | 0.0979 |
| T 12 -10 | 0.115 | -0.118 | 2.49 | 2.35 | 4.87 | 0.2241 | 0.0837 |
| T 15 10 | 0.146 | 0.107 | 2.37 | 2.49 | 5.23 | 0.2870 | 0.1138 |
| T 15 -10 | 0.149 | -0.132 | 2.49 | 2.33 | 4.84 | 0.2896 | 0.1075 |
| T 7.5 20 | 0.074 | 0.226 | 2.40 | 2.65 | 5.65 | 0.1468 | 0.0620 |
| T 10 20 | 0.099 | 0.219 | 2.48 | 2.73 | 5.83 | 0.1967 | 0.0856 |
| T 10 -20 | 0.096 | -0.228 | 2.46 | 2.19 | 4.48 | 0.1847 | 0.0642 |
| T 12 20 | 0.123 | 0.220 | 2.59 | 2.91 | 6.24 | 0.2481 | 0.1149 |
| T 12 -20 | 0.116 | -0.233 | 2.51 | 2.22 | 4.55 | 0.2246 | 0.0795 |
| T 15 20 | 0.151 | 0.222 | 2.41 | 2.66 | 5.67 | 0.2985 | 0.1264 |
| T 15 -20 | 0.147 | -0.232 | 2.52 | 2.24 | 4.58 | 0.2847 | 0.1013 |
| T 17.5 -20 | 0.177 | -0.227 | 2.53 | 2.25 | 4.65 | 0.3405 | 0.1220 |
| T 7.5 40 | 0.076 | 0.449 | 2.44 | 2.95 | 6.30 | 0.1555 | 0.0731 |
| T 10 40 | 0.098 | 0.449 | 2.60 | 3.14 | 6.79 | 0.1997 | 0.0998 |
| T 10 -40 | 0.101 | -0.453 | 2.51 | 1.94 | 3.91 | 0.1848 | 0.0572 |
| T 12 40 | 0.119 | 0.443 | 2.45 | 2.95 | 6.36 | 0.2389 | 0.1121 |
| T 12 -40 | 0.118 | -0.442 | 2.62 | 2.03 | 4.10 | 0.2183 | 0.0703 |
| T 15 -40 | 0.146 | -0.437 | 2.47 | 1.93 | 3.94 | 0.2615 | 0.0807 |
| T 18.5 -40 | 0.186 | -0.429 | 2.39 | 1.88 | 3.82 | 0.3254 | 0.0976 |

Table 3.2: Characteristic wave parameters

| | |
|---|---|
| EXPERIMENT NO. | [illegible] |
| WATERTEMPERATURE T (°C) | [illegible] |

**WAVE AND CURRENT PARAMETERS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | [illegible] | 0.039 | [illegible] |
| ZERO-CROSS PERIOD Tz (s) | [illegible] | [illegible] | [illegible] |
| PEAK PERIOD Tp (s) | [illegible] | [illegible] | [illegible] |
| RATIO $H_{1\%}/Hs$ (-) | — | — | — |
| WATERDEPTH TO MEAN BED h (m) | [illegible] | 0.507 | 0.508 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | [illegible] | 0.116 | 0.119 |

**RIPPLE PARAMETERS**

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | [illegible] | 0.004 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.092 | 0.021 |
| RIPPLE VELOCITY $u_r$ (m/s) | +7.45 × $10^{-7}$ | [illegible] |
| RIPPLE SHAPE | 2 DIMENSIONAL<br>TRANSITION | |

**CONCENTRATIONS AND VELOCITIES**

| | TEST 1 (h (m) = 0.508) | | | TEST 2 (h (m) = 0.507) | | | TEST 3 (h (m) = 0.507) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.025 | [illegible] | [illegible] | [illegible] | 0.0111 | 0.077 | 0.030 | [illegible] | [illegible] | 0.015 | 0.064 |
| 2 | [illegible] | [illegible] | 0.061 | 0.052 | [illegible] | [illegible] | [illegible] | [illegible] | 0.050 | 0.025 | 0.071 |
| 3 | [illegible] | [illegible] | 0.062 | 0.073 | [illegible] | [illegible] | [illegible] | 0.0056 | 0.061 | 0.035 | 0.083 |
| 4 | 0.104 | [illegible] | 0.066 | 0.103 | 0.0009 | [illegible] | 0.099 | 0.0009 | 0.067 | 0.050 | 0.090 |
| 5 | [illegible] | 0 | [illegible] | 0.152 | 0 | 0.095 | 0.148 | 0 | 0.095 | 0.075 | 0.109 |
| 6 | [illegible] | 0 | [illegible] | [illegible] | 0 | 0.110 | 0.227 | 0 | 0.099 | 0.115 | 0.105 |
| 7 | [illegible] | 0 | [illegible] | 0.340 | 0 | 0.122 | 0.345 | 0 | 0.126 | 0.175 | 0.118 |
| 8 | 0.460 | 0 | [illegible] | 0.465 | 0 | 0.131 | 0.464 | 0 | 0.129 | 0.235 | [illegible] |
| 9 | [illegible] | 0 | [illegible] | 0.576 | 0 | 0.132 | 0.572 | 0 | 0.133 | 0.295 | [illegible] |
| 10 | [illegible] | 0 | [illegible] | 0.729 | 0 | 0.141 | 0.770 | 0 | 0.130 | 0.365 | [illegible] |

**COMBINATION OF TEST 1, 2 AND 3**

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.017 | 0.0111 | 0.0073 | 0.0147 | [illegible] | [illegible] | [illegible] |
| 2 | 0.052 | 0.027 | [illegible] | 0.0034 | 0.0082 | [illegible] | [illegible] | 0.057 |
| 3 | 0.072 | 0.037 | 0.0038 | 0.0012 | 0.0051 | [illegible] | [illegible] | 0.062 |
| 4 | 0.102 | 0.052 | 0.0006 | 0.0001 | [illegible] | [illegible] | 0.066 | 0.076 |
| 5 | 0.151 | 0.077 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] |
| 6 | 0.230 | 0.117 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | 0.177 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | 0 | 0 | 0 | 0.136 | 0.133 | 0.142 |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | 0.141 | 0.139 | 0.142 |

**FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL**

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | — |
| 1 | — |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | — |

**LOADS AND TRANSPORTS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | 2.42 × [illegible] | [illegible] | 2.38 × $10^{-4}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | 1.18 × $10^{-5}$ | [illegible] |

**PARTICLE DIAMETER BED MATERIAL (m)**

| | |
|---|---|
| $D_{10}$ | 159 × $10^{-6}$ |
| $D_{50}$ | 212 × $10^{-6}$ |
| $D_{90}$ | 314 × $10^{-6}$ |

Table 3.3 A : Measuring data reproducibility

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| WATERTEMPERATURE T (°C) | : [illegible] |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.098 | 0.096 | 0.099 |
| ZERO-CROSS PERIOD Tz (s) | [illegible] | [illegible] | [illegible] |
| PEAK PERIOD Tp (s) | [illegible] | 2.50 | 2.52 |
| RATIO $H_{1\%}/Hs$ (-) | — | — | — |
| WATERDEPTH TO MEAN BED h (m) | [illegible] | [illegible] | 0.494 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.218 | -0.217 | -0.219 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.016 | 0.005 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.105 | 0.015 |
| RIPPLE VELOCITY $u_r$ (m/s) | [illegible] | [illegible] $\times 10^{-6}$ |
| RIPPLE SHAPE | 2½ DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.494) | | | TEST 2 (h (m) = [illegible]) | | | TEST 3 (h (m) = 0.493) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | 0.043 | [illegible] | [illegible] | [illegible] | 0.1130 | [illegible] | 0.043 | 0.1480 | [illegible] | 0.024 | -0.116 |
| 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.144 |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.158 |
| 4 | [illegible] | [illegible] | [illegible] | 0.120 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.059 | -0.168 |
| 5 | [illegible] | [illegible] | -0.156 | 0.121 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.084 | -0.187 |
| 6 | [illegible] | [illegible] | -0.193 | 0.252 | [illegible] | [illegible] | [illegible] | [illegible] | -0.190 | 0.174 | -0.201 |
| 7 | [illegible] | [illegible] | -0.214 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.216 | 0.184 | -0.248 |
| 8 | [illegible] | [illegible] | [illegible] | 0.496 | [illegible] | [illegible] | 0.405 | [illegible] | [illegible] | — | — |
| 9 | [illegible] | [illegible] | [illegible] | 0.618 | 0 | -0.263 | 0.613 | [illegible] | [illegible] | — | — |
| 10 | [illegible] | — | [illegible] | 0.760 | 0 | [illegible] | [illegible] | 0 | [illegible] | — | — |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|
| | | | MEAN | MIN. | MAX. | MEAN | MIN. | MAX. |
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.076 | -0.082 |
| 2 | [illegible] | [illegible] | [illegible] | 0.0745 | [illegible] | [illegible] | [illegible] | -0.097 |
| 3 | [illegible] | [illegible] | [illegible] | 0.0611 | [illegible] | -0.112 | [illegible] | [illegible] |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0453 | [illegible] | [illegible] | [illegible] |
| 5 | [illegible] | [illegible] | 0.0200 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0096 | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | 0.615 | [illegible] | [illegible] | 0 | [illegible] | -0.268 | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | — |
| 1 | — |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | |
| MIXTURE | |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | [illegible] |
| $D_{50}$ | [illegible] |
| $D_{90}$ | [illegible] |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | [illegible] | $1.68 \times 10^{-3}$ | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | $8.01 \times 10^{-3}$ | [illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $-4.42 \times 10^{-5}$ | $3.48 \times 10^{-5}$ | $-1.23 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.3 B : Measuring data reproducibility

EXPERIMENT NO. : R15,10
WATERTEMPERATURE T (°C) : 21

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.148 | 0.146 | 0.149 |
| ZERO-CROSS PERIOD Tz (s) | 1.[illegible] | 1.35 | 1.96 |
| PEAK PERIOD Tp (s) | [illegible] | 2.31 | 2.33 |
| RATIO $H_{1\%}/Hs$ (-) | — | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.502 | 0.50[illegible] | 0.503 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.107 | 0.104 | 0.112 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.017 | 0.001 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.108 | 0.006 |
| RIPPLE VELOCITY $u_r$ (m/s) | [illegible] | $4.83 \times 10^{-6}$ |
| RIPPLE SHAPE | 2 DIMENSIONAL TRANSITION | |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.503) | | | TEST 2 (h (m) = 0.502) | | | TEST 3 (h (m) = 0.502) | | | ONLY CURRENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | HEIGHT TO MEAN BED z (m) | VEL. u (m/s) |
| 1 | [illegible] | 0.5220 | 0.042 | 0.042 | 0.4820 | 0.026 | 0.050 | 0.4110 | 0.024 | — | — |
| 2 | [illegible] | 0.3110 | 0.049 | 0.062 | [illegible] | 0.046 | 0.070 | 0.2850 | 0.038 | — | — |
| 3 | 0.046 | 0.1720 | 0.054 | 0.082 | 0.1540 | 0.049 | [illegible] | 0.1760 | 0.043 | — | — |
| 4 | [illegible] | 0.1130 | 0.088 | 0.112 | 0.0702 | 0.057 | 0.120 | 0.0906 | 0.065 | — | — |
| 5 | 0.155 | 0.0304 | 0.101 | 0.161 | 0.0159 | 0.087 | 0.170 | 0.0203 | 0.098 | — | — |
| 6 | 0.245 | 0.0032 | 0.123 | 0.241 | 0.0037 | 0.107 | [illegible] | 0.0032 | 0.106 | — | — |
| 7 | [illegible] | 0 | 0.128 | 0.361 | 0 | 0.125 | [illegible] | 0.0006 | 0.119 | — | — |
| 8 | [illegible] | 0 | 0.127 | 0.480 | 0 | 0.125 | 0.488 | 0.0003 | 0.127 | — | — |
| 9 | [illegible] | 0 | 0.128 | 0.600 | 0 | 0.121 | 0.608 | 0 | 0.119 | — | — |
| 10 | [illegible] | 0 | [illegible] | 0.739 | 0 | 0.113 | 0.742 | 0 | 0.116 | — | — |

COMBINATION OF TEST 1, 2 AND 3

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.042 | 0.021 | 0.4766 | 0.4511 | 0.4984 | 0.030 | 0.019 | 0.044 |
| 2 | 0.062 | 0.031 | 0.2965 | [illegible] | 0.3125 | 0.043 | 0.033 | 0.050 |
| 3 | 0.082 | 0.041 | 0.1806 | 0.1515 | 0.2162 | 0.050 | 0.041 | 0.061 |
| 4 | 0.112 | 0.056 | 0.0943 | 0.0696 | 0.1117 | 0.060 | 0.053 | 0.070 |
| 5 | 0.162 | 0.081 | 0.0249 | 0.0158 | 0.0308 | [illegible] | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | 0.0041 | [illegible] | 0.0053 | [illegible] | [illegible] | [illegible] |
| 7 | 0.361 | [illegible] | 0.0003 | 0 | 0.0008 | [illegible] | 0.118 | [illegible] |
| 8 | [illegible] | [illegible] | 0.0001 | 0 | 0.0003 | 0.126 | 0.125 | 0.127 |
| 9 | [illegible] | [illegible] | 0 | 0 | 0 | 0.123 | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | 0 | 0 | 0 | 0.116 | 0.113 | [illegible] |

FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | — |
| 1 | — |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | — |

PARTICLE DIAMETER BED MATERIAL (m)

| | |
|---|---|
| $D_{10}$ | $161 \times 10^{-6}$ |
| $D_{50}$ | $218 \times 10^{-6}$ |
| $D_{90}$ | $303 \times 10^{-6}$ |

LOADS AND TRANSPORTS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $9.38 \times 10^{-3}$ | [illegible] | [illegible] |
| SUSPENDED LOAD $L_s$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| TOTAL LOAD $L_t$ (kg/m²) | [illegible] | [illegible] | [illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | $9.62 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.3 C : Measuring data reproducibility

EXPERIMENT NO. : R15,-10
WATERTEMPERATURE T (°C) : 21

**WAVE AND CURRENT PARAMETERS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.154 | 0.153 | 0.155 |
| ZERO-CROSS PERIOD Tz (s) | 1.81 | 1.80 | 1.82 |
| PEAK PERIOD Tp (s) | 2.44 | 2.44 | 2.45 |
| RATIO $H_{1\%}/Hs$ (-) | — | — | — |
| WATERDEPTH TO MEAN BED h (m) | 0.510 | 0.510 | 0.511 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | -0.126 | -0.125 | -0.127 |

**RIPPLE PARAMETERS**

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.016 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.105 | 0.009 |
| RIPPLE VELOCITY $u_r$ (m/s) | [illegible] | [illegible] |
| RIPPLE SHAPE | 2 DIMENSIONAL WAVE DOMINATED | |

**CONCENTRATIONS AND VELOCITIES**

| LEVEL NO. | TEST 1 (h (m) = 0.510) z/h (-) | TEST 1 CONC. c (kg/m³) | TEST 1 VEL. u (m/s) | TEST 2 (h (m) = 0.510) z/h (-) | TEST 2 CONC. c (kg/m³) | TEST 2 VEL. u (m/s) | TEST 3 (h (m) = 0.510) z/h (-) | TEST 3 CONC. c (kg/m³) | TEST 3 VEL. u (m/s) | ONLY CURRENT HEIGHT TO MEAN BED z (m) | ONLY CURRENT VEL. u (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | [illegible] | -0.024 | [illegible] | [illegible] | -0.028 | [illegible] | 0.7880 | [illegible] | 0.019 | -0.058 |
| 2 | [illegible] | 0.5690 | -0.033 | [illegible] | [illegible] | [illegible] | [illegible] | 0.4720 | [illegible] | 0.029 | [illegible] |
| 3 | 0.076 | [illegible] | -0.041 | [illegible] | [illegible] | [illegible] | 0.076 | 0.3270 | [illegible] | 0.039 | -0.067 |
| 4 | [illegible] | 0.2160 | [illegible] | 0.110 | [illegible] | [illegible] | [illegible] | 0.1900 | -0.051 | 0.054 | -0.091 |
| 5 | 0.151 | [illegible] | [illegible] | 0.155 | 0.0611 | [illegible] | 0.155 | 0.0600 | -0.084 | 0.079 | -0.091 |
| 6 | 0.229 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.0110 | -0.094 | 0.118 | -0.111 |
| 7 | [illegible] | [illegible] | [illegible] | 0.351 | [illegible] | [illegible] | 0.351 | [illegible] | -0.120 | 0.178 | -0.118 |
| 8 | 0.465 | 0 | [illegible] | [illegible] | 0 | [illegible] | [illegible] | 0.0002 | -0.131 | 0.238 | -0.125 |
| 9 | [illegible] | 0 | [illegible] | [illegible] | 0 | [illegible] | 0.586 | 0 | -0.142 | [illegible] | -0.127 |
| 10 | [illegible] | 0 | [illegible] | [illegible] | 0 | -0.17 | 0.72 | 0 | -0.160 | [illegible] | [illegible] |

**COMBINATION OF TEST 1, 2 AND 3**

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION c (kg/m³) MEAN | MIN. | MAX. | VELOCITY u (m/s) MEAN | MIN. | MAX. |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.037 | 0.019 | [illegible] | [illegible] | 0.8612 | -0.024 | -0.020 | [illegible] |
| 2 | 0.057 | 0.029 | 0.5140 | [illegible] | 0.5458 | [illegible] | -0.031 | [illegible] |
| 3 | 0.076 | 0.039 | 0.3371 | [illegible] | 0.3479 | [illegible] | -0.034 | [illegible] |
| 4 | 0.106 | 0.054 | 0.1090 | [illegible] | 0.2050 | [illegible] | -0.051 | [illegible] |
| 5 | 0.155 | [illegible] | 0.0678 | 0.0603 | [illegible] | [illegible] | -0.072 | [illegible] |
| 6 | [illegible] | 0.119 | 0.0111 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | 0.0019 | 0.0017 | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | 0.468 | [illegible] | 0.0001 | 0 | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | 0 | 0 | 0 | [illegible] | -0.148 | [illegible] |
| 10 | 0.722 | [illegible] | 0 | [illegible] | 0 | [illegible] | -0.163 | [illegible] |

**FALL VELOCITY OF SUSPENDED SEDIMENT AND BED MATERIAL**

| LEVEL NO. | $w_{50}$ (m/s) |
|---|---|
| BED | — |
| 1 | — |
| 2 | — |
| 3 | — |
| 4 | — |
| 5 | — |
| 6 TO 10 | — |
| MIXTURE | — |

**PARTICLE DIAMETER BED MATERIAL (m)**

| | |
|---|---|
| $D_{10}$ | $136 \times 10^{-6}$ |
| $D_{50}$ | $211 \times 10^{-6}$ |
| $D_{90}$ | $393 \times 10^{-6}$ |

**LOADS AND TRANSPORTS**

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD $L_b$ (kg/m²) | $1.36 \times 10^{-2}$ | $1.24 \times 10^{-2}$ | $1.54 \times 10^{-2}$ |
| SUSPENDED LOAD $L_s$ (kg/m²) | $2.99 \times 10^{-2}$ | $2.87 \times 10^{-2}$ | $3.18 \times 10^{-2}$ |
| TOTAL LOAD $L_t$ (kg/m²) | $4.35 \times 10^{-2}$ | $4.16 \times 10^{-2}$ | [illegible] |
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | [illegible] | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | [illegible] | [illegible] | $-1.24 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | [illegible] | [illegible] | [illegible] |

Table 3.3 D : Measuring data reproducibility

| Experiment no. | U* [m/s] | | | Ks [m] | | | corr. coef. |
|---|---|---|---|---|---|---|---|
| | min. | mean | max. | min. | mean | max. | |
| T 7.5 10 | 0.0098 | 0.0106 | 0.0113 | 0.0443 | 0.0628 | 0.0833 | 0.9511 |
| T 10 10 | 0.0091 | 0.0099 | 0.0105 | 0.0392 | 0.0584 | 0.0781 | 0.9921 |
| T 10 -10 | -0.0113 | -0.0121 | -0.0128 | 0.0552 | 0.0745 | 0.0959 | 0.9883 |
| T 12 10 | 0.0077 | 0.0083 | 0.0086 | 0.0339 | 0.0485 | 0.0651 | 0.9532 |
| T 12 -10 | -0.0096 | -0.0102 | -0.0107 | 0.0567 | 0.0749 | 0.0950 | 0.9646 |
| T 15 10 | 0.0099 | 0.0102 | 0.0113 | 0.0572 | 0.0780 | 0.1012 | 0.9602 |
| T 15 -10 | -0.0119 | -0.0125 | -0.0131 | 0.0861 | 0.1084 | 0.1326 | 0.9908 |
| T 7.5 20 | 0.0203 | 0.0214 | 0.0224 | 0.0783 | 0.0992 | 0.1220 | 0.9873 |
| T 10 20 | 0.0211 | 0.0225 | 0.0239 | 0.0804 | 0.1068 | 0.1357 | 0.9826 |
| T 10 -20 | -0.0262 | -0.0276 | -0.0289 | 0.1230 | 0.1516 | 0.1823 | 0.9932 |
| T 12 20 | 0.0222 | 0.0238 | 0.0252 | 0.1029 | 0.1351 | 0.1697 | 0.9899 |
| T 12 -20 | -0.0217 | -0.0232 | -0.0246 | 0.0531 | 0.0722 | 0.0935 | 0.9869 |
| T 15 20 | 0.0208 | 0.0221 | 0.0232 | 0.0666 | 0.0862 | 0.1079 | 0.9729 |
| T 15 -20 | -0.0202 | -0.0213 | -0.0224 | 0.0543 | 0.0708 | 0.0892 | 0.9781 |
| T 17.5 -20 | -0.0178 | -0.0190 | -0.0200 | 0.0314 | 0.0431 | 0.0565 | 0.9749 |
| T 7.5 40 | 0.0303 | 0.0320 | 0.0337 | 0.0200 | 0.0276 | 0.0365 | 0.9802 |
| T 10 40 | ****** | ****** | ****** | ****** | ****** | ****** | ****** |
| T 10 -40 | -0.0442 | -0.0462 | -0.0480 | 0.0946 | 0.1143 | 0.1357 | 0.9969 |
| T 12 40 | ****** | ****** | ****** | ****** | ****** | ****** | ****** |
| T 12 -40 | -0.0329 | -0.0346 | -0.0363 | 0.0309 | 0.0407 | 0.0519 | 0.9819 |
| T 15 -40 | -0.0388 | -0.0397 | -0.0407 | 0.1283 | 0.1440 | 0.1607 | 0.9956 |
| T 18.5 -40 | -0.0402 | -0.0418 | -0.0434 | 0.0850 | 0.1016 | 0.1196 | 0.9812 |

Table 3.4: Shear velocity and bed roughness

| Experiment no. | Sb1 $*10^{-6}$ [Kg/ms] | | | Sb2 $*10^{-6}$ [Kg/ms] | | |
|---|---|---|---|---|---|---|
| | max. | mean | min. | max. | mean | min. |
| T 7.5 0 | ** | ** | ** | 41 | 24 | 7 |
| T 9 0 | ** | ** | ** | 80 | 46 | 12 |
| T 10 0 | ** | ** | ** | 61 | 40 | 19 |
| T 12 0 | ** | ** | ** | 227 | 98 | -31 |
| T 15 0 | ** | ** | ** | 239 | 167 | 95 |
| T 7.5 10 | 14 | 13 | 12 | 9 | 4 | -1 |
| T 10 10 | 45 | 27 | 18 | 99 | 62 | 25 |
| T 10 -10 | -37 | -27 | -18 | 56 | 31 | 6 |
| T 12 10 | 110 | 83 | 65 | 348 | 188 | 28 |
| T 12 -10 | -58 | -42 | -33 | 74 | 34 | -6 |
| T 15 10 | 202 | 140 | 109 | 143 | 117 | 91 |
| T 15 -10 | -187 | -147 | -127 | 124 | 83 | 42 |
| T 7.5 20 | 79 | 52 | 32 | 296 | 190 | 84 |
| T 10 20 | 130 | 126 | 124 | 322 | 240 | 158 |
| T 10 -20 | -121 | -103 | -90 | -227 | -129 | -31 |
| T 12 20 | 339 | 269 | 245 | 547 | 354 | 161 |
| T 12 -20 | -255 | -184 | -143 | -318 | -170 | -22 |
| T 15 20 | 778 | 597 | 492 | 899 | 675 | 451 |
| T 15 -20 | -271 | -248 | -229 | -229 | -105 | 19 |
| T 17.5 -20 | -459 | -359 | -275 | -713 | -461 | -209 |
| T 0 40 | **** | 476 | **** | 3230 | 1980 | 730 |
| T 7.5 40 | 2010 | 1630 | 1360 | 2810 | 1650 | 490 |
| T 10 40 | 1840 | 1670 | 1540 | 4390 | 2750 | 1110 |
| T 10 -40 | -3320 | -3180 | -3120 | -5180 | -3750 | -2320 |
| T 12 40 | 2710 | 2500 | 2360 | 7990 | 5220 | 2450 |
| T 12 -40 | -3280 | -3230 | -3190 | -6030 | -3610 | -1190 |
| T 15 -40 | -4950 | -4620 | -4320 | -12200 | -8300 | -4500 |
| T 18.5 -40 | -9470 | -8580 | -6890 | -12800 | -8300 | -4100 |

Table 3.5: Bed load transport according to method 1 and method 2

| Experiment no. | Ss *10^-6 [Kg/ms] max. | mean | min. |
|---|---|---|---|
| T 7.5 10 | 23 | 22 | 21 |
| T 10 10 | 104 | 84 | 68 |
| T 10 -10 | -154 | -144 | -134 |
| T 12 10 | 398 | 351 | 299 |
| T 12 -10 | -288 | -258 | -222 |
| T 15 10 | 767 | 722 | 651 |
| T 15 -10 | -1220 | -1030 | -940 |
| T 7.5 20 | 280 | 206 | 158 |
| T 10 20 | 978 | 927 | 833 |
| T 10 -20 | -852 | -780 | -664 |
| T 12 20 | 1820 | 1690 | 1530 |
| T 12 -20 | -1860 | -1600 | -1350 |
| T 15 20 | 5800 | 4570 | 3820 |
| T 15 -20 | -3320 | -3090 | -2850 |
| T 17.5 -20 | -3740 | -3640 | -3550 |
| T 0 40 | ***** | 3050 | ***** |
| T 7.5 40 | 12700 | 11200 | 10400 |
| T 10 40 | 22000 | 19800 | 18400 |
| T 10 -40 | -26100 | -25200 | -24100 |
| T 12 40 | 26800 | 25000 | 24000 |
| T 12 -40 | -29000 | -28500 | -28000 |
| T 15 -40 | -40400 | -39800 | -39200 |
| T 18.5 -40 | -64100 | -60800 | -56800 |

Table 3.6: Suspended load transport

| Experiment no. | St1 $*10^{-6}$ [Kg/ms] | | | St2 $*10^{-6}$ [Kg/ms] | | |
|---|---|---|---|---|---|---|
| | max. | mean | min. | max. | mean | min. |
| T 7.5 10 | 37 | 35 | 33 | 32 | 26 | 20 |
| T 10 10 | 149 | 111 | 86 | 203 | 146 | 93 |
| T 10 -10 | -191 | -171 | -152 | -148 | -113 | -78 |
| T 12 10 | 508 | 434 | 364 | 746 | 539 | 327 |
| T 12 -10 | -346 | -300 | -255 | -296 | -224 | -148 |
| T 15 10 | 969 | 862 | 760 | 910 | 839 | 742 |
| T 15 -10 | -1400 | -1180 | -1070 | -1180 | -940 | -900 |
| T 7.5 20 | 395 | 258 | 190 | 576 | 396 | 224 |
| T 10 20 | 1110 | 1050 | 960 | 1300 | 1170 | 990 |
| T 10 -20 | -970 | -880 | -750 | -1080 | -910 | -700 |
| T 12 20 | 2160 | 1960 | 1780 | 2370 | 2040 | 1690 |
| T 12 -20 | -2110 | -1780 | -1490 | -2180 | -1770 | -1370 |
| T 15 20 | 6580 | 5160 | 4310 | 6700 | 5240 | 4270 |
| T 15 -20 | -3600 | -3330 | -3080 | -3560 | -3190 | -2830 |
| T 17.5 -20 | -4200 | -4000 | -3830 | -4460 | -4100 | -3760 |
| T 0 40 | ***** | 3520 | ***** | 6270 | 5020 | 3770 |
| T 7.5 40 | 14700 | 12900 | 11800 | 15400 | 12900 | 10900 |
| T 10 40 | 23800 | 21400 | 19900 | 26400 | 22500 | 19500 |
| T 10 -40 | -29400 | -28400 | -27200 | -31300 | -29000 | -26400 |
| T 12 40 | 29600 | 27500 | 26300 | 34800 | 30200 | 26500 |
| T 12 -40 | -32300 | -31800 | -31200 | -35000 | -32100 | -29200 |
| T 15 -40 | -45300 | -44400 | -43600 | -52600 | -48100 | -43700 |
| T 18.5 -40 | -72500 | -69400 | -63700 | -76900 | -69300 | -60900 |

Table 3.7: Total load transport according to method 1 and method 2

| | |
|---|---|
| EXPERIMENT NO. | : S12,10 |
| WATERTEMPERATURE T (°C) | : 20.5 |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | [illegible] | 0.119 | 0.119 |
| ZERO-CROSS PERIOD Tz (s) | 2.01 | 1.95 | 2.06 |
| PEAK PERIOD Tp (s) | 2.43 | 2.42 | 2.44 |
| WATERDEPTH TO MEAN BED h (m) | 0.512 | 0.512 | 0.512 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.120 | 0.116 | 0.124 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.014 | 0.003 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.104 | 0.014 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+4.20 \times 10^{-6}$ | $5.00 \times 10^{-6}$ |

CONCENTRATIONS AND VELOCITIES

| LEVEL NO. | TEST 1 (h (m) = 0.512) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 2 (h (m) = 0.512) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | TEST 3 (h (m) = 0.512) z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.025 | [illegible] | 0.014 | 0.025 | 0.2470 | 0.023 | 0.025 | 0.4080 | 0.028 |
| 2 | 0.045 | 0.1540 | 0.026 | 0.045 | 0.1480 | 0.041 | 0.045 | 0.2560 | 0.042 |
| 3 | 0.064 | [illegible] | 0.051 | 0.064 | 0.0912 | 0.065 | 0.064 | 0.1600 | [illegible] |
| 4 | [illegible] | [illegible] | 0.062 | 0.094 | 0.0379 | 0.072 | [illegible] | [illegible] | [illegible] |
| 5 | 0.143 | 0.0112 | 0.073 | 0.142 | 0.0103 | 0.104 | 0.143 | 0.0205 | 0.092 |
| 6 | 0.221 | [illegible] | 0.101 | 0.221 | 0.0019 | 0.131 | 0.221 | 0.0028 | 0.120 |
| 7 | 0.338 | 0 | 0.125 | 0.338 | 0 | 0.136 | 0.338 | 0.0006 | 0.134 |
| 8 | 0.455 | 0 | 0.137 | 0.455 | 0 | 0.137 | 0.455 | 0 | 0.130 |
| 9 | 0.572 | 0 | 0.134 | 0.572 | 0 | 0.137 | 0.572 | 0 | 0.141 |
| 10 | 0.709 | 0 | 0.137 | 0.709 | 0 | 0.136 | 0.709 | 0 | 0.135 |

| PARTICLE DIAMETER BED MATERIAL (m) | |
|---|---|
| $D_{10}$ | $148 \times 10^{-6}$ |
| $D_{50}$ | $207 \times 10^{-6}$ |
| $D_{90}$ | $298 \times 10^{-6}$ |

TRANSPORTS COMPUTED FROM RIPPLE PARAMETERS, CONCENTRATION AND VELOCITY

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $5.60 \times 10^{-5}$ | $-1.17 \times 10^{-5}$ | $1.23 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $3.77 \times 10^{-4}$ | $2.45 \times 10^{-4}$ | $5.70 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $4.33 \times 10^{-4}$ | $2.33 \times 10^{-4}$ | $6.03 \times 10^{-4}$ |

SAND BALANCE DATA

| | |
|---|---|
| INTEGRATION LENGTH L (m) | 12.08 |
| TIME PERIOD T (s) | 15480 |

| LONGITUDINAL SECTION | HEIGHT DIFFERENCE $\delta_{s,t=0} - \delta_{s,t=T}$ (m) | VOLUME DIFFERENCE $\Delta V$ (m³/m') | TRANSPORT $S_{balance}$ (kg/s.m) |
|---|---|---|---|
| 1 | $(-2.18 \pm 0.42) \times 10^{-3}$ | $(-2.62 \pm 0.51) \times 10^{-2}$ | $(-7.30 \pm 2.57) \times 10^{-4}$ |
| 2 | $(0.92 \pm 0.42) \times 10^{-3}$ | $(0.88 \pm 0.51) \times 10^{-2}$ | $(9.00 \pm 2.72) \times 10^{-4}$ |
| 3 | $(3.50 \pm 0.42) \times 10^{-3}$ | $(4.23 \pm 0.51) \times 10^{-2}$ | $(5.35 \pm 2.57) \times 10^{-4}$ |
| AVERAGE OVER THREE LONGITUDINAL SECTIONS | $(0.69 \pm 0.24) \times 10^{-3}$ | $(0.15 \pm 0.29) \times 10^{-2}$ | $(8.50 \pm 3.02) \times 10^{-4}$ |

Table 3.8 A : Sand balance measuring data

EXPERIMENT NO. : S12,20
WATERTEMPERATURE T (°C) : 20

| WAVE AND CURRENT PARAMETERS | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.123 | 0.122 | 0.124 |
| ZERO-CROSS PERIOD Tz (s) | 1.94 | 1.93 | 1.95 |
| PEAK PERIOD Tp (s) | 2.45 | 2.45 | 2.45 |
| WATERDEPTH TO MEAN BED h (m) | 0.511 | 0.511 | 0.511 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.215 | 0.214 | 0.217 |

| RIPPLE PARAMETERS | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.019 | 0.004 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.119 | 0.012 |
| RIPPLE VELOCITY $u_r$ (m/s) | $+1.86 \times 10^{-5}$ | $3.80 \times 10^{-6}$ |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.511 ) | | | TEST 2 (h (m) = 0.511 ) | | | TEST 3 (h (m) = – ) | | |
|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) |
| 1 | [illegible] | 0.4340 | 0.081 | 0.035 | 0.5560 | 0.065 | – | – | – |
| 2 | [illegible] | [illegible] | 0.103 | 0.059 | 0.3610 | 0.096 | – | – | – |
| 3 | [illegible] | [illegible] | 0.117 | 0.074 | 0.2760 | 0.118 | – | – | – |
| 4 | [illegible] | [illegible] | 0.131 | 0.104 | 0.1580 | 0.128 | – | – | – |
| 5 | [illegible] | 0.0625 | 0.163 | 0.153 | 0.0809 | 0.168 | – | – | – |
| 6 | [illegible] | [illegible] | 0.183 | 0.231 | 0.0277 | 0.200 | – | – | – |
| 7 | [illegible] | [illegible] | 0.219 | 0.348 | 0.0035 | 0.218 | – | – | – |
| 8 | 0.466 | [illegible] | 0.243 | 0.466 | 0.0037 | 0.257 | – | – | – |
| 9 | 0.583 | 0 | 0.254 | 0.583 | 0 | 0.242 | – | – | – |
| 10 | 0.720 | 0 | [illegible] | 0.720 | 0 | 0.241 | – | – | – |

| PARTICLE DIAMETER BED MATERIAL (m) | |
|---|---|
| $D_{10}$ | $151 \times 10^{-6}$ |
| $D_{50}$ | $205 \times 10^{-6}$ |
| $D_{90}$ | $284 \times 10^{-6}$ |

| TRANSPORTS COMPUTED FROM RIPPLE PARAMETERS, CONCENTRATION AND VELOCITY | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $3.37 \times 10^{-4}$ | $2.38 \times 10^{-4}$ | $4.36 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.32 \times 10^{-3}$ | $2.06 \times 10^{-3}$ | $2.57 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $2.66 \times 10^{-3}$ | $2.30 \times 10^{-3}$ | $3.01 \times 10^{-3}$ |

| SAND BALANCE DATA | |
|---|---|
| INTEGRATION LENGTH L (m) | 12.08 |
| TIME PERIOD T (s) | 10680 |

| LONGITUDINAL SECTION | HEIGHT DIFFERENCE $\delta_{s,t=0} - \delta_{s,t=T}$ (m) | VOLUME DIFFERENCE $\Delta V$ (m³/m') | TRANSPORT $S_{balance}$ (kg/s.m) |
|---|---|---|---|
| 1 | $(-2.98 \pm 0.42) \times 10^{-3}$ | $(-3.60 \pm 0.51) \times 10^{-2}$ | $(-5.36 \pm 0.76) \times 10^{-3}$ |
| 2 | $(-3.84 \pm 0.42) \times 10^{-3}$ | $(-4.64 \pm 0.51) \times 10^{-2}$ | $(-6.90 \pm 0.76) \times 10^{-3}$ |
| 3 | $(2.26 \pm 0.42) \times 10^{-3}$ | $(2.73 \pm 0.51) \times 10^{-2}$ | $(4.06 \pm 0.76) \times 10^{-3}$ |
| AVERAGE OVER THREE LONGITUDINAL SECTIONS | $(-1.52 \pm 0.24) \times 10^{-3}$ | $(-1.84 \pm 0.29) \times 10^{-2}$ | $(-2.73 \pm 0.44) \times 10^{-3}$ |

Table 3.8 B : Sand balance measuring data

| | |
|---|---|
| EXPERIMENT NO. | : S12,40 |
| WATERTEMPERATURE T (°C) | : [illegible] |

WAVE AND CURRENT PARAMETERS

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| SIGNIFICANT WAVEHEIGHT Hs (m) | 0.116 | 0.116 | 0.116 |
| ZERO-CROSS PERIOD Tz (s) | 1.92 | 1.91 | 1.92 |
| PEAK PERIOD Tp (s) | 2.32 | 2.32 | 2.32 |
| WATERDEPTH TO MEAN BED h (m) | 0.514 | 0.514 | 0.514 |
| DEPTH AVERAGED VELOCITY $u_m$ (m/s) | 0.412 | 0.398 | 0.425 |

RIPPLE PARAMETERS

| | MEAN | STANDARD DEVIATION |
|---|---|---|
| RIPPLE HEIGHT $\Delta_r$ (m) | 0.022 | 0.010 |
| RIPPLE LENGTH $\lambda_r$ (m) | 0.182 | 0.042 |
| RIPPLE VELOCITY $u_r$ (m/s) | $-1.65\times10^{-4}$ | $6.80\times10^{-5}$ |

CONCENTRATIONS AND VELOCITIES

| | TEST 1 (h (m) = 0.514) | | | TEST 2 (h (m) = 0.514) | | | TEST 3 (h (m) = — ) | | |
|---|---|---|---|---|---|---|---|---|---|
| LEVEL NO. | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) | z/h (-) | CONC. c (kg/m³) | VEL. u (m/s) |
| 1 | 0.041 | 1.6490 | 0.249 | 0.041 | 1.5310 | 0.223 | — | — | — |
| 2 | 0.060 | [illegible] | 0.278 | 0.060 | 0.8810 | 0.246 | — | — | — |
| 3 | 0.080 | [illegible] | 0.284 | 0.080 | 0.5560 | 0.266 | — | — | — |
| 4 | 0.109 | [illegible] | 0.313 | 0.109 | 0.4700 | 0.275 | — | — | — |
| 5 | 0.158 | 0.3340 | 0.359 | 0.158 | 0.2850 | 0.313 | — | — | — |
| 6 | 0.235 | 0.1140 | [illegible] | 0.235 | 0.1240 | 0.364 | — | — | — |
| 7 | 0.352 | 0.0816 | [illegible] | 0.352 | 0.0426 | 0.402 | — | — | — |
| 8 | 0.469 | 0.0377 | [illegible] | 0.469 | 0.0203 | 0.384 | — | — | — |
| 9 | 0.586 | 0.0213 | 0.407 | 0.586 | 0.0111 | 0.459 | — | — | — |
| 10 | 0.723 | [illegible] | [illegible] | 0.723 | 0.0065 | 0.468 | — | — | — |

| PARTICLE DIAMETER BED MATERIAL (m) | |
|---|---|
| $D_{10}$ | $170\times10^{-6}$ |
| $D_{50}$ | $222\times10^{-6}$ |
| $D_{90}$ | $330\times10^{-6}$ |

TRANSPORTS COMPUTED FROM RIPPLE PARAMETERS, CONCENTRATION AND VELOCITY

| | MEAN | MIN. | MAX. |
|---|---|---|---|
| BED LOAD TRANSPORT $S_b$ (kg/s.m) | $3.46\times10^{-3}$ | $1.35\times10^{-3}$ | $5.58\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT $S_s$ (kg/s.m) | $2.36\times10^{-2}$ | $1.98\times10^{-2}$ | $2.74\times10^{-2}$ |
| TOTAL LOAD TRANSPORT $S_t$ (kg/s.m) | $2.71\times10^{-2}$ | $2.11\times10^{-2}$ | $3.30\times10^{-2}$ |

SAND BALANCE DATA

| | |
|---|---|
| INTEGRATION LENGTH L (m) | 12.08 |
| TIME PERIOD T (s) | 11220 |

| LONGITUDINAL SECTION | HEIGHT DIFFERENCE $\delta_{s,t=0} - \delta_{s,t=T}$ (m) | VOLUME DIFFERENCE $\Delta V$ (m³/m') | TRANSPORT $S_{balance}$ (kg/s.m) |
|---|---|---|---|
| 1 | $(5.58 \pm 0.42)\times10^{-3}$ | $(6.74 \pm 0.51)\times10^{-2}$ | $(9.55 \pm 0.72)\times10^{-3}$ |
| 2 | $(4.64 \pm 0.42)\times10^{-3}$ | $(5.61 \pm 0.51)\times10^{-2}$ | $(7.95 \pm 0.72)\times10^{-3}$ |
| 3 | $(5.09 \pm 0.42)\times10^{-3}$ | $(6.15 \pm 0.51)\times10^{-2}$ | $(8.71 \pm 0.72)\times10^{-3}$ |
| AVERAGE OVER THREE LONGITUDINAL SECTIONS | $(5.10 \pm 0.24)\times10^{-3}$ | $(6.16 \pm 0.29)\times10^{-2}$ | $(8.74 \pm 0.42)\times10^{-3}$ |

Table 3.8 C : Sand balance measuring data

| Experiment no. | $\overline{\Delta_r}$ [m] | $\overline{\lambda_r}$ [m] | $\lambda_1$ [m] | $\lambda_2$ [m] | $\frac{\lambda_1}{\lambda_2}$ | $\frac{\overline{\lambda_r}}{\lambda_0}$ | $\frac{\overline{\Delta_r}}{\Delta_0}$ | $\frac{U_m}{\hat{U}_b}$ | $\frac{U_m^2}{\Delta g D_{50}}$ | $\frac{\hat{U}_b^2}{\Delta g D_{50}}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| T 7.5 0 | 0.015 | 0.090 | 0.044 | 0.043 | 1.014 | 1.000 | 1.000 | 0 | 0 | 6.879 |
| T 9 0 | 0.011 | 0.093 | 0.047 | 0.046 | 1.017 | 1.000 | 1.000 | 0 | 0 | 9.327 |
| T 10 0 | 0.015 | 0.091 | 0.046 | 0.046 | 1.000 | 1.000 | 1.000 | 0 | 0 | 13.031 |
| T 12 0 | 0.018 | 0.110 | 0.057 | 0.057 | 1.000 | 1.000 | 1.000 | 0 | 0 | 15.973 |
| T 15 0 | 0.018 | 0.115 | 0.059 | 0.059 | 1.022 | 1.000 | 1.000 | 0 | 0 | 27.033 |
| T 7.5 10 | 0.016 | 0.093 | 0.055 | 0.038 | 1.436 | 1.033 | 1.067 | 0.745 | 3.925 | 7.073 |
| T 10 10 | 0.017 | 0.092 | 0.055 | 0.037 | 1.466 | 1.011 | 1.133 | 0.561 | 4.196 | 13.316 |
| T 10 -10 | 0.013 | 0.089 | 0.046 | 0.041 | 1.141 | 0.980 | 0.867 | -0.669 | 4.843 | 10.818 |
| T 12 10 | 0.016 | 0.100 | 0.063 | 0.043 | 1.457 | 0.909 | 0.889 | 0.394 | 2.569 | 16.529 |
| T 12 -10 | 0.016 | 0.102 | 0.053 | 0.047 | 1.126 | 0.927 | 0.889 | -0.523 | 4.058 | 14.635 |
| T 15 10 | 0.018 | 0.099 | 0.057 | 0.039 | 1.456 | 0.861 | 1.000 | 0.378 | 3.245 | 23.343 |
| T 15 -10 | 0.017 | 0.109 | 0.056 | 0.048 | 1.160 | 0.948 | 0.944 | -0.456 | 4.827 | 23.235 |
| T 7.5 20 | 0.015 | 0.099 | 0.060 | 0.038 | 1.563 | 1.100 | 1.000 | 1.540 | 15.544 | 6.559 |
| T 10 20 | 0.017 | 0.099 | 0.059 | 0.042 | 1.404 | 1.088 | 1.133 | 1.113 | 13.977 | 11.275 |
| T 10 -20 | 0.015 | 0.114 | 0.066 | 0.050 | 1.317 | 1.253 | 1.267 | -1.234 | 15.366 | 10.084 |
| T 12 20 | 0.017 | 0.108 | 0.070 | 0.046 | 1.535 | 0.982 | 0.944 | 0.887 | 14.730 | 18.733 |
| T 12 -20 | 0.018 | 0.111 | 0.076 | 0.049 | 1.558 | 1.009 | 1.000 | -1.037 | 16.281 | 15.129 |
| T 15 20 | 0.016 | 0.111 | 0.066 | 0.038 | 1.713 | 0.965 | 0.889 | 0.744 | 14.430 | 26.089 |
| T 15 -20 | 0.013 | 0.092 | 0.049 | 0.033 | 1.474 | 0.800 | 0.722 | -0.815 | 16.221 | 24.427 |
| T 17.5 -20 | 0.013 | 0.091 | 0.047 | 0.036 | 1.301 | ***** | ***** | -0.667 | 15.529 | 34.940 |
| T 0 40 | 0.019 | 0.108 | 0.072 | 0.046 | 1.581 | ***** | ***** | ****** | 59.970 | ****** |
| T 7.5 40 | 0.014 | 0.134 | 0.082 | 0.052 | 1.569 | 1.489 | 0.933 | 2.888 | 61.354 | 7.359 |
| T 10 40 | 0.019 | 0.153 | 0.082 | 0.052 | 1.563 | 1.681 | 1.267 | 2.248 | 60.756 | 12.019 |
| T 10 -40 | 0.021 | 0.156 | 0.100 | 0.073 | 1.362 | 1.714 | 1.400 | -2.451 | 61.543 | 10.242 |
| T 12 40 | 0.018 | 0.174 | 0.108 | 0.068 | 1.587 | 1.582 | 1.000 | 1.854 | 59.433 | 17.284 |
| T 12 -40 | 0.020 | 0.155 | 0.096 | 0.067 | 1.440 | 1.409 | 1.111 | -2.025 | 60.348 | 14.721 |
| T 15 -40 | 0.024 | 0.188 | 0.096 | 0.075 | 1.289 | 1.635 | 1.333 | -1.671 | 58.990 | 21.123 |
| T 18.5 -40 | 0.029 | 0.200 | 0.114 | 0.080 | 1.437 | ***** | ***** | -1.318 | 53.886 | 31.002 |

Table 3.9: Bed form parameters

| Suction level | T 7.5 0 z [m] | T 7.5 0 W(z)/Wbed [-] | T 9 0 z [m] | T 9 0 W(z)/Wbed [-] | T 10 0 z [m] | T 10 0 W(z)/Wbed [-] | T 12 0 z [m] | T 12 0 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.017 | ***** | 0.018 | 0.972 | 0.016 | 0.972 | 0.019 | 0.989 |
| 2 | 0.027 | ***** | 0.028 | ***** | 0.026 | 0.968 | 0.029 | 0.978 |
| 3 | 0.037 | ***** | 0.036 | ***** | 0.036 | ***** | 0.039 | 0.907 |
| 4 | 0.052 | ***** | 0.053 | ***** | 0.051 | ***** | 0.054 | 0.893 |
| 5 | 0.077 | ***** | 0.078 | ***** | 0.076 | ***** | 0.079 | ***** |
| 6-10 | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |

| Suction level | T 15 0 z [m] | T 15 0 W(z)/Wbed [-] | T 7.5 10 z [m] | T 7.5 10 W(z)/Wbed [-] | T 10 10 z [m] | T 10 10 W(z)/Wbed [-] | T 10 -10 z [m] | T 10 -10 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.020 | 0.929 | 0.015 | ***** | 0.015 | 0.977 | 0.017 | 0.958 |
| 2 | 0.030 | 0.933 | 0.025 | ***** | 0.025 | 0.969 | 0.027 | 0.939 |
| 3 | 0.040 | 0.929 | 0.035 | ***** | 0.035 | ***** | 0.037 | ***** |
| 4 | 0.055 | 0.873 | 0.050 | ***** | 0.050 | ***** | 0.052 | ***** |
| 5 | 0.080 | 0.820 | 0.075 | ***** | 0.075 | ***** | 0.077 | ***** |
| 6-10 | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |

| Suction level | T 12 10 z [m] | T 12 10 W(z)/Wbed [-] | T 12 -10 z [m] | T 12 -10 W(z)/Wbed [-] | T 15 10 z [m] | T 15 10 W(z)/Wbed [-] | T 15 -10 z [m] | T 15 -10 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.017 | 0.978 | 0.019 | 0.985 | 0.019 | 0.913 | 0.022 | 0.924 |
| 2 | 0.027 | 0.952 | 0.029 | 0.974 | 0.029 | 0.920 | 0.032 | 0.893 |
| 3 | 0.037 | 0.892 | 0.039 | 0.933 | 0.039 | 0.887 | 0.042 | 0.910 |
| 4 | 0.052 | 0.851 | 0.054 | ***** | 0.054 | 0.796 | 0.057 | 0.862 |
| 5 | 0.077 | ***** | 0.079 | ***** | 0.079 | ***** | 0.082 | 0.789 |
| 6-10 | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |

W(z) = Median fall velocity of suspended sediment at height z above bed

Wbed = Median fall velocity of bed material sample

Table 3.10A: Fall velocity data of sediment samples

| Suction level | T 7.5 20 z [m] | T 7.5 20 W(z)/Wbed [-] | T 10 20 z [m] | T 10 20 W(z)/Wbed [-] | T 10 -20 z [m] | T 10 -20 W(z)/Wbed [-] | T 12 20 z [m] | T 12 20 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.022 | ***** | 0.017 | 0.905 | 0.025 | 0.943 | 0.019 | 0.930 |
| 2 | 0.032 | ***** | 0.027 | 0.890 | 0.035 | 0.901 | 0.029 | 0.922 |
| 3 | 0.042 | ***** | 0.037 | 0.826 | 0.045 | 0.916 | 0.039 | 0.883 |
| 4 | 0.057 | ***** | 0.052 | 0.818 | 0.060 | ***** | 0.054 | 0.871 |
| 5 | 0.082 | ***** | 0.077 | ***** | 0.085 | ***** | 0.079 | 0.852 |
| 6-10 | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |

| Suction level | T 12 -20 z [m] | T 12 -20 W(z)/Wbed [-] | T 15 20 z [m] | T 15 20 W(z)/Wbed [-] | T 15 -20 z [m] | T 15 -20 W(z)/Wbed [-] | T 17.5 -20 z [m] | T 17.5 -20 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.019 | 0.965 | 0.022 | 0.955 | 0.023 | 0.879 | 0.021 | 0.957 |
| 2 | 0.029 | 0.926 | 0.032 | 0.898 | 0.033 | 0.809 | 0.031 | 0.863 |
| 3 | 0.039 | 0.903 | 0.042 | 0.910 | 0.043 | 0.809 | 0.041 | 0.883 |
| 4 | 0.054 | 0.872 | 0.057 | 0.887 | 0.058 | 0.781 | 0.056 | 0.828 |
| 5 | 0.079 | 0.852 | 0.082 | 0.861 | 0.083 | 0.738 | 0.081 | 0.785 |
| 6-10 | ***** | ***** | 0.144 | 0.797 | 0.148 | 0.652 | 0.141 | 0.613 |

| Suction level | T 0 40 z [m] | T 0 40 W(z)/Wbed [-] | T 7.5 40 z [m] | T 7.5 40 W(z)/Wbed [-] | T 10 40 z [m] | T 10 40 W(z)/Wbed [-] | T 10 -40 z [m] | T 10 -40 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.021 | 0.880 | 0.019 | 0.886 | 0.028 | 0.762 | 0.034 | 0.806 |
| 2 | 0.031 | 0.694 | 0.029 | 0.846 | 0.038 | 0.754 | 0.044 | 0.795 |
| 3 | 0.041 | 0.659 | 0.039 | 0.811 | 0.048 | 0.746 | 0.054 | 0.767 |
| 4 | 0.056 | 0.635 | 0.054 | 0.815 | 0.063 | 0.754 | 0.069 | 0.756 |
| 5 | 0.081 | 0.583 | 0.079 | 0.724 | 0.088 | 0.726 | 0.094 | 0.702 |
| 6-10 | 0.182 | 0.544 | 0.155 | 0.689 | 0.180 | 0.639 | 0.178 | 0.647 |

W(z) = Median fall velocity of suspended sediment at height z above bed

Wbed = Median fall velocity of bed material sample

Table 3.10B: Fall velocity data of sediment samples

| Suction level | T 12 40 z [m] | T 12 40 W(z)/Wbed [-] | T 12 -40 z [m] | T 12 -40 W(z)/Wbed [-] | T 15 -40 z [m] | T 15 -40 W(z)/Wbed [-] | T 18.5 -40 z [m] | T 18.5 -40 W(z)/Wbed [-] |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.017 | 0.822 | 0.026 | 0.769 | 0.030 | 0.887 | 0.037 | 0.850 |
| 2 | 0.027 | 0.775 | 0.036 | 0.781 | 0.040 | 0.887 | 0.047 | 0.891 |
| 3 | 0.037 | 0.752 | 0.046 | 0.777 | 0.050 | 0.887 | 0.057 | 0.846 |
| 4 | 0.052 | 0.787 | 0.061 | 0.761 | 0.065 | 0.862 | 0.072 | 0.854 |
| 5 | 0.077 | 0.744 | 0.086 | 0.753 | 0.090 | 0.846 | 0.097 | 0.801 |
| 6-10 | 0.168 | 0.703 | 0.165 | 0.704 | 0.166 | 0.794 | 0.177 | 0.809 |

W(z) = Median fall velocity of suspended sediment at height z above bed

Wbed = Median fall velocity of bed material sample

Table 3.10C: Fall velocity data of sediment samples

| Experiment no. | W50,sus [mm/s] | D50,sus [ m] | D50,bed [ m] | meas. D50,sus / D50,bed [-] | Um / Ub [-] | calc. D50,sus / D50,bed [-] | rel. dif. [%] |
|---|---|---|---|---|---|---|---|
| T 7.5 0 | 24.4 | 198 | 201 | 0.985 | 0 | 0.975 | 1.02 |
| T 9 0 | 23.9 | 196 | 201 | 0.975 | 0 | 0.975 | 0 |
| T 10 0 | 24.0 | 196 | 201 | 0.975 | 0 | 0.975 | 0 |
| T 12 0 | 26.0 | 202 | 206 | 0.971 | 0 | 0.975 | -0.41 |
| T 15 0 | 24.6 | 194 | 205 | 0.946 | 0 | 0.975 | -3.07 |
| T 7.5 10 | 24.5 | 197 | 201 | 0.980 | 0.745 | 0.936 | 4.49 |
| T 10 10 | 24.9 | 193 | 205 | 0.971 | 0.561 | 0.945 | 2.68 |
| T 10 -10 | 24.3 | 198 | 209 | 0.947 | -0.669 | 0.940 | 0.74 |
| T 12 10 | 25.5 | 201 | 208 | 0.966 | 0.334 | 0.954 | 1.24 |
| T 12 -10 | 26.0 | 207 | 212 | 0.976 | -0.527 | 0.947 | 2.97 |
| T 15 10 | 24.7 | 202 | 218 | 0.927 | 0.373 | 0.955 | -3.02 |
| T 15 -10 | 26.1 | 208 | 223 | 0.933 | -0.456 | 0.951 | -1.93 |
| T 7.5 20 | 22.5 | 187 | 203 | 0.921 | 1.540 | 0.898 | 2.50 |
| T 10 20 | 23.0 | 193 | 212 | 0.910 | 1.113 | 0.918 | -0.88 |
| T 10 -20 | 24.1 | 197 | 209 | 0.943 | -1.234 | 0.912 | 3.29 |
| T 12 20 | 23.2 | 190 | 203 | 0.936 | 0.887 | 0.929 | 0.75 |
| T 12 -20 | 23.8 | 195 | 206 | 0.947 | -1.037 | 0.922 | 2.64 |
| T 15 20 | 24.4 | 199 | 211 | 0.943 | 0.744 | 0.936 | 0.74 |
| T 15 -20 | 21.1 | 180 | 205 | 0.878 | -0.815 | 0.932 | -6.15 |
| T 17.5 -20 | 22.8 | 190 | 205 | 0.927 | -0.667 | 0.940 | -1.40 |
| T 0 40 | 19.1 | 167 | 204 | 0.819 | ***** | ***** | **** |
| T 7.5 40 | 21.4 | 181 | 203 | 0.892 | 2.888 | 0.845 | 5.27 |
| T 10 40 | 18.9 | 170 | 205 | 0.829 | 2.248 | 0.869 | -4.83 |
| T 10 -40 | 20.0 | 174 | 206 | 0.845 | -2.451 | 0.861 | -1.89 |
| T 12 40 | 20.2 | 173 | 204 | 0.848 | 1.854 | 0.885 | -4.36 |
| T 12 -40 | 19.0 | 168 | 200 | 0.840 | -2.025 | 0.878 | -4.52 |
| T 15 -40 | 21.7 | 184 | 200 | 0.920 | -1.671 | 0.893 | 2.93 |
| T 18.5 -40 | 22.8 | 190 | 211 | 0.900 | -1.318 | 0.908 | -0.89 |

Table 3.11: Sizes and fall velocity of suspended sediment mixture

EXPERIMENT NO. : T6,40
METHOD : PROBABILISTIC

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 8.35×10⁻² | 2.15×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.5 | 44.1 |
| PARAMETER z* (-) | 1.55 | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1008 | [illegible] |
| BED LOAD Lb ($kg/m^2$) | 8.42×10⁻³ | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | 6.08×10⁻³ | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | 1.45×10⁻² | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | 2.22×10⁻³ | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 2.54×10⁻³ | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 4.76×10⁻³ | [illegible] |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 8.35×10⁻² | 2.15×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.5 | 44.1 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 3.52×10⁻² | 1.55×10⁻² |

NIELSEN METHOD

| | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | — |
| RIPPLE LENGTH $\lambda r$ (m) | — |
| RIPPLE STEEPNESS RST (-) | — |
| BED ROUGHNESS Ks (m) | — |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | — |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | — |
| ZERO INTERCEPT z0 (m) | — |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | — |
| BED CONCENTRATION Cb ($kg/m^3$) | — |
| CONCENTRATION LENGTHSCALE Lc (m) | — |
| TOTAL LOAD Lt ($kg/m^2$) | — |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | — |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | — |
| TOTAL TRANSPORT Stot (kg/s.m) | — |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.041 | 0.021 | 0.1006 | 0.2994 | — | — | 0.219 | 0.273 | — |
| 2 | 0.061 | 0.031 | 0.1008 | 0.1373 | — | — | 0.259 | 0.304 | — |
| 3 | 0.081 | 0.041 | 0.1008 | 0.0743 | — | — | 0.288 | 0.326 | — |
| 4 | 0.110 | 0.056 | 0.1008 | 0.0368 | — | — | 0.320 | 0.350 | — |
| 5 | 0.160 | 0.081 | 0.1008 | 0.0154 | — | — | 0.355 | 0.379 | — |
| 6 | 0.239 | 0.121 | 0.0492 | 0.0056 | — | — | 0.400 | 0.411 | — |
| 7 | 0.357 | 0.181 | 0.0203 | 0.0017 | — | — | 0.447 | 0.442 | — |
| 8 | 0.475 | 0.241 | 0.0095 | 0.0006 | — | — | 0.472 | 0.463 | — |
| 9 | 0.594 | 0.301 | 0.0049 | 0.0002 | — | — | 0.495 | 0.483 | — |
| 10 | 0.732 | 0.371 | 0.0017 | 0.0001 | — | — | 0.516 | 0.499 | — |

Table 4.1 A : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T7½,0<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| PARAMETER z* (-) | — | — |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | — | — |
| BED LOAD Lb ($kg/m^2$) | — | — |
| SUSPENDED LOAD Ls ($kg/m^2$) | — | — |
| TOTAL LOAD Lt ($kg/m^2$) | — | — |
| BED LOAD TRANSPORT Sb (kg/s.m) | — | — |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.29 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $9.12 \times 10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.18 | |
| BED ROUGHNESS Ks (m) | $2.36 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.033 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 | |
| ZERO INTERCEPT z0 (m) | $7.89 \times 10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $7.89 \times 10^{-4}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3370 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $4.55 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $3.35 \times 10^{-3}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.033 | 0.017 | — | — | 0.0081 | — | — | — | 0 |
| 2 | 0.053 | 0.027 | — | — | 0.0009 | — | — | — | 0 |
| 3 | 0.073 | 0.037 | — | — | 0.0001 | — | — | — | 0 |
| 4 | 0.102 | 0.052 | — | — | 0.0000 | — | — | — | 0 |
| 5 | 0.151 | 0.077 | — | — | 0.0000 | — | — | — | 0 |
| 6 | 0.230 | 0.117 | — | — | 0.0000 | — | — | — | 0 |
| 7 | 0.348 | 0.177 | — | — | 0.0000 | — | — | — | 0 |
| 8 | 0.466 | 0.237 | — | — | 0.0000 | — | — | — | 0 |
| 9 | 0.583 | 0.297 | — | — | 0.0000 | — | — | — | 0 |
| 10 | 0.721 | 0.367 | — | — | 0.0000 | — | — | — | 0 |

Table 4.1 B : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T7½,10<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 6.85×10⁻² | 1.81×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.1 | 45.5 |
| PARAMETER z* (-) | 2.63 | 3.18 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.0593 | 0.1247 |
| BED LOAD Lb ($kg/m^2$) | $4.08\times10^{-3}$ | $2.76\times10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $3.85\times10^{-3}$ | $1.77\times10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $7.94\times10^{-3}$ | $4.53\times10^{-3}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $2.60\times10^{-4}$ | $1.11\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $4.04\times10^{-4}$ | $1.44\times10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $6.65\times10^{-4}$ | $2.56\times10^{-4}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $6.88\times10^{-2}$ | $1.81\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.1 | 45.5 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $5.80\times10^{-3}$ | $1.65\times10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.44\times10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.02\times10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.18 | |
| BED ROUGHNESS Ks (m) | $2.55\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.032 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.010 | |
| ZERO INTERCEPT z0 (m) | $8.52\times10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $2.54\times10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3115 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $5.10\times10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $3.47\times10^{-3}$ | $4.33\times10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $1.52\times10^{-4}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-5.40\times10^{-5}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $9.83\times10^{-5}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.029 | 0.015 | 0.0593 | 0.1247 | 0.0165 | 0.0283 | 0.050 | 0.064 | 0.046 |
| 2 | 0.049 | 0.025 | 0.0593 | 0.0432 | 0.0023 | 0.0085 | 0.062 | 0.074 | 0.059 |
| 3 | 0.068 | 0.035 | 0.0593 | 0.0139 | 0.0003 | 0.0031 | 0.071 | 0.080 | 0.068 |
| 4 | 0.098 | 0.050 | 0.0593 | 0.0040 | 0.0000 | 0.0009 | 0.080 | 0.087 | 0.077 |
| 5 | 0.146 | 0.075 | 0.0456 | 0.0009 | 0.0000 | 0.0002 | 0.090 | 0.095 | 0.082 |
| 6 | 0.225 | 0.115 | 0.0115 | 0.0002 | 0.0000 | 0.0000 | 0.101 | 0.103 | 0.098 |
| 7 | 0.342 | 0.175 | 0.0025 | 0.0000 | 0.0000 | 0.0000 | 0.111 | 0.112 | 0.109 |
| 8 | 0.459 | 0.235 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.119 | 0.117 | 0.117 |
| 9 | 0.576 | 0.295 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.124 | 0.122 | 0.123 |
| 10 | 0.713 | 0.365 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.130 | 0.126 | 0.128 |

Table 4.1 C : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : 4,20 | | |
| METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 5.68 × 10⁻² | 1.70 × 10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.6 | 46.0 |
| PARAMETER z* (-) | 2.08 | 2.58 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.0998 | 0.2142 |
| BED LOAD Lb ($kg/m^2$) | 5.67 × 10⁻³ | 3.62 × 10⁻³ |
| SUSPENDED LOAD Ls ($kg/m^2$) | 5.56 × 10⁻³ | 2.90 × 10⁻³ |
| TOTAL LOAD Lt ($kg/m^2$) | 1.12 × 10⁻² | 6.52 × 10⁻³ |
| BED LOAD TRANSPORT Sb (kg/s.m) | 6.05 × 10⁻⁴ | 3.13 × 10⁻⁴ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 1.13 × 10⁻³ | 4.72 × 10⁻⁴ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 1.73 × 10⁻³ | 7.85 × 10⁻⁴ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 5.68 × 10⁻² | 1.70 × 10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.6 | 46.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 1.41 × 10⁻⁴ | 4.73 × 10⁻⁴ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.35 × 10⁻² | |
| RIPPLE LENGTH λr (m) | 9.53 × 10⁻² | |
| RIPPLE STEEPNESS RST (-) | 0.14 | |
| BED ROUGHNESS Ks (m) | 2.30 × 10⁻² | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.031 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.017 | |
| ZERO INTERCEPT z0 (m) | 7.77 × 10⁻⁴ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 1.07 × 10⁻³ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.2763 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 6.64 × 10⁻³ | |
| TOTAL LOAD Lt ($kg/m^2$) | 2.75 × 10⁻³ 3.94 × 10⁻³ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 5.61 × 10⁻⁴ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | -1.24 × 10⁻⁴ | |
| TOTAL TRANSPORT Stot (kg/s.m) | 4.36 × 10⁻⁴ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.043 | 0.022 | 0.0998 | 0.1067 | 0.0024 | 0.0133 | 0.123 | 0.141 | 0.132 |
| 2 | 0.063 | 0.032 | 0.0868 | 0.0384 | 0.0003 | 0.0058 | 0.141 | 0.158 | 0.148 |
| 3 | 0.082 | 0.042 | 0.0758 | 0.0180 | 0.0000 | 0.0029 | 0.154 | 0.169 | 0.160 |
| 4 | 0.112 | 0.057 | 0.0591 | 0.0075 | 0.0000 | 0.0013 | 0.169 | 0.180 | 0.173 |
| 5 | 0.161 | 0.082 | 0.0413 | 0.0025 | 0.0000 | 0.0004 | 0.186 | 0.194 | 0.189 |
| 6 | 0.239 | 0.122 | 0.0147 | 0.0007 | 0.0000 | 0.0001 | 0.205 | 0.210 | 0.206 |
| 7 | 0.357 | 0.182 | 0.0045 | 0.0002 | 0.0000 | 0.0000 | 0.219 | 0.225 | 0.224 |
| 8 | 0.515 | 0.262 | 0.0016 | 0.0000 | 0.0000 | 0.0000 | 0.238 | 0.236 | 0.236 |
| 9 | 0.702 | 0.362 | 0.0006 | 0.0000 | 0.0000 | 0.0000 | 0.249 | 0.247 | 0.246 |
| 10 | 0.929 | 0.472 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.259 | 0.256 | 0.255 |

Table 4.1 D : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T4½,40<br>METHOD : PROBABILISTIC | | |
| BIJKER METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $3.65\times10^{-2}$ | $1.51\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 39.9 | 46.8 |
| PARAMETER z* (-) | 1.46 | 1.77 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.4071 | 0.2866 |
| BED LOAD Lb ($kg/m^2$) | $1.48\times10^{-2}$ | $1.19\times10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.80\times10^{-2}$ | $1.28\times10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.29\times10^{-2}$ | $2.48\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $3.32\times10^{-3}$ | $2.27\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $6.91\times10^{-3}$ | $4.25\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.02\times10^{-2}$ | $6.52\times10^{-3}$ |
| ADAPTED ENGELUND-HANSEN METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $3.65\times10^{-2}$ | $1.51\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 39.9 | 46.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $6.30\times10^{-2}$ | $3.02\times10^{-2}$ |
| NIELSEN METHOD | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.56\times10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.10\times10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.18 | |
| BED ROUGHNESS Ks (m) | $2.74\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.033 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.034 | |
| ZERO INTERCEPT z0 (m) | $9.15\times10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $4.40\times10^{-4}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3183 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $6.24\times10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $3.86\times10^{-3}$ | $3.86\times10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $8.00\times10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-6.10\times10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $7.39\times10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.036 | 0.019 | 0.4071 | 0.5191 | 0.0152 | 0.0523 | 0.249 | 0.279 | 0.255 |
| 2 | 0.058 | 0.029 | 0.4071 | 0.2466 | 0.0031 | 0.0403 | 0.287 | 0.310 | 0.291 |
| 3 | 0.078 | 0.039 | 0.3679 | 0.1146 | 0.0006 | 0.0255 | 0.313 | 0.333 | 0.316 |
| 4 | 0.108 | 0.054 | 0.2184 | 0.0313 | 0.0001 | 0.0126 | 0.341 | 0.357 | 0.344 |
| 5 | 0.157 | 0.079 | 0.1155 | 0.0328 | 0.0000 | 0.0069 | 0.374 | 0.385 | 0.376 |
| 6 | 0.232 | 0.115 | 0.0550 | 0.0133 | 0.0000 | 0.0035 | 0.410 | 0.416 | 0.411 |
| 7 | 0.353 | 0.150 | 0.0272 | 0.0048 | 0.0000 | 0.0013 | [illegible] | 0.447 | 0.446 |
| 8 | 0.466 | 0.233 | 0.0115 | 0.0020 | 0.0000 | 0.0010 | 0.473 | 0.468 | 0.470 |
| 9 | 0.598 | 0.299 | 0.0052 | 0.0008 | 0.0000 | 0.0007 | 0.491 | 0.485 | 0.489 |
| 10 | 0.725 | 0.364 | 0.0023 | 0.0005 | 0.0000 | 0.0005 | 0.510 | 0.501 | 0.507 |

Table 4.1 E : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T9,0<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| PARAMETER z* (-) | — | — |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | — | — |
| BED LOAD Lb ($kg/m^2$) | — | — |
| SUSPENDED LOAD Ls ($kg/m^2$) | — | — |
| TOTAL LOAD Lt ($kg/m^2$) | — | — |
| BED LOAD TRANSPORT Sb (kg/s.m) | — | — |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |

| NIELSEN METHOD | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.40\times10^{-2}$ |
| RIPPLE LENGTH $\lambda r$ (m) | $9.85\times10^{-2}$ |
| RIPPLE STEEPNESS RST (-) | 0.18 |
| BED ROUGHNESS Ks (m) | $7.77\times10^{-2}$ |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.038 |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 |
| ZERO INTERCEPT z0 (m) | $9.06\times10^{-4}$ |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $9.06\times10^{-4}$ |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.6551 |
| CONCENTRATION LENGTHSCALE Lc (m) | $5.89\times10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $8.17\times10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.035 | 0.018 | — | — | 0.0309 | — | — | — | 0 |
| 2 | 0.055 | 0.028 | — | — | 0.0057 | — | — | — | 0 |
| 3 | 0.075 | 0.038 | — | — | 0.0010 | — | — | — | 0 |
| 4 | 0.104 | 0.053 | — | — | 0.0001 | — | — | — | 0 |
| 5 | 0.153 | 0.078 | — | — | 0.0000 | — | — | — | 0 |
| 6 | 0.231 | 0.118 | — | — | 0.0000 | — | — | — | 0 |
| 7 | 0.349 | 0.178 | — | — | 0.0000 | — | — | — | 0 |
| 8 | 0.467 | 0.238 | — | — | 0.0000 | — | — | — | 0 |
| 9 | 0.584 | 0.298 | — | — | 0.0000 | — | — | — | 0 |
| 10 | 0.722 | 0.368 | — | — | 0.0000 | — | — | — | 0 |

Table 4.1 F : Calculated data probabilistic method

| EXPERIMENT NO. : T10,0<br>METHOD : PROBABILISTIC | | |
|---|---|---|
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| PARAMETER z* (-) | — | — |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | — | — |
| BED LOAD Lb ($kg/m^2$) | — | — |
| SUSPENDED LOAD Ls ($kg/m^2$) | — | — |
| TOTAL LOAD Lt ($kg/m^2$) | — | — |
| BED LOAD TRANSPORT Sb (kg/s.m) | — | — |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.55 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.09 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.12 | |
| BED ROUGHNESS Ks (m) | $3.07 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.043 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 | |
| ZERO INTERCEPT z0 (m) | $1.02 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.02 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.0913 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $7.53 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.66 \times 10^{-2}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.032 | 0.016 | — | — | 0.1304 | — | — | — | 0 |
| 2 | 0.052 | 0.026 | — | — | 0.0346 | — | — | — | 0 |
| 3 | 0.071 | 0.036 | — | — | 0.0092 | — | — | — | 0 |
| 4 | 0.101 | 0.051 | — | — | 0.0013 | — | — | — | 0 |
| 5 | 0.151 | 0.076 | — | — | 0.0000 | — | — | — | 0 |
| 6 | 0.230 | 0.116 | — | — | 0.0000 | — | — | — | 0 |
| 7 | 0.349 | 0.176 | — | — | 0.0000 | — | — | — | 0 |
| 8 | 0.468 | 0.236 | — | — | 0.0000 | — | — | — | 0 |
| 9 | 0.587 | 0.296 | — | — | 0.0000 | — | — | — | 0 |
| 10 | 0.726 | 0.366 | — | — | 0.0000 | — | — | — | 0 |

Table 4.1 G : Calculated data probabilistic method

| EXPERIMENT NO. : T10,10<br>METHOD : PROBABILISTIC | | |
|---|---|---|
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.85 \times 10^{-2}$ | $1.94 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.1 | 45.0 |
| PARAMETER z* (-) | 2.00 | 2.66 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1142 | 0.2253 |
| BED LOAD Lb ($kg/m^2$) | $9.01 \times 10^{-3}$ | $5.55 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $9.70 \times 10^{-3}$ | $5.18 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $1.87 \times 10^{-2}$ | $1.07 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $6.18 \times 10^{-4}$ | $7.78 \times 10^{-5}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $1.10 \times 10^{-3}$ | $4.60 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.71 \times 10^{-3}$ | $5.38 \times 10^{-4}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.85 \times 10^{-2}$ | $1.94 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.1 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.90 \times 10^{-2}$ | $2.38 \times 10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.80 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.26 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $3.46 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.045 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.012 | |
| ZERO INTERCEPT z0 (m) | $1.15 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $4.55 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.2222 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $8.90 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $2.18 \times 10^{-2}$ | $2.87 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $1.17 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-3.07 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $8.72 \times 10^{-4}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.029 | 0.015 | 0.1142 | 0.2253 | 0.2266 | 0.2838 | 0.050 | 0.066 | 0.037 |
| 2 | 0.049 | 0.025 | 0.1142 | 0.1569 | 0.0737 | 0.1293 | 0.063 | 0.077 | 0.053 |
| 3 | 0.068 | 0.035 | 0.1142 | 0.0530 | 0.0240 | 0.0653 | 0.072 | 0.083 | 0.063 |
| 4 | 0.097 | 0.050 | 0.1142 | 0.0189 | 0.0044 | 0.0270 | 0.082 | 0.091 | 0.074 |
| 5 | 0.146 | 0.075 | 0.1142 | 0.0056 | 0.0003 | 0.0081 | 0.093 | 0.099 | 0.087 |
| 6 | 0.223 | 0.115 | 0.0430 | 0.0014 | 0.0000 | 0.0018 | 0.105 | 0.108 | 0.100 |
| 7 | 0.340 | 0.175 | 0.0172 | 0.0003 | 0.0000 | 0.0004 | 0.116 | 0.116 | 0.113 |
| 8 | 0.456 | 0.235 | 0.0046 | 0.0001 | 0.0000 | 0.0001 | 0.124 | 0.127 | 0.123 |
| 9 | 0.573 | 0.295 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.130 | [illegible] | 0.130 |
| 10 | 0.709 | 0.365 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.136 | [illegible] | 0.136 |

Table 4.1 H : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T10-10<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 4.74 x 10^-2 | 1.48 x 10^-2 |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 37.7 | 46.8 |
| PARAMETER z* (-) | 2.30 | 2.50 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1759 | 0.2880 |
| BED LOAD Lb ($kg/m^2$) | 8.35 x 10^-3 | 4.26 x 10^-3 |
| SUSPENDED LOAD Ls ($kg/m^2$) | 9.66 x 10^-3 | 3.73 x 10^-3 |
| TOTAL LOAD Lt ($kg/m^2$) | 1.80 x 10^-2 | 8.00 x 10^-3 |
| BED LOAD TRANSPORT Sb (kg/s.m) | -5.62 x 10^-4 | -2.31 x 10^-4 |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | -1.10 x 10^-3 | -3.42 x 10^-4 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | -1.66 x 10^-3 | -5.24 x 10^-4 |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 4.74 x 10^-2 | 1.48 x 10^-2 |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 37.7 | 46.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | -1.30 x 10^-2 | -3.12 x 10^-3 |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.43 x 10^-2 | |
| RIPPLE LENGTH λr (m) | 1.00 x 10^-1 | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | 2.91 x 10^-2 | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.042 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.013 | |
| ZERO INTERCEPT z0 (m) | 9.70 x 10^-4 | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 3.78 x 10^-3 | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.9461 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 6.79 x 10^-3 | |
| TOTAL LOAD Lt ($kg/m^2$) | 1.24 x 10^-2 | 1.62 x 10^-2 |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | -6.75 x 10^-4 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 2.02 x 10^-4 | |
| TOTAL TRANSPORT Stot (kg/s.m) | -4.73 x 10^-4 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.017 | 0.1759 | 0.1906 | 0.0635 | 0.1070 | -0.065 | -0.072 | -0.051 |
| 2 | 0.055 | 0.027 | [illegible] | 0.0472 | 0.0130 | 0.0411 | -0.078 | -0.082 | -0.066 |
| 3 | 0.075 | 0.037 | [illegible] | 0.0170 | 0.0026 | 0.0183 | -0.086 | -0.094 | -0.076 |
| 4 | 0.105 | 0.052 | 0.1003 | 0.0061 | 0.0002 | 0.0066 | -0.095 | -0.101 | -0.086 |
| 5 | 0.156 | 0.077 | 0.0494 | 0.0014 | 0.0000 | 0.0017 | -0.105 | -0.110 | -0.099 |
| 6 | 0.237 | 0.117 | 0.0150 | 0.0004 | 0.0000 | 0.0003 | -0.116 | -0.119 | -0.112 |
| 7 | 0.358 | 0.177 | 0.0039 | 0.0001 | 0.0000 | 0.0001 | -0.127 | -0.127 | -0.125 |
| 8 | 0.480 | 0.237 | 0.0012 | 0.0000 | 0.0000 | 0.0000 | -0.135 | -0.134 | -0.134 |
| 9 | 0.601 | 0.297 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | -0.141 | -0.138 | -0.141 |
| 10 | 0.743 | 0.367 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.148 | [illegible] | -0.148 |

Table 4.1 I : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T10,20 | | |
| METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.29 \times 10^{-2}$ | $1.93 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | 45.0 |
| PARAMETER z* (-) | 1.82 | 2.35 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1295 | 0.3134 |
| BED LOAD Lb ($kg/m^2$) | $9.45 \times 10^{-3}$ | $6.13 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $9.34 \times 10^{-3}$ | $5.79 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $1.93 \times 10^{-2}$ | $1.19 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $1.18 \times 10^{-3}$ | $5.02 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $2.06 \times 10^{-3}$ | $9.50 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $3.25 \times 10^{-3}$ | $1.51 \times 10^{-3}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.29 \times 10^{-2}$ | $1.93 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $3.78 \times 10^{-2}$ | $4.35 \times 10^{-2}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.72 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.21 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.14 | |
| BED ROUGHNESS Ks (m) | $3.31 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.042 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.019 | |
| ZERO INTERCEPT z0 (m) | $1.10 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.87 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.0032 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $7.85 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.45 \times 10^{-2}$ | $2.15 \times 10^{-5}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $2.89 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-5.22 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $2.36 \times 10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.033 | 0.017 | 0.1295 | 0.3134 | 0.1037 | 0.1676 | 0.101 | 0.128 | 0.104 |
| 2 | 0.053 | 0.027 | 0.1295 | 0.1389 | 0.0290 | 0.0825 | 0.123 | 0.145 | 0.126 |
| 3 | 0.073 | 0.037 | 0.1255 | 0.0630 | 0.0081 | 0.0437 | 0.139 | 0.163 | 0.141 |
| 4 | 0.102 | 0.052 | 0.1165 | 0.0267 | 0.0012 | 0.0220 | 0.156 | 0.180 | 0.157 |
| 5 | 0.151 | 0.077 | 0.1055 | 0.0091 | 0.0000 | 0.0085 | 0.175 | 0.185 | 0.175 |
| 6 | 0.230 | 0.117 | 0.0851 | 0.0022 | 0.0000 | 0.0027 | 0.196 | 0.201 | 0.195 |
| 7 | 0.348 | 0.177 | 0.0474 | 0.0007 | 0.0000 | 0.0008 | 0.216 | 0.217 | 0.215 |
| 8 | 0.466 | 0.237 | 0.0164 | 0.0002 | 0.0000 | 0.0004 | 0.231 | 0.228 | 0.228 |
| 9 | 0.583 | 0.297 | 0.0032 | 0.0001 | 0.0000 | 0.0002 | 0.242 | 0.237 | 0.239 |
| 10 | 0.721 | 0.367 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.252 | 0.245 | 0.249 |

Table 4.1 J : Calculated data probabilistic method

EXPERIMENT NO. : T10,-20
METHOD : PROBABILISTIC

| BIJKER METHOD | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $7.91 \times 10^{-2}$ | $2.14 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | 43.9 |
| PARAMETER $z_*$ (-) | 1.84 | 2.21 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1048 | 0.3579 |
| BED LOAD Lb ($kg/m^2$) | $6.29 \times 10^{-3}$ | $2.67 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $9.96 \times 10^{-3}$ | $3.91 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $1.62 \times 10^{-2}$ | $1.55 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-1.11 \times 10^{-3}$ | $-7.90 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-1.74 \times 10^{-3}$ | $-1.39 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-2.85 \times 10^{-3}$ | $-2.18 \times 10^{-3}$ |

| ADAPTED ENGELUND-HANSEN METHOD | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $7.91 \times 10^{-2}$ | $2.14 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.7 | 43.9 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-3.00 \times 10^{-2}$ | $-1.18 \times 10^{-2}$ |

| NIELSEN METHOD | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.31 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $9.24 \times 10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $2.71 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.041 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.019 | |
| ZERO INTERCEPT z0 (m) | $9.03 \times 10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.47 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.8537 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $5.56 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $9.92 \times 10^{-3}$ | $1.46 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-1.88 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $3.77 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-1.50 \times 10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.051 | 0.025 | 0.1048 | 0.2508 | 0.0046 | 0.0475 | -0.123 | -0.148 | -0.133 |
| 2 | 0.071 | 0.035 | 0.1048 | 0.1136 | 0.0016 | 0.0234 | -0.141 | -0.161 | -0.149 |
| 3 | 0.091 | 0.045 | 0.1048 | 0.0621 | 0.0003 | 0.0130 | -0.154 | -0.172 | -0.161 |
| 4 | 0.121 | 0.060 | 0.1048 | 0.0305 | 0.0000 | 0.0062 | -0.170 | -0.183 | -0.174 |
| 5 | 0.172 | 0.085 | 0.0896 | [illegible] | 0.0000 | 0.0024 | -0.188 | -0.197 | -0.191 |
| 6 | 0.253 | 0.125 | 0.0366 | 0.0042 | 0.0000 | 0.0008 | -0.208 | -0.213 | -0.209 |
| 7 | 0.374 | 0.185 | 0.0125 | 0.0012 | 0.0000 | 0.0002 | -0.229 | -0.229 | -0.227 |
| 8 | 0.496 | 0.245 | 0.0052 | 0.0004 | 0.0000 | 0.0001 | -0.244 | -0.240 | -0.240 |
| 9 | 0.617 | 0.305 | 0.0021 | 0.0001 | 0.0000 | 0.0000 | -0.255 | -0.249 | -0.251 |
| 10 | 0.759 | 0.375 | 0.0006 | 0.0000 | 0.0000 | 0.0000 | -0.266 | -0.257 | -0.260 |

Table 4.1 K : Calculated data probabilistic method

EXPERIMENT NO. : T10,H0
METHOD : PROBABILISTIC

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $5.59 \times 10^{-2}$ | $2.08 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.3 | 44.4 |
| PARAMETER z* (-) | 1.23 | 1.57 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.3111 | 0.2034 |
| BED LOAD Lb ($kg/m^2$) | $1.83 \times 10^{-2}$ | $1.48 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.29 \times 10^{-2}$ | $1.88 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.12 \times 10^{-2}$ | $3.37 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $4.50 \times 10^{-3}$ | $2.97 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $9.71 \times 10^{-3}$ | $6.65 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] $\times 10^{-2}$ | $9.63 \times 10^{-3}$ |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $5.59 \times 10^{-2}$ | $2.08 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.3 | 44.4 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] $\times 10^{-1}$ | $4.83 \times 10^{-2}$ |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT Δr (m) | $1.98 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.39 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.14 | |
| BED ROUGHNESS Ks (m) | $3.63 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.042 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.036 | |
| ZERO INTERCEPT z0 (m) | $1.21 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.28 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.8855 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.01 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.69 \times 10^{-2}$ | $3.54 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $3.10 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-2.01 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $2.90 \times 10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.055 | 0.028 | 0.3111 | 0.4380 | 0.0554 | 0.1682 | 0.265 | 0.299 | 0.277 |
| 2 | 0.074 | 0.038 | 0.3111 | 0.2678 | 0.0206 | 0.1189 | 0.295 | 0.323 | 0.305 |
| 3 | 0.094 | 0.048 | 0.3111 | 0.1763 | 0.0073 | 0.0891 | 0.317 | 0.341 | 0.326 |
| 4 | 0.123 | 0.063 | 0.2837 | 0.1093 | 0.0017 | 0.0621 | 0.344 | 0.363 | 0.350 |
| 5 | 0.172 | 0.088 | 0.1751 | 0.0592 | 0.0001 | 0.0387 | 0.376 | 0.389 | 0.380 |
| 6 | 0.250 | 0.128 | 0.0976 | 0.0282 | 0.0000 | 0.0221 | 0.412 | 0.419 | 0.414 |
| 7 | 0.368 | 0.188 | 0.0493 | 0.0118 | 0.0000 | 0.0121 | 0.449 | 0.446 | 0.448 |
| 8 | 0.485 | 0.248 | 0.0272 | 0.0056 | 0.0000 | 0.0072 | 0.476 | 0.471 | 0.473 |
| 9 | 0.603 | 0.308 | 0.0151 | 0.0026 | 0.0000 | 0.0054 | 0.502 | 0.488 | 0.493 |
| 10 | 0.720 | 0.368 | 0.0070 | 0.0010 | 0.0000 | 0.0038 | 0.516 | 0.504 | 0.511 |

Table 4.1 L : Calculated data probabilistic method

EXPERIMENT NO. : T10,-45
METHOD : probabilistic

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $7.06\times10^{-2}$ | $2.32\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | 43.3 |
| PARAMETER z* (-) | 1.74 | 1.49 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2522 | 0.3615 |
| BED LOAD Lb ($kg/m^2$) | $1.78\times10^{-2}$ | $1.72\times10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.01\times10^{-2}$ | $2.39\times10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.80\times10^{-2}$ | $4.12\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-4.62\times10^{-3}$ | $-3.53\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-8.70\times10^{-3}$ | $-8.80\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.33\times10^{-2}$ | $-1.23\times10^{-2}$ |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $7.06\times10^{-2}$ | $2.32\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | 43.3 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.37\times10^{-1}$ | $-7.17\times10^{-2}$ |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.16\times10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $9.22\times10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | $7.54\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.041 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.034 | |
| ZERO INTERCEPT z0 (m) | $8.48\times10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $9.14\times10^{-4}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.9977 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $9.37\times10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.04\times10^{-2}$ | $2.15\times10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-1.46\times10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $1.22\times10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-1.34\times10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.069 | 0.034 | 0.2522 | 0.4065 | 0.0018 | 0.0622 | -0.287 | -0.316 | -0.309 |
| 2 | 0.089 | 0.044 | 0.2522 | 0.2682 | 0.0003 | 0.0423 | -0.308 | -0.337 | -0.321 |
| 3 | 0.109 | 0.054 | 0.2522 | 0.1913 | 0.0000 | 0.0307 | -0.329 | -0.354 | -0.348 |
| 4 | 0.139 | 0.069 | 0.2522 | 0.1742 | 0.0000 | 0.0207 | -0.354 | -0.374 | -0.369 |
| 5 | 0.190 | 0.094 | 0.1653 | [illegible] | 0.0000 | 0.0123 | -0.386 | -0.396 | -0.396 |
| 6 | 0.271 | 0.134 | 0.0936 | 0.0368 | 0.0000 | 0.0067 | -0.422 | -0.428 | -0.426 |
| 7 | 0.392 | 0.194 | 0.0423 | 0.0162 | 0.0000 | 0.0035 | -0.459 | -0.458 | -0.458 |
| 8 | 0.513 | 0.254 | 0.0258 | 0.0078 | 0.0000 | 0.0021 | -0.482 | -0.480 | -0.481 |
| 9 | 0.634 | 0.314 | 0.0139 | 0.0037 | 0.0000 | 0.0014 | -0.500 | -0.497 | -0.499 |
| 10 | 0.776 | 0.384 | 0.0059 | 0.0013 | 0.0000 | 0.0010 | -0.520 | -0.511 | -0.516 |

Table 4.1 M : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T12,0<br>METHOD : PROBABILISTIC | | |
| BIJKER METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| PARAMETER z* (-) | – | – |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | – | – |
| BED LOAD Lb ($kg/m^2$) | – | – |
| SUSPENDED LOAD Ls ($kg/m^2$) | – | – |
| TOTAL LOAD Lt ($kg/m^2$) | – | – |
| BED LOAD TRANSPORT Sb (kg/s.m) | – | – |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |
| ADAPTED ENGELUND-HANSEN METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |

| NIELSEN METHOD | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.67 \times 10^{-2}$ |
| RIPPLE LENGTH $\lambda r$ (m) | $1.17 \times 10^{-1}$ |
| RIPPLE STEEPNESS RST (-) | 0.17 |
| BED ROUGHNESS Ks (m) | $3.44 \times 10^{-2}$ |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.050 |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 |
| ZERO INTERCEPT z0 (m) | $1.14 \times 10^{-3}$ |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.14 \times 10^{-3}$ |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.9519 |
| CONCENTRATION LENGTHSCALE Lc (m) | $8.76 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.35 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.036 | 0.019 | – | – | 0.2234 | – | – | – | 0 |
| 2 | 0.055 | 0.029 | – | – | 0.0714 | – | – | – | 0 |
| 3 | 0.074 | 0.039 | – | – | 0.0228 | – | – | – | 0 |
| 4 | 0.103 | 0.054 | – | – | 0.0041 | – | – | – | 0 |
| 5 | 0.151 | 0.079 | – | – | 0.0002 | – | – | – | 0 |
| 6 | 0.227 | 0.119 | – | – | 0.0000 | – | – | – | 0 |
| 7 | 0.342 | 0.179 | – | – | 0.0000 | – | – | – | 0 |
| 8 | 0.456 | 0.239 | – | – | 0.0000 | – | – | – | 0 |
| 9 | 0.571 | 0.299 | – | – | 0.0000 | – | – | – | 0 |
| 10 | 0.704 | 0.369 | – | – | 0.0000 | – | – | – | 0 |

Table 4.1 N : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T12,10 | | |
| METHOD : PROBABILISTIC | | |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.39 \times 10^{-2}$ | $1.82 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.8 | 45.6 |
| PARAMETER z* (-) | 2.12 | 2.70 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1815 | 0.3601 |
| BED LOAD Lb ($kg/m^2$) | $1.16 \times 10^{-2}$ | $6.57 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.39 \times 10^{-2}$ | $6.57 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $2.55 \times 10^{-2}$ | $1.31 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $5.09 \times 10^{-4}$ | $2.66 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $1.70 \times 10^{-3}$ | $4.57 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.80 \times 10^{-3}$? | $7.23 \times 10^{-4}$ |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.39 \times 10^{-2}$ | $1.87 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.8 | 45.6 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.90 \times 10^{-2}$ | $3.97 \times 10^{-3}$ |

**NIELSEN METHOD**

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.81 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.27 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17? | |
| BED ROUGHNESS Ks (m) | $3.64 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.050 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.011 | |
| ZERO INTERCEPT z0 (m) | $1.21 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $7.68 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.9577 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $9.74 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $3.70 \times 10^{-2}$ | $4.73 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $1.18 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-3.69 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $8.12 \times 10^{-4}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.017 | 0.1815 | 0.3601 | 0.3421? | 0.4242? | 0.044 | 0.055 | 0.023 |
| 2 | 0.052 | 0.027 | 0.1815 | 0.1193 | 0.1226 | 0.2015 | 0.053 | 0.062 | 0.036 |
| 3 | 0.071 | 0.037 | 0.1815 | 0.0482 | 0.0430 | 0.1040 | 0.060 | 0.067 | 0.045 |
| 4 | 0.100 | 0.052 | 0.1815 | 0.0177 | 0.0094 | 0.0435 | 0.067 | 0.077 | 0.054 |
| 5 | 0.148 | 0.077 | 0.1153 | 0.0053 | 0.0007 | 0.0179 | 0.075 | 0.079 | 0.065 |
| 6 | 0.225 | 0.117 | 0.0388 | 0.0013 | 0.0000 | 0.0028 | 0.083 | 0.085 | 0.077 |
| 7 | [illegible] | [illegible] | 0.0114 | 0.0003 | 0.0000 | 0.0005 | 0.091 | 0.092 | 0.089? |
| 8 | [illegible] | [illegible] | 0.0041 | 0.0001 | 0.0000 | 0.0001 | 0.097 | 0.096 | 0.095? |
| 9 | 0.577 | [illegible] | 0.0015 | 0.0000 | 0.0000 | 0.0000 | 0.102 | 0.100 | [illegible] |
| 10 | 0.707 | [illegible] | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.104 | 0.103 | 0.110 |

Table 4.1 0 : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T12,-10<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $6.27 \times 10^{-2}$ | $1.81 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.6 | 45.3 |
| PARAMETER $z_*$ (-) | 2.10 | 2.61 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1716 | 0.3689 |
| BED LOAD Lb ($kg/m^2$) | $1.03 \times 10^{-2}$ | $6.68 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.26 \times 10^{-2}$ | $6.69 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $2.34 \times 10^{-2}$ | $1.33 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-2.08 \times 10^{-4}$ | $-3.45 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-1.39 \times 10^{-3}$ | $-5.93 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | $-9.30 \times 10^{-4}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $6.27 \times 10^{-2}$ | $1.81 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.6 | 45.3 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-7.25 \times 10^{-2}$ | $-5.15 \times 10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.59 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.12 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $3.32 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.049 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.013 | |
| ZERO INTERCEPT z0 (m) | $1.10 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $4.91 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.3163 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $8.10 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $2.36 \times 10^{-2}$ | $3.62 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-1.31 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $3.75 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-9.44 \times 10^{-4}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.038 | [illegible] | 0.1716 | 0.3243 | 0.1644 | 0.2464 | -0.059 | [illegible] | -0.043 |
| 2 | 0.058 | 0.029 | 0.1716 | 0.1017 | 0.0478 | 0.1116 | -0.070 | [illegible] | -0.052 |
| 3 | 0.078 | 0.039 | 0.1716 | [illegible] | 0.0129 | 0.0561 | -0.078 | [illegible] | -0.066 |
| 4 | 0.109 | 0.054 | 0.1716 | [illegible] | 0.0022 | 0.0231 | -0.086 | [illegible] | [illegible] |
| 5 | 0.159 | 0.079 | 0.0935 | [illegible] | 0.0001 | 0.0069 | [illegible] | -0.101 | [illegible] |
| 6 | 0.239 | 0.119 | 0.0354 | [illegible] | 0.0000 | 0.0015 | -0.103 | -0.109 | [illegible] |
| 7 | 0.360 | 0.179 | [illegible] | [illegible] | 0.0000 | [illegible] | -0.113 | -0.118 | -0.115 |
| 8 | 0.481 | 0.239 | [illegible] | [illegible] | 0.0000 | 0.0001 | [illegible] | [illegible] | -0.124 |
| 9 | 0.602 | 0.299 | 0.0012 | [illegible] | 0.0000 | 0.0000 | -0.121 | -0.129 | [illegible] |
| 10 | [illegible] | [illegible] | 0.0003 | [illegible] | 0.0000 | 0.0000 | -0.126 | -0.132 | -0.132 |

Table 4.1 P : Calculated data probabilistic method

| | |
|---|---|
| EXPERIMENT NO. | : T12,7A |
| METHOD | : PROBABILISTIC |

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.68\times10^{-1}$ | $1.02\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 45.3 | 45.0 |
| PARAMETER z* (-) | 1.56 | 2.09 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2063 | 0.4491 |
| BED LOAD Lb ($kg/m^2$) | $1.38\times10^{-2}$ | $8.62\times10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.72\times10^{-2}$ | $9.77\times10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.10\times10^{-2}$ | $1.84\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $1.70\times10^{-3}$ | [illegible]$\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $3.60\times10^{-3}$ | $1.64\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $5.31\times10^{-3}$ | $2.48\times10^{-3}$ |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $1.68\times10^{-1}$ | $1.92\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.4 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $5.85\times10^{-1}$ | $1.32\times10^{-2}$ |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $2.02\times10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.42\times10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $3.92\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}*$ (m/s) | 0.052 | |
| CURRENT FRICTION VELOCITY $\bar{u}*$ (m/s) | 0.020 | |
| ZERO INTERCEPT z0 (m) | $1.30\times10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $2.62\times10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 2.2501 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.70\times10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $5.00\times10^{-2}$ | $7.77\times10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $1.15\times10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-1.58\times10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $1.00\times10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.037 | 0.019 | 0.2063 | 0.4491 | 0.4639 | 0.6263 | 0.109 | 0.134 | 0.101 |
| 2 | 0.053 | 0.027 | 0.2063 | 0.1818 | 0.2021 | 0.3764 | 0.129 | 0.149 | 0.123 |
| 3 | 0.073 | 0.037 | 0.2063 | 0.0935 | 0.0890 | 0.2430 | 0.144 | 0.160 | 0.138 |
| 4 | 0.106 | 0.054 | 0.2063 | 0.0442 | 0.0293 | 0.1388 | 0.160 | 0.173 | 0.154 |
| 5 | 0.155 | 0.079 | 0.1523 | 0.0177 | 0.0032 | 0.0652 | 0.178 | 0.187 | 0.174 |
| 6 | [illegible] | 0.119 | 0.0550 | 0.0061 | 0.0001 | 0.0239 | 0.198 | 0.203 | 0.195 |
| 7 | [illegible] | 0.174 | [illegible] | 0.0018 | 0.0000 | 0.0094 | 0.218 | 0.218 | 0.216 |
| 8 | [illegible] | [illegible] | [illegible] | 0.0007 | 0.0000 | 0.0041 | 0.232 | 0.229 | 0.230 |
| 9 | [illegible] | [illegible] | [illegible] | 0.0002 | 0.0000 | 0.0024 | 0.243 | 0.238 | 0.242 |
| 10 | [illegible] | 0.363 | [illegible] | 0.0001 | 0.0000 | 0.0013 | 0.253 | 0.246 | 0.252 |

Table 4.1 Q : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T12-20 | | |
| METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.29 \times 10^{-2}$ | $2.03 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.3 | 44.3 |
| PARAMETER z* (-) | 1.60 | 2.00 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1702 | 0.4032 |
| BED LOAD Lb ($kg/m^2$) | $1.24 \times 10^{-2}$ | $1.00 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.44 \times 10^{-2}$ | $1.18 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $2.68 \times 10^{-2}$ | $2.19 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-1.67 \times 10^{-3}$ | $-1.04 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-3.23 \times 10^{-3}$ | $-2.15 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-4.90 \times 10^{-3}$ | $-3.20 \times 10^{-3}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.29 \times 10^{-2}$ | $2.03 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.3 | 44.3 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-6.07 \times 10^{-2}$ | $-1.70 \times 10^{-2}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.50 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.05 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $3.19 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.049 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.020 | |
| ZERO INTERCEPT z0 (m) | $1.06 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.97 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.8835 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $8.08 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $7.93 \times 10^{-2}$ | $4.58 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-6.49 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $9.77 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-5.51 \times 10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.039 | 0.019 | 0.1702 | 0.4932 | 0.1794 | 0.3251 | -0.114 | -0.141 | -0.116 |
| 2 | 0.059 | 0.029 | 0.1702 | 0.2345 | 0.0521 | 0.1716 | -0.136 | -0.158 | -0.137 |
| 3 | 0.080 | 0.039 | 0.1702 | 0.1241 | 0.0151 | 0.1008 | -0.152 | -0.170 | -0.152 |
| 4 | 0.110 | 0.054 | 0.1502 | 0.0605 | 0.0024 | 0.0522 | -0.169 | -0.184 | -0.169 |
| 5 | 0.161 | 0.079 | 0.1464 | 0.0251 | 0.0001 | 0.0220 | -0.183 | -0.199 | -0.189 |
| 6 | 0.243 | 0.119 | 0.0644 | 0.0090 | 0.0000 | 0.0079 | -0.211 | -0.216 | -0.210 |
| 7 | 0.365 | 0.179 | 0.0252 | 0.0028 | 0.0000 | 0.0023 | -0.233 | -0.234 | -0.230 |
| 8 | 0.488 | 0.239 | 0.0113 | 0.0010 | 0.0000 | 0.0017 | -0.248 | -0.245 | -0.245 |
| 9 | 0.610 | 0.299 | 0.0051 | 0.0004 | 0.0000 | 0.0006 | -0.260 | -0.254 | -0.253 |
| 10 | 0.753 | 0.369 | 0.0017 | 0.0001 | 0.0000 | 0.0003 | -0.271 | -0.262 | -0.263 |

Table 4.1 R : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T12,4r<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $4.65 \times 10^{-2}$ | $1.92 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 38.1 | 45.0 |
| PARAMETER z* (-) | 1.25 | 1.56 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.4324 | 0.8451 |
| BED LOAD Lb ($kg/m^2$) | $2.01 \times 10^{-2}$ | $1.62 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.83 \times 10^{-2}$ | $2.17 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.85 \times 10^{-2}$ | $3.79 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $4.64 \times 10^{-3}$ | $3.17 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $1.13 \times 10^{-2}$ | $7.52 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.59 \times 10^{-2}$ | $1.07 \times 10^{-2}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $4.65 \times 10^{-2}$ | $1.92 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 38.1 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.27 \times 10^{-1}$ | $5.68 \times 10^{-2}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $2.07 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.45 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.14 | |
| BED ROUGHNESS Ks (m) | $3.96 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.050 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.037 | |
| ZERO INTERCEPT z0 (m) | $1.32 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.48 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.9711 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.22 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $4.36 \times 10^{-2}$ | $9.06 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $6.60 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-4.12 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $6.18 \times 10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.033 | 0.017 | 0.4324 | 0.8451 | 0.4900 | 0.7063 | 0.226 | [illegible] | 0.223 |
| 2 | 0.053 | 0.027 | 0.4324 | 0.4853 | 0.2161 | 0.4701 | 0.267 | [illegible] | 0.265 |
| 3 | 0.073 | 0.037 | 0.4324 | 0.2870 | 0.0953 | 0.3378 | 0.296 | [illegible] | 0.294 |
| 4 | 0.102 | 0.052 | 0.3710 | 0.1603 | 0.0279 | 0.2259 | 0.323 | [illegible] | 0.325 |
| 5 | 0.151 | 0.077 | 0.2116 | 0.0794 | 0.0026 | 0.1348 | 0.363 | [illegible] | 0.361 |
| 6 | 0.230 | 0.117 | 0.1110 | 0.0355 | 0.0001 | 0.0739 | 0.400 | 0.402 | 0.399 |
| 7 | 0.348 | 0.177 | 0.0528 | 0.0142 | 0.0000 | 0.0391 | 0.430 | [illegible] | 0.432 |
| 8 | 0.466 | 0.237 | 0.0291 | 0.0066 | 0.0000 | 0.0246 | 0.464 | 0.461 | 0.464 |
| 9 | 0.583 | 0.297 | 0.0161 | 0.0032 | 0.0000 | 0.0170 | 0.485 | 0.436 | 0.484 |
| 10 | 0.721 | 0.367 | 0.0075 | 0.0012 | 0.0000 | 0.0120 | 0.504 | 0.465 | 0.504 |

Table 4.1 S : Calculated data probabilistic method

EXPERIMENT NO. : T12-45
METHOD : PROBABILISTIC

| BIJKER METHOD | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.45 \times 10^{-1}$ | $2.19 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.4 | 43.8 |
| PARAMETER z* (-) | 1.14 | 1.40 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.3029 | 0.8141 |
| BED LOAD Lb ($kg/m^2$) | $1.05 \times 10^{-2}$ | $1.78 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.65 \times 10^{-2}$ | $2.79 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.60 \times 10^{-2}$ | $4.58 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-4.84 \times 10^{-3}$ | $-3.5? \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-1.11 \times 10^{-2}$ | $-1.00 \times 10^{-2}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.60 \times 10^{-2}$ | $-1.36 \times 10^{-2}$ |

| ADAPTED ENGELUND-HANSEN METHOD | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.45 \times 10^{-2}$ | $2.19 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.4 | 43.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.90 \times 10^{-1}$ | $-7.90 \times 10^{-2}$ |

| NIELSEN METHOD | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.36 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $9.58 \times 10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $3.98 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.048 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.035 | |
| ZERO INTERCEPT z0 (m) | $9.93 \times 10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.17 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.9466 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $7.72 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $3.75 \times 10^{-2}$ | $5.95 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-3.67 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $2.48 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-3.42 \times 10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.052 | 0.026 | 0.3029 | 0.6350? | 0.0671 | 0.2939 | -0.258? | -0.288 | -0.27? |
| 2 | 0.072 | 0.036 | 0.3029 | 0.3906? | 0.0184 | 0.1971 | -0.284 | -0.314 | -0.300 |
| 3 | 0.093 | 0.046 | 0.3029 | 0.2687 | 0.0050 | 0.1422 | -0.308 | [illegible] | -0.321? |
| 4 | 0.123 | 0.061 | 0.3029 | 0.1726 | 0.0007 | 0.0955 | [illegible] | [illegible] | -0.34? |
| 5 | 0.173 | 0.086 | 0.2056 | 0.0982? | 0.0000 | 0.0571 | -0.369? | [illegible] | -0.37? |
| 6 | 0.254 | 0.126 | 0.1181 | 0.0400? | 0.0000 | 0.0313 | -0.406? | -0.413? | -0.409? |
| 7 | 0.374? | 0.186 | 0.0618 | 0.0224 | 0.0000 | 0.0166 | [illegible] | [illegible] | -0.41? |
| 8 | 0.465? | 0.216 | 0.0351? | [illegible] | 0.0000 | 0.0104 | [illegible] | -0.465? | -0.46? |
| 9 | 0.616 | 0.306 | 0.0200? | [illegible] | 0.0000 | 0.0072 | [illegible] | -0.488? | -0.486 |
| 10 | 0.757? | 0.376 | 0.0094? | [illegible] | 0.0000 | 0.0050 | -0.51? | [illegible] | -0.504 |

Table 4.1 T : Calculated data probabilistic method

| EXPERIMENT NO. : T15,r | | |
|---|---|---|
| METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| PARAMETER $z_*$ (-) | — | — |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | — | — |
| BED LOAD Lb ($kg/m^2$) | — | — |
| SUSPENDED LOAD Ls ($kg/m^2$) | — | — |
| TOTAL LOAD Lt ($kg/m^2$) | — | — |
| BED LOAD TRANSPORT Sb (kg/s.m) | — | — |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.87 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.33 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | $3.94 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.062 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 | |
| ZERO INTERCEPT z0 (m) | $1.31 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.31 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 4.5863 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.27 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.00 \times 10^{-1}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.040 | 0.020 | — | — | 0.9550 | — | — | — | 0 |
| 2 | 0.060 | 0.030 | — | — | 0.4358 | — | — | — | 0 |
| 3 | 0.080 | 0.040 | — | — | 0.1988 | — | — | — | 0 |
| 4 | 0.109 | 0.055 | — | — | 0.0613 | — | — | — | 0 |
| 5 | 0.159 | 0.080 | — | — | 0.0086 | — | — | — | 0 |
| 6 | 0.239 | 0.120 | — | — | 0.0004 | — | — | — | 0 |
| 7 | 0.358 | 0.180 | — | — | 0.0000 | — | — | — | 0 |
| 8 | 0.477 | 0.240 | — | — | 0.0000 | — | — | — | 0 |
| 9 | 0.596 | 0.300 | — | — | 0.0000 | — | — | — | 0 |
| 10 | 0.736 | 0.370 | — | — | 0.0000 | — | — | — | 0 |

Table 4.1 U : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T15,10<br>METHOD : probabilistic | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $8.18\times10^{-2}$ | $2.04\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.6 | 44.4 |
| PARAMETER z* (-) | 1.38 | 2.30 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | [illegible] | 0.4908 |
| BED LOAD Lb ($kg/m^2$) | $1.54\times10^{-2}$ | $1.02\times10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.86\times10^{-2}$ | $1.21\times10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.40\times10^{-2}$ | $2.23\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $3.76\times10^{-4}$ | $4.89\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $1.55\times10^{-3}$ | $1.01\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.93\times10^{-3}$ | $1.50\times10^{-3}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $8.18\times10^{-2}$ | $2.04\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.6 | 44.4 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $4.23\times10^{-3}$ | $8.23\times10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.91\times10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.35\times10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | $4.03\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.060 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.014 | |
| ZERO INTERCEPT z0 (m) | $1.34\times10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $8.46\times10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 3.2212 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.22\times10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $8.13\times10^{-2}$ $1.08\times10^{-1}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $3.64\times10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-8.87\times10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $2.76\times10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.038 | 0.019 | 0.1889 | 0.4908 | 0.7864 | 0.9593 | 0.051 | 0.064 | 0.028 |
| 2 | 0.058 | 0.029 | 0.1889 | 0.2162 | 0.3470 | 0.5321 | 0.061 | 0.077 | 0.042 |
| 3 | 0.078 | 0.039 | 0.1889 | 0.1013 | 0.1531 | 0.3138 | 0.068 | 0.078 | 0.052 |
| 4 | 0.107 | 0.054 | 0.1886 | 0.0458 | 0.0449 | 0.1557 | 0.076 | 0.084 | 0.063 |
| 5 | 0.157 | 0.079 | 0.1883 | 0.0168 | 0.0058 | 0.0680 | 0.086 | 0.091 | 0.076 |
| 6 | 0.237 | 0.119 | 0.0824 | 0.0052 | 0.0002 | 0.0164 | 0.096 | 0.099 | 0.090 |
| 7 | 0.356 | 0.179 | 0.0225 | 0.0014 | 0.0000 | 0.0039 | 0.106 | 0.106 | 0.104 |
| 8 | 0.475 | 0.239 | 0.0123 | 0.0004 | 0.0000 | 0.0013 | 0.113 | 0.112 | 0.114 |
| 9 | 0.594 | 0.299 | 0.0052 | 0.0001 | 0.0000 | 0.0005 | 0.119 | 0.116 | 0.121 |
| 10 | 0.734 | 0.369 | 0.0012 | 0.0000 | 0.0000 | 0.0002 | 0.124 | 0.120 | 0.128 |

Table 4.1 V : Calculated data probabilistic method

EXPERIMENT NO. : [illegible]
METHOD : probabilistic

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.62 \times 10^{-2}$ | $1.92 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.2 | 44.9 |
| PARAMETER z* (-) | 1.80 | 2.33 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2503 | 0.5653 |
| BED LOAD Lb ($kg/m^2$) | $1.65 \times 10^{-2}$ | $1.08 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.08 \times 10^{-2}$ | $1.22 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.74 \times 10^{-2}$ | $2.31 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-1.23 \times 10^{-3}$ | $-6.35 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-2.61 \times 10^{-3}$ | $-1.24 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-3.85 \times 10^{-3}$ | $-1.88 \times 10^{-3}$ |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.62 \times 10^{-2}$ | $1.92 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.2 | 44.9 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-5.35 \times 10^{-2}$ | $-1.13 \times 10^{-2}$ |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.81 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.28 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.14 | |
| BED ROUGHNESS Ks (m) | $3.94 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.061 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.015 | |
| ZERO INTERCEPT z0 (m) | $1.31 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $6.41 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 3.8802 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.11 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $7.87 \times 10^{-2}$ | $1.07 \times 10^{-1}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-4.91 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $1.13 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-3.78 \times 10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.044 | 0.022 | 0.2503 | 0.4086 | 0.5378 | 0.7465 | -0.070 | -0.083 | -0.048 |
| 2 | 0.064 | 0.032 | 0.2503 | 0.1626 | 0.2100 | 0.4128 | -0.081 | -0.092 | -0.062 |
| 3 | 0.084 | 0.042 | 0.2503 | 0.0821 | 0.0892 | 0.2441 | -0.089 | -0.098 | -0.073 |
| 4 | 0.114 | 0.057 | 0.2503 | 0.0373 | 0.0232 | 0.1222 | -0.098 | -0.105 | -0.084 |
| 5 | 0.165 | 0.082 | 0.1593 | 0.0140 | 0.0025 | 0.0465 | -0.108 | -0.114 | -0.098 |
| 6 | 0.245 | 0.122 | 0.0650 | 0.0044 | 0.0001 | 0.0137 | -0.120 | -0.123 | -0.114 |
| 7 | 0.365 | 0.182 | 0.0231 | 0.0012 | 0.0000 | 0.0034 | -0.132 | -0.132 | -0.129 |
| 8 | 0.486 | 0.242 | 0.0094 | 0.0004 | 0.0000 | 0.0012 | -0.140 | -0.138 | -0.140 |
| 9 | 0.606 | 0.302 | 0.0039 | 0.0001 | 0.0000 | 0.0005 | -0.147 | -0.143 | -0.149 |
| 10 | 0.747 | 0.372 | 0.0012 | 0.0000 | 0.0000 | 0.0002 | -0.153 | -0.115 | -0.157 |

Table 4.1 W : Calculated data probabilistic method

| EXPERIMENT NO. : T15,20 | | |
|---|---|---|
| METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $5.76 \times 10^{-2}$ | $1.79 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.5 | 45.6 |
| PARAMETER z* (-) | 1.47 | 2.00 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.3060 | 0.6268 |
| BED LOAD Lb ($kg/m^2$) | [illegible] | $1.17 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] $\times 10^{-2}$ | $1.41 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.25 \times 10^{-2}$ | $2.54 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $2.13 \times 10^{-3}$ | $1.08 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $5.13 \times 10^{-3}$ | $2.42 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $7.27 \times 10^{-3}$ | $3.51 \times 10^{-3}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $5.76 \times 10^{-2}$ | $1.79 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.5 | 45.6 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $8.33 \times 10^{-2}$ | $1.97 \times 10^{-2}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $2.05 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.45 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | $4.15 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.061 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.022 | |
| ZERO INTERCEPT z0 (m) | $1.39 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $3.33 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 4.19 10 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.40 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.01 \times 10^{-1}$ | $1.60 \times 10^{-1}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $2.31 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-2.68 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $2.04 \times 10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.043 | 0.022 | 0.3069 | 0.4113 | 0.8728 | 1.1813 | 0.170 | 0.141 | 0.103 |
| 2 | 0.063 | 0.032 | 0.3069 | 0.1864 | 0.4278 | 0.7621 | 0.128 | 0.155 | 0.123 |
| 3 | 0.082 | 0.042 | 0.3069 | 0.1036 | 0.2096 | 0.5195 | 0.151 | 0.165 | 0.138 |
| 4 | 0.112 | 0.057 | 0.3069 | 0.0527 | 0.0719 | 0.3159 | 0.165 | 0.172 | 0.154 |
| 5 | 0.160 | 0.082 | 0.1686 | 0.0227 | 0.0121 | 0.1596 | 0.183 | 0.190 | 0.174 |
| 6 | 0.239 | 0.122 | 0.0814 | 0.0084 | 0.0007 | 0.0682 | 0.201 | 0.206 | 0.196 |
| 7 | 0.356 | 0.182 | 0.0353 | 0.0023 | 0.0000 | 0.0264 | 0.220 | 0.221 | 0.218 |
| 8 | 0.474 | 0.242 | 0.0173 | 0.0010 | 0.0000 | 0.0178 | 0.234 | 0.232 | 0.233 |
| 9 | 0.591 | 0.302 | 0.0086 | 0.0004 | 0.0000 | 0.0092 | 0.244 | 0.240 | 0.245 |
| 10 | 0.728 | 0.372 | 0.0035 | 0.0001 | 0.0000 | 0.0041 | 0.254 | 0.248 | 0.256 |

Table 4.1 X : Calculated data probabilistic method

| | |
|---|---|
| EXPERIMENT NO. | : T15-20 |
| METHOD | : PROBABILISTIC |

## BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.59 \times 10^{-2}$ | $1.47 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 37.9 | 46.8 |
| PARAMETER $z_*$ (-) | 1.46 | 1.97 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.3801 | 0.3646 |
| BED LOAD Lb ($kg/m^2$) | $1.74 \times 10^{-2}$ | $1.12 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.67 \times 10^{-2}$ | $1.47 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.42 \times 10^{-2}$ | $2.60 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-3.11 \times 10^{-3}$ | $-1.11 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-5.66 \times 10^{-3}$ | $-2.56 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-7.78 \times 10^{-3}$ | $-3.70 \times 10^{-3}$ |

## ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.59 \times 10^{-2}$ | $1.47 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 37.9 | 46.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-7.80 \times 10^{-2}$ | $-1.92 \times 10^{-2}$ |

## NIELSEN METHOD

| | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.68 \times 10^{-2}$ |
| RIPPLE LENGTH $\lambda r$ (m) | $1.19 \times 10^{-1}$ |
| RIPPLE STEEPNESS RST (-) | 0.16 |
| BED ROUGHNESS Ks (m) | $3.67 \times 10^{-2}$ |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.060 |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.022 |
| ZERO INTERCEPT z0 (m) | $1.22 \times 10^{-3}$ |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $2.78 \times 10^{-3}$ |
| BED CONCENTRATION Cb ($kg/m^3$) | 4.1834 |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.14 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $8.22 \times 10^{-2}$ $1.34 \times 10^{-1}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-1.96 \times 10^{-2}$ |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $2.24 \times 10^{-3}$ |
| TOTAL TRANSPORT Stot (kg/s.m) | $-1.73 \times 10^{-2}$ |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.047 | 0.023 | 0.3801 | 0.3085 | 0.5566 | 0.9037 | -0.134 | -0.152 | -0.116 |
| 2 | 0.067 | 0.033 | 0.3801 | 0.1452 | 0.2316 | 0.5610 | -0.151 | -0.166 | -0.136 |
| 3 | 0.088 | 0.043 | 0.3801 | 0.0825 | 0.0963 | 0.3325 | -0.164 | -0.177 | -0.150 |
| 4 | 0.118 | 0.058 | 0.2596 | 0.0428 | 0.0259 | 0.2208 | -0.178 | -0.188 | -0.162 |
| 5 | 0.169 | 0.083 | 0.1409 | 0.0188 | 0.0029 | 0.1001 | -0.195 | -0.202 | -0.182 |
| 6 | 0.251 | 0.123 | 0.0682 | 0.0071 | 0.0001 | 0.0461 | -0.214 | -0.217 | -0.208 |
| 7 | 0.373 | 0.183 | 0.0294 | 0.0023 | 0.0000 | 0.0179 | -0.233 | -0.233 | -0.230 |
| 8 | 0.495 | 0.243 | 0.0142 | 0.0008 | 0.0000 | 0.0088 | -0.246 | -0.243 | -0.246 |
| 9 | 0.617 | 0.303 | 0.0068 | 0.0003 | 0.0000 | 0.0049 | -0.257 | -0.252 | -0.258 |
| 10 | 0.760 | 0.373 | 0.0026 | 0.0001 | 0.0000 | 0.0020 | -0.267 | -0.260 | -0.269 |

Table 4.1 Y : Calculated data probabilistic method

| EXPERIMENT NO. : T15-40<br>METHOD : PROBABILISTIC | | |
|---|---|---|
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.65 \times 10^{-2}$ | $2.61 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.2 | 42.6 |
| PARAMETER z* (-) | 1.05 | 1.27 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2838 | 0.7935 |
| BED LOAD Lb ($kg/m^2$) | $2.17 \times 10^{-2}$ | $2.07 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $3.01 \times 10^{-2}$ | $2.70 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $5.19 \times 10^{-2}$ | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-3.51 \times 10^{-3}$ | $-4.22 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-1.30 \times 10^{-2}$ | $-1.37 \times 10^{-2}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | $-1.79 \times 10^{-2}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $7.65 \times 10^{-2}$ | $2.61 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.2 | 42.6 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-3.05 \times 10^{-1}$ | $-1.27 \times 10^{-1}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.40 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $9.89 \times 10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | $3.23 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.057 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.035 | |
| ZERO INTERCEPT z0 (m) | $1.07 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.37 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 3.6490 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $9.74 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $5.82 \times 10^{-2}$ | $1.28 \times 10^{-1}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-6.94 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $4.17 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-6.54 \times 10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.059 | 0.030 | 0.2838 | 0.6596 | 0.1473 | 0.5814 | -0.255 | -0.291 | -0.275 |
| 2 | 0.079 | 0.040 | 0.2838 | 0.4456 | 0.0483 | 0.4124 | -0.283 | -0.314 | -0.300 |
| 3 | 0.098 | 0.050 | 0.2838 | 0.3266 | 0.0144 | 0.3034 | -0.306 | -0.331 | -0.319 |
| 4 | 0.128 | 0.065 | 0.2838 | 0.2243 | 0.0022 | 0.2163 | -0.332 | -0.352 | -0.343 |
| 5 | 0.177 | 0.090 | 0.2318 | 0.1379 | 0.0003 | 0.1251 | -0.364 | -0.378 | -0.371 |
| 6 | 0.255 | 0.130 | 0.1418 | 0.0761 | 0.0000 | 0.0771 | -0.401 | -0.408 | -0.404 |
| 7 | 0.353 | 0.180 | [illegible] | 0.0377 | 0.0000 | 0.0422 | -0.438 | -0.438 | -0.437 |
| 8 | 0.451 | 0.230 | 0.0438 | 0.0204 | 0.0000 | 0.0230 | -0.466 | -0.460 | -0.461 |
| 9 | 0.608 | 0.310 | 0.0289 | 0.0111 | 0.0000 | 0.0189 | -0.482 | [illegible] | -0.480 |
| 10 | 0.745 | 0.380 | 0.0148 | 0.0050 | 0.0000 | 0.0134 | -0.507 | [illegible] | -0.498 |

Table 4.1 Z : Calculated data probabilistic method

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| METHOD | : PROBABILISTIC |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.64\times10^{-2}$ | $1.47\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 38.0 | 46.9 |
| PARAMETER z* (-) | 1.32 | 1.83 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.4465 | 0.2371 |
| BED LOAD Lb ($kg/m^2$) | $2.07\times10^{-2}$ | $1.38\times10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $3.50\times10^{-2}$ | $2.09\times10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $5.57\times10^{-2}$ | $3.47\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-2.46\times10^{-3}$ | $-1.33\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-3.32\times10^{-3}$ | $-3.67\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-5.78\times10^{-3}$ | $-5.00\times10^{-3}$ |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.64\times10^{-2}$ | $1.57\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 38.0 | 46.9 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.15\times10^{-1}$ | $-2.77\times10^{-2}$ |

**NIELSEN METHOD**

| | | |
|---|---|---|
| RIPPLE HEIGHT Δr (m) | $1.76\times10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.27\times10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.15 | |
| BED ROUGHNESS Ks (m) | $3.92\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.069 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.023 | |
| ZERO INTERCEPT z0 (m) | $1.30\times10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $3.58\times10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 6.5403 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.38\times10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.43\times10^{-1}$ | $2.40\times10^{-1}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-3.37\times10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $3.41\times10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-3.03\times10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.042 | 0.021 | 0.4465 | 0.4815 | 1.4336 | 1.9434 | -0.126 | -0.145 | -0.101 |
| 2 | 0.062 | 0.031 | 0.4465 | 0.2272 | 0.6959 | 1.2591 | -0.144 | -0.160 | -0.123 |
| 3 | 0.082 | 0.041 | 0.4465 | 0.1310 | 0.3378 | 0.8847 | -0.157 | -0.170 | -0.139 |
| 4 | 0.112 | 0.056 | 0.3386 | 0.0697 | 0.1142 | 0.5331 | -0.172 | -0.187 | -0.156 |
| 5 | 0.163 | 0.081 | 0.1924 | 0.0319 | 0.0158 | 0.2763 | [illegible] | -0.206 | -0.177 |
| 6 | 0.243 | 0.121 | 0.0869 | 0.0177 | [illegible] | 0.1730 | [illegible] | -0.211 | -0.200 |
| 7 | [illegible] | 0.181 | 0.0467 | 0.0044 | 0.0000 | 0.0502 | [illegible] | [illegible] | -0.223 |
| 8 | [illegible] | 0.241 | 0.0230 | 0.0015 | 0.0000 | 0.0255 | [illegible] | [illegible] | -0.240 |
| 9 | [illegible] | 0.301 | 0.0126 | 0.0007 | 0.0000 | 0.0148 | [illegible] | [illegible] | -0.252 |
| 10 | [illegible] | [illegible] | 0.0053 | 0.0002 | 0.0000 | 0.0083 | -0.260 | [illegible] | -0.264 |

Table 4.1α : Calculated data probabilistic method

| | | |
|---|---|---|
| EXPERIMENT NO. : T15½,-4c<br>METHOD : PROBABILISTIC | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $1.05 \times 10^{-1}$ | $3.19 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 31.8 | 41.2 |
| PARAMETER z* (-) | 0.99 | 1.21 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2384 | 0.7806 |
| BED LOAD Lb ($kg/m^2$) | $2.50 \times 10^{-2}$ | $2.49 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $3.00 \times 10^{-2}$ | $4.62 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $5.51 \times 10^{-2}$ | $7.11 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-5.70 \times 10^{-3}$ | $-5.15 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-1.32 \times 10^{-2}$ | $-1.73 \times 10^{-2}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.90 \times 10^{-2}$ | $-2.24 \times 10^{-2}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $1.05 \times 10^{-1}$ | $3.19 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 31.8 | 41.2 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-5.60 \times 10^{-1}$ | $-2.20 \times 10^{-1}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.48 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.06 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.15 | |
| BED ROUGHNESS Ks (m) | $3.62 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.069 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.036 | |
| ZERO INTERCEPT z0 (m) | $1.20 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.70 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 6.2651 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.09 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.12 \times 10^{-1}$ | $2.40 \times 10^{-1}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-1.09 \times 10^{-1}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $6.84 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-1.02 \times 10^{-1}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.072 | 0.037 | 0.2384 | 0.6449 | 0.2160 | 0.9233 | -0.258 | -0.296 | -0.279 |
| 2 | 0.091 | 0.047 | 0.2384 | 0.4707 | 0.0869 | 0.6864 | -0.283 | -0.316 | -0.301 |
| 3 | 0.111 | 0.057 | 0.2384 | 0.3632 | 0.0350 | 0.5317 | -0.302 | -0.331 | -0.318 |
| 4 | 0.150 | 0.077 | 0.2384 | 0.2630 | 0.0089 | 0.3834 | -0.322 | -0.350 | -0.339 |
| 5 | 0.188 | 0.097 | 0.2384 | 0.1710 | 0.0009 | 0.2465 | -0.359 | -0.375 | -0.366 |
| 6 | 0.266 | 0.137 | 0.1691 | 0.0937 | 0.0000 | 0.1436 | -0.395 | -0.403 | -0.398 |
| 7 | 0.383 | 0.197 | 0.0992 | 0.0522 | 0.0000 | 0.0702 | -0.433 | -0.436 | -0.431 |
| 8 | 0.499 | 0.257 | 0.0619 | 0.0294 | 0.0000 | 0.0505 | -0.461 | -0.454 | -0.455 |
| 9 | 0.616 | 0.317 | 0.0386 | 0.0165 | 0.0000 | 0.0352 | -0.483 | -0.471 | -0.474 |
| 10 | 0.751 | 0.387 | 0.0205 | 0.0072 | 0.0000 | 0.0249 | -0.504 | -0.487 | -0.492 |

Table 4.1 β : Calculated data probabilistic method

EXPERIMENT NO. : [illegible]
METHOD : [illegible]

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $6.35 \times 10^{-2}$ | $2.15 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.5 | 44.1 |
| PARAMETER z* (-) | 1.55 | 2.04 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1008 | 0.2004 |
| BED LOAD Lb ($kg/m^2$) | $8.42 \times 10^{-3}$ | $6.46 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $6.08 \times 10^{-3}$ | $4.98 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $1.40 \times 10^{-2}$ | $1.14 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $2.22 \times 10^{-3}$ | $1.73 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | $1.64 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | $2.15 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.5 | 44.1 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | $1.55 \times 10^{-3}$ |

NIELSEN METHOD

| | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | — |
| RIPPLE LENGTH $\lambda r$ (m) | — |
| RIPPLE STEEPNESS RST (-) | — |
| BED ROUGHNESS Ks (m) | — |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | — |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | — |
| ZERO INTERCEPT z0 (m) | — |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | — |
| BED CONCENTRATION Cb ($kg/m^3$) | — |
| CONCENTRATION LENGTHSCALE Lc (m) | — |
| TOTAL LOAD Lt ($kg/m^2$) | — |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | — |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | — |
| TOTAL TRANSPORT Stot (kg/s.m) | — |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.041 | 0.021 | 0.1008 | 0.2004 | — | — | 0.219 | 0.273 | — |
| 2 | 0.061 | 0.031 | 0.1008 | 0.1523 | — | — | 0.259 | 0.304 | — |
| 3 | 0.081 | 0.041 | 0.1008 | 0.0245 | — | — | 0.288 | 0.326 | — |
| 4 | 0.110 | 0.055 | 0.1008 | 0.0548 | — | — | 0.320 | 0.350 | — |
| 5 | 0.160 | 0.081 | 0.1008 | 0.0154 | — | — | 0.359 | 0.379 | — |
| 6 | 0.240 | 0.121 | 0.0492 | 0.0065 | — | — | 0.400 | 0.411 | — |
| 7 | 0.357 | 0.181 | 0.0203 | 0.0012 | — | — | 0.447 | 0.443 | — |
| 8 | 0.472 | 0.241 | 0.0065 | 0.0006 | — | — | 0.427 | 0.465 | — |
| 9 | 0.594 | 0.301 | 0.0024 | 0.0003 | — | — | 0.465 | 0.483 | — |
| 10 | [illegible] | 0.351 | 0.0017 | 0.0001 | — | — | 0.516 | 0.499 | — |

Table 4.2 A : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T[illegible]<br>METHOD : MEAN WAVE HEIGHT | | |
| BIJKER METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| PARAMETER z* (-) | – | – |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | – | – |
| BED LOAD Lb ($kg/m^2$) | – | – |
| SUSPENDED LOAD Ls ($kg/m^2$) | – | – |
| TOTAL LOAD Lt ($kg/m^2$) | – | – |
| BED LOAD TRANSPORT Sb (kg/s.m) | – | – |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |
| ADAPTED ENGELUND-HANSEN METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |
| NIELSEN METHOD | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.29 \times 10^{[illegible]}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $9.12 \times 10^{[illegible]}$ | |
| RIPPLE STEEPNESS RST (-) | 0.15 | |
| BED ROUGHNESS Ks (m) | $2.36 \times 10^{[illegible]}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.036 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 | |
| ZERO INTERCEPT z0 (m) | $7.89 \times 10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $7.89 \times 10^{-4}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.0646 | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] | |
| TOTAL LOAD Lt ($kg/m^2$) | $2.28 \times 10^{[illegible]}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.033 | 0.017 | – | – | 0.0005 | – | – | – | – |
| 2 | 0.053 | 0.027 | – | – | 0.0001 | – | – | – | – |
| 3 | 0.073 | 0.037 | – | – | 0.0000 | – | – | – | – |
| 4 | 0.102 | 0.052 | – | – | 0.0000 | – | – | – | – |
| 5 | 0.151 | 0.077 | – | – | 0.0000 | – | – | – | – |
| 6 | 0.230 | 0.117 | – | – | 0.0000 | – | – | – | – |
| 7 | 0.346 | 0.177 | – | – | 0.0000 | – | – | – | – |
| 8 | 0.466 | 0.237 | – | – | 0.0000 | – | – | – | – |
| 9 | 0.583 | 0.297 | – | – | 0.0000 | – | – | – | – |
| 10 | 0.721 | 0.367 | – | – | 0.0000 | – | – | – | – |

Table 4.2 B : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T3½,10 | | |
| METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 6.88 x $10^{-2}$ | 1.81 x $10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.1 | 45.5 |
| PARAMETER z* (-) | 2.20 | 2.31 |
| BED LAYER CONCENTRATION Cb (kg/$m^3$) | 0.0205 | 0.0707 |
| BED LOAD Lb (kg/$m^2$) | 1.41 x $10^{-5}$ | 1.28 x $10^{-5}$ |
| SUSPENDED LOAD Ls (kg/$m^2$) | 7.45 x $10^{-4}$ | 6.73 x $10^{-4}$ |
| TOTAL LOAD Lt (kg/$m^2$) | 2.15 x $10^{-3}$ | 1.95 x $10^{-3}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | 9.03 x $10^{-5}$ | 6.32 x $10^{-5}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 7.33 x $10^{-5}$ | 5.22 x $10^{-5}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 1.64 x $10^{-4}$ | 1.15 x $10^{-4}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 6.88 x $10^{-2}$ | 1.81 x $10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.1 | 45.5 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 2.13 x $10^{-3}$ | 1.21 x $10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.44 x $10^{-2}$ | |
| RIPPLE LENGTH λr (m) | 1.02 x $10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.18 | |
| BED ROUGHNESS Ks (m) | 2.55 x $10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.036 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.011 | |
| ZERO INTERCEPT z0 (m) | 8.52 x $10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 2.68 x $10^{-3}$ | |
| BED CONCENTRATION Cb (kg/$m^3$) | 0.0587 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 3.07 x $10^{-2}$ | |
| TOTAL LOAD Lt (kg/$m^2$) | 2.33 x $10^{-4}$ | 2.80 x $10^{-4}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 6.11 x $10^{-6}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | -3.67 x $10^{-6}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | 2.39 x $10^{-6}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C (kg/$m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.029 | 0.015 | 0.0205 | 0.0707 | 0.0014 | [illegible] | 0.050 | 0.064 | 0.046 |
| 2 | 0.049 | 0.025 | 0.0205 | 0.0287 | 0.0001 | [illegible] | 0.062 | 0.074 | 0.059 |
| 3 | 0.068 | 0.035 | 0.0205 | 0.0109 | 0.0000 | 0.0000 | 0.071 | 0.080 | 0.068 |
| 4 | 0.098 | 0.050 | 0.0205 | 0.0028 | 0.0000 | 0.0001 | 0.080 | 0.082 | 0.078 |
| 5 | 0.146 | 0.075 | 0.0165 | 0.0011 | 0.0000 | 0.0000 | 0.090 | 0.095 | 0.089 |
| 6 | 0.225 | 0.115 | 0.0052 | 0.0003 | 0.0000 | 0.0000 | 0.101 | 0.105 | 0.100 |
| 7 | 0.342 | 0.175 | 0.0014 | 0.0001 | [illegible] | 0.0000 | 0.111 | 0.117 | 0.111 |
| 8 | [illegible] | [illegible] | 0.0005 | 0.0000 | [illegible] | [illegible] | 0.119 | 0.112 | [illegible] |
| 9 | [illegible] | 0.295 | 0.0002 | 0.0000 | [illegible] | [illegible] | 0.124 | [illegible] | [illegible] |
| 10 | [illegible] | 0.365 | 0.0000 | 0.0000 | [illegible] | [illegible] | 0.130 | [illegible] | [illegible] |

Table 4.2 C : Calculated data characteristic waveheight

| EXPERIMENT NO. : 78,20 | |
|---|---|
| METHOD : MEAN WAVEHEIGHT | |

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 5.68×10⁻² | 1.20×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.6 | 46.0 |
| PARAMETER z* (-) | 1.06 | [illegible] |
| BED LAYER CONCENTRATION Cb (kg/m³) | 0.0430 | [illegible] |
| BED LOAD Lb (kg/m²) | 3.69×10⁻³ | 3.02×10⁻³ |
| SUSPENDED LOAD Ls (kg/m²) | 2.20×10⁻³ | 1.88×10⁻³ |
| TOTAL LOAD Lt (kg/m²) | 6.02×10⁻³ | 4.90×10⁻³ |
| BED LOAD TRANSPORT Sb (kg/s.m) | 4.52×10⁻⁴ | 3.05×10⁻⁴ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 4.64×10⁻⁴ | 2.54×10⁻⁴ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 9.17×10⁻⁴ | 5.89×10⁻⁴ |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 5.68×10⁻² | 1.20×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.6 | 46.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 2.22×10⁻³ | 3.93×10⁻³ |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | 1.35×10⁻² | |
| RIPPLE LENGTH $\lambda r$ (m) | 9.57×10⁻² | |
| RIPPLE STEEPNESS RST (-) | 0.18 | |
| BED ROUGHNESS Ks (m) | 2.39×10⁻² | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.035 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.017 | |
| ZERO INTERCEPT z0 (m) | 7.97×10⁻⁴ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 1.05×10⁻³ | |
| BED CONCENTRATION Cb (kg/m³) | 0.0527 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 3.71×10⁻³ | |
| TOTAL LOAD Lt (kg/m²) | 1.95×10⁻⁴ | 2.69×10⁻⁴ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 4.60×10⁻⁵ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | -9.83×10⁻⁶ | |
| TOTAL TRANSPORT Stot (kg/s.m) | 3.62×10⁻⁵ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C (kg/m³) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.042 | 0.022 | 0.0650 | 0.0932 | 0.0001 | 0.0016 | 0.123 | 0.144 | 0.133 |
| 2 | 0.063 | 0.032 | 0.0650 | 0.0450 | 0.0000 | 0.0006 | 0.141 | 0.158 | 0.149 |
| 3 | 0.082 | 0.042 | 0.0650 | 0.0170 | 0.0000 | 0.0003 | 0.154 | 0.169 | 0.161 |
| 4 | 0.112 | 0.057 | 0.0645 | 0.0078 | 0.0000 | 0.0001 | 0.169 | 0.180 | 0.174 |
| 5 | 0.161 | 0.082 | 0.0283 | 0.0022 | 0.0000 | 0.0000 | 0.186 | 0.194 | 0.190 |
| 6 | 0.239 | 0.122 | 0.0107 | 0.0009 | 0.0000 | 0.0000 | 0.205 | 0.210 | 0.208 |
| 7 | 0.357 | 0.182 | 0.0035 | [illegible] | 0.0000 | 0.0000 | 0.225 | 0.225 | 0.225 |
| 8 | 0.475 | 0.242 | 0.0014 | 0.0001 | 0.0000 | 0.0000 | 0.238 | 0.236 | 0.237 |
| 9 | 0.592 | 0.302 | [illegible] | [illegible] | 0.0000 | 0.0000 | 0.249 | 0.244 | 0.247 |
| 10 | 0.729 | 0.372 | [illegible] | [illegible] | 0.0000 | 0.0000 | 0.259 | 0.252 | 0.256 |

Table 4.2 D : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T3½ ... | | |
| METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 3.65×10^-2 | 1.51×10^-2 |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 39.9 | 46.8 |
| PARAMETER z* (-) | 1.42 | 1.37 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.0462 | 0.0464 |
| BED LOAD Lb ($kg/m^2$) | 1.52×10^-4 | 1.19×10^-2 |
| SUSPENDED LOAD Ls ($kg/m^2$) | 1.33×10^-2 | 1.22×10^-2 |
| TOTAL LOAD Lt ($kg/m^2$) | 3.25×10^-2 | 2.41×10^-2 |
| BED LOAD TRANSPORT Sb (kg/s.m) | 3.40×10^-3 | 2.27×10^-3 |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 6.53×10^-3 | 4.05×10^-3 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 9.08×10^-3 | 6.32×10^-3 |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 3.65×10^-2 | 1.51×10^-2 |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 39.9 | 46.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 5.62×10^-2 | 2.83×10^-2 |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.5×10^-2 | |
| RIPPLE LENGTH λr (m) | 1.10×10^-1 | |
| RIPPLE STEEPNESS RST (-) | 0.18 | |
| BED ROUGHNESS Ks (m) | 2.74×10^-2 | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.037 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.034 | |
| ZERO INTERCEPT z0 (m) | 9.15×10^-4 | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 5.30×10^-4 | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.0592 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 5.38×10^-4 | |
| TOTAL LOAD Lt ($kg/m^2$) | 3.42×10^-4 | 3.11×10^-4 |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 2.03×10^-3 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | -1.06×10^-4 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 1.93×10^-4 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | [illegible] | 0.4168 | [illegible] | 0.0024 | [illegible] | [illegible] | [illegible] | 0.356 |
| 2 | [illegible] | [illegible] | 0.4168 | [illegible] | 0.0004 | [illegible] | [illegible] | [illegible] | [illegible] |
| 3 | [illegible] | [illegible] | 0.2335 | [illegible] | 0.0001 | [illegible] | [illegible] | [illegible] | 0.313 |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | 0.345 |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | 0.332 |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.431 |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.510 | [illegible] | [illegible] |

Table 4.2 E : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : F3,0<br>METHOD : mean waveheight | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| PARAMETER z* (-) | – | – |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | – | – |
| BED LOAD Lb ($kg/m^2$) | – | – |
| SUSPENDED LOAD Ls ($kg/m^2$) | – | – |
| TOTAL LOAD Lt ($kg/m^2$) | – | – |
| BED LOAD TRANSPORT Sb (kg/s.m) | – | – |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.40 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $9.85 \times 10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.14 | |
| BED ROUGHNESS Ks (m) | $2.37 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.042 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0 | |
| ZERO INTERCEPT z0 (m) | $9.06 \times 10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $9.06 \times 10^{-4}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.1233 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $5.00 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $6.16 \times 10^{-4}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.035 | 0.018 | – | – | 0.0034 | – | – | – | – |
| 2 | 0.055 | 0.028 | – | – | 0.0005 | – | – | – | – |
| 3 | 0.075 | 0.038 | – | – | 0.0001 | – | – | – | – |
| 4 | 0.104 | 0.053 | – | – | 0.0000 | – | – | – | – |
| 5 | 0.153 | 0.078 | – | – | 0.0000 | – | – | – | – |
| 6 | 0.231 | 0.118 | – | – | 0.0000 | – | – | – | – |
| 7 | 0.310 | 0.158 | – | – | 0.0000 | – | – | – | – |
| 8 | 0.467 | 0.238 | – | – | 0.0000 | – | – | – | – |
| 9 | 0.584 | 0.298 | – | – | 0.0000 | – | – | – | – |
| 10 | 0.722 | 0.368 | – | – | 0.0000 | – | – | – | – |

Table 4.2 F : Calculated data characteristic waveheight

| EXPERIMENT NO. : [illegible] | | |
|---|---|---|
| METHOD : [illegible] WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| PARAMETER z* (-) | — | — |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | — | — |
| BED LOAD Lb ($kg/m^2$) | — | — |
| SUSPENDED LOAD Ls ($kg/m^2$) | — | — |
| TOTAL LOAD Lt ($kg/m^2$) | — | — |
| BED LOAD TRANSPORT Sb (kg/s.m) | — | — |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.55 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.00 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $3.07 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.048 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 | |
| ZERO INTERCEPT z0 (m) | $1.02 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.02 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.2007 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $7.00 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.40 \times 10^{-3}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 | |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.033 | 0.016 | — | — | 0.0204 | — | — | — | — |
| 2 | 0.052 | 0.026 | — | — | 0.0040 | — | — | — | — |
| 3 | 0.071 | 0.036 | — | — | 0.0012 | — | — | — | — |
| 4 | 0.101 | 0.051 | — | — | 0.0001 | — | — | — | — |
| 5 | 0.151 | 0.076 | — | — | 0.0000 | — | — | — | — |
| 6 | 0.230 | 0.116 | — | — | 0.0000 | — | — | — | — |
| 7 | 0.349 | 0.176 | — | — | 0.0000 | — | — | — | — |
| 8 | 0.468 | 0.236 | — | — | 0.0000 | — | — | — | — |
| 9 | 0.587 | 0.296 | — | — | 0.0000 | — | — | — | — |
| 10 | 0.726 | 0.366 | — | — | 0.0000 | — | — | — | — |

Table 4.2 G : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T[illegible]<br>METHOD : MEAN WAVEHEIGHT | | |
| BIJKER METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 7.85×10⁻² | 1.94×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.1 | 45.0 |
| PARAMETER z* (-) | 1.67 | 2.27 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.0856 | 0.2210 |
| BED LOAD Lb ($kg/m^2$) | 6.21×10⁻[illegible] | 4.29×10⁻³ |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | 2.88×10⁻³ |
| TOTAL LOAD Lt ($kg/m^2$) | 1.1[illegible]×10⁻[illegible] | [illegible].18×10⁻³ |
| BED LOAD TRANSPORT Sb (kg/s.m) | 4.61×10⁻⁴ | [illegible]×10⁻⁴ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 5.05×10⁻⁴ | [illegible]×10⁻⁴ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 9.66×10⁻⁴ | 4.66×10⁻⁴ |
| ADAPTED ENGELUND-HANSEN METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 7.85×10⁻² | 1.94×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.1 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 7.18×10⁻³ | [illegible]×10⁻³ |
| NIELSEN METHOD | | |
| RIPPLE HEIGHT Δr (m) | 1.80×10⁻² | |
| RIPPLE LENGTH λr (m) | 1.26×10⁻¹ | |
| RIPPLE STEEPNESS RST (-) | 0.1[illegible] | |
| BED ROUGHNESS Ks (m) | [illegible]×10⁻² | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.05[illegible] | |
| CURRENT FRICTION VELOCITY ū* (m/s) | [illegible] | |
| ZERO INTERCEPT z0 (m) | 1.15×10⁻³ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 4.86×10⁻³ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.2200 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 8.36×10⁻³ | |
| TOTAL LOAD Lt ($kg/m^2$) | 1.83×10⁻³ | [illegible] |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | [illegible] | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | − [illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.029 | 0.015 | 0.0856 | 0.2210 | 0.0366 | [illegible] | 0.050 | 0.066 | 0.036 |
| 2 | [illegible] | 0.025 | 0.0856 | [illegible] | [illegible] | [illegible] | 0.063 | [illegible] | [illegible] |
| 3 | [illegible] | 0.035 | 0.0856 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.064 |
| 4 | 0.097 | 0.050 | 0.0856 | [illegible] | [illegible] | [illegible] | [illegible] | 0.091 | 0.075 |
| 5 | [illegible] | [illegible] | 0.0856 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.088 |
| 6 | [illegible] | 0.115 | [illegible] | [illegible] | [illegible] | [illegible] | 0.105 | [illegible] | 0.102 |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.116 | 0.116 | 0.116 |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.130 | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.136 | [illegible] | [illegible] |

Table 4.2 H : Calculated data characteristic waveheight

EXPERIMENT NO. : T[illegible]
METHOD : MEAN WAVEHEIGHT

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.34 \times 10^{-2}$ | $1.48 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 37.7 | 46.8 |
| PARAMETER z* (-) | 1.85 | 2.91 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1311 | 0.2101 |
| BED LOAD Lb ($kg/m^2$) | $6.22 \times 10^{-3}$ | $3.10 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $4.55 \times 10^{-3}$ | $1.85 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $1.07 \times 10^{-2}$ | $4.06 \times 10^{-3}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-4.19 \times 10^{-4}$ | $-1.68 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-4.93 \times 10^{-4}$ | $-1.60 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-9.12 \times 10^{-4}$ | $-3.28 \times 10^{-4}$ |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.34 \times 10^{-2}$ | $1.48 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 37.7 | 46.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-5.95 \times 10^{-3}$ | $-2.18 \times 10^{-3}$ |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT Δr (m) | $1.43 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.04 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | $1.91 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.046 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.013 | |
| ZERO INTERCEPT z0 (m) | [illegible] | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | [illegible] | |
| BED CONCENTRATION Cb ($kg/m^3$) | [illegible] | |
| CONCENTRATION LENGTHSCALE Lc (m) | $5.48 \times 10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $9.73 \times 10^{-4}$ | $1.21 \times 10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-3.61 \times 10^{-5}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | [illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.017 | 0.1311 | 0.1468 | 0.0080 | 0.0158 | -0.065 | -0.077 | -0.051 |
| 2 | 0.055 | 0.027 | 0.1311 | 0.0427 | 0.0013 | [illegible] | -0.078 | -0.085 | -0.066 |
| 3 | 0.075 | 0.037 | 0.1311 | 0.0188 | 0.0002 | [illegible] | -0.086 | -0.094 | -0.077 |
| 4 | 0.105 | 0.052 | 0.1087 | 0.0074 | 0.0000 | [illegible] | -0.095 | -0.101 | -0.088 |
| 5 | 0.156 | 0.077 | 0.0477 | 0.0024 | 0.0000 | [illegible] | -0.105 | -0.110 | -0.100 |
| 6 | 0.232 | 0.112 | 0.0181 | [illegible] | [illegible] | [illegible] | -0.116 | -0.119 | [illegible] |
| 7 | [illegible] | [illegible] | 0.0061 | [illegible] | [illegible] | [illegible] | -0.123 | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | 0.0024 | [illegible] | [illegible] | [illegible] | -0.135 | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.138 | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.142 | [illegible] | [illegible] |

Table 4.2 I : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T10,20 | | |
| METHOD : [illegible] | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | [illegible] | 1.93×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | 45.0 |
| PARAMETER z* (-) | 1.64 | 2.12 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1053 | [illegible] |
| BED LOAD Lb ($kg/m^2$) | 2.66×10⁻³ | 5.49×10⁻³ |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | [illegible] | 1.93×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | 6.46×10⁻⁵ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.77×10⁻² | |
| RIPPLE LENGTH λr (m) | 1.21×10⁻¹ | |
| RIPPLE STEEPNESS RST (-) | [illegible] | |
| BED ROUGHNESS Ks (m) | 3.31×10⁻² | |
| WAVE FRICTION VELOCITY ũ* (m/s) | [illegible] | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.019 | |
| ZERO INTERCEPT z0 (m) | 1.10×10⁻³ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 1.90×10⁻³ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.1651 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 6.96×10⁻³ | |
| TOTAL LOAD Lt ($kg/m^2$) | 1.14×10⁻³ | 1.61×10⁻³ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 7.21×10⁻⁵ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | −6.85×10⁻⁵ | |
| TOTAL TRANSPORT Stot (kg/s.m) | 1.53×10⁻⁴ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.012 | 0.1053 | [illegible] | 0.0144 | 0.0260 | 0.101 | 0.178 | 0.104 |
| 2 | 0.053 | 0.022 | [illegible] | [illegible] | 0.0034 | 0.0122 | 0.123 | 0.145 | 0.127 |
| 3 | 0.073 | 0.032 | [illegible] | [illegible] | 0.0008 | 0.0066 | 0.139 | 0.157 | 0.142 |
| 4 | 0.102 | 0.052 | [illegible] | [illegible] | 0.0001 | 0.0031 | 0.156 | 0.170 | 0.158 |
| 5 | 0.151 | 0.072 | [illegible] | [illegible] | 0.0000 | [illegible] | 0.175 | 0.185 | 0.172 |
| 6 | 0.230 | 0.117 | [illegible] | [illegible] | 0.0000 | [illegible] | 0.196 | 0.201 | 0.196 |
| 7 | 0.348 | 0.177 | [illegible] | [illegible] | 0.0000 | 0.0001 | 0.216 | 0.212 | 0.216 |
| 8 | 0.466 | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0000 | 0.231 | 0.228 | 0.230 |
| 9 | 0.583 | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0000 | 0.242 | 0.237 | 0.241 |
| 10 | 0.721 | 0.362 | [illegible] | [illegible] | 0.0000 | 0.0000 | 0.252 | 0.245 | 0.251 |

Table 4.2 J : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : [illegible] | | |
| METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 7.91 × 10^-? | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| PARAMETER z* (-) | 1.69 | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.0[illegible] | [illegible] |
| BED LOAD Lb ($kg/m^2$) | [illegible] | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | [illegible] | 2.14 × $10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.3 | 43.9 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | -1.36 × 10^-? | -9.64 × $10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.21 × 10^-? | |
| RIPPLE LENGTH λr (m) | 9.24 × 10^-? | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | 2.91 × 10^-? | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.045 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.013 | |
| ZERO INTERCEPT z0 (m) | 9.03 × $10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 1.45 × 10^-? | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.1673 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 4.34 × 10^-? | |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | 1.08 × 10^-? |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | [illegible] | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 4.6[illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.051 | 0.025 | 0.0505 | 0.2616 | 0.0008 | 0.0066 | -0.123 | -0.148 | -0.134 |
| 2 | 0.071 | 0.035 | 0.0805 | 0.1793 | 0.0001 | 0.0031 | -0.141 | -0.161 | -0.150 |
| 3 | 0.091 | 0.045 | [illegible] | 0.0755 | 0.0000 | [illegible] | -0.154 | -0.172 | -0.162 |
| 4 | 0.121 | 0.060 | [illegible] | 0.0401 | 0.0000 | 0.0008 | -0.170 | -0.183 | -0.176 |
| 5 | 0.172 | 0.085 | [illegible] | [illegible] | 0.0000 | 0.0003 | -0.188 | -0.197 | -0.192 |
| 6 | 0.252 | 0.125 | [illegible] | [illegible] | [illegible] | [illegible] | -0.208 | -0.213 | -0.210 |
| 7 | [illegible] | 0.185 | [illegible] | [illegible] | [illegible] | [illegible] | -0.229 | -0.226 | -0.226 |
| 8 | [illegible] | 0.245 | [illegible] | [illegible] | [illegible] | [illegible] | -0.244 | -0.240 | -0.242 |
| 9 | 0.617 | 0.305 | [illegible] | [illegible] | [illegible] | [illegible] | -0.255 | -0.250 | -0.252 |
| 10 | [illegible] | 0.375 | [illegible] | [illegible] | [illegible] | [illegible] | -0.266 | -0.253 | -0.262 |

Table 4.2 K : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T10,40 | | |
| METHOD : [illegible] WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $5.89\times10^{-2}$ | $7.08\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.3 | 44.4 |
| PARAMETER z* (-) | 1.20 | 1.54 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.3164 | 0.7155 |
| BED LOAD Lb ($kg/m^2$) | $1.66\times10^{-2}$ | $1.50\times10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.17\times10^{-2}$ | $1.79\times10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.03\times10^{-2}$ | $3.29\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $4.58\times10^{-3}$ | $3.01\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $8.92\times10^{-3}$ | $4.74\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.35\times10^{-2}$ | $7.75\times10^{-3}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $5.89\times10^{-2}$ | $7.08\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 36.3 | 44.4 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $9.72\times10^{-2}$ | $4.40\times10^{-2}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.08\times10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.50\times10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | $3.43\times10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.053 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.036 | |
| ZERO INTERCEPT z0 (m) | $1.31\times10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.76\times10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.1923 | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.46\times10^{-3}$ | $3.15\times10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $7.15\times10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-4.12\times10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $6.83\times10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.055 | 0.028 | 0.3164 | 0.4432 | 0.0073 | 0.0273 | 0.265 | 0.200 | 0.279 |
| 2 | 0.074 | 0.038 | 0.3164 | [illegible] | 0.0026 | 0.0191 | 0.280 | [illegible] | 0.306 |
| 3 | 0.094 | 0.048 | 0.3164 | 0.1877 | 0.0009 | 0.0142 | 0.312 | 0.241 | 0.327 |
| 4 | 0.123 | 0.062 | 0.2893 | 0.1143 | 0.0002 | 0.0098 | [illegible] | [illegible] | 0.351 |
| 5 | 0.172 | 0.087 | 0.1808 | 0.0635 | 0.0000 | 0.0061 | [illegible] | [illegible] | 0.382 |
| 6 | 0.250 | 0.125 | 0.1023 | [illegible] | 0.0000 | 0.0031 | [illegible] | 0.419 | 0.415 |
| 7 | 0.368 | 0.184 | 0.0424 | 0.0172 | 0.0000 | 0.0019 | [illegible] | [illegible] | 0.450 |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0012 | [illegible] | [illegible] | 0.475 |
| 9 | 0.607 | [illegible] | 0.0166 | 0.0050 | 0.0000 | 0.0008 | [illegible] | [illegible] | 0.494 |
| 10 | [illegible] | [illegible] | 0.0078 | 0.0011 | 0.0000 | 0.0006 | 0.514 | 0.504 | 0.513 |

Table 4.2 L : Calculated data characteristic waveheight

EXPERIMENT NO. : [illegible]
METHOD : MEAN WAVEHEIGHT

## BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 7.06×10⁻² | [illegible].32×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | [illegible]3.3 |
| PARAMETER z* (-) | [illegible].23 | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2461 | [illegible] |
| BED LOAD Lb ($kg/m^2$) | 1.43×10⁻² | 1.86×10⁻² |
| SUSPENDED LOAD Ls ($kg/m^2$) | 1.49×10⁻² | [illegible].46×10⁻² |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible]×10⁻² | [illegible].32×10⁻² |
| BED LOAD TRANSPORT Sb (kg/s.m) | −[illegible]×10⁻³ | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | −[illegible]×10⁻³ | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | −1.[illegible]×10⁻² | −[illegible].28×10⁻² |

## ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 7.06×10⁻² | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.6 | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | −[illegible]×10⁻² | −[illegible]×10⁻² |

## NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT Δr (m) | 1.16×10⁻² | |
| RIPPLE LENGTH λr (m) | 8.22×10⁻² | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | 2.54×10⁻² | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.045 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | −0.034 | |
| ZERO INTERCEPT z0 (m) | 6.48×10⁻⁴ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 8.88×10⁻⁴ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.1931 | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible].66×10⁻³ | |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible]×10⁻⁴ | 1.93×10⁻³ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | −3.55×10⁻³ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | [illegible]×10⁻⁴ | |
| TOTAL TRANSPORT Stot (kg/s.m) | −3.20×10⁻³ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.069 | 0.034 | 0.2461 | [illegible] | 0.0002 | 0.0103 | −0.2[illegible] | −0.316 | −0.311 |
| 2 | 0.086 | [illegible] | 0.2461 | [illegible] | 0.0000 | 0.0070 | [illegible] | −0.333 | −0.333 |
| 3 | 0.104 | 0.054 | 0.2461 | 0.2222 | 0.0000 | 0.0050 | −0.3[illegible] | −0.354 | −0.350 |
| 4 | 0.139 | 0.069 | 0.2461 | 0.1408 | 0.0000 | 0.0034 | [illegible] | −0.334 | −0.371 |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0020 | [illegible] | [illegible] | −0.392 |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0011 | −0.43[illegible] | −0.438 | −0.436 |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0006 | [illegible] | −0.458 | −0.459 |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0003 | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | −0.500 | [illegible] | −0.500 |
| 10 | 0.996 | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | −0.51[illegible] | −0.514 | −0.512 |

Table 4.2 M : Calculated data characteristic waveheight

EXPERIMENT NO. : [illegible]
METHOD : MEAN WAVEHEIGHT

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| PARAMETER z* (-) | – | – |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | – | – |
| BED LOAD Lb ($kg/m^2$) | – | – |
| SUSPENDED LOAD Ls ($kg/m^2$) | – | – |
| TOTAL LOAD Lt ($kg/m^2$) | – | – |
| BED LOAD TRANSPORT Sb (kg/s.m) | – | – |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | – | – |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | – | – |
| TOTAL LOAD TRANSPORT St (kg/s.m) | – | – |

NIELSEN METHOD

| | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.67 \times 10^{-2}$ |
| RIPPLE LENGTH $\lambda r$ (m) | $1.10 \times 10^{-1}$ |
| RIPPLE STEEPNESS RST (-) | 0.17 |
| BED ROUGHNESS Ks (m) | $3.44 \times 10^{-2}$ |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.055 |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 |
| ZERO INTERCEPT z0 (m) | $1.14 \times 10^{-3}$ |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.14 \times 10^{-3}$ |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3538 |
| CONCENTRATION LENGTHSCALE Lc (m) | $8.55 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $3.02 \times 10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.036 | 0.019 | – | – | 0.0384 | – | – | – | – |
| 2 | 0.055 | 0.029 | – | – | 0.0119 | – | – | – | – |
| 3 | 0.074 | 0.039 | – | – | 0.0037 | – | – | – | – |
| 4 | 0.103 | 0.054 | – | – | 0.0006 | – | – | – | – |
| 5 | 0.151 | 0.079 | – | – | 0.0000 | – | – | – | – |
| 6 | 0.223 | 0.119 | – | – | 0.0000 | – | – | – | – |
| 7 | 0.347 | 0.1[illegible]9 | – | – | 0.0000 | – | – | – | – |
| 8 | 0.456 | 0.239 | – | – | 0.0000 | – | – | – | – |
| 9 | 0.571 | 0.299 | – | – | 0.0000 | – | – | – | – |
| 10 | 0.704 | 0.369 | – | – | 0.0000 | – | – | – | – |

Table 4.2 N : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T12.10 | | |
| METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 6.39×10⁻² | 1.82×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.8 | 45.6 |
| PARAMETER z* (-) | 1.58 | 2.25 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1670 | 0.3050 |
| BED LOAD Lb ($kg/m^2$) | 1.06×10⁻⁴ | 5.56×10⁻⁵ |
| SUSPENDED LOAD Ls ($kg/m^2$) | 8.68×10⁻⁵ | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | 1.93×10⁻⁴ | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | 5.51×10⁻⁴ | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | 7.23×10⁻⁴ | 2.91×10⁻⁴ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 1.27×10⁻³ | [illegible] |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 6.39×10⁻² | 1.82×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.8 | 45.6 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | 8.50×10⁻⁵ | 2.62×10⁻⁵ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.81×10⁻² | |
| RIPPLE LENGTH λr (m) | 1.27×10⁻¹ | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | 3.64×10⁻² | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.055 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.012 | |
| ZERO INTERCEPT z0 (m) | 1.21×10⁻³ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 8.30×10⁻³ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3502 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 9.62×10⁻³ | |
| TOTAL LOAD Lt ($kg/m^2$) | 3.37×10⁻³ | 4.09×10⁻³ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | [illegible] | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | [illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.033 | 0.013 | 0.1670 | 0.3050 | 0.0599 | 0.0753 | 0.044 | 0.055 | 0.022 |
| 2 | 0.057 | [illegible] | 0.1670 | 0.1714 | [illegible] | 0.0359 | 0.053 | 0.062 | 0.035 |
| 3 | 0.071 | [illegible] | 0.1670 | 0.0571 | 0.0035 | 0.0187 | 0.060 | 0.067 | 0.044 |
| 4 | 0.100 | [illegible] | 0.1670 | 0.0247 | 0.0016 | 0.0079 | 0.067 | [illegible] | 0.054 |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0001 | 0.0024 | 0.075 | [illegible] | 0.066 |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0005 | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | 0.0008 | 0.0000 | 0.0001 | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | 0.0003 | 0.0000 | 0.0000 | [illegible] | [illegible] | 0.100 |
| 9 | [illegible] | [illegible] | 0.0048 | 0.0001 | 0.0000 | 0.0000 | [illegible] | [illegible] | 0.106 |
| 10 | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0000 | 0.0000 | [illegible] | [illegible] | [illegible] |

Table 4.2 0 : Calculated data characteristic waveheight

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| METHOD | : [illegible] |

BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | 1.81 x 10^-2 |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.6 | 45.3 |
| PARAMETER z* (-) | 1.64 | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1446 | [illegible] |
| BED LOAD Lb ($kg/m^2$) | [illegible] | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | 1.81 x 10^-2 |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.6 | 45.3 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT Δr (m) | 1.50 x 10^-2 | |
| RIPPLE LENGTH λr (m) | 1.12 x 10^-1 | |
| RIPPLE STEEPNESS RST (-) | [illegible] | |
| BED ROUGHNESS Ks (m) | [illegible] | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.054 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.013 | |
| ZERO INTERCEPT z0 (m) | 1.10 x 10^-3 | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | [illegible] | |
| BED CONCENTRATION Cb ($kg/m^3$) | [illegible] | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] | |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | [illegible] | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | [illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.066 |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 4.2 P : Calculated data characteristic waveheight

| EXPERIMENT NO. : T12.25 | | |
|---|---|---|
| METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 5.65×10⁻¹ [illegible] | 1.92×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.2 | 45.0 |
| PARAMETER z* (-) | 1.33 | 1.92 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2128 | 0.4320 |
| BED LOAD Lb ($kg/m^2$) | $1.44\times10^{-2}$ | $8.30\times10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.38\times10^{-2}$ | $7.15\times10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $2.82\times10^{-2}$ | $1.54\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $1.28\times10^{-3}$ | $5.05\times10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $7.81\times10^{-4}$ | $1.15\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $4.60\times10^{-3}$ | $1.36\times10^{-3}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $6.66\times10^{-2}$ | $1.92\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.2 | 45.0 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | $9.68\times10^{-3}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $2.02\times10^{-2}$ | |
| RIPPLE LENGTH λr (m) | [illegible] | |
| RIPPLE STEEPNESS RST (-) | 0.13 | |
| BED ROUGHNESS Ks (m) | [illegible] | |
| WAVE FRICTION VELOCITY ũ* (m/s) | [illegible] | |
| CURRENT FRICTION VELOCITY ū* (m/s) | [illegible] | |
| ZERO INTERCEPT z0 (m) | $1.30\times10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | [illegible] | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3034 | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] | |
| TOTAL LOAD Lt ($kg/m^2$) | $4.88\times10^{-3}$ $7.18\times10^{-3}$ | |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $1.06\times10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-2.60\times10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $8.01\times10^{-4}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.037 | 0.019 | 0.2158 | [illegible] | 0.0851 | [illegible] | 0.109 | 0.133 | 0.102 |
| 2 | 0.057 | 0.029 | 0.2158 | [illegible] | [illegible] | [illegible] | 0.129 | 0.149 | 0.124 |
| 3 | 0.077 | 0.039 | 0.2158 | [illegible] | [illegible] | 0.0450 | 0.144 | 0.160 | 0.139 |
| 4 | 0.106 | 0.054 | 0.2158 | [illegible] | [illegible] | 0.0260 | 0.160 | 0.172 | 0.156 |
| 5 | 0.155 | 0.079 | 0.1666 | [illegible] | [illegible] | 0.0124 | [illegible] | 0.182 | 0.175 |
| 6 | 0.224 | 0.113 | 0.0846 | [illegible] | 0.0000 | 0.0050 | [illegible] | [illegible] | 0.197 |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0018 | 0.218 | 0.218 | 0.218 |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0009 | [illegible] | 0.229 | 0.233 |
| 9 | 0.582 | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0005 | [illegible] | 0.238 | 0.244 |
| 10 | 0.725 | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0003 | [illegible] | 0.246 | 0.255 |

Table 4.2 Q : Calculated data characteristic waveheight

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| METHOD | : MEAN WAVEHEIGHT |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | 44.3 |
| PARAMETER z* (-) | [illegible] | 1.80 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | [illegible] | [illegible] |
| BED LOAD Lb ($kg/m^2$) | 1.16x10⁻² | 1.02x10⁻² |
| SUSPENDED LOAD Ls ($kg/m^2$) | 9.34x10⁻² | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | 2.10x10⁻¹ | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | -1.53x10⁻³ | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | -2.11x10⁻² | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | 2.03x10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | 44.3 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | -1.32x10⁻² |

**NIELSEN METHOD**

| | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | 1.50x10⁻² |
| RIPPLE LENGTH $\lambda r$ (m) | 1.05x10⁻¹ |
| RIPPLE STEEPNESS RST (-) | 0.17 |
| BED ROUGHNESS Ks (m) | 3.19x10⁻² |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.055 |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.021 |
| ZERO INTERCEPT z0 (m) | 1.06x10⁻³ |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 7.02x10⁻³ |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3467 |
| CONCENTRATION LENGTHSCALE Lc (m) | 2.86x10⁻² |
| TOTAL LOAD Lt ($kg/m^2$) | 7.72x10⁻⁴ 4.01x10⁻³ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | -5.86x10⁻⁴ |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 1.64x10⁻⁴ |
| TOTAL TRANSPORT Stot (kg/s.m) | -4.27x10⁻⁴ |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.029 | 0.014 | 0.1599 | [illegible] | 0.0310 | [illegible] | -0.114 | -0.141 | -0.116 |
| 2 | 0.055 | 0.026 | [illegible] | [illegible] | [illegible] | [illegible] | -0.136 | -0.158 | -0.138 |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.0179 | -0.152 | -0.170 | -0.152 |
| 4 | 0.110 | 0.054 | [illegible] | [illegible] | [illegible] | 0.0063 | -0.166 | -0.184 | -0.170 |
| 5 | 0.161 | 0.079 | [illegible] | [illegible] | [illegible] | [illegible] | -0.186 | -0.199 | [illegible] |
| 6 | 0.242 | 0.119 | [illegible] | [illegible] | [illegible] | 0.0014 | -0.211 | -0.216 | -0.211 |
| 7 | 0.365 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0005 | [illegible] | -0.233 | [illegible] |
| 8 | 0.488 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0002 | -0.248 | -0.245 | [illegible] |
| 9 | 0.610 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0001 | [illegible] | [illegible] | [illegible] |
| 10 | 0.793 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0001 | [illegible] | [illegible] | [illegible] |

Table 4.2 R : Calculated data characteristic waveheight

EXPERIMENT NO. : [illegible]
METHOD : [illegible]

## BIJKER METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] $\times 10^{-2}$ | $1.92 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 38.1 | 45.0 |
| PARAMETER $z_*$ (-) | 1.16 | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.4232 | [illegible] |
| BED LOAD Lb ($kg/m^2$) | $2.22 \times 10^{-2}$ | $1.65 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | $2.07 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $5.23 \times 10^{-2}$ | $3.68 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $5.12 \times 10^{-3}$ | $3.23 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | $6.91 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

## ADAPTED ENGELUND-HANSEN METHOD

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.65 \times 10^{-2}$ | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 38.1 | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.23 \times 10^{-1}$ | [illegible] |

## NIELSEN METHOD

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | [illegible] | |
| RIPPLE LENGTH $\lambda r$ (m) | [illegible] | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | [illegible] | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | [illegible] | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.036 | |
| ZERO INTERCEPT z0 (m) | [illegible] | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | [illegible] | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3445 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.17 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $4.05 \times 10^{-3}$ | $8.55 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $1.30 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-8.60 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $1.21 \times 10^{-2}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0613 | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | 0.053 | [illegible] | [illegible] | [illegible] | 0.0348 | [illegible] | [illegible] | [illegible] | 0.267 |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0159 | 0.0566 | 0.296 | 0.319 | 0.296 |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.0236 | 0.327 | 0.345 | 0.322 |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.362 | [illegible] | 0.362 |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.400 | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.465 |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.0028 | [illegible] | 0.478 | 0.486 |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 4.2 S : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : T17,-40<br>METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $6.45\times10^{-2}$ | $7.19\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.4 | 43.8 |
| PARAMETER z* (-) | 1.17 | 1.34 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.3062 | 0.8596 |
| BED LOAD Lb ($kg/m^2$) | $1.96\times10^{-2}$ | $1.88\times10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.33\times10^{-2}$ | $2.79\times10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $4.30\times10^{-2}$ | $4.67\times10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-4.82\times10^{-3}$ | $-3.88\times10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-9.67\times10^{-3}$ | $-9.72\times10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.45\times10^{-2}$ | $-1.36\times10^{-2}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $6.45\times10^{-2}$ | $2.19\times10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 35.4 | 43.8 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.18\times10^{-1}$ | $-2.03\times10^{-2}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | $1.36\times10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $9.58\times10^{-2}$ | |
| RIPPLE STEEPNESS RST (-) | 0.17 | |
| BED ROUGHNESS Ks (m) | $2.98\times10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.053 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.035 | |
| ZERO INTERCEPT z0 (m) | $9.93\times10^{-4}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.09\times10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.3678 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $2.20\times10^{-3}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $2.64\times10^{-3}$ | $5.67\times10^{-3}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-2.71\times10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $5.47\times10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-2.16\times10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.052 | 0.026 | 0.3047 | 0.6777 | 0.0103 | 0.0511 | -0.252 | -0.288 | -0.274 |
| 2 | 0.072 | 0.036 | 0.3047 | 0.4258 | 0.0026 | 0.0310 | -0.284 | -0.314 | -0.307 |
| 3 | 0.093 | 0.046 | 0.3047 | 0.2977 | 0.0007 | 0.0244 | -0.308 | -0.335 | -0.323 |
| 4 | 0.123 | 0.061 | 0.3047 | 0.1940 | 0.0001 | 0.0163 | -0.335 | -0.356 | -0.348 |
| 5 | 0.173 | 0.086 | 0.2067 | 0.1132 | 0.0000 | 0.0097 | -0.369 | -0.382 | -0.377 |
| 6 | 0.254 | 0.126 | 0.1215 | 0.0594 | 0.0000 | 0.0053 | -0.406 | -0.413 | -0.410 |
| 7 | 0.374 | 0.186 | 0.0645 | 0.0258 | 0.0000 | 0.0028 | -0.444 | -0.440 | -0.444 |
| 8 | 0.435 | 0.216 | 0.0372 | 0.0144 | 0.0000 | 0.0017 | -0.471 | -0.465 | -0.468 |
| 9 | 0.616 | 0.306 | 0.0215 | 0.0074 | 0.0000 | 0.0012 | -0.497 | -0.483 | -0.487 |
| 10 | 0.757 | 0.376 | 0.0105 | 0.0031 | 0.0000 | 0.0008 | -0.512 | -0.499 | -0.505 |

Table 4.2 T : Calculated data characteristic waveheight

| | |
|---|---|
| EXPERIMENT NO. : [illegible] | |
| METHOD : [illegible] | |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| PARAMETER z* (-) | — | — |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | — | — |
| BED LOAD Lb ($kg/m^2$) | — | — |
| SUSPENDED LOAD Ls ($kg/m^2$) | — | — |
| TOTAL LOAD Lt ($kg/m^2$) | — | — |
| BED LOAD TRANSPORT Sb (kg/s.m) | — | — |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | — | — |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | — | — |
| TOTAL LOAD TRANSPORT St (kg/s.m) | — | — |

**NIELSEN METHOD**

| | |
|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | [illegible] |
| RIPPLE LENGTH $\lambda r$ (m) | [illegible] |
| RIPPLE STEEPNESS RST (-) | 0.16 |
| BED ROUGHNESS Ks (m) | [illegible] |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | [illegible] |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0 |
| ZERO INTERCEPT z0 (m) | [illegible] |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | [illegible] |
| BED CONCENTRATION Cb ($kg/m^3$) | [illegible] |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | 0 |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 0 |
| TOTAL TRANSPORT Stot (kg/s.m) | 0 |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 2 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 3 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 4 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 5 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 6 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 7 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 8 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 9 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |
| 10 | [illegible] | [illegible] | — | — | [illegible] | — | — | — | — |

Table 4.2 U : Calculated data characteristic waveheight

EXPERIMENT NO. : T5/0
METHOD : MEAN WAVEHEIGHT

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $8.18 \times 10^{-2}$ | $2.04 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.6 | 44.4 |
| PARAMETER z* (-) | 1.33 | 1.36 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.1937 | 0.1867 |
| BED LOAD Lb ($kg/m^2$) | $1.58 \times 10^{-2}$ | $9.96 \times 10^{-3}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $1.39 \times 10^{-2}$ | $8.51 \times 10^{-3}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $2.95 \times 10^{-2}$ | $1.84 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $1.00 \times 10^{-3}$ | $1.36 \times 10^{-4}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $1.30 \times 10^{-3}$ | $6.73 \times 10^{-4}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $2.39 \times 10^{-3}$ | $1.15 \times 10^{-3}$ |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $8.18 \times 10^{-2}$ | $2.04 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 33.6 | 44.4 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $1.92 \times 10^{-3}$ | $1.02 \times 10^{-3}$ |

**NIELSEN METHOD**

| | | |
|---|---|---|
| RIPPLE HEIGHT Δr (m) | $1.91 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.35 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | $4.03 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.066 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | 0.014 | |
| ZERO INTERCEPT z0 (m) | $1.34 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $7.16 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 6.6560 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.31 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $8.64 \times 10^{-3}$ | $1.09 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $2.97 \times 10^{-4}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-1.45 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $1.51 \times 10^{-4}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 0.010 | [illegible] | [illegible] | 0.1951 | 0.1858 | 0.051 | [illegible] | 0.027 |
| 2 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0326 | 0.1071 | 0.061 | [illegible] | 0.041 |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0345 | 0.0653 | 0.068 | [illegible] | 0.052 |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0109 | 0.0338 | 0.076 | [illegible] | 0.063 |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0017 | 0.0134 | [illegible] | [illegible] | 0.077 |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0001 | 0.0041 | [illegible] | [illegible] | 0.092 |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0010 | [illegible] | [illegible] | 0.106 |
| 8 | [illegible] | [illegible] | [illegible] | 0.0014 | 0.0000 | 0.0004 | 0.115 | [illegible] | 0.116 |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0001 | 0.119 | [illegible] | 0.124 |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0001 | [illegible] | [illegible] | 0.132 |

Table 4.2 V : Calculated data characteristic waveheight

| | |
|---|---|
| EXPERIMENT NO. : | [illegible] |
| METHOD : | [illegible] |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | 6.67×10⁻² | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| PARAMETER z* (-) | [illegible] | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | [illegible] | [illegible] |
| BED LOAD Lb ($kg/m^2$) | [illegible] | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | 1.65×10⁻² | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

**NIELSEN METHOD**

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | 1.81×10⁻² | |
| RIPPLE LENGTH $\lambda r$ (m) | 1.28×10⁻¹ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | [illegible] | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.048 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.016 | |
| ZERO INTERCEPT z0 (m) | 1.31×10⁻³ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 6.03×10⁻³ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.6018 | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] | |
| TOTAL LOAD Lt ($kg/m^2$) | 8.15×10⁻³ | 1.04×10⁻² |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | -3.01×10⁻⁴ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 1.85×10⁻⁴ | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | 0.1070 | 0.1453 | [illegible] | [illegible] | -0.046 |
| 2 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0458 | 0.0828 | [illegible] | [illegible] | -0.061 |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0196 | 0.0503 | [illegible] | [illegible] | [illegible] |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0055 | 0.0260 | [illegible] | [illegible] | [illegible] |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0007 | 0.0104 | [illegible] | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0003 | [illegible] | -0.138 | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0001 | [illegible] | -0.142 | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0001 | [illegible] | -0.148 | [illegible] |

Table 4.2 W : Calculated data characteristic waveheight

| | | |
|---|---|---|
| EXPERIMENT NO. : [illegible]<br>METHOD : MEAN WAVEHEIGHT | | |
| BIJKER METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | [illegible] | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| PARAMETER z* (-) | [illegible] | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | [illegible] | [illegible] |
| BED LOAD Lb ($kg/m^2$) | [illegible] | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |
| ADAPTED ENGELUND-HANSEN METHOD | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | [illegible] | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |
| NIELSEN METHOD | | |
| RIPPLE HEIGHT Δr (m) | $2.05 \times 10^{-2}$ | |
| RIPPLE LENGTH λr (m) | $1.45 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | $4.1[illegible] \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY ũ* (m/s) | [illegible] | |
| CURRENT FRICTION VELOCITY ū* (m/s) | 0.022 | |
| ZERO INTERCEPT z0 (m) | $1.2[illegible] \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $3.41 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.7248 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.54 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.11 \times 10^{-2}$ | $1.66 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $2.33 \times 10^{-3}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $-4.94 \times 10^{-4}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $1.84 \times 10^{-3}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.043 | [illegible] | [illegible] | [illegible] | 0.1738 | 0.2254 | [illegible] | 0.141 | 0.103 |
| 2 | 0.063 | [illegible] | 0.3688 | [illegible] | 0.0908 | 0.1495 | 0.138 | 0.155 | 0.124 |
| 3 | 0.087 | [illegible] | 0.2688 | [illegible] | 0.0424 | 0.1042 | 0.151 | 0.165 | 0.139 |
| 4 | 0.112 | [illegible] | [illegible] | [illegible] | 0.0170 | 0.0651 | [illegible] | [illegible] | 0.156 |
| 5 | 0.160 | [illegible] | [illegible] | [illegible] | 0.0035 | 0.0329 | [illegible] | [illegible] | 0.176 |
| 6 | [illegible] | [illegible] | 0.1268 | [illegible] | 0.0003 | 0.0156 | 0.201 | 0.206 | 0.198 |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0060 | 0.220 | [illegible] | 0.220 |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0030 | [illegible] | [illegible] | 0.236 |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0017 | [illegible] | [illegible] | 0.248 |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0010 | [illegible] | [illegible] | 0.260 |

Table 4.2 X : Calculated data characteristic waveheight

| | |
|---|---|
| EXPERIMENT NO. | : [illegible] |
| METHOD | : MEAN WAVEHEIGHT |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| PARAMETER $z_*$ (-) | [illegible] | [illegible] |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.4560 | [illegible] |
| BED LOAD Lb ($kg/m^2$) | [illegible] | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | [illegible] | [illegible] |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| BED LOAD TRANSPORT Sb (kg/s.m) | [illegible] | [illegible] |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | [illegible] |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | [illegible] |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | [illegible] |

**NIELSEN METHOD**

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.68 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.10 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | [illegible] | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.066 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.027 | |
| ZERO INTERCEPT z0 (m) | [illegible] | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | [illegible] | |
| BED CONCENTRATION Cb ($kg/m^3$) | [illegible] | |
| CONCENTRATION LENGTHSCALE Lc (m) | [illegible] | |
| TOTAL LOAD Lt ($kg/m^2$) | [illegible] | [illegible] |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | [illegible] | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | [illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | 0.1126 | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 3 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.152 |
| 4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | -0.168 |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 4.2 Y : Calculated data characteristic waveheight

| EXPERIMENT NO. : [illegible] | | |
|---|---|---|
| METHOD : [illegible] | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 2.65×10⁻² | 2.61×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 34.2 | 47.6 |
| PARAMETER z* (-) | 1.01 | 1.19 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2923 | 0.8596 |
| BED LOAD Lb ($kg/m^2$) | 2.24×10⁻² | [illegible] |
| SUSPENDED LOAD Ls ($kg/m^2$) | 2.35×10⁻² | 3.32×10⁻² |
| TOTAL LOAD Lt ($kg/m^2$) | 4.62×10⁻² | 5.97×10⁻² |
| BED LOAD TRANSPORT Sb (kg/s.m) | -0.68×10⁻² | -4.52×10⁻³ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | -1.15×10⁻² | -1.36×10⁻² |
| TOTAL LOAD TRANSPORT St (kg/s.m) | -1.32×10⁻² | -1.81×10⁻² |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | 2.65×10⁻² | 2.61×10⁻² |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | [illegible] | 47.6 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | -1.68×10⁻¹ | -1.16×10⁻¹ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT Δr (m) | 1.40×10⁻² | |
| RIPPLE LENGTH λr (m) | 9.89×10⁻² | |
| RIPPLE STEEPNESS RST (-) | 0.16 | |
| BED ROUGHNESS Ks (m) | 3.23×10⁻² | |
| WAVE FRICTION VELOCITY ũ* (m/s) | 0.063 | |
| CURRENT FRICTION VELOCITY ū* (m/s) | -0.035 | |
| ZERO INTERCEPT z0 (m) | 1.07×10⁻³ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | 1.79×10⁻² | |
| BED CONCENTRATION Cb ($kg/m^3$) | 0.6635 | |
| CONCENTRATION LENGTHSCALE Lc (m) | 0.49×10⁻³ | |
| TOTAL LOAD Lt ($kg/m^2$) | 6.33×10⁻² | 1.36×10⁻² |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | -1.25×10⁻² | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | 9.78×10⁻⁴ | |
| TOTAL TRANSPORT Stot (kg/s.m) | -1.15×10⁻² | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.050 | 0.030 | 0.2929 | 0.7233 | 0.0283 | 0.1096 | -0.255 | -0.291 | -0.271 |
| 2 | 0.080 | 0.040 | 0.2929 | 0.5012 | 0.0090 | 0.0779 | -0.282 | -0.316 | -0.302 |
| 3 | 0.098 | 0.050 | 0.2979 | 0.3748 | 0.0036 | 0.0586 | -0.306 | -0.331 | -0.321 |
| 4 | 0.128 | 0.065 | 0.2676 | [illegible] | 0.0007 | 0.0411 | -0.337 | -0.352 | [illegible] |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0001 | 0.0252 | -0.364 | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0081 | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | 0.0130 | 0.0000 | 0.0036 | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | 0.0026 | -0.507 | [illegible] | [illegible] |

Table 4.2 Z : Calculated data characteristic waveheight

| | |
|---|---|
| EXPERIMENT NO. : | [illegible] |
| METHOD : | MEAN WAVEHEIGHT |

**BIJKER METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | $4.69 \times 10^{-2}$ | $1.47 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}$/s) | [illegible] | 46.9 |
| PARAMETER $z_*$ (-) | 1.06 | 1.66 |
| BED LAYER CONCENTRATION Cb (kg/$m^3$) | 0.7887 | 0.0836 |
| BED LOAD Lb (kg/$m^2$) | [illegible] | $1.46 \times 10^{-2}$ |
| SUSPENDED LOAD Ls (kg/$m^2$) | [illegible] | $1.66 \times 10^{-2}$ |
| TOTAL LOAD Lt (kg/$m^2$) | $6.29 \times 10^{-2}$ | $3.11 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-2.96 \times 10^{-3}$ | $-1.20 \times 10^{-3}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-7.31 \times 10^{-3}$ | $-2.97 \times 10^{-3}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | $-4.12 \times 10^{-3}$ |

**ADAPTED ENGELUND-HANSEN METHOD**

| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
|---|---|---|
| BED ROUGHNESS Ks (m) | [illegible] | $1.47 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}$/s) | [illegible] | 46.9 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | [illegible] | $-1.90 \times 10^{-2}$ |

**NIELSEN METHOD**

| | | |
|---|---|---|
| RIPPLE HEIGHT $\Delta r$ (m) | $1.76 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.27 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.15 | |
| BED ROUGHNESS Ks (m) | $3.72 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.025 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.023 | |
| ZERO INTERCEPT z0 (m) | $1.30 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $3.69 \times 10^{-3}$ | |
| BED CONCENTRATION Cb (kg/$m^3$) | 1.1321 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.08 \times 10^{-2}$ | |
| TOTAL LOAD Lt (kg/$m^2$) | [illegible] | [illegible] |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | [illegible] | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | [illegible] | |
| TOTAL TRANSPORT Stot (kg/s.m) | [illegible] | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C (kg/$m^3$) | | | | VELOCITY u (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
| 1 | 0.044 | 0.021 | 0.5387 | 0.5396 | [illegible] | [illegible] | -0.126 | [illegible] | [illegible] |
| 2 | 0.067 | 0.031 | [illegible] | 0.2342 | [illegible] | [illegible] | -0.144 | -0.160 | [illegible] |
| 3 | [illegible] | 0.041 | [illegible] | 0.1669 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 4 | 0.112 | 0.056 | [illegible] | 0.0945 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0000 | [illegible] | [illegible] | [illegible] | [illegible] |

Table 4.2 $\alpha$ : Calculated data characteristic waveheight

| EXPERIMENT NO. : 71014,-40 | | |
|---|---|---|
| METHOD : MEAN WAVEHEIGHT | | |
| **BIJKER METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $1.05 \times 10^{-1}$ | $3.19 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 30.8 | 41.2 |
| PARAMETER z* (-) | 0.93 | 1.10 |
| BED LAYER CONCENTRATION Cb ($kg/m^3$) | 0.2528 | 0.5640 |
| BED LOAD Lb ($kg/m^2$) | $2.65 \times 10^{-2}$ | $2.75 \times 10^{-2}$ |
| SUSPENDED LOAD Ls ($kg/m^2$) | $2.83 \times 10^{-2}$ | $4.75 \times 10^{-2}$ |
| TOTAL LOAD Lt ($kg/m^2$) | $5.48 \times 10^{-2}$ | $7.50 \times 10^{-2}$ |
| BED LOAD TRANSPORT Sb (kg/s.m) | $-7.10 \times 10^{-3}$ | $-5.20 \times 10^{-2}$ |
| SUSPENDED LOAD TRANSPORT Ss (kg/s.m) | $-1.23 \times 10^{-2}$ | $-1.75 \times 10^{-2}$ |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-1.94 \times 10^{-2}$ | $-2.27 \times 10^{-2}$ |
| **ADAPTED ENGELUND-HANSEN METHOD** | | |
| | SWART ROUGHNESS | VAN RIJN ROUGHNESS |
| BED ROUGHNESS Ks (m) | $1.05 \times 10^{-1}$ | $3.19 \times 10^{-2}$ |
| CHEZY COEFFICIENT C ($m^{\frac{1}{2}}/s$) | 31.8 | 41.2 |
| TOTAL LOAD TRANSPORT St (kg/s.m) | $-2.23 \times 10^{-1}$ | $-1.82 \times 10^{-1}$ |
| **NIELSEN METHOD** | | |
| RIPPLE HEIGHT $\Delta r$ (m) | $1.48 \times 10^{-2}$ | |
| RIPPLE LENGTH $\lambda r$ (m) | $1.06 \times 10^{-1}$ | |
| RIPPLE STEEPNESS RST (-) | 0.15 | |
| BED ROUGHNESS Ks (m) | $3.67 \times 10^{-2}$ | |
| WAVE FRICTION VELOCITY $\tilde{u}_*$ (m/s) | 0.072 | |
| CURRENT FRICTION VELOCITY $\bar{u}_*$ (m/s) | -0.036 | |
| ZERO INTERCEPT z0 (m) | $1.20 \times 10^{-3}$ | |
| ZERO INTERCEPT IN PRESENCE OF WAVES z1 (m) | $1.48 \times 10^{-3}$ | |
| BED CONCENTRATION Cb ($kg/m^3$) | 1.1233 | |
| CONCENTRATION LENGTHSCALE Lc (m) | $1.20 \times 10^{-2}$ | |
| TOTAL LOAD Lt ($kg/m^2$) | $1.35 \times 10^{-2}$ | $2.24 \times 10^{-2}$ |
| CONVECTIVE TRANSPORT Scon (kg/s.m) | $-1.49 \times 10^{-2}$ | |
| DIFFUSIVE TRANSPORT Sdiff (kg/s.m) | $4.45 \times 10^{-3}$ | |
| TOTAL TRANSPORT Stot (kg/s.m) | $-1.50 \times 10^{-1}$ | |

| LEVEL NO. | z/h (-) | HEIGHT TO MEAN BED z (m) | CONCENTRATION C ($kg/m^3$) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN (NORMAL) | NIELSEN (ADAPTED) | VELOCITY u (m/s) BIJKER (SWART) | BIJKER (VAN RIJN) | NIELSEN |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.022 | 0.027 | 0.2528 | 0.7262 | 0.0570 | 0.1844 | -0.258 | -0.296 | -0.280 |
| 2 | 0.091 | 0.042 | 0.2528 | 0.5453 | 0.0277 | 0.1354 | -0.283 | -0.316 | -0.302 |
| 3 | 0.111 | 0.057 | 0.2528 | 0.4507 | 0.0090 | 0.1029 | -0.303 | -0.331 | -0.319 |
| 4 | 0.140 | 0.072 | 0.2528 | 0.3211 | 0.0028 | 0.0384 | -0.327 | -0.350 | -0.340 |
| 5 | 0.188 | 0.092 | 0.2528 | 0.2170 | 0.0004 | 0.0509 | -0.359 | -0.375 | -0.363 |
| 6 | 0.266 | 0.132 | 0.1831 | 0.1320 | 0.0000 | 0.0275 | -0.395 | -0.408 | [illegible] |
| 7 | 0.383 | 0.192 | 0.1110 | 0.0754 | 0.0000 | 0.0166 | -0.429 | [illegible] | -0.432 |
| 8 | 0.500 | 0.252 | 0.0713 | 0.0483 | 0.0000 | 0.0106 | -0.461 | -0.454 | -0.456 |
| 9 | 0.616 | 0.312 | 0.0458 | 0.0250 | 0.0000 | 0.0034 | -0.483 | -0.471 | -0.470 |
| 10 | 0.791 | 0.392 | 0.0294 | 0.0160 | 0.0000 | 0.0055 | -0.504 | -0.482 | -0.483 |

Table 4.2 β : Calculated data characteristic waveheight

| Experiment no. | Bijker | | Engelund-Hansen | | Nielsen |
|---|---|---|---|---|---|
| | St,prob. / St,$\bar{H}$ (Swart) | St,prob. / St,$\bar{H}$ (van Rijn) | St,prob. / St,$\bar{H}$ (Swart) | St,prob. / St,$\bar{H}$ (van Rijn) | St,prob. / St,$\bar{H}$ (convective) |
| T 7.5 10 | 4.05 | 2.22 | 2.72 | 1.37 | 23.71 |
| T 10 10 | 1.77 | 1.58 | 2.65 | 1.44 | 16.74 |
| T 10 -10 | 1.82 | 1.74 | 2.18 | 1.43 | 18.70 |
| T 12 10 | 1.42 | 1.52 | 2.24 | 1.50 | 16.19 |
| T 12 -10 | 1.58 | 1.47 | 2.47 | 1.44 | 16.31 |
| T 15 10 | 1.23 | 1.30 | 2.47 | 1.50 | 12.26 |
| T 15 -10 | 1.15 | 1.28 | 2.07 | 1.49 | 12.56 |
| T 7.5 20 | 1.96 | 1.40 | 1.95 | 1.20 | 12.20 |
| T 10 20 | 1.56 | 1.34 | 2.18 | 1.29 | 13.08 |
| T 10 -20 | 1.63 | 1.18 | 2.21 | 1.23 | 12.53 |
| T 12 20 | 1.15 | 1.27 | 1.79 | 1.36 | 10.85 |
| T 12 -20 | 1.33 | 1.17 | 2.31 | 1.29 | 11.08 |
| T 15 20 | 0.94 | 1.23 | 1.35 | 1.42 | 9.91 |
| T 15 -20 | 0.95 | 1.23 | 1.33 | 1.40 | 9.51 |
| T 17.5 -20 | 0.92 | 1.20 | 1.29 | 1.46 | 8.64 |
| T 7.5 40 | 1.02 | 1.04 | 1.11 | 1.06 | 3.86 |
| T 10 40 | 1.05 | 1.04 | 1.28 | 1.10 | 4.28 |
| T 10 -40 | 1.11 | 0.96 | 1.47 | 1.05 | 4.11 |
| T 12 40 | 0.94 | 1.06 | 1.08 | 1.14 | 5.08 |
| T 12 -40 | 1.10 | 1.01 | 1.62 | 1.12 | 4.76 |
| T 15 -40 | 1.07 | 0.99 | 1.81 | 1.09 | 5.57 |
| T 18.5 -40 | 1.03 | 0.96 | 2.05 | 1.21 | 6.61 |

Table 4.3: Ratio probability-weighted total load transport and the total load transport computed with $\bar{H}$

| Experiment no. | Lt *10^-4 [Kg/m2] measured | Bijker (Swart) | Bijker (van Rijn) | Nielsen (normal) | Nielsen (adapted) |
|---|---|---|---|---|---|
| T 7.5 0 | 15 | ** | ** | 33 | 33 |
| T 9 0 | 39 | ** | ** | 82 | 82 |
| T 10 0 | 50 | ** | ** | 166 | 166 |
| T 12 0 | 183 | ** | ** | 335 | 335 |
| T 15 0 | 465 | ** | ** | 1000 | 1000 |
| T 7.5 10 | 12 | 79 | 40 | 35 | 43 |
| T 10 10 | 47 | 187 | 105 | 218 | 287 |
| T 10 -10 | 55 | 180 | 80 | 124 | 162 |
| T 12 10 | 146 | 255 | 131 | 370 | 473 |
| T 12 -10 | 122 | 234 | 133 | 276 | 362 |
| T 15 10 | 309 | 340 | 233 | 813 | 1080 |
| T 15 -10 | 416 | 374 | 231 | 787 | 1070 |
| T 7.5 20 | 27 | 112 | 65 | 28 | 39 |
| T 10 20 | 122 | 193 | 119 | 145 | 215 |
| T 10 -20 | 100 | 162 | 155 | 99 | 146 |
| T 12 20 | 200 | 310 | 184 | 500 | 779 |
| T 12 -20 | 168 | 268 | 219 | 293 | 458 |
| T 15 20 | 528 | 425 | 254 | 1010 | 1600 |
| T 15 -20 | 364 | 442 | 260 | 822 | 1340 |
| T 17.5 -20 | 471 | 557 | 347 | 1430 | 2400 |
| T 0 40 | 105 | 145 | 114 | **** | **** |
| T 7.5 40 | 481 | 329 | 248 | 39 | 79 |
| T 10 40 | 666 | 417 | 337 | 169 | 354 |
| T 10 -40 | 987 | 380 | 412 | 104 | 215 |
| T 12 40 | 874 | 485 | 379 | 436 | 906 |
| T 12 -40 | 1180 | 460 | 458 | 275 | 595 |
| T 15 -40 | 1650 | 519 | 578 | 582 | 1280 |
| T 18.5 -40 | 2690 | 551 | 711 | 1120 | 2400 |

Table 4.4: Measured and calculated probabilty-weighted total loads

| Experiment no. | Lcalc. / Lmeas. Bijker (Swart) | Bijker (van Rijn) | Nielsen (normal) | Nielsen (adapted) |
|---|---|---|---|---|
| T 7.5 0 | **** | **** | 2.20 | 2.20 |
| T 9 0 | **** | **** | 2.10 | 2.10 |
| T 10 0 | **** | **** | 3.32 | 3.32 |
| T 12 0 | **** | **** | 1.83 | 1.83 |
| T 15 0 | **** | **** | 2.15 | 2.15 |
| T 7.5 10 | 6.58 | 3.32 | 2.91 | 3.58 |
| T 10 10 | 3.97 | 2.23 | 4.63 | 6.11 |
| T 10 -10 | 3.27 | 1.45 | 2.25 | 2.95 |
| T 12 10 | 1.75 | 0.90 | 2.53 | 3.24 |
| T 12 -10 | 1.92 | 1.09 | 2.26 | 2.97 |
| T 15 10 | 1.10 | 0.75 | 2.63 | 3.50 |
| T 15 -10 | 0.90 | 0.56 | 1.89 | 2.57 |
| T 7.5 20 | 4.14 | 2.41 | 1.04 | 1.44 |
| T 10 20 | 1.58 | 0.98 | 1.19 | 1.76 |
| T 10 -20 | 1.62 | 1.55 | 0.99 | 1.46 |
| T 12 20 | 1.55 | 0.92 | 2.50 | 3.90 |
| T 12 -20 | 1.60 | 1.30 | 1.74 | 2.73 |
| T 15 20 | 0.81 | 0.48 | 1.91 | 3.03 |
| T 15 -20 | 1.21 | 0.71 | 2.26 | 3.68 |
| T 17.5 -20 | 1.18 | 0.73 | 3.03 | 5.10 |
| T 0 40 | 1.38 | 1.09 | **** | **** |
| T 7.5 40 | 0.68 | 0.52 | 0.08 | 0.16 |
| T 10 40 | 0.63 | 0.51 | 0.25 | 0.53 |
| T 10 -40 | 0.39 | 0.42 | 0.11 | 0.22 |
| T 12 40 | 0.56 | 0.43 | 0.50 | 1.04 |
| T 12 -40 | 0.39 | 0.39 | 0.23 | 0.50 |
| T 15 -40 | 0.31 | 0.35 | 0.35 | 0.78 |
| T 18.5 -40 | 0.21 | 0.26 | 0.42 | 0.99 |

Table 4.5: Ratio calculated probability-weighted and measured total load

| Experiment no. | St $*10^{-6}$ [Kg/ms] measured | Bijker (Swart) | Bijker (van Rijn) | Engelund (Swart) | Engelund (van Rijn) | Nielsen (convective) |
|---|---|---|---|---|---|---|
| T 7.5 10 | 26 | 665 | 256 | 5800 | 1650 | 152 |
| T 10 10 | 146 | 1710 | 738 | 19000 | 3980 | 1170 |
| T 10 -10 | -113 | -1660 | -574 | -13000 | -3120 | -675 |
| T 12 10 | 539 | 1800 | 723 | 19000 | 3920 | 1180 |
| T 12 -10 | -224 | -2100 | -934 | -22500 | -5150 | -1310 |
| T 15 10 | 839 | 2930 | 1500 | 47300 | 8730 | 3640 |
| T 15 -10 | -940 | -3850 | -1880 | -53500 | -11300 | -4910 |
| T 7.5 20 | 396 | 1820 | 825 | 14100 | 4730 | 561 |
| T 10 20 | 1170 | 3250 | 1540 | 32800 | 8350 | 2890 |
| T 10 -20 | -909 | -2850 | -2180 | -30000 | -11800 | -1880 |
| T 12 20 | 2040 | 5310 | 2480 | 58500 | 13300 | 11500 |
| T 12 -20 | -1170 | -4900 | -3200 | -60200 | -17000 | -6490 |
| T 15 20 | 5240 | 7270 | 3510 | 83300 | 19700 | 23100 |
| T 15 -20 | -3190 | -7780 | -3700 | -78000 | -19900 | -19600 |
| T 17.5 -20 | -4100 | -9780 | -5000 | -115000 | -27700 | -33700 |
| T 0 40 | 5020 | 4760 | 2930 | 35200 | 15500 | **** |
| T 7.5 40 | 12900 | 10200 | 6520 | 63000 | 30200 | 8000 |
| T 10 40 | 22500 | 14200 | 9630 | 125000 | 48300 | 31000 |
| T 10 -40 | -29000 | -13300 | -12300 | -137000 | -71200 | -14600 |
| T 12 40 | 30200 | 15900 | 10700 | 137000 | 56800 | 66000 |
| T 12 -40 | -32100 | -16000 | -13600 | -190000 | -79000 | -36700 |
| T 15 -40 | -48100 | -18400 | -17900 | -305000 | -127000 | -69600 |
| T 18.5 -40 | -69300 | -19900 | -22400 | -560000 | -222000 | -109000 |

Table 4.6: Measured and calculated probability-weighted total load transports

| Experiment no. | Scalc./Smeas. Bijker (Swart) | Bijker (van Rijn) | Engelund (Swart) | Engelund (van Rijn) | Nielsen (convective) |
|---|---|---|---|---|---|
| T 7.5 10 | 25.58 | 9.84 | 223.08 | 63.83 | 5.88 |
| T 10 10 | 11.71 | 5.05 | 130.14 | 27.26 | 8.01 |
| T 10 -10 | 14.69 | 5.07 | 115.04 | 27.61 | 5.97 |
| T 12 10 | 3.33 | 1.34 | 35.25 | 7.27 | 2.18 |
| T 12 -10 | 9.38 | 4.17 | 100.45 | 22.99 | 5.85 |
| T 15 10 | 3.49 | 1.79 | 56.37 | 10.41 | 4.34 |
| T 15 -10 | 4.08 | 1.99 | 56.67 | 11.97 | 5.20 |
| T 7.5 20 | 4.59 | 2.08 | 35.61 | 11.94 | 1.42 |
| T 10 20 | 2.78 | 1.32 | 28.03 | 7.14 | 2.47 |
| T 10 -20 | 3.14 | 2.40 | 33.00 | 12.98 | 2.07 |
| T 12 20 | 2.60 | 1.22 | 26.68 | 6.52 | 5.64 |
| T 12 -20 | 2.77 | 1.81 | 34.01 | 9.60 | 3.67 |
| T 15 20 | 1.39 | 0.67 | 15.90 | 3.76 | 4.41 |
| T 15 -20 | 2.44 | 1.16 | 24.45 | 6.24 | 6.14 |
| T 17.5 -20 | 2.39 | 1.22 | 28.05 | 6.76 | 8.22 |
| T 0 40 | 0.95 | 0.58 | 7.01 | 3.09 | **** |
| T 7.5 40 | 0.79 | 0.51 | 4.88 | 2.34 | 0.62 |
| T 10 40 | 0.63 | 0.43 | 5.56 | 2.15 | 1.38 |
| T 10 -40 | 0.46 | 0.42 | 4.72 | 2.46 | 0.50 |
| T 12 40 | 0.53 | 0.36 | 4.54 | 1.88 | 2.19 |
| T 12 -40 | 0.50 | 0.42 | 5.92 | 2.46 | 1.14 |
| T 15 -40 | 0.38 | 0.37 | 6.34 | 2.64 | 1.45 |
| T 18.5 -40 | 0.29 | 0.33 | 8.08 | 3.20 | 1.57 |

Table 4.7: Ratio calculated probability-weighted and measured total load transport

| Experiment no. | Scon. $*10^{-6}$ [Kg/ms] | Sdiff. $*10^{-6}$ [Kg/ms] | $\left\lvert \frac{Sdiff.}{Scon.} \right\rvert$ |
|---|---|---|---|
| T 7.5 10 | 152 | -54 | 0.355 |
| T 10 10 | 1170 | -307 | 0.262 |
| T 10 -10 | -675 | 202 | 0.299 |
| T 12 10 | 1180 | -369 | 0.313 |
| T 12 -10 | -1310 | 375 | 0.286 |
| T 15 10 | 3640 | -887 | 0.244 |
| T 15 -10 | -4910 | 1130 | 0.230 |
| T 7.5 20 | 561 | -124 | 0.221 |
| T 10 20 | 2890 | -522 | 0.181 |
| T 10 -20 | -1880 | 377 | 0.201 |
| T 12 20 | 11500 | -1480 | 0.129 |
| T 12 -20 | -6490 | 972 | 0.150 |
| T 15 20 | 23100 | -2680 | 0.116 |
| T 15 -20 | -19600 | 2240 | 0.114 |
| T 17.5 -20 | -33700 | 3410 | 0.101 |
| T 7.5 40 | 8000 | -610 | 0.076 |
| T 10 40 | 31000 | -2010 | 0.065 |
| T 10 -40 | -14600 | 1220 | 0.084 |
| T 12 40 | 66000 | -4120 | 0.062 |
| T 12 -40 | -36700 | 2480 | 0.068 |
| T 15 -40 | -69600 | 4170 | 0.060 |
| T 18.5 -40 | -109000 | 6840 | 0.063 |

Table 4.8: Transports according to the Nielsen method

| Experiment no. | Ks [m] | | | | | |
|---|---|---|---|---|---|---|
| | Swart | van Rijn | G & M | fitted | | |
| | | | | max. | mean | min. |
| T 7.5 10 | 0.0688 | 0.0181 | 0.0255 | 0.0833 | 0.0628 | 0.0443 |
| T 10 10 | 0.0785 | 0.0194 | 0.0346 | 0.0781 | 0.0584 | 0.0393 |
| T 10 -10 | 0.0474 | 0.0148 | 0.0291 | 0.0959 | 0.0745 | 0.0552 |
| T 12 10 | 0.0639 | 0.0182 | 0.0364 | 0.0651 | 0.0485 | 0.0339 |
| T 12 -10 | 0.0627 | 0.0181 | 0.0332 | 0.0950 | 0.0749 | 0.0567 |
| T 15 10 | 0.0818 | 0.0204 | 0.0403 | 0.1012 | 0.0780 | 0.0572 |
| T 15 -10 | 0.0662 | 0.0192 | 0.0394 | 0.1326 | 0.1084 | 0.0861 |
| T 7.5 20 | 0.0568 | 0.0170 | 0.0239 | 0.1220 | 0.0992 | 0.0783 |
| T 10 20 | 0.0729 | 0.0193 | 0.0331 | 0.1357 | 0.1068 | 0.0804 |
| T 10 -20 | 0.0791 | 0.0214 | 0.0271 | 0.1823 | 0.1516 | 0.1230 |
| T 12 20 | 0.0668 | 0.0192 | 0.0392 | 0.1697 | 0.1351 | 0.1029 |
| T 12 -20 | 0.0729 | 0.0203 | 0.0319 | 0.0935 | 0.0722 | 0.0531 |
| T 15 20 | 0.0576 | 0.0179 | 0.0419 | 0.1079 | 0.0862 | 0.0666 |
| T 15 -20 | 0.0459 | 0.0147 | 0.0367 | 0.0892 | 0.0708 | 0.0543 |
| T 17.5 -20 | 0.0464 | 0.0147 | 0.0392 | 0.0565 | 0.0431 | 0.0314 |
| T 7.5 40 | 0.0365 | 0.0151 | 0.0274 | 0.0365 | 0.0276 | 0.0200 |
| T 10 40 | 0.0589 | 0.0208 | 0.0363 | ****** | ****** | ****** |
| T 10 -40 | 0.0706 | 0.0232 | 0.0254 | 0.1357 | 0.1143 | 0.0946 |
| T 12 40 | 0.0465 | 0.0192 | 0.0396 | ****** | ****** | ****** |
| T 12 -40 | 0.0645 | 0.0219 | 0.0298 | 0.0519 | 0.0407 | 0.0309 |
| T 15 -40 | 0.0765 | 0.0261 | 0.0323 | 0.1607 | 0.1440 | 0.1283 |
| T 18.5 -40 | 0.1050 | 0.0319 | 0.0362 | 0.1196 | 0.1016 | 0.0850 |

Table 4.9: Measured and calculated roughness values

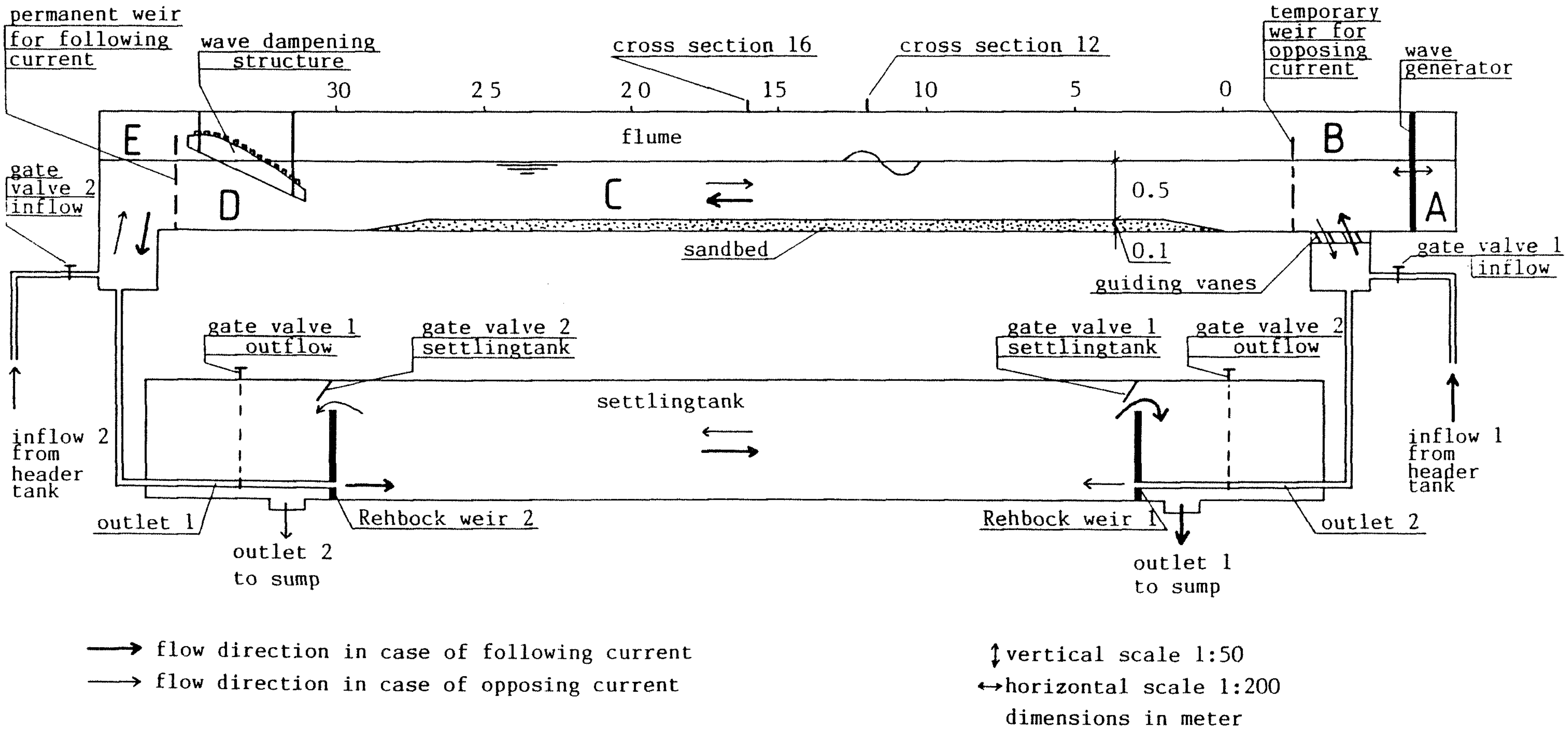
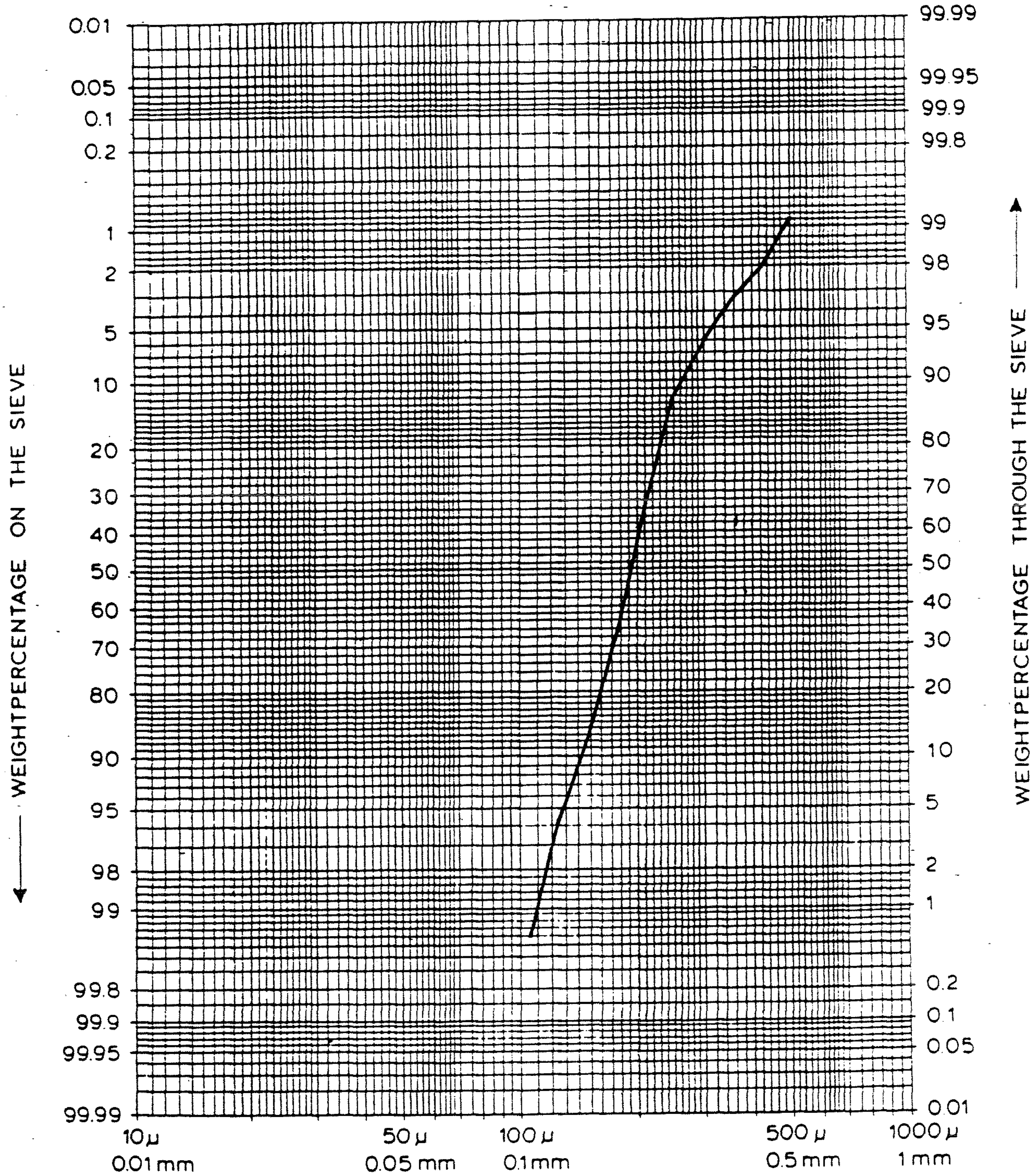
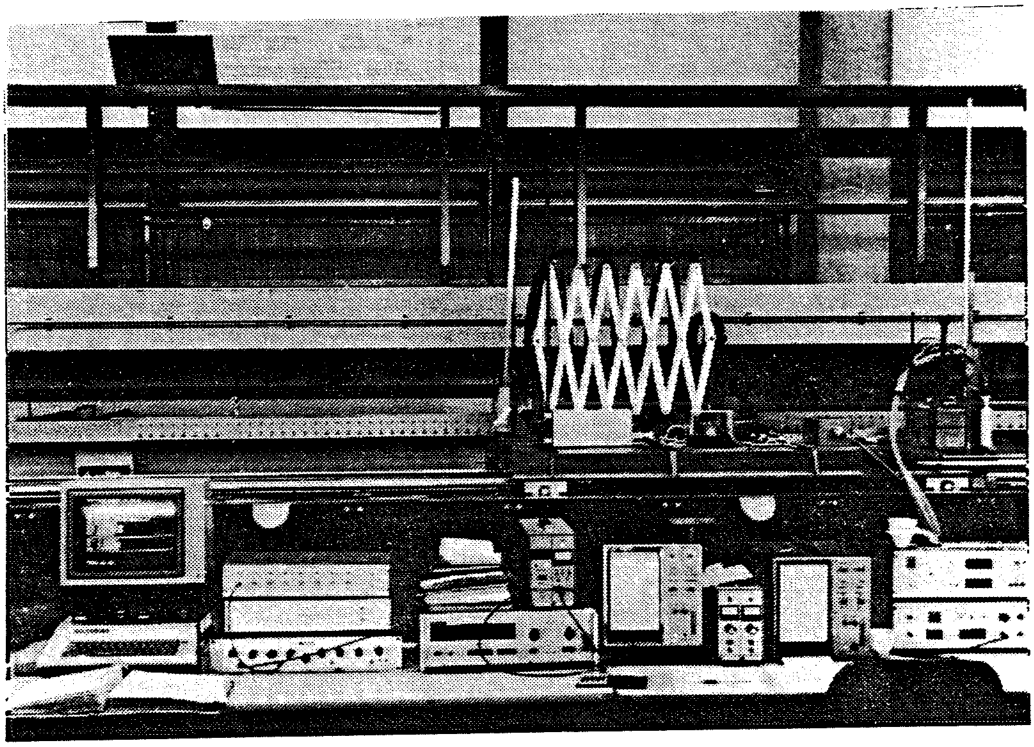



FIG. 2.1 FLUME LAYOUT AND FLOW SYSTEM



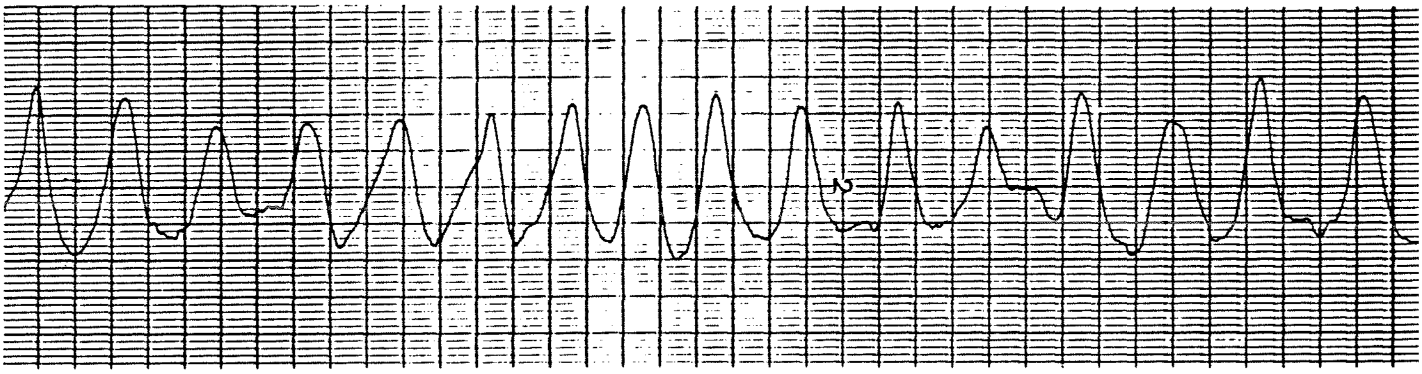

SIZE DISTRIBUTION OF BED MATERIAL

FIG. 2.2



ELECTRONIC MEASURING INSTRUMENTS

FIG. 2.3

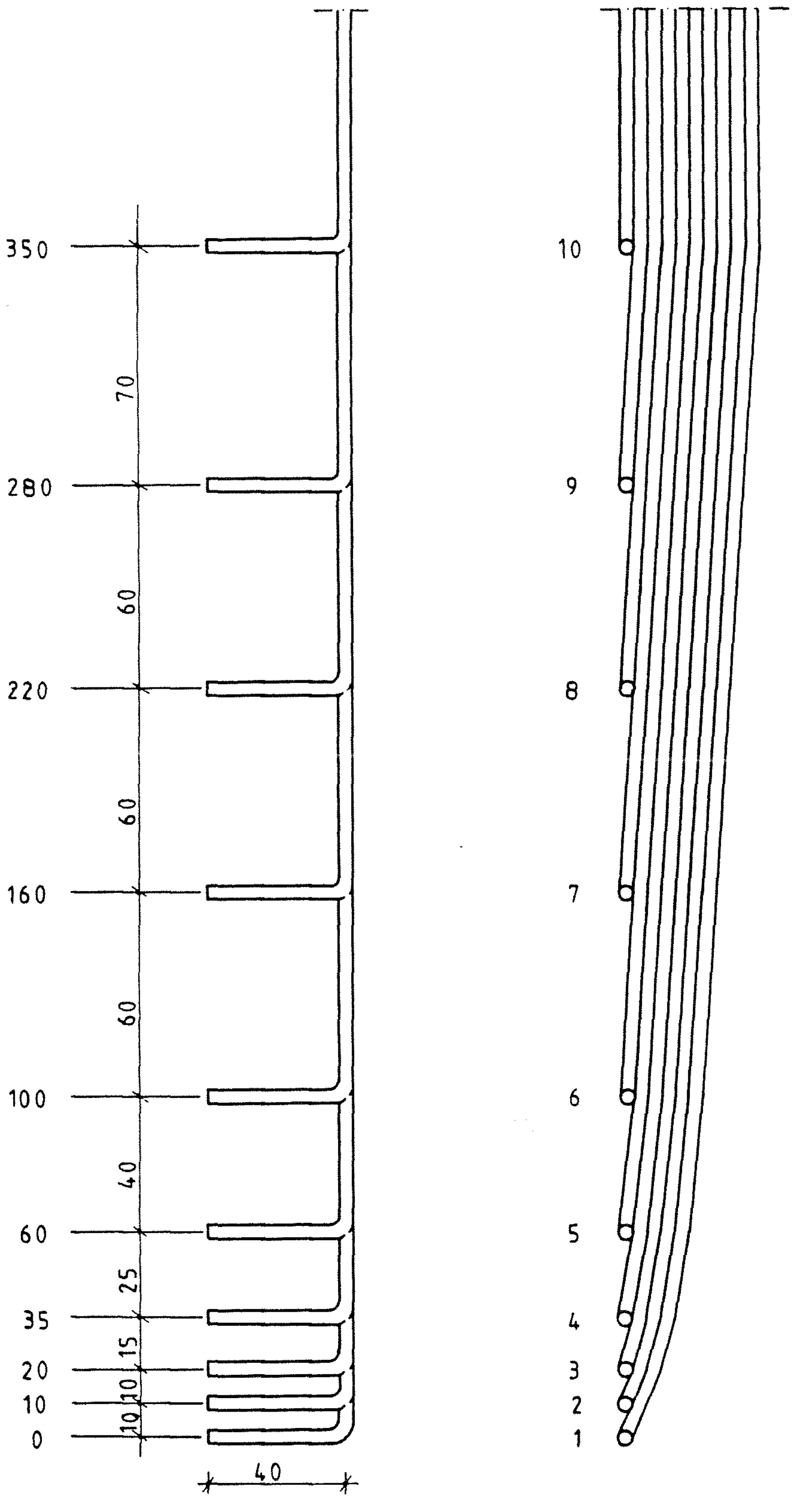


Experiment T 12,10

↕ vertical scale 1:5
↔ horizontal scale 5(mm):1(sec)

EXAMPLE OF WAVE REGISTRATION

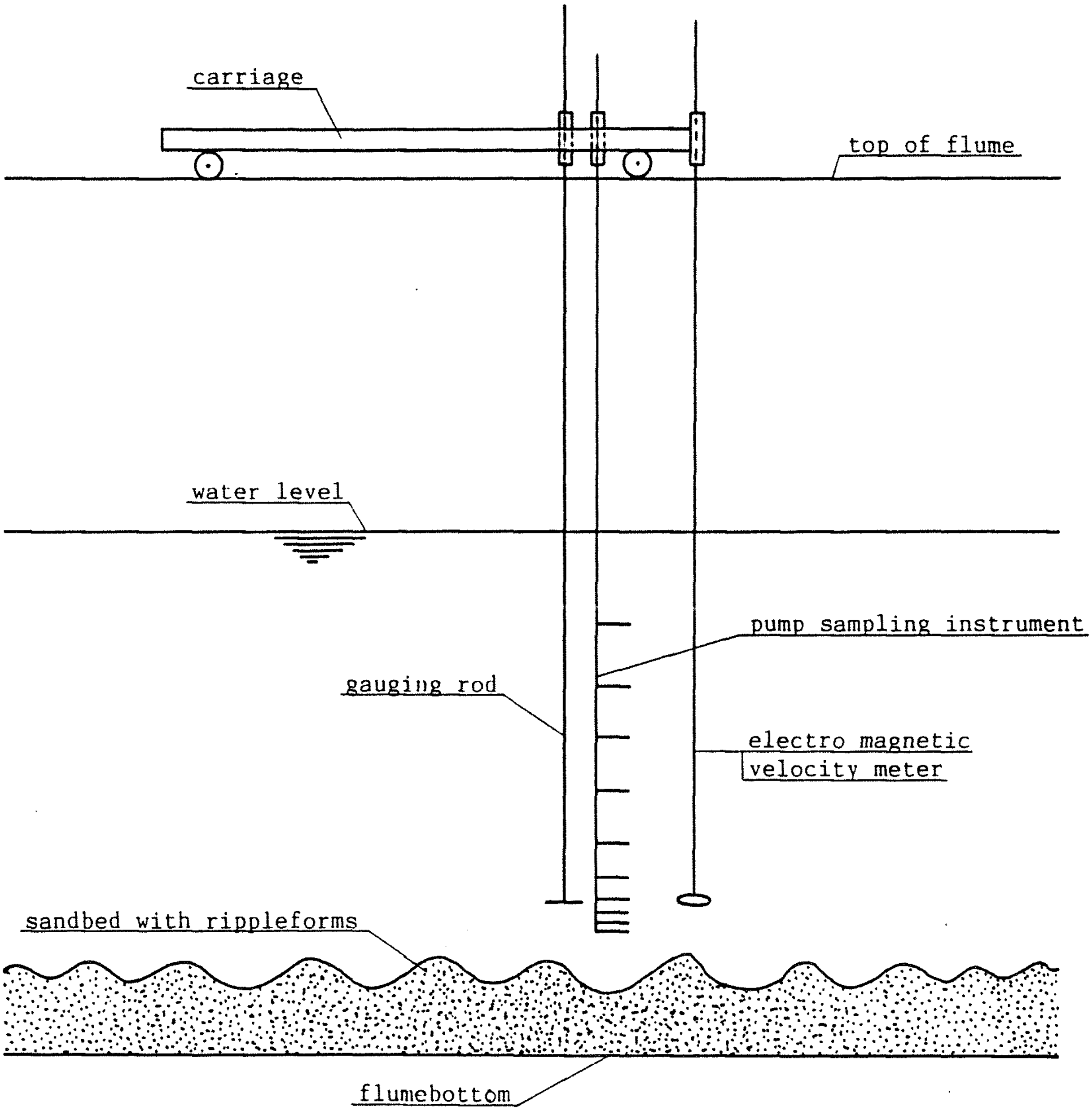
FIG. 2.4




scale 1:2
dimensions in mm
internal tube diameter 3 mm

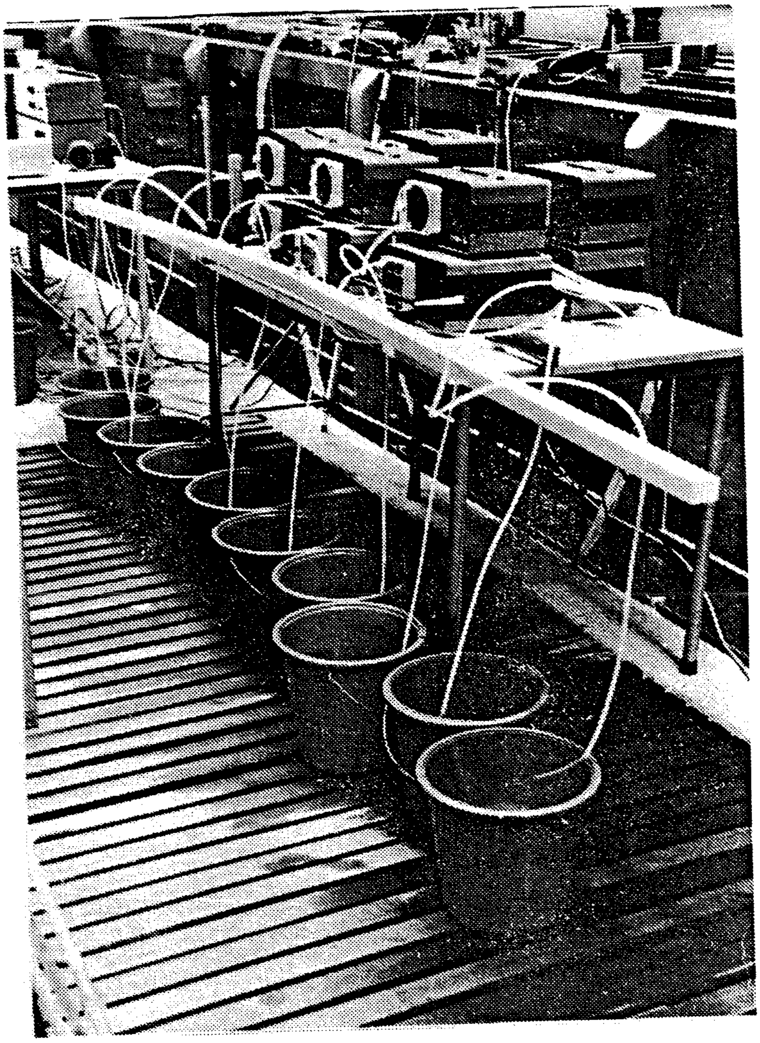
INTAKE TUBES OF PUMP SAMPLING INSTRUMENT

FIG. 2.5



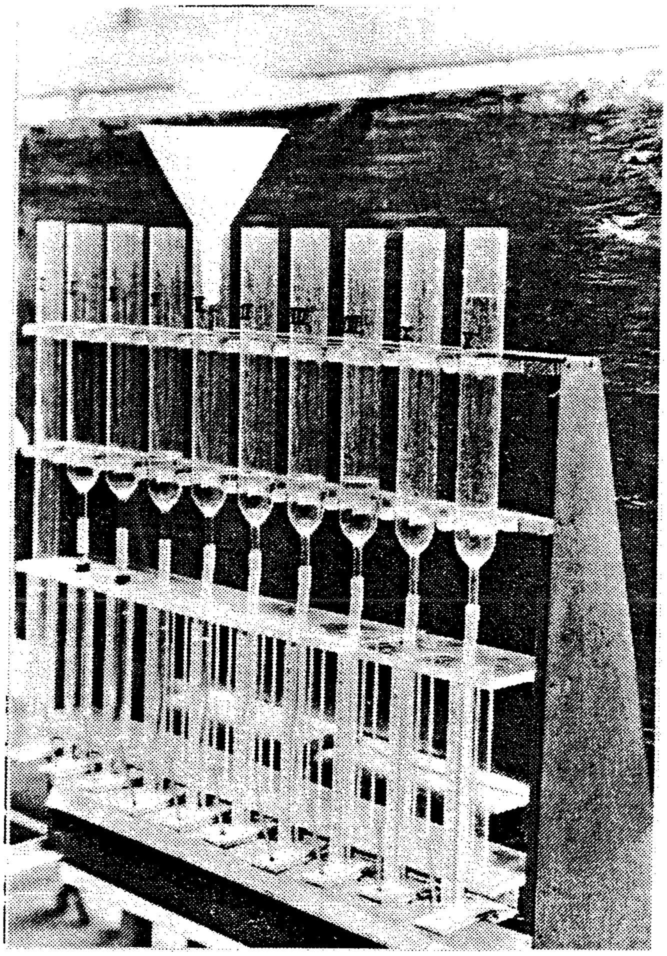

GAUGING ROD, PUMP SAMPLING INSTRUMENT AND VELOCITY METER

FIG. 2.6



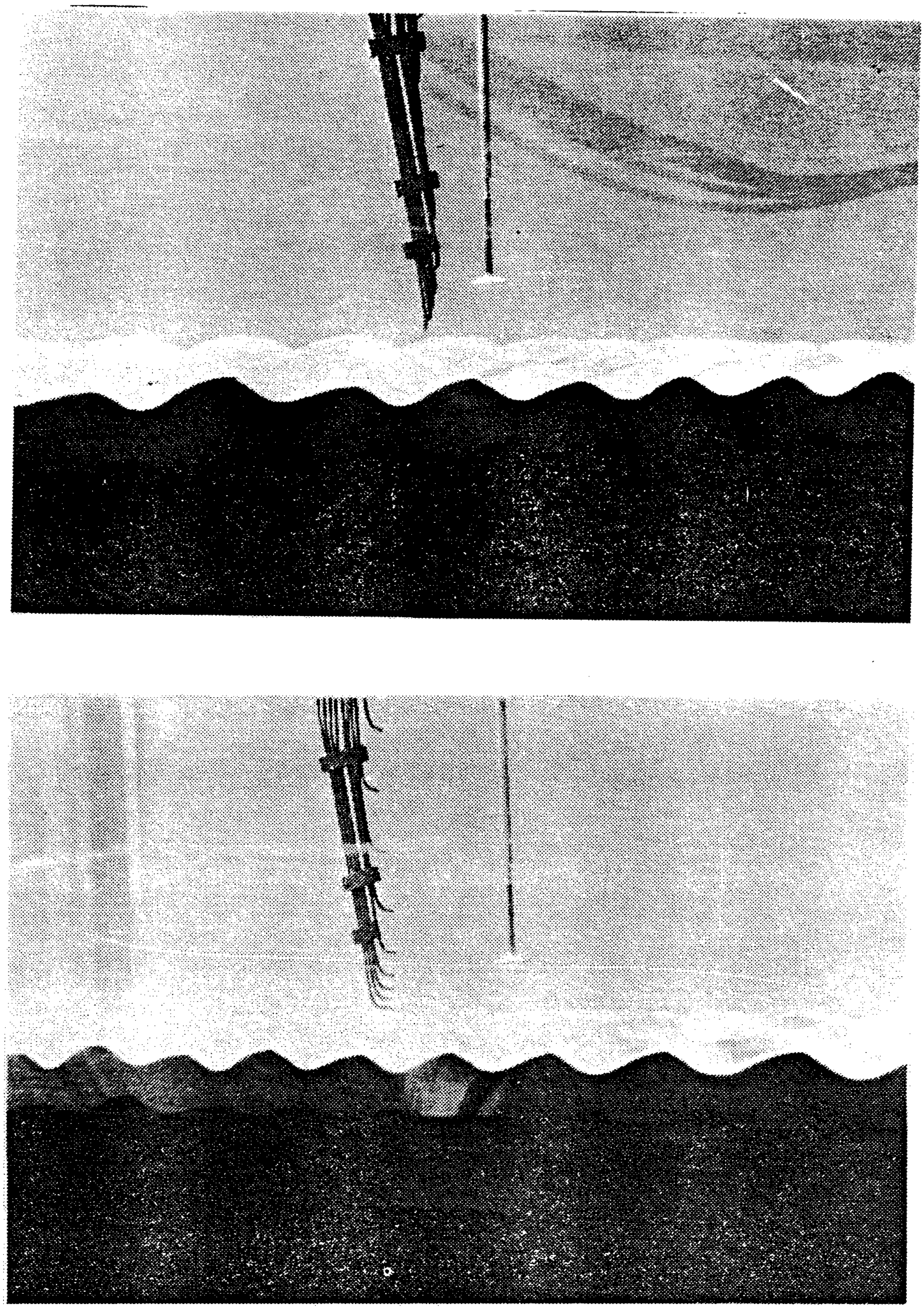
PERISTALTIC PUMPS AND BUCKETS

FIG. 2.7



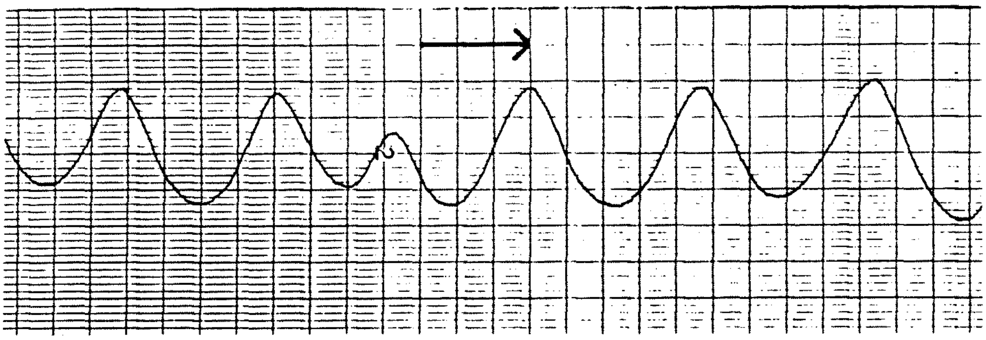
VOLUME METER

FIG. 2.8

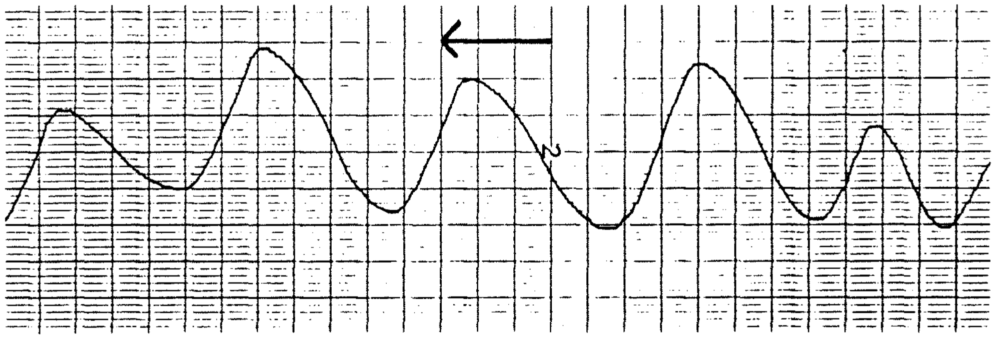


PUMP SAMPLING INSTRUMENT AND E.M.S. VELOCITY METER
ABOVE SANDBED

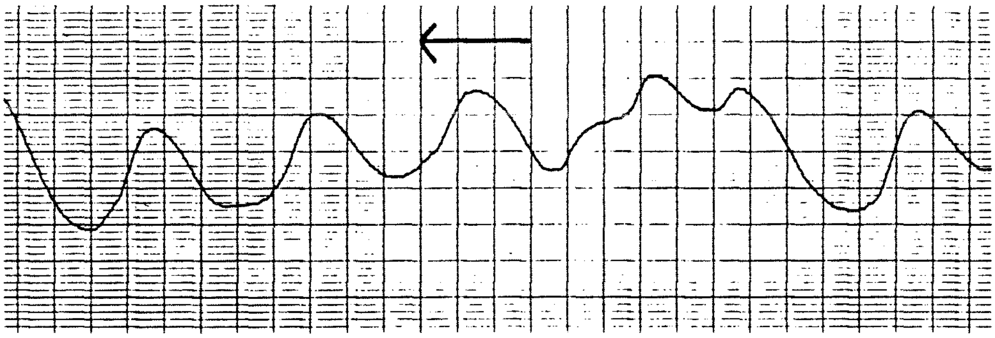
FIG. 2.9



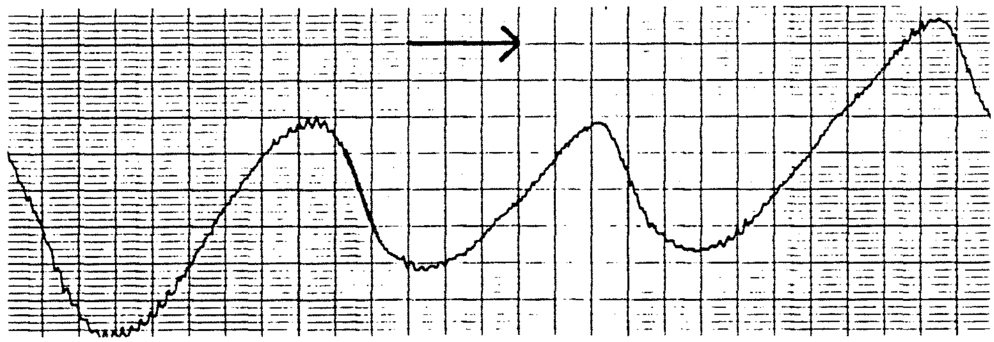
Experiment T 12,-10
2 dimensional ripples
wave dominated ripples



Experiment T 12,-20
2 dimensional ripples
current dominated ripples



Experiment T 17.5,-20
3 dimensional ripples
wave dominated ripples



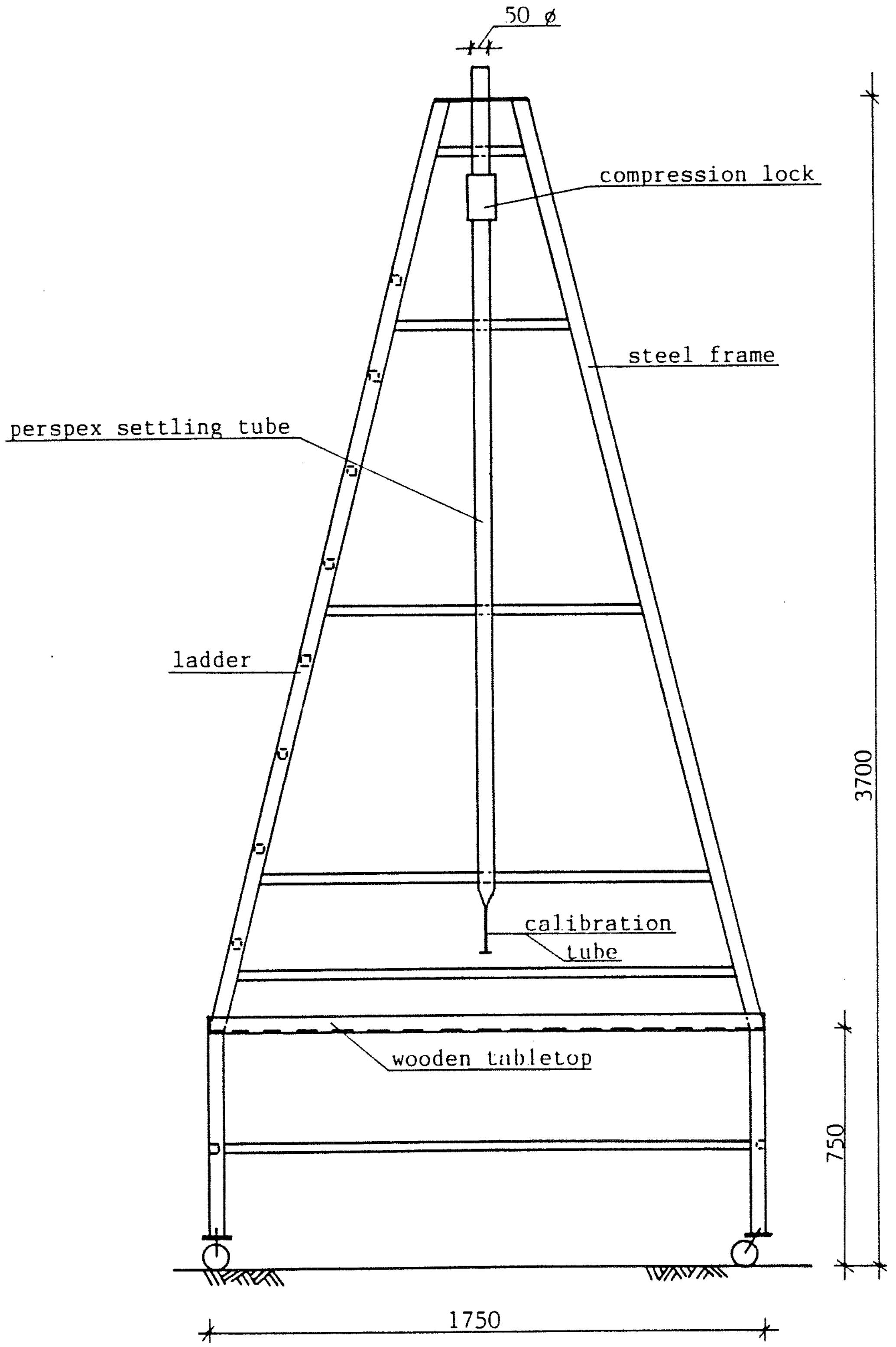
Experiment T 10,-40
3 dimensional ripples
current dominated ripples

⟶ direction of the current

↕ vertical scale 1:1
↔ horizontal scale 1:4

EXAMPLES OF RIPPLE REGISTRATION

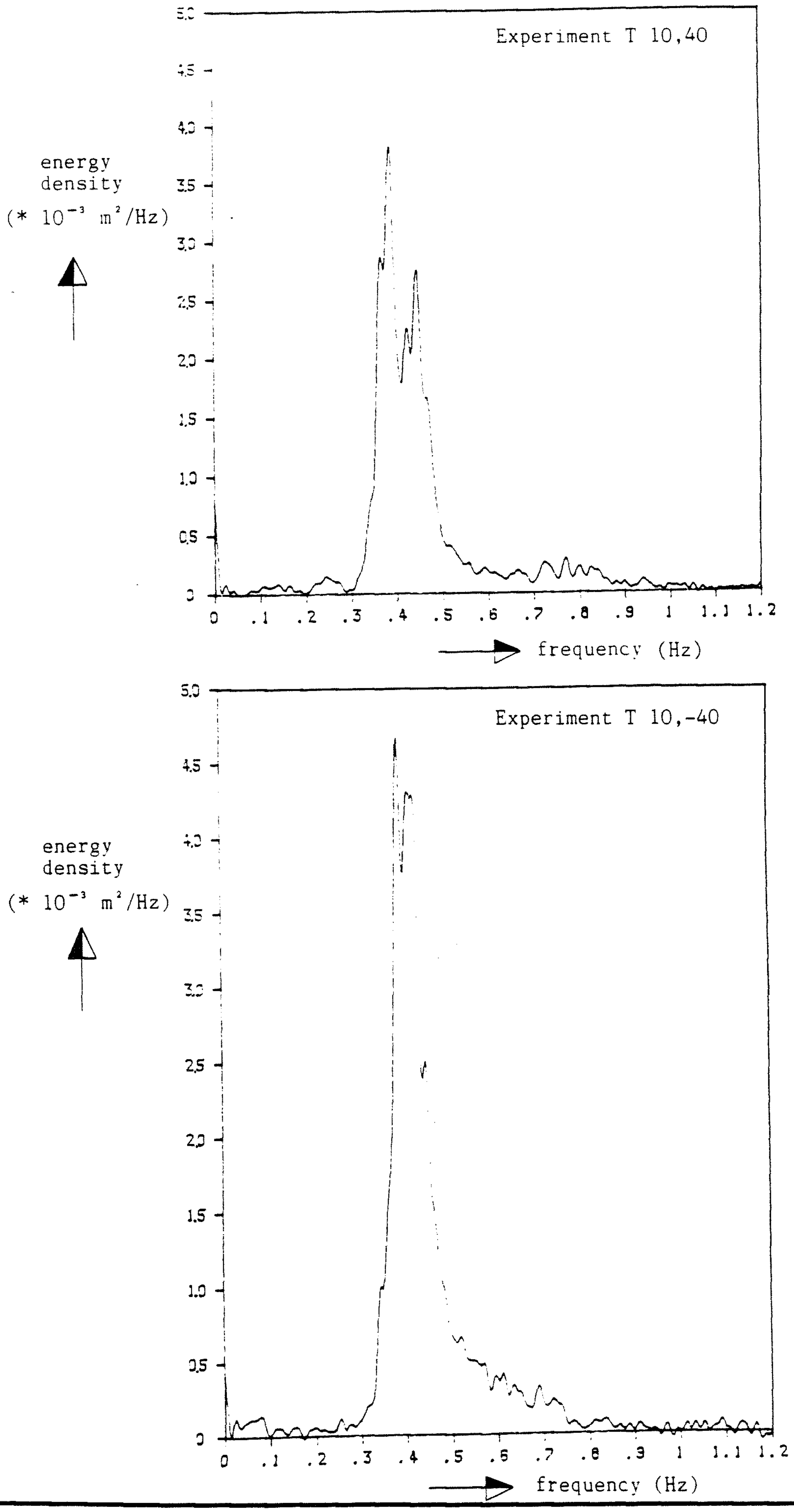
FIG. 2.10




scale 1:20
dimensions in mm

VISUAL ACCUMULATION TUBE

FIG. 2.11




EXAMPLES OF WAVE SPECTRA

FIG. 3.1

MEASURED CONCENTRATIONS WITH ERROR RANGES

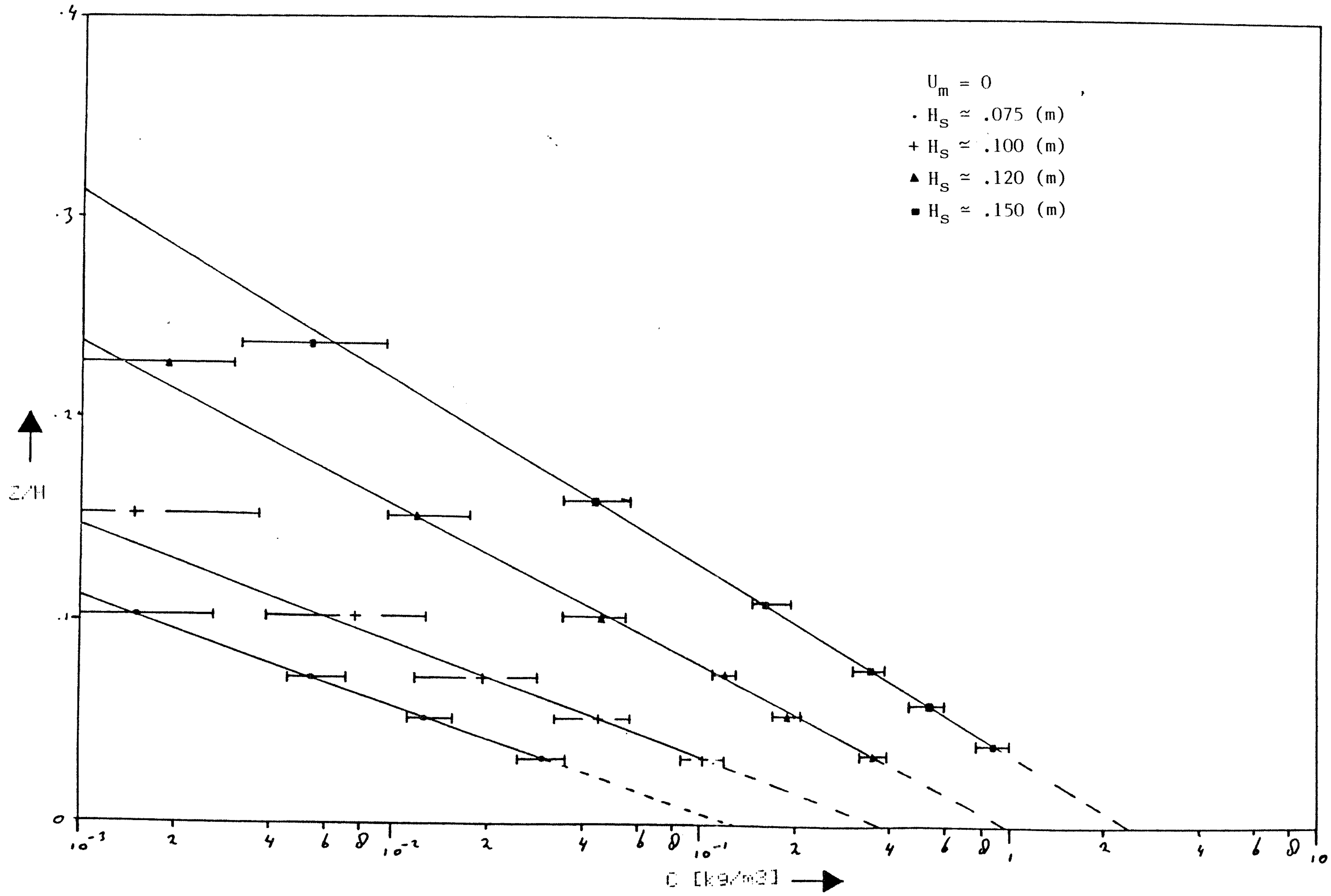



FIG. 3.2 A

MEASURED CONCENTRATIONS WITH ERROR RANGES

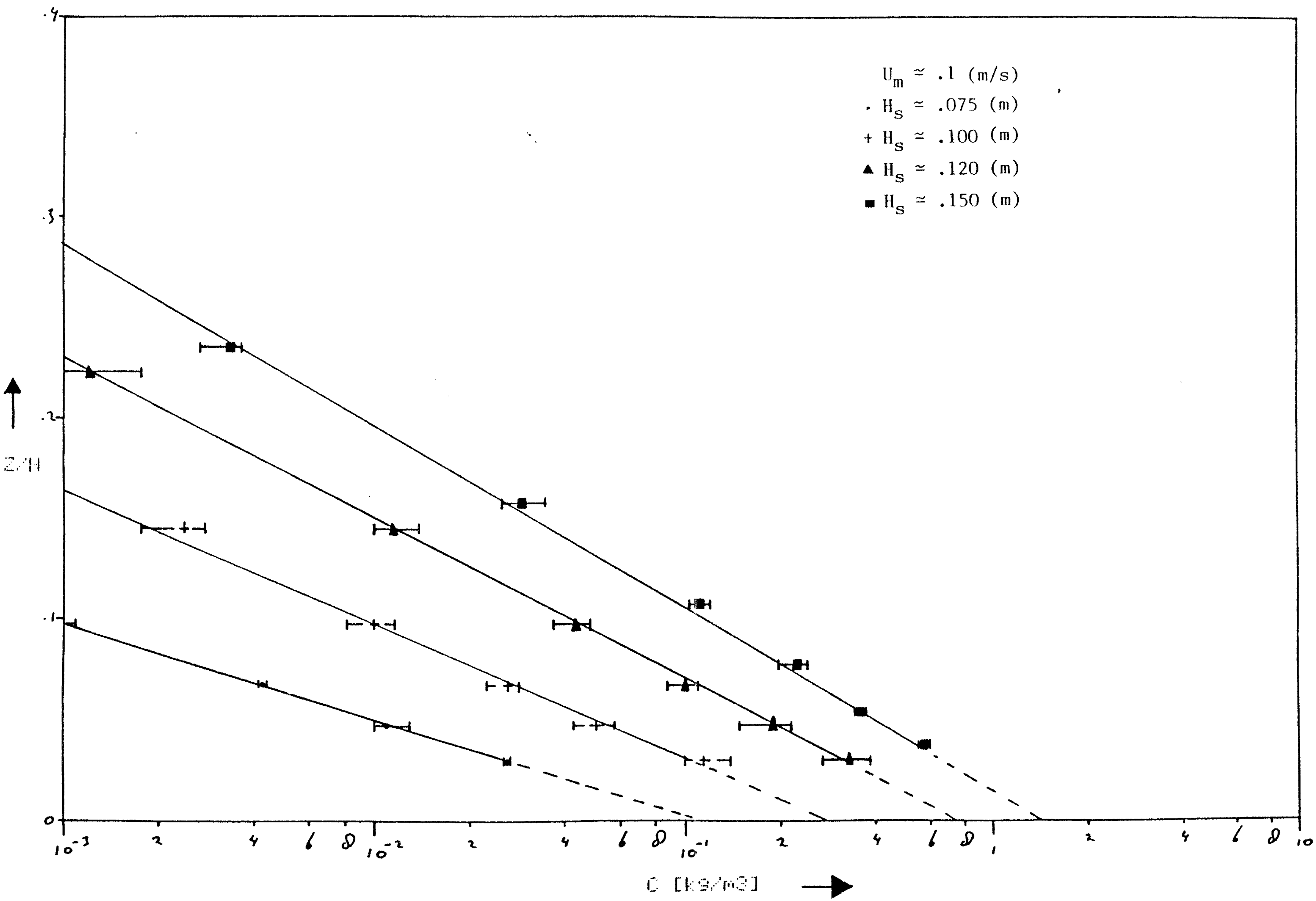



FIG. 3.2 B

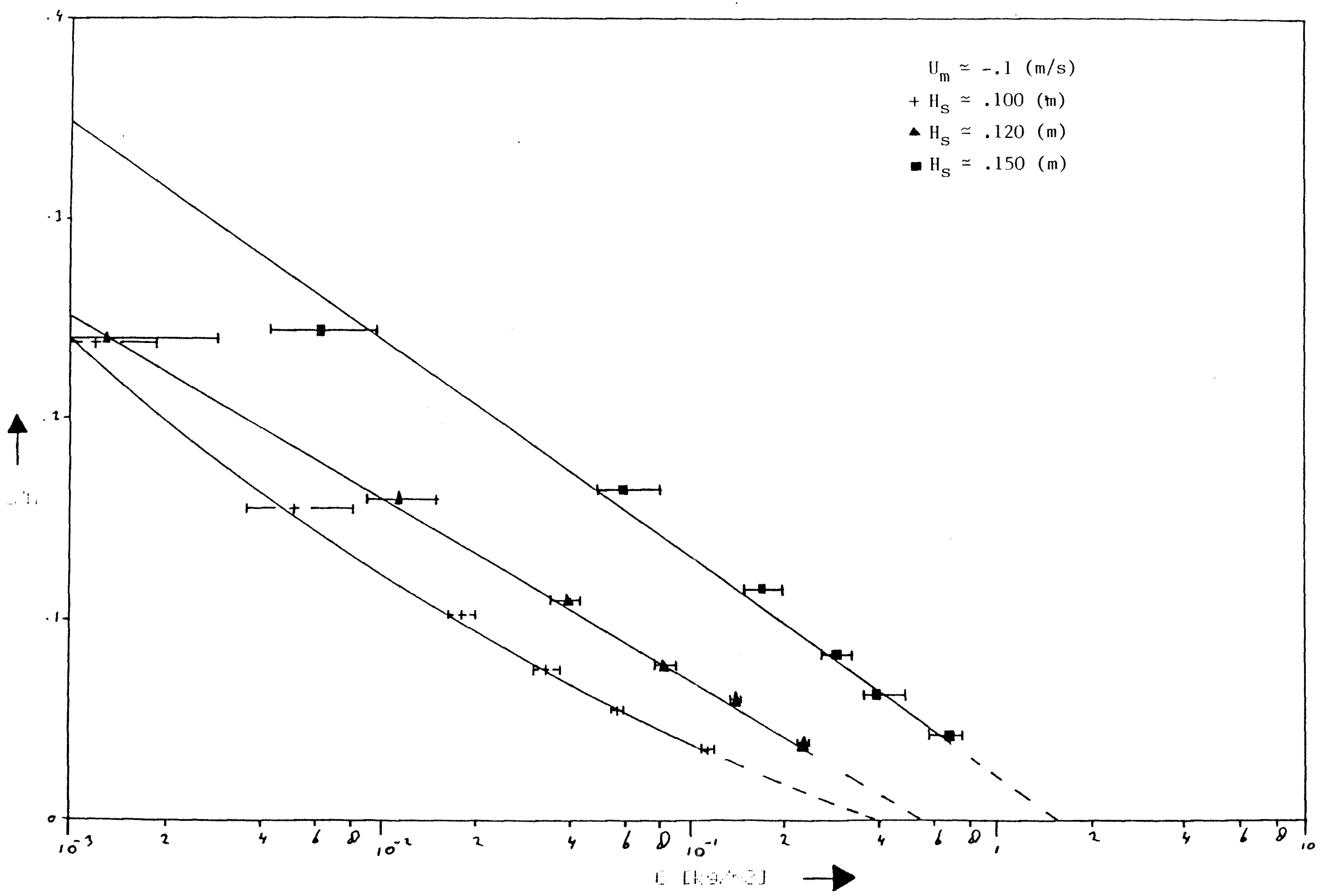



FIG. 3.2 C

MEASURED CONCENTRATIONS WITH ERROR RANGES

MEASURED CONCENTRATIONS WITH ERROR RANGES

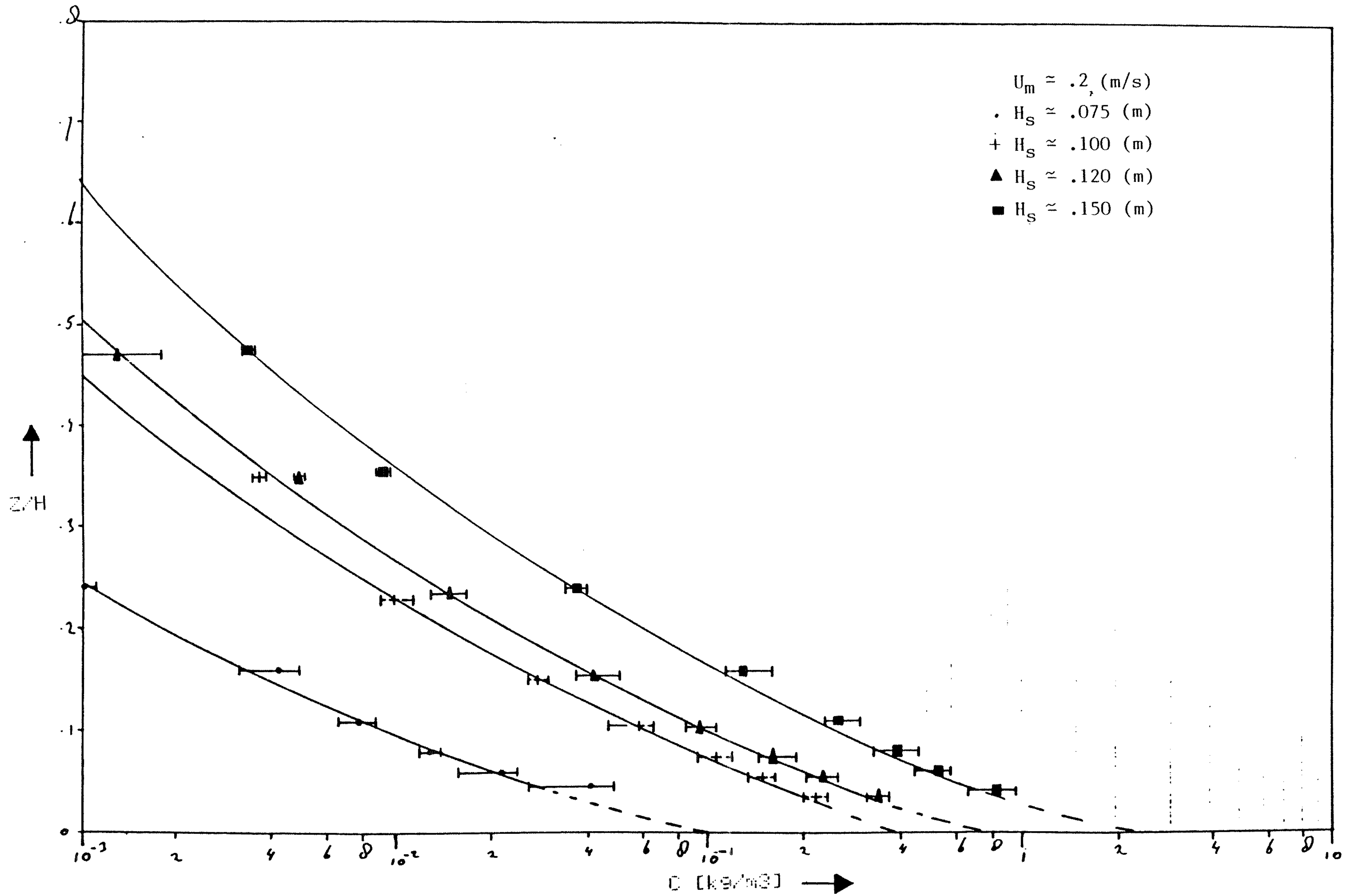
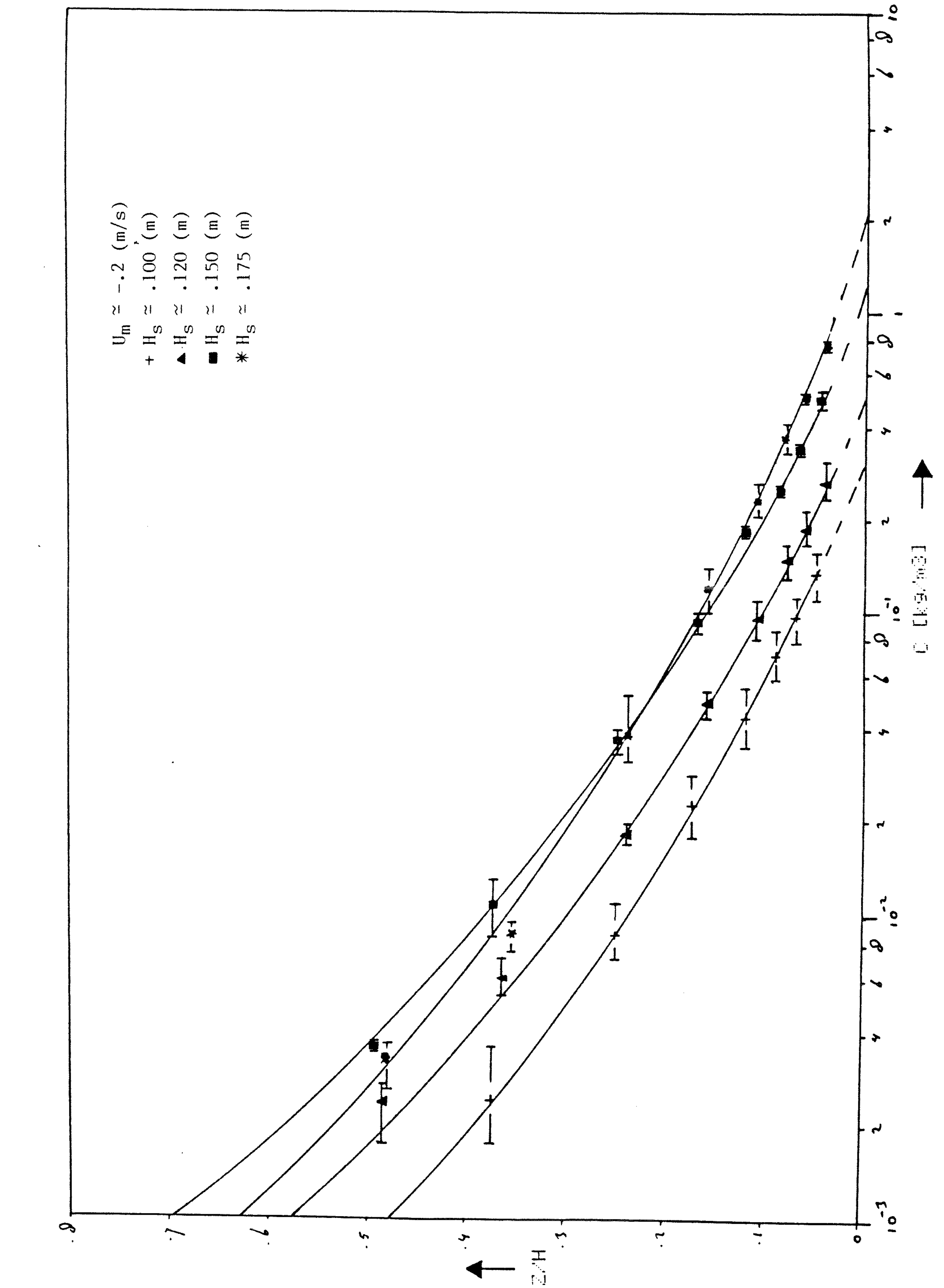
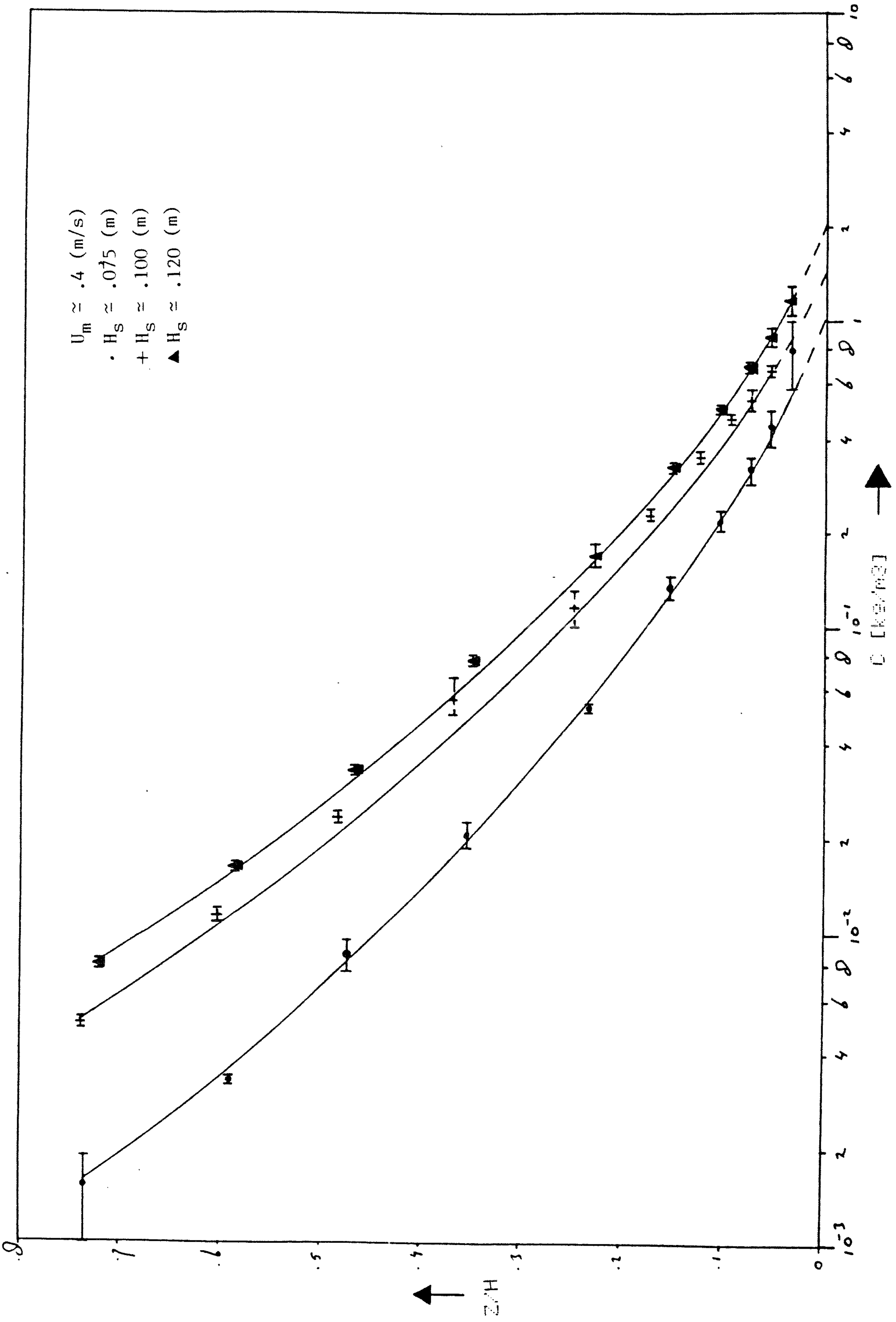



FIG. 3.2 D



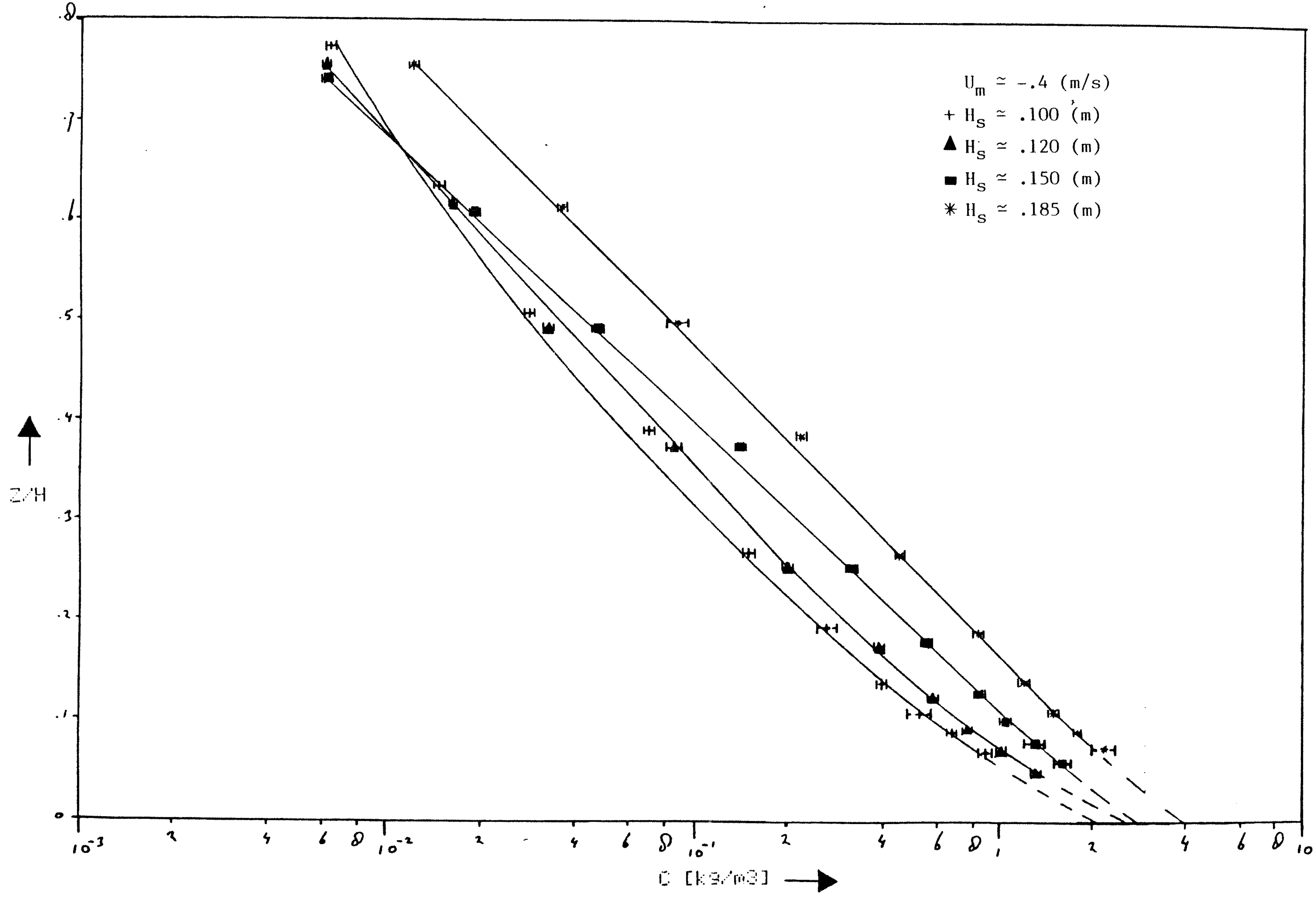

MEASURED CONCENTRATIONS WITH ERROR RANGES

FIG. 3.2 E



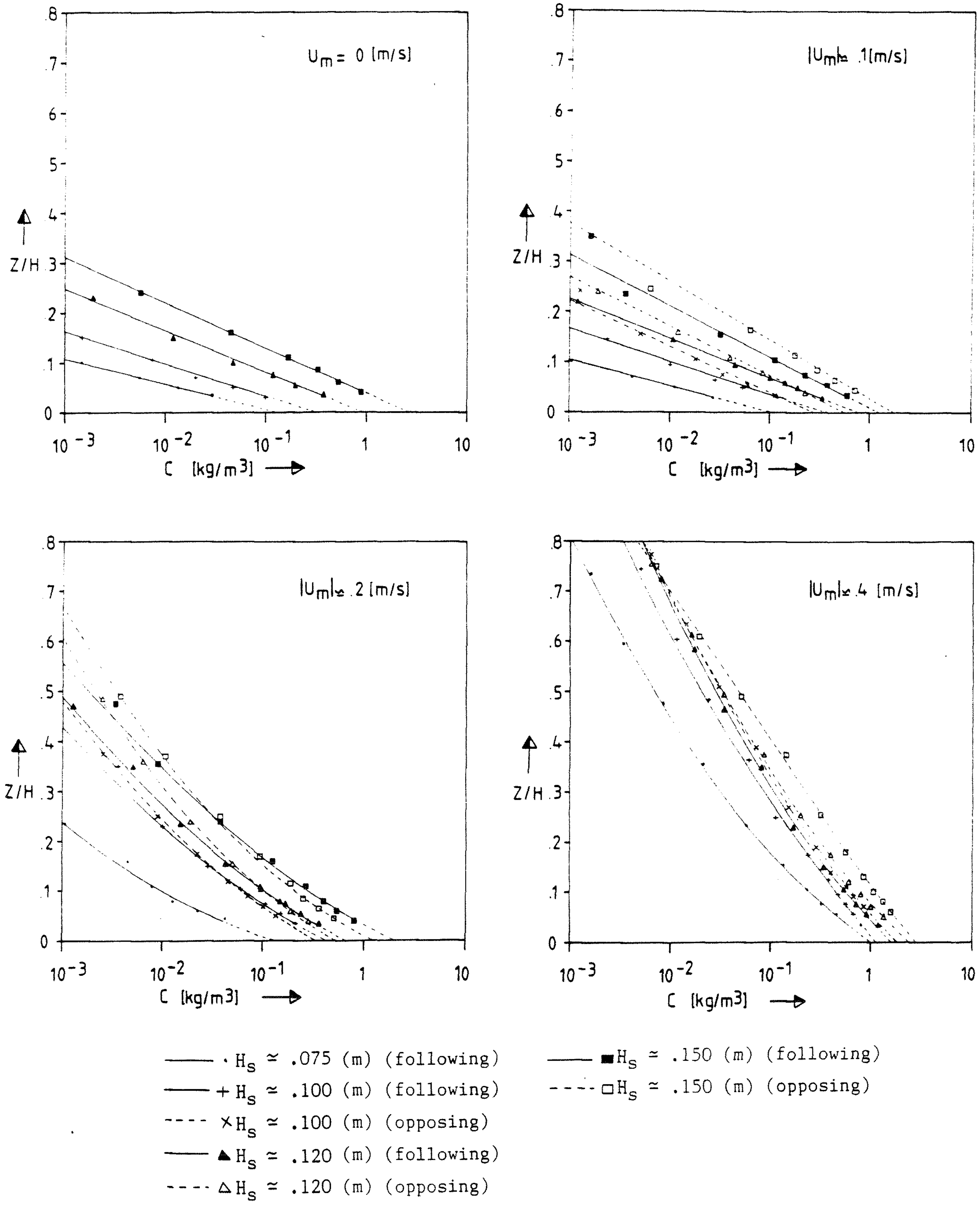

MEASURED CONCENTRATIONS WITH ERROR RANGES

FIG. 3.2 F



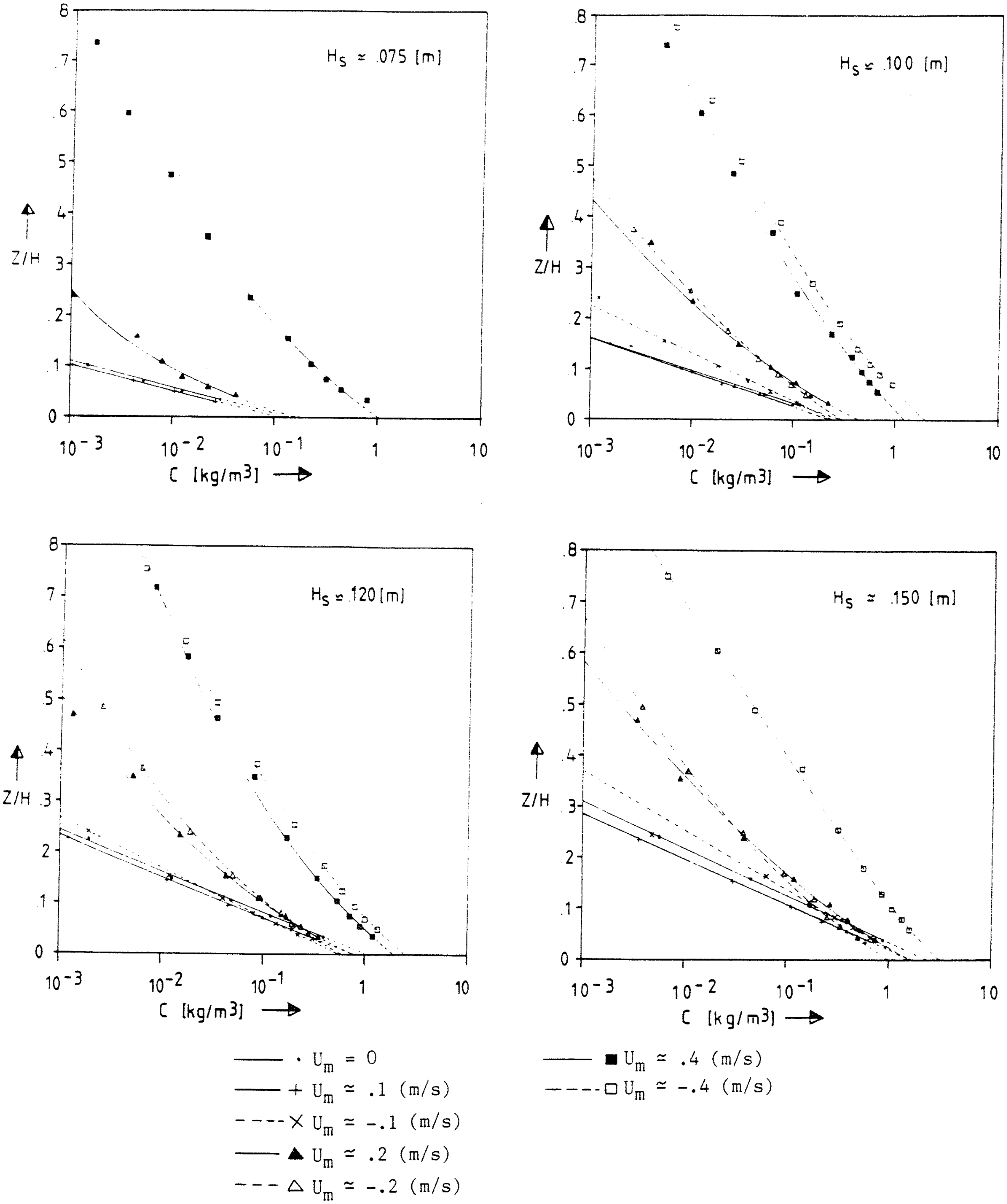

MEASURED CONCENTRATIONS WITH ERROR RANGES

FIG. 3.2 G



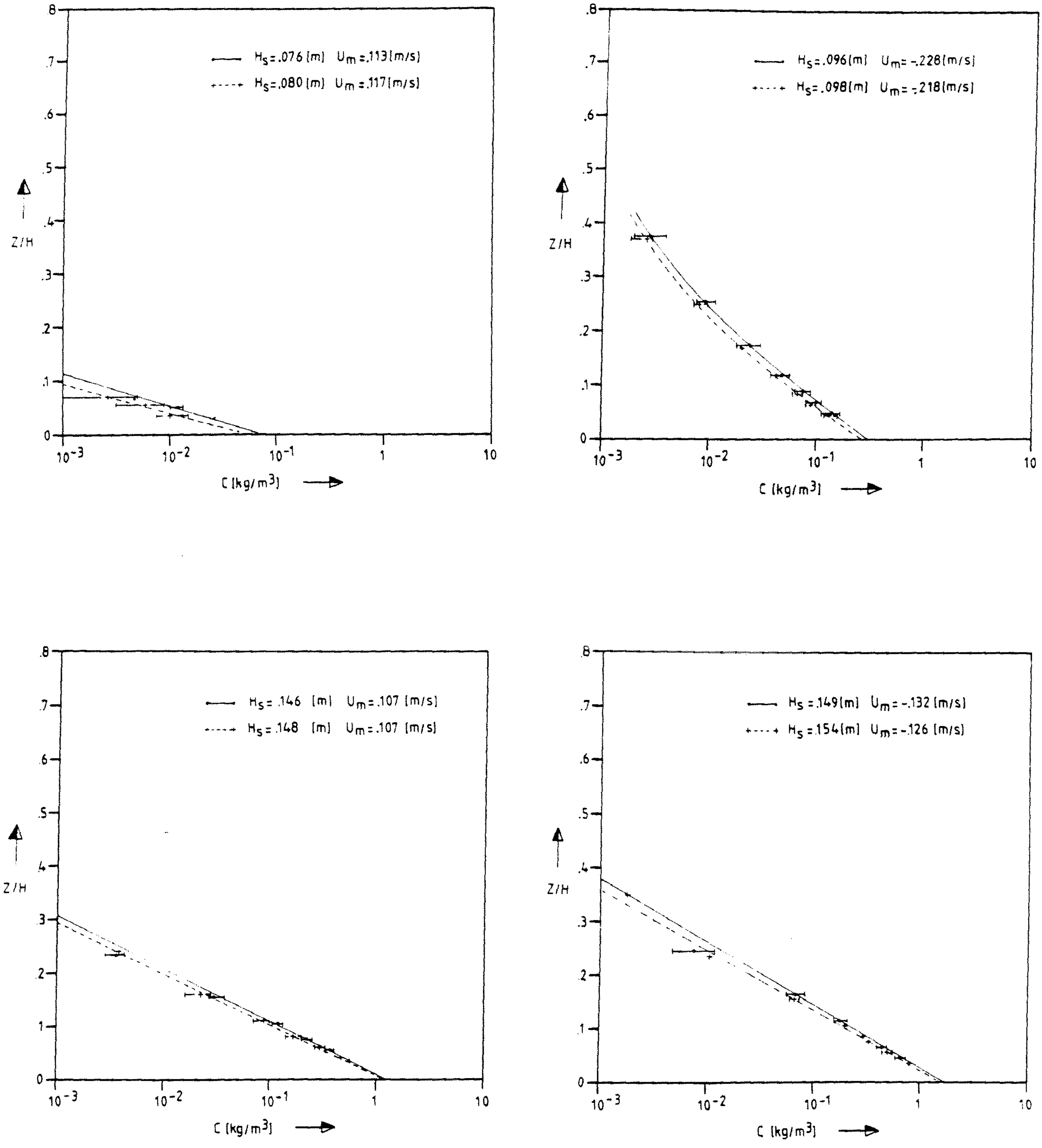

INFLUENCE OF WAVEHEIGHT ON CONCENTRATION DISTRIBUTION

FIG. 3.3



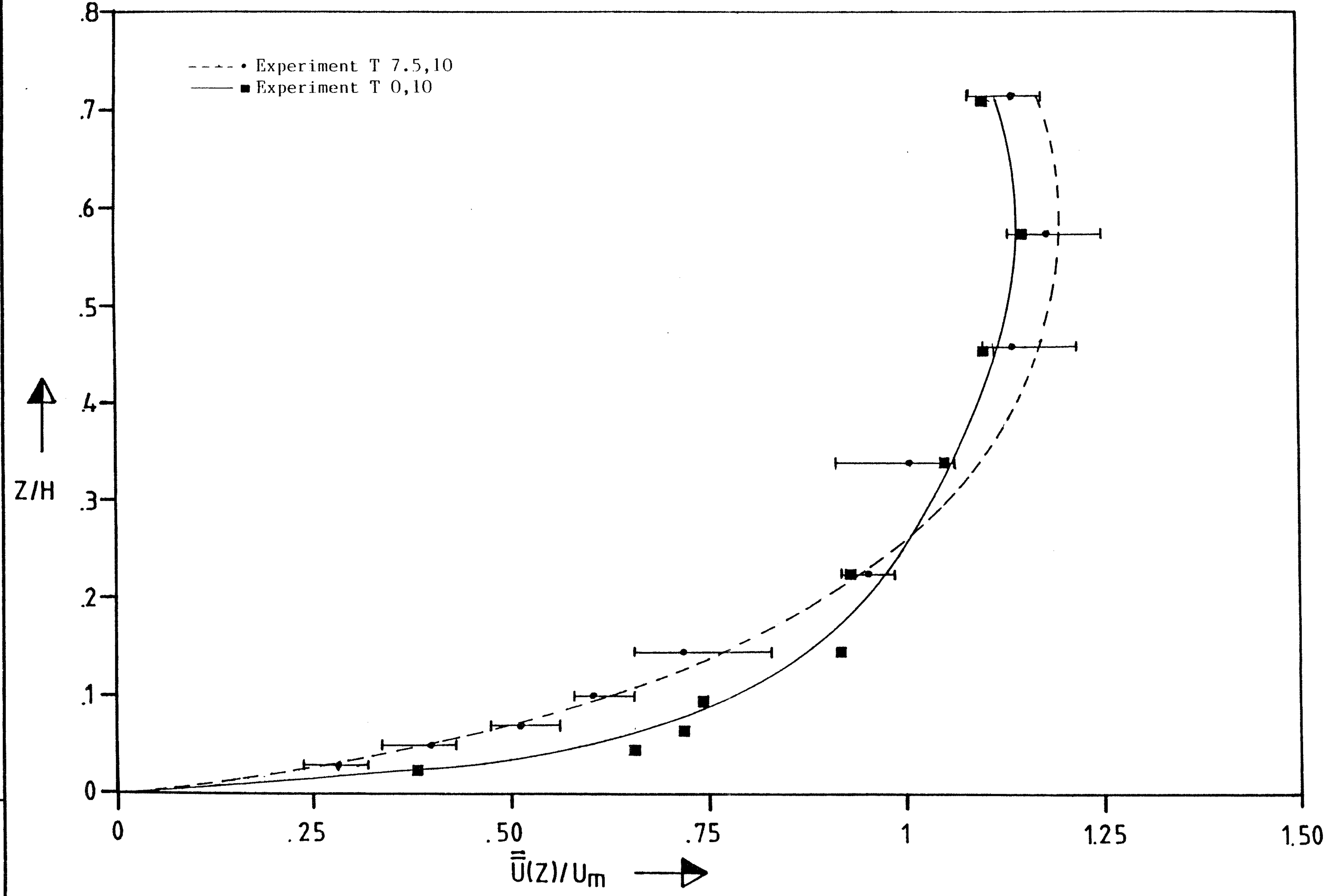

INFLUENCE OF DEPTH AVERAGED VELOCITY ON CONCENTRATION DISTRIBUTION

FIG. 3.4



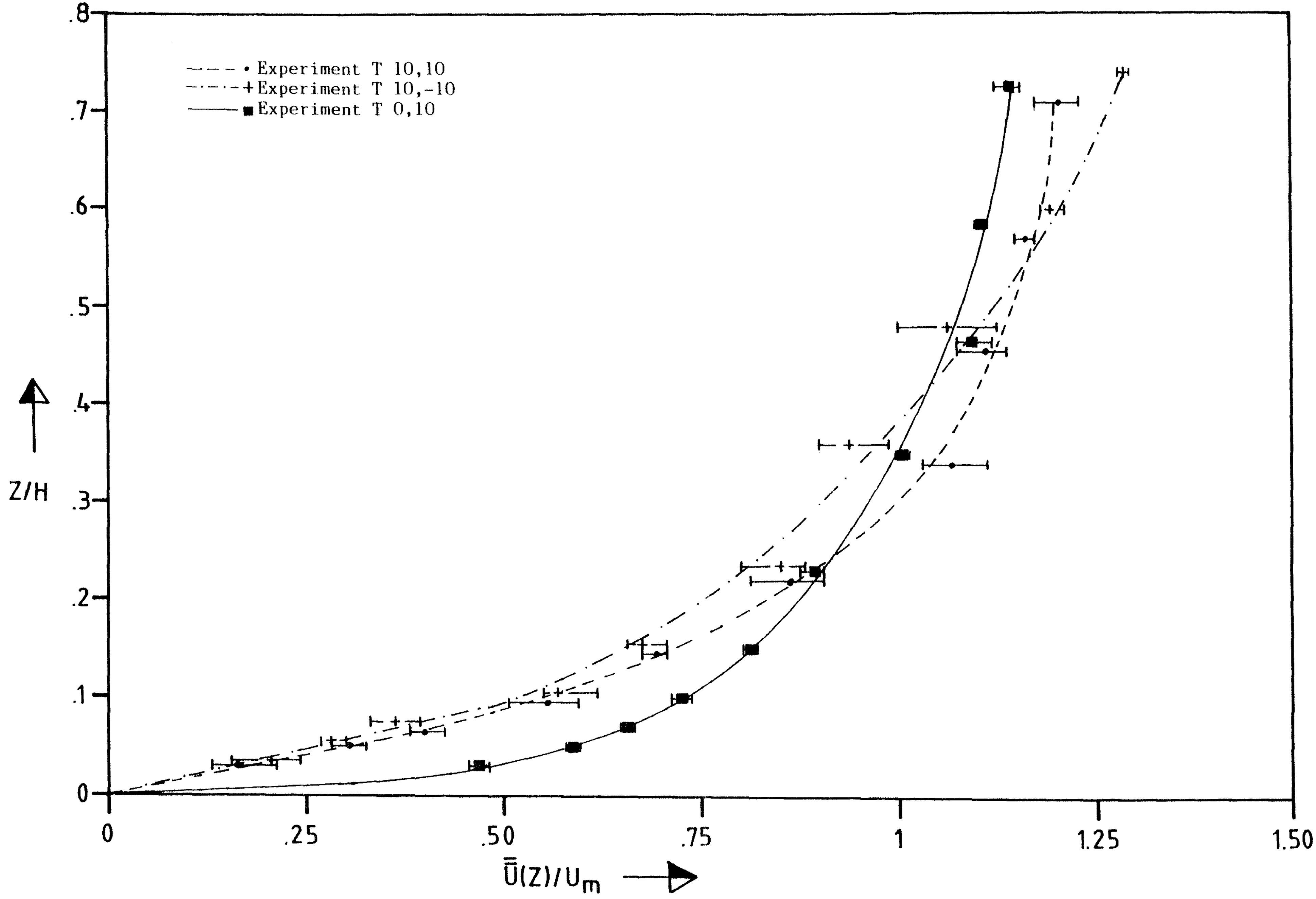

REPRODUCIBILITY OF CONCENTRATION PROFILES

FIG. 3.5



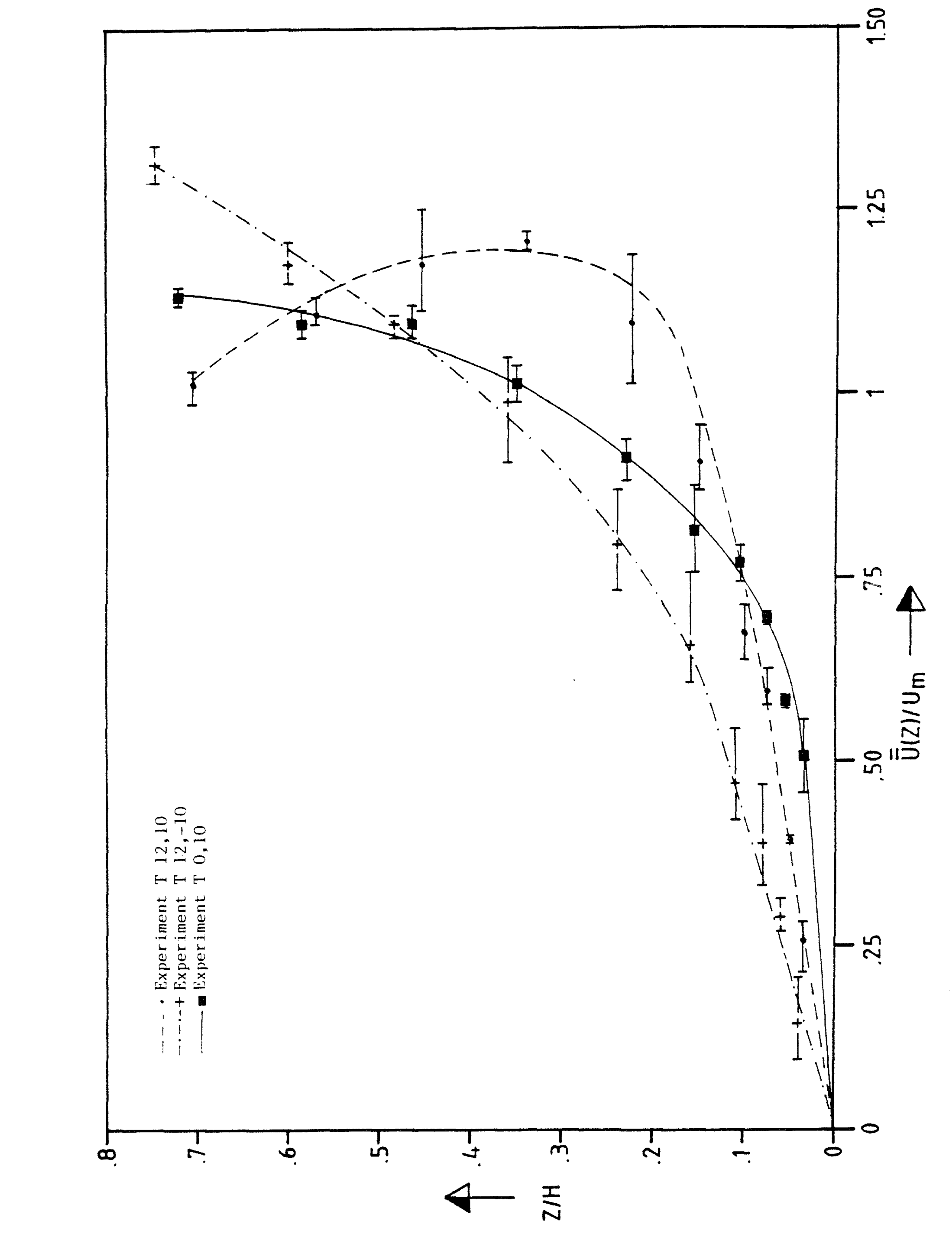

MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 A




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 B




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 C

MEASURED VELOCITIES WITH ERROR RANGES

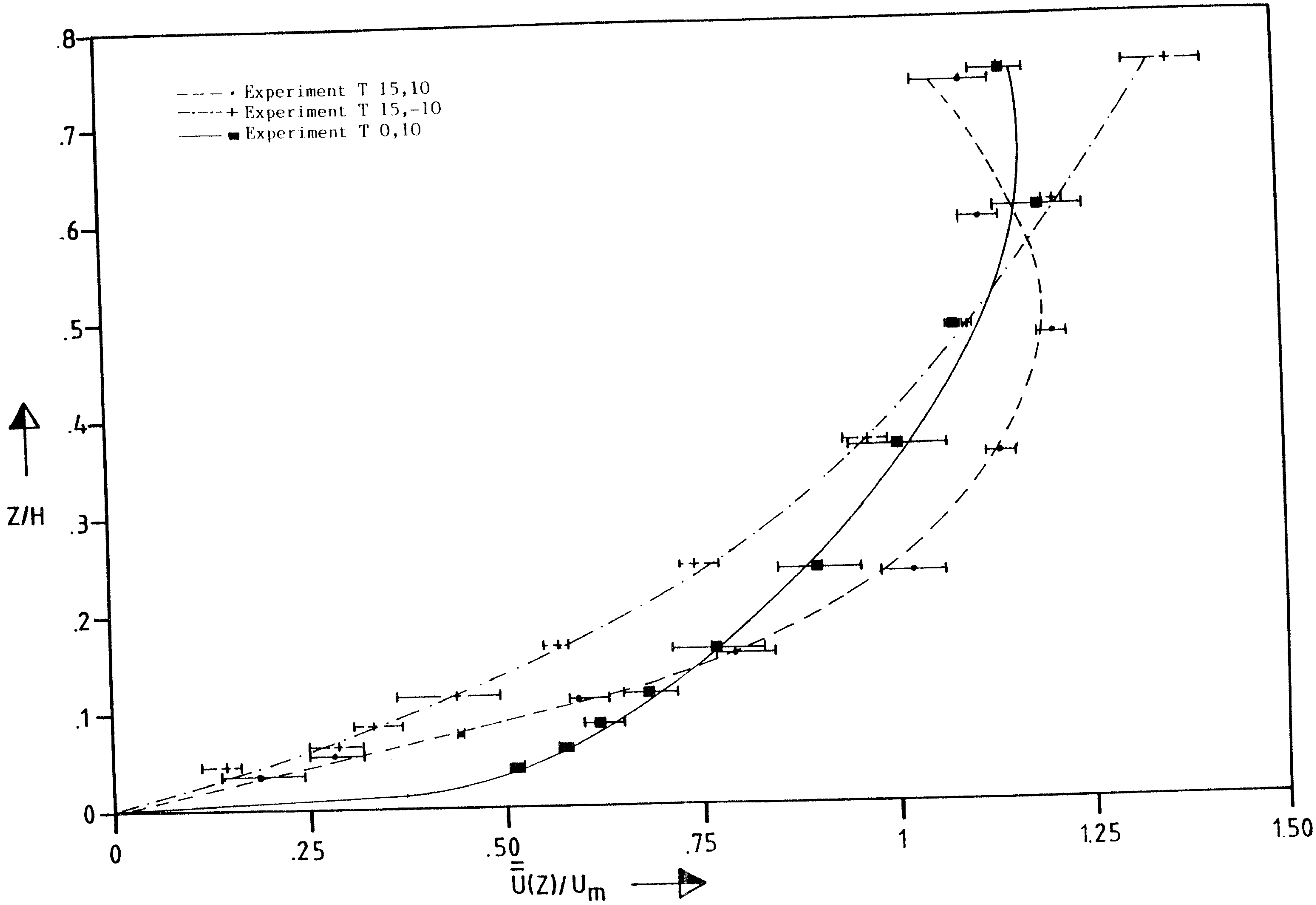
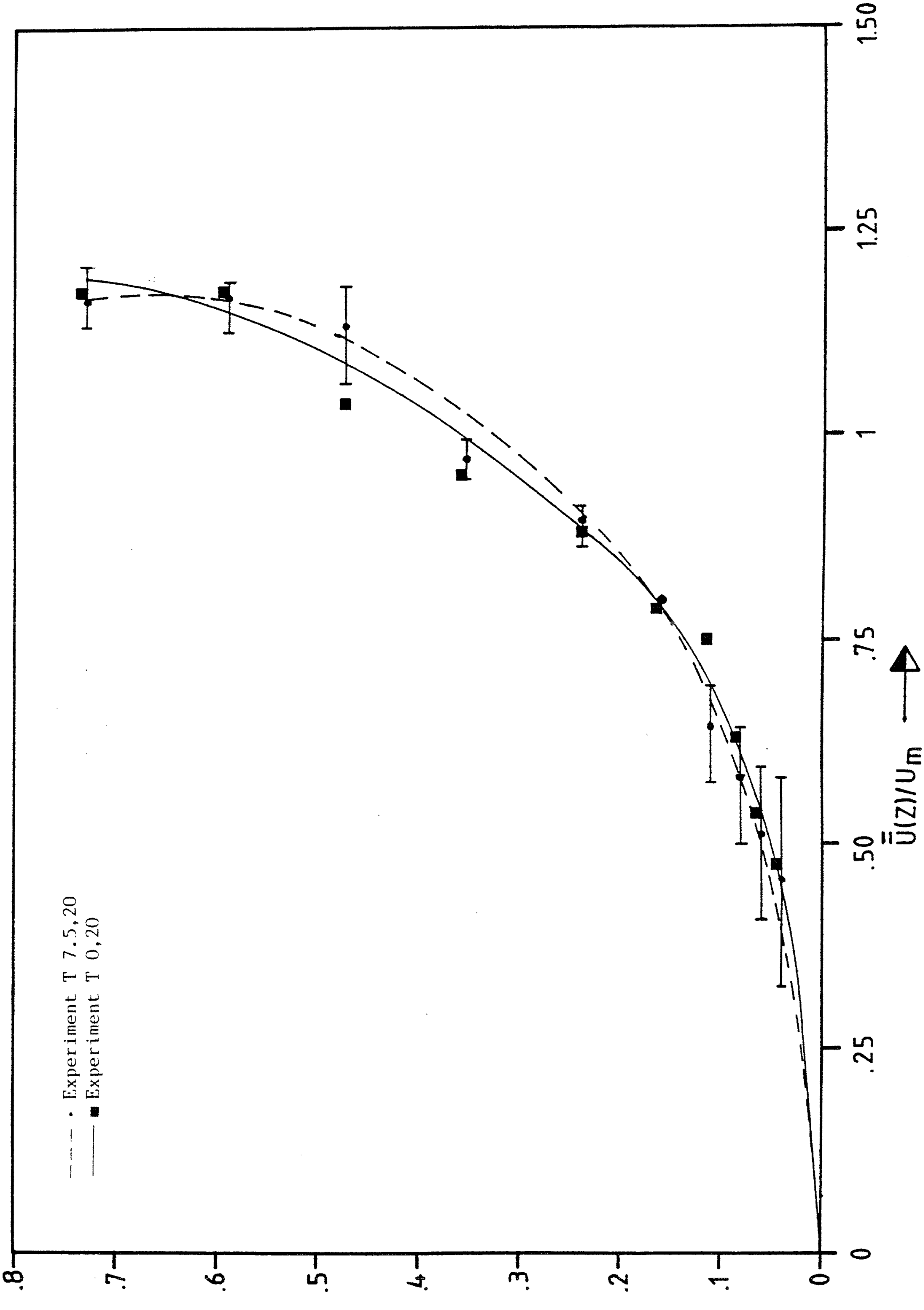



FIG. 3.6 D




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 E

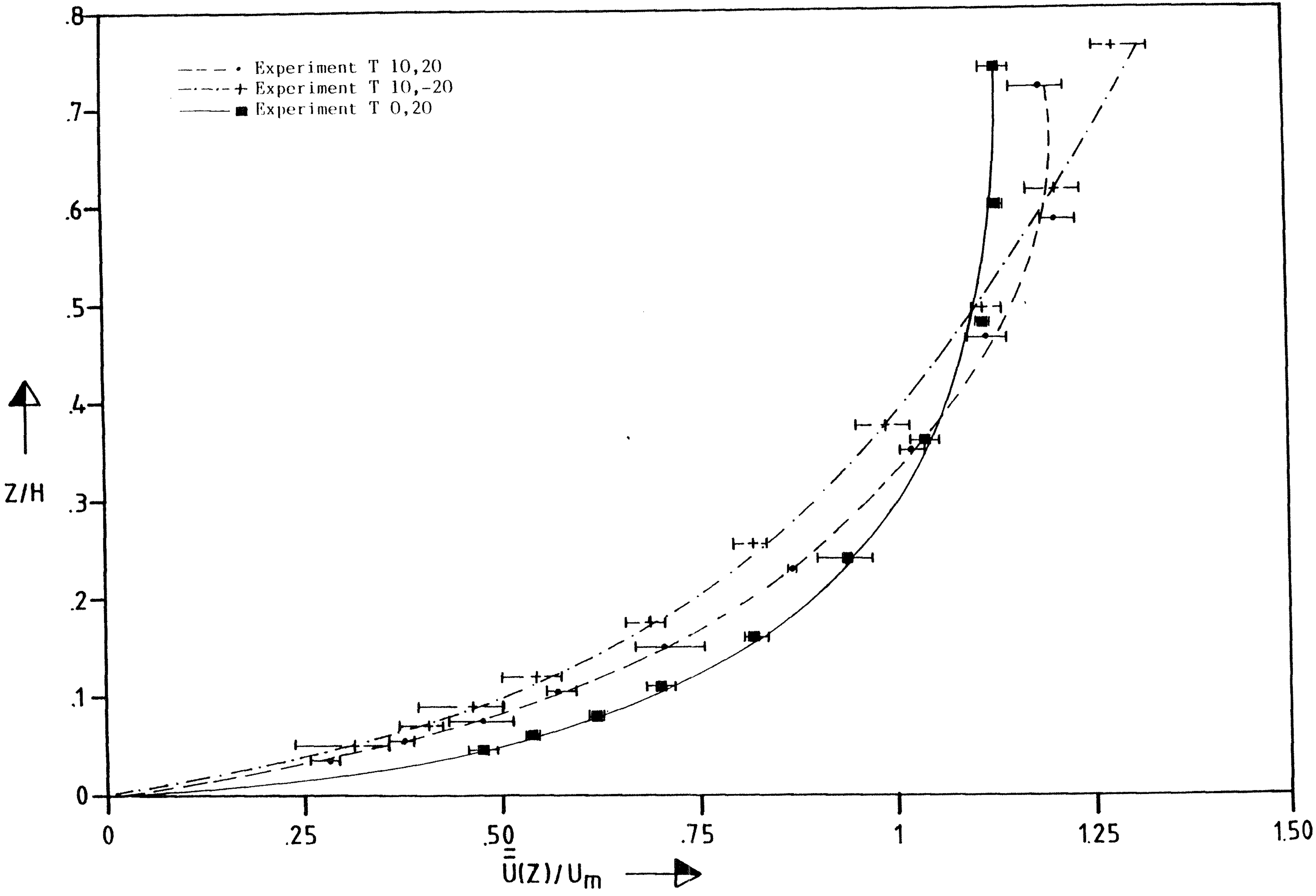



FIG. 3.6 F MEASURED VELOCITIES WITH ERROR RANGES

MEASURED VELOCITIES WITH ERROR RANGES

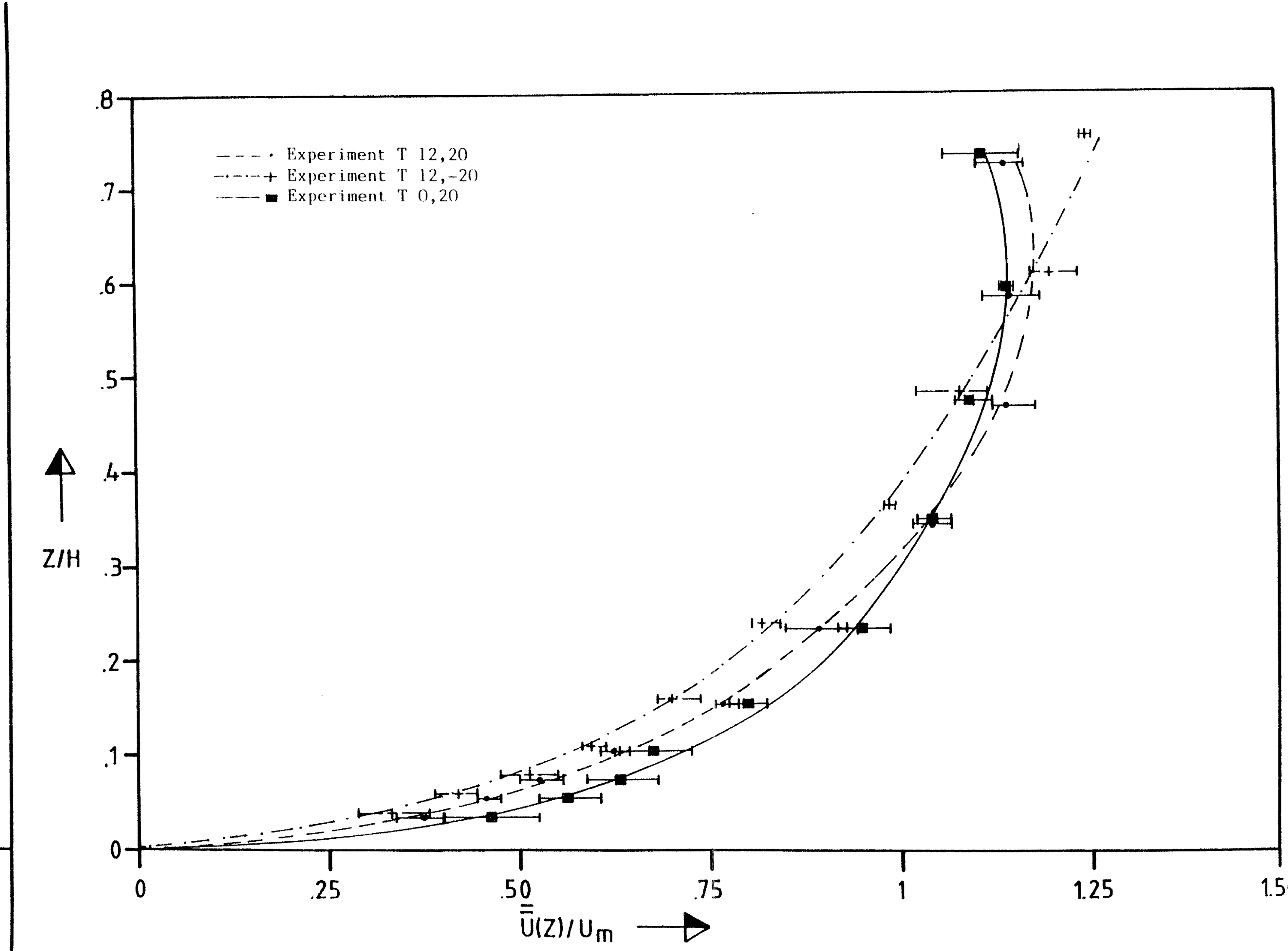
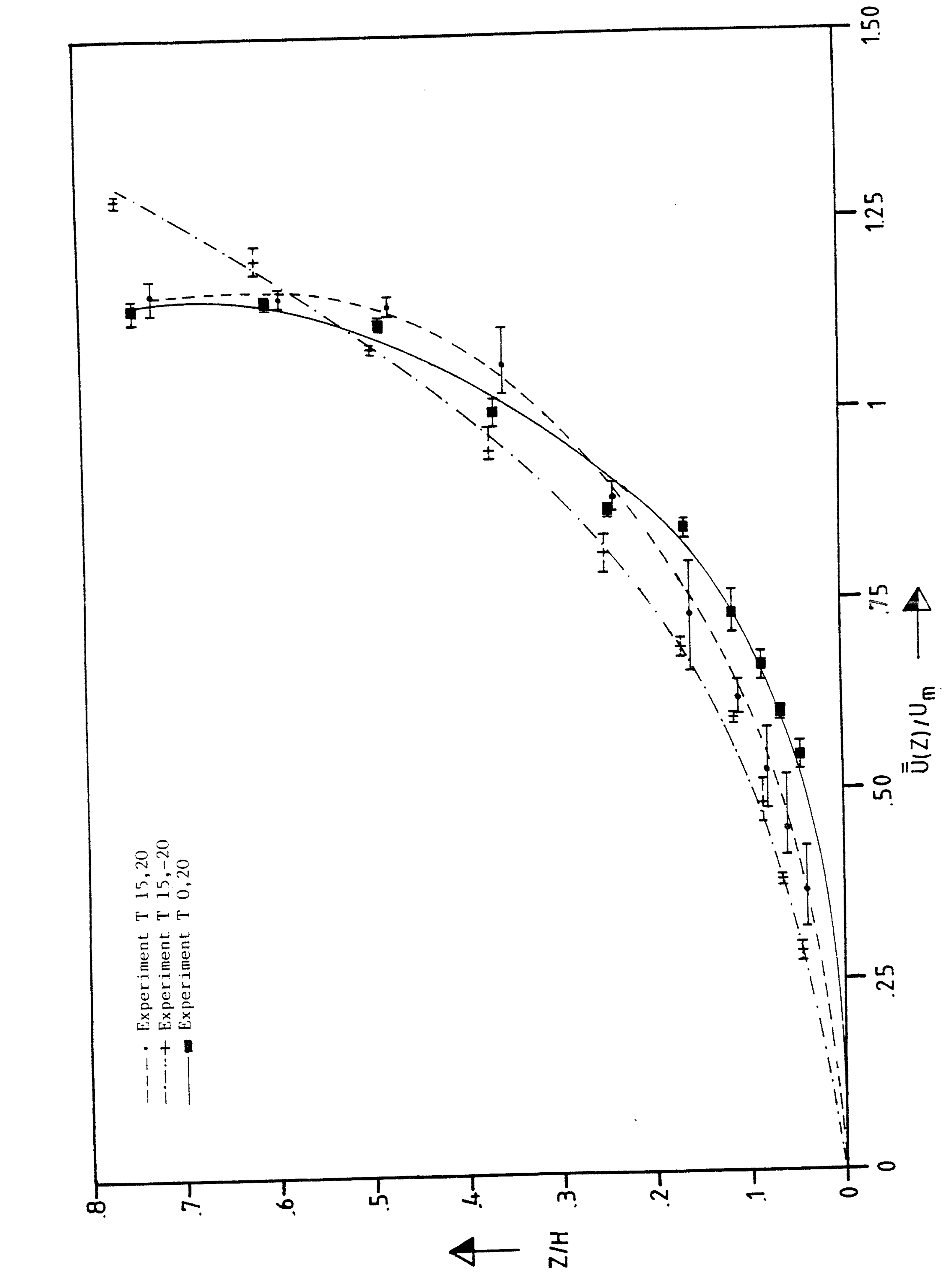
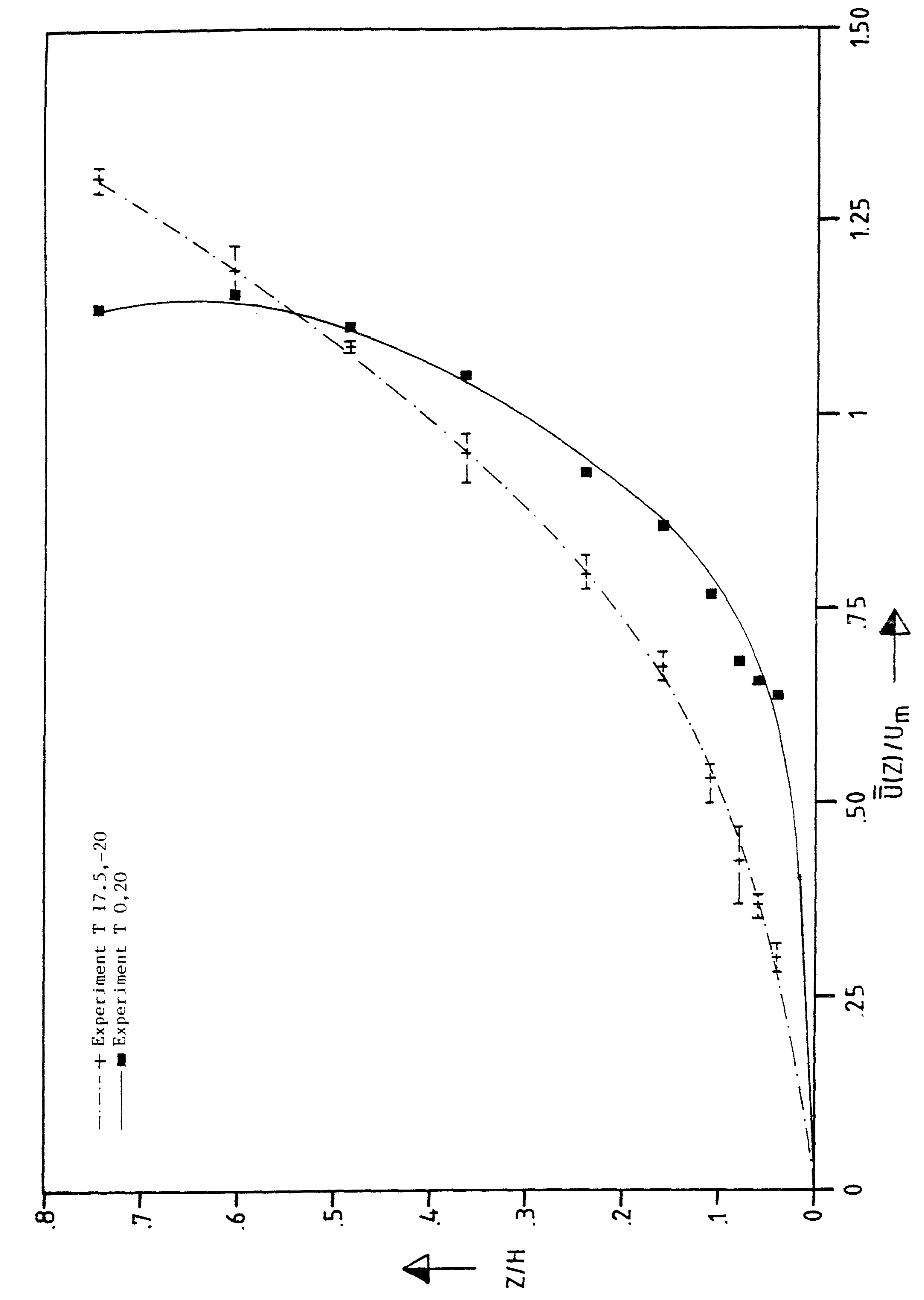



FIG. 3.6 G




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 H




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 I

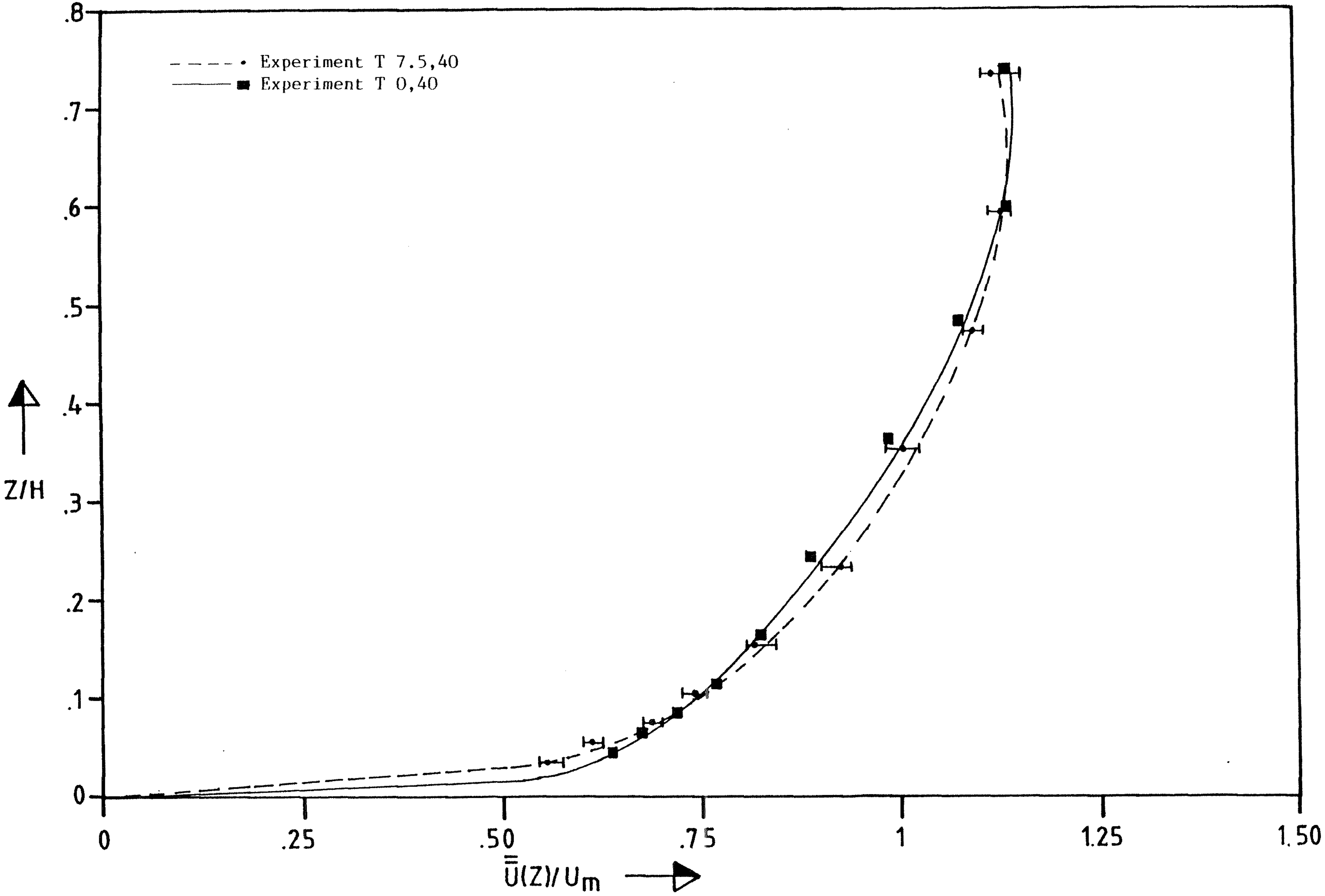
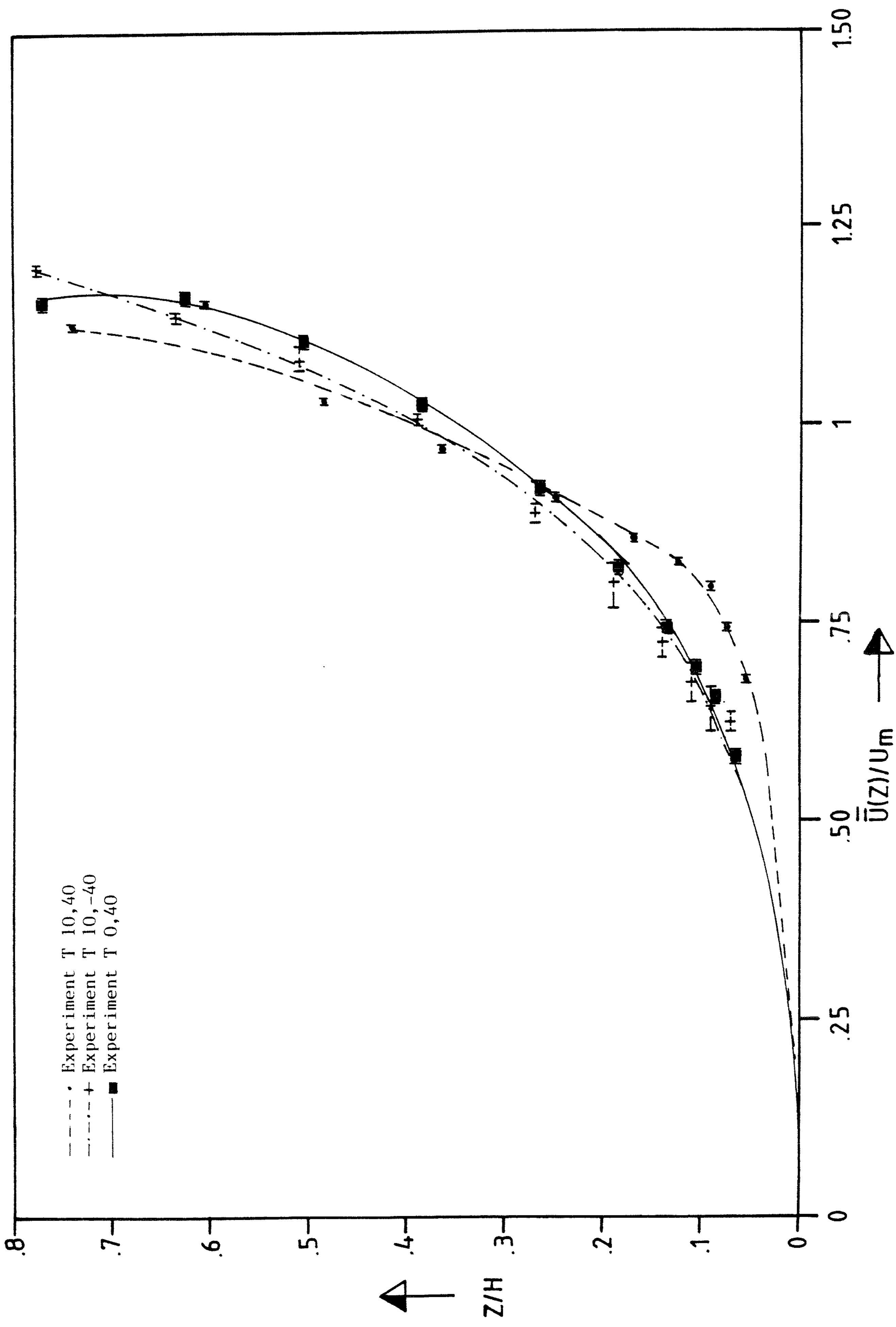


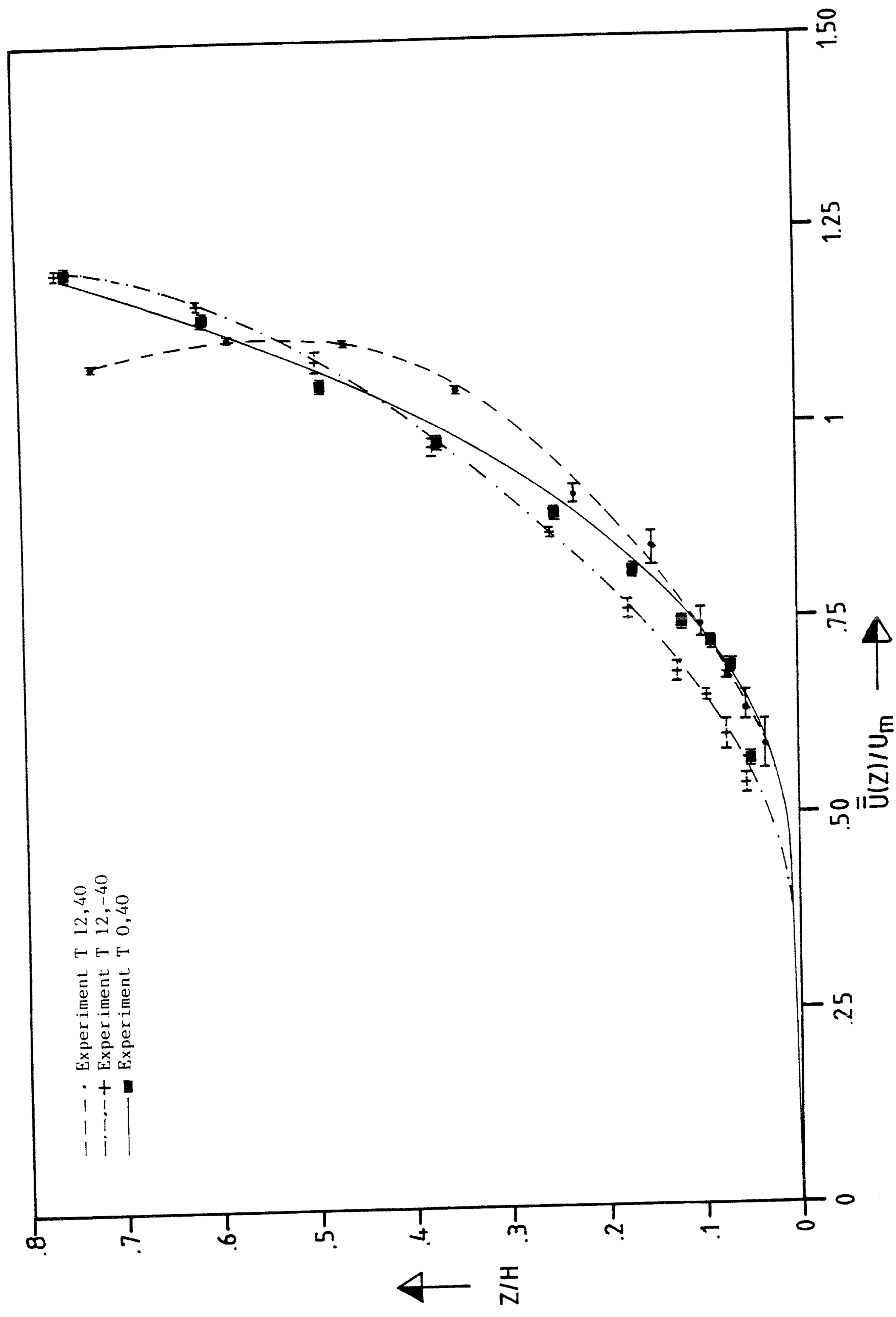

FIG. 3.6 J

MEASURED VELOCITIES WITH ERROR RANGES




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 K




MEASURED VELOCITIES WITH ERROR RANGES

FIG. 3.6 L

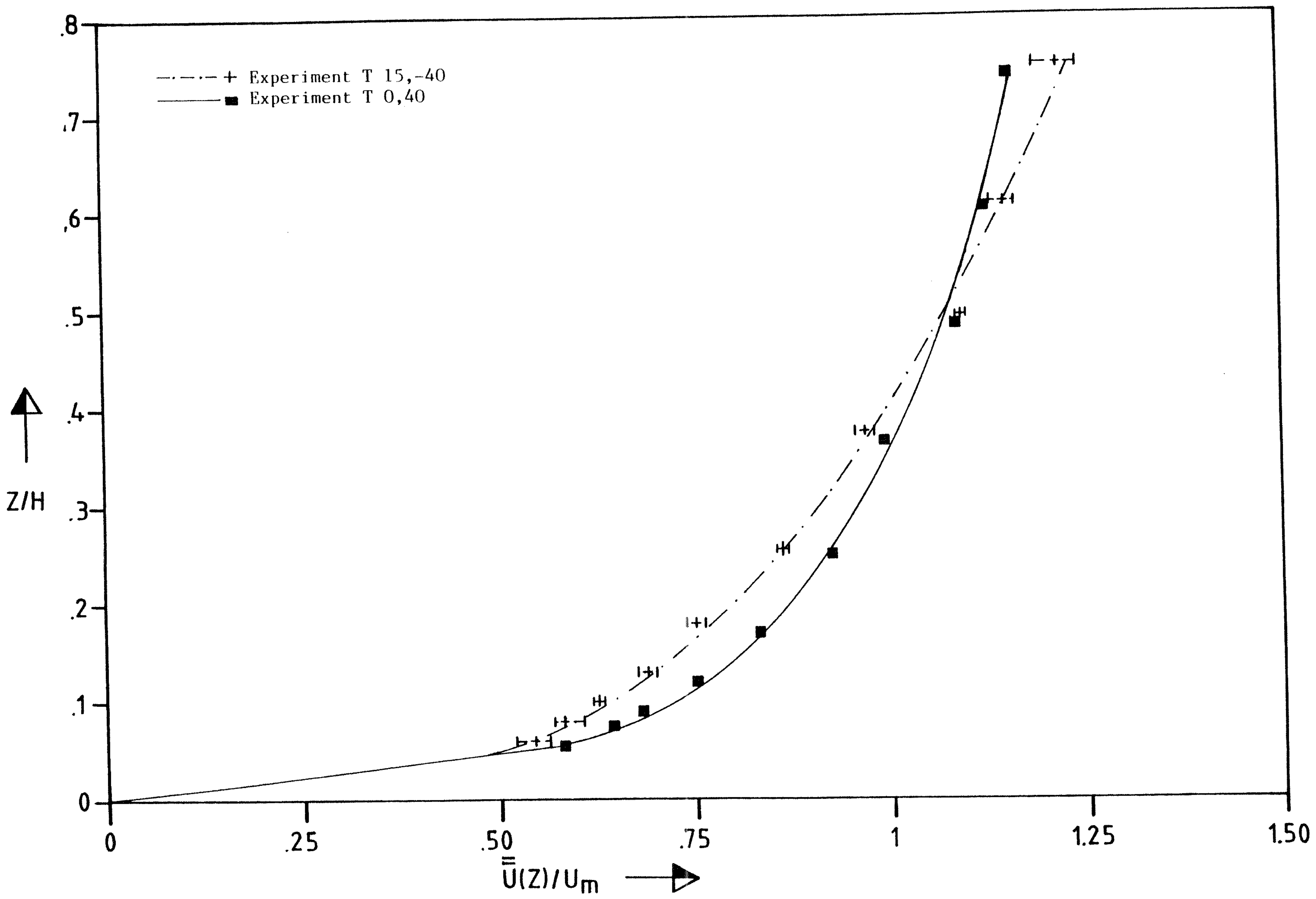



FIG. 3.6 M

MEASURED VELOCITIES WITH ERROR RANGES

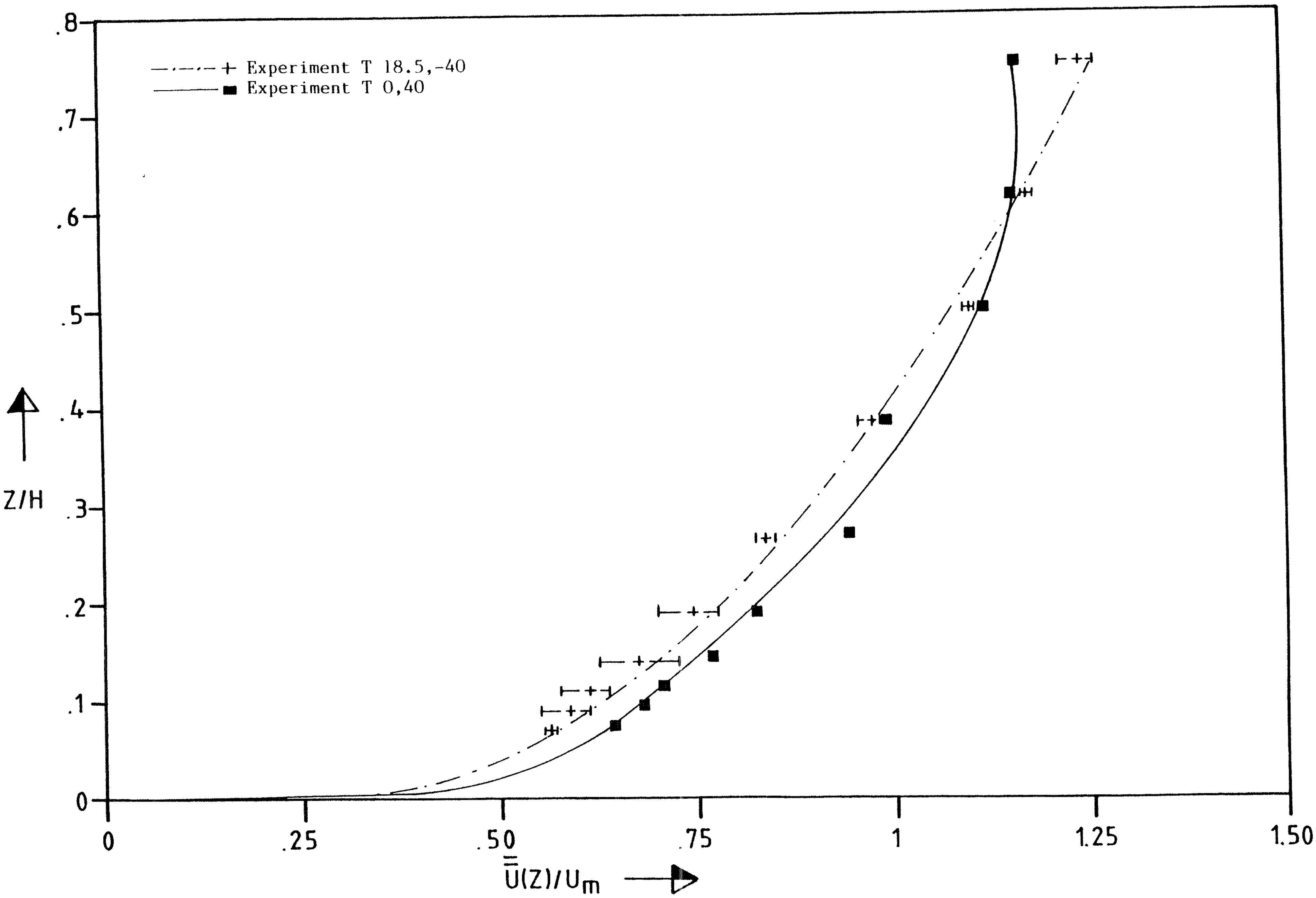
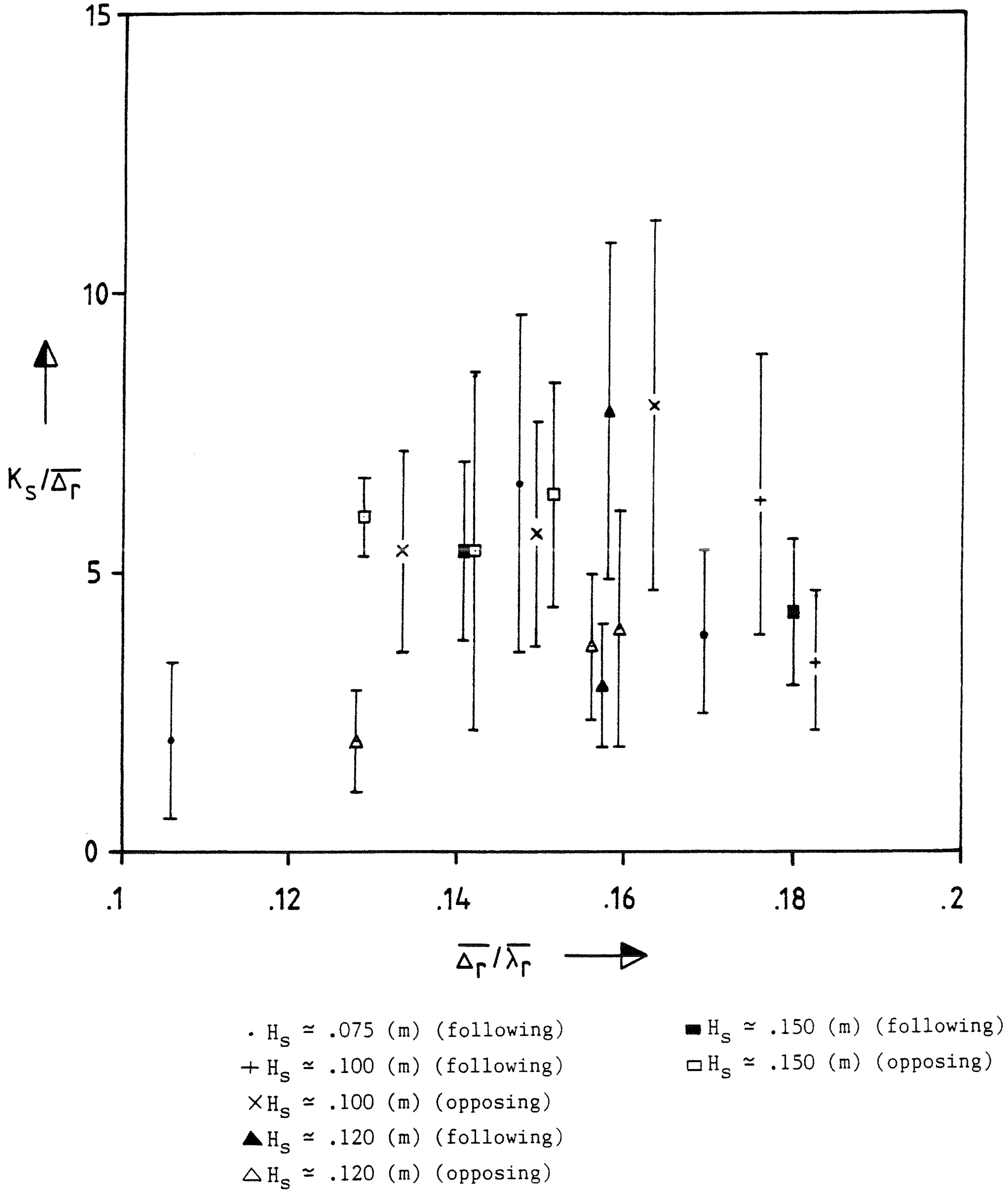
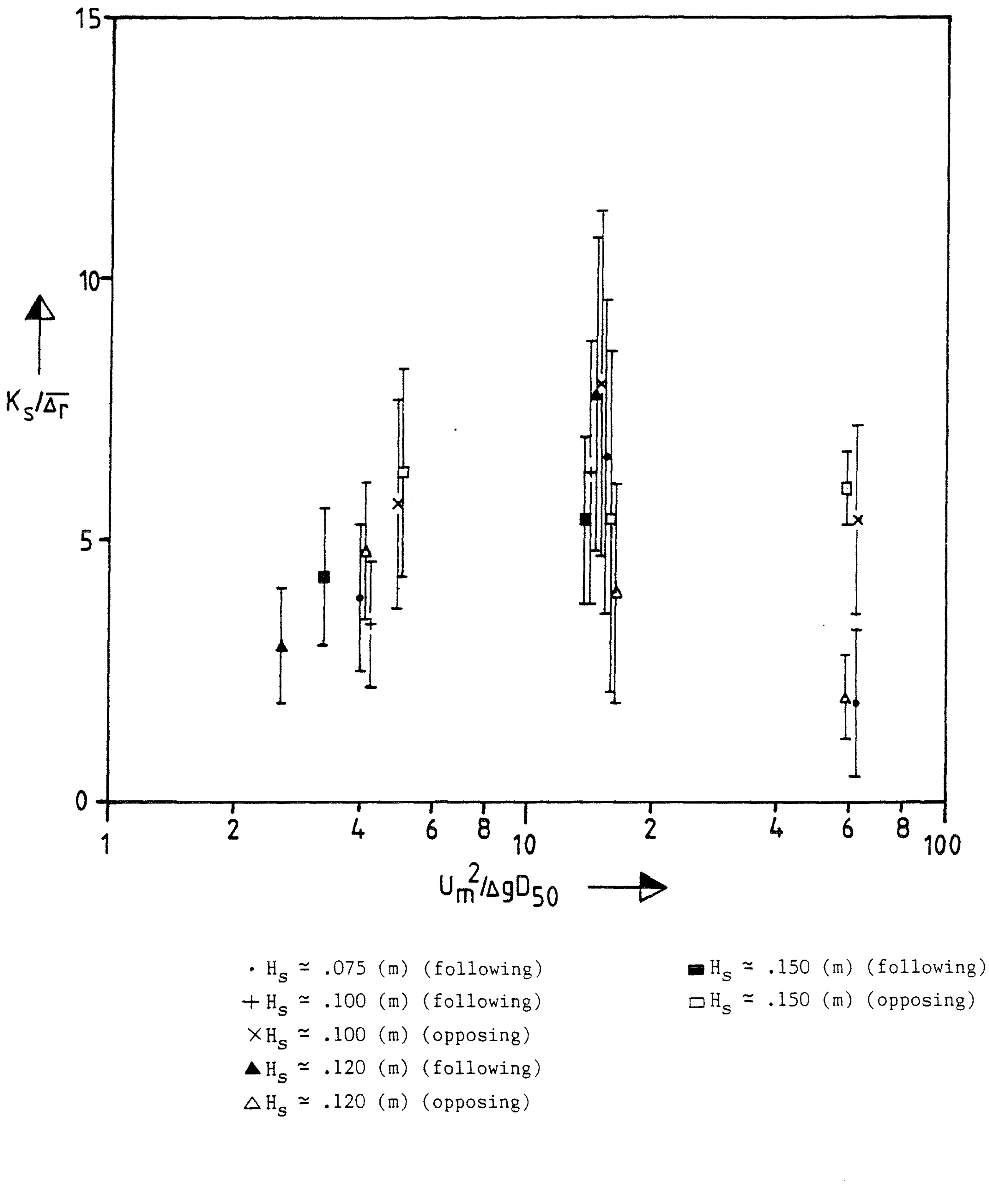



FIG. 3.6 MEASURED VELOCITIES WITH ERROR RANGES



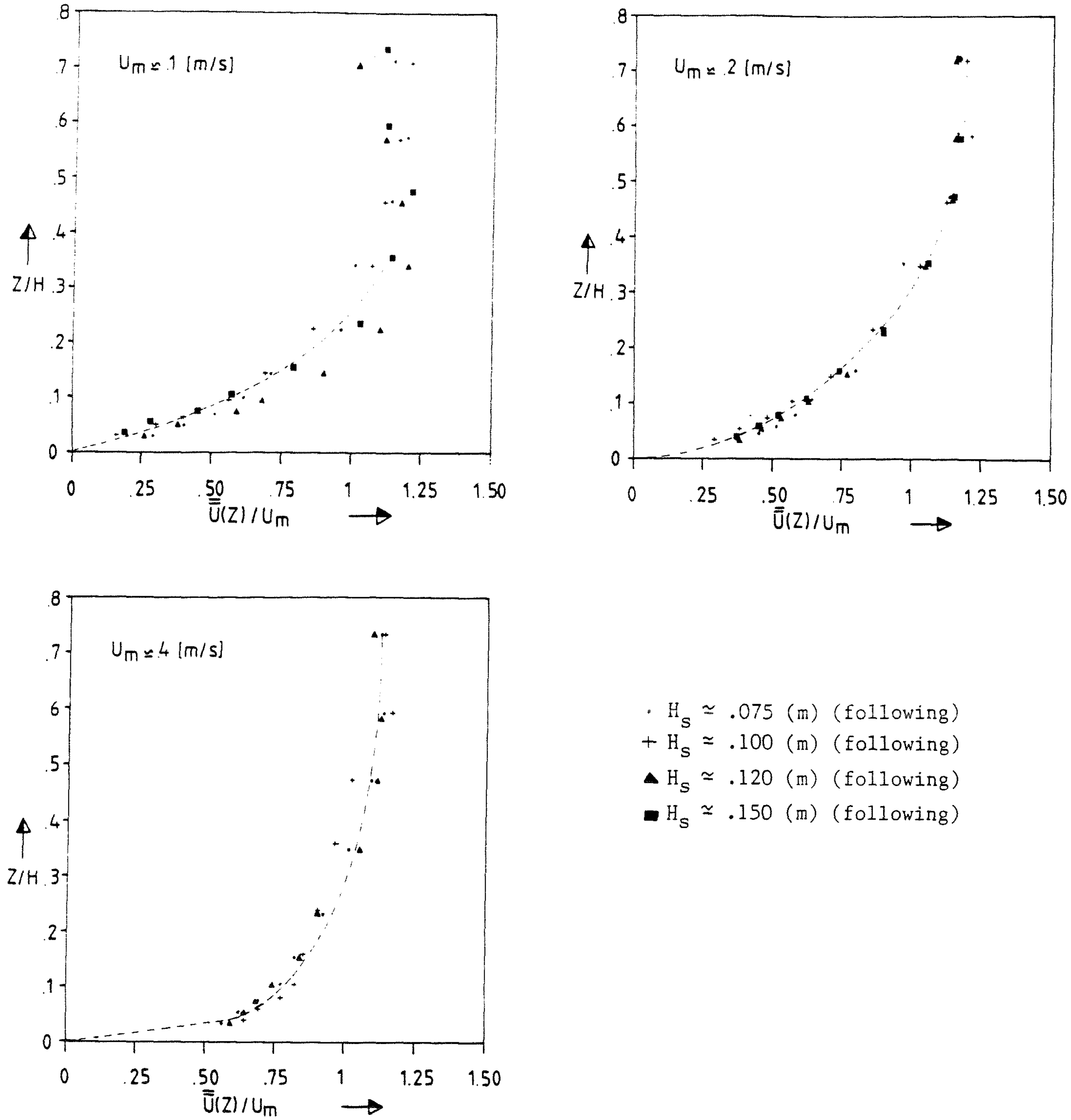

DEPENDENCE OF RELATIVE BED ROUGHNESS ON RIPPLE STEEPNESS

FIG. 3.7



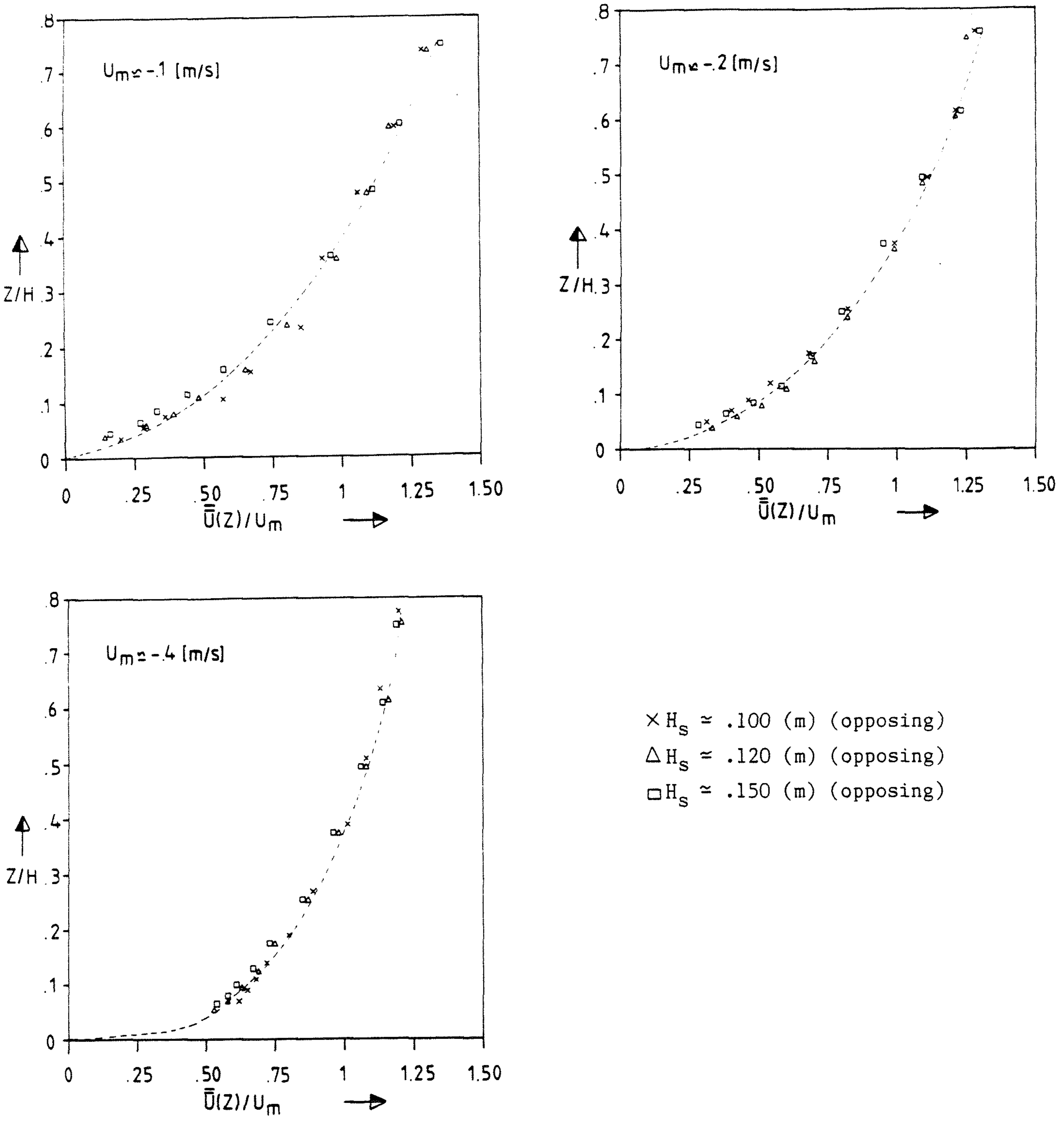

DEPENDENCE OF RELATIVE BED ROUGHNESS ON DIMENSIONLESS CURRENT PARAMETER

FIG. 3.8



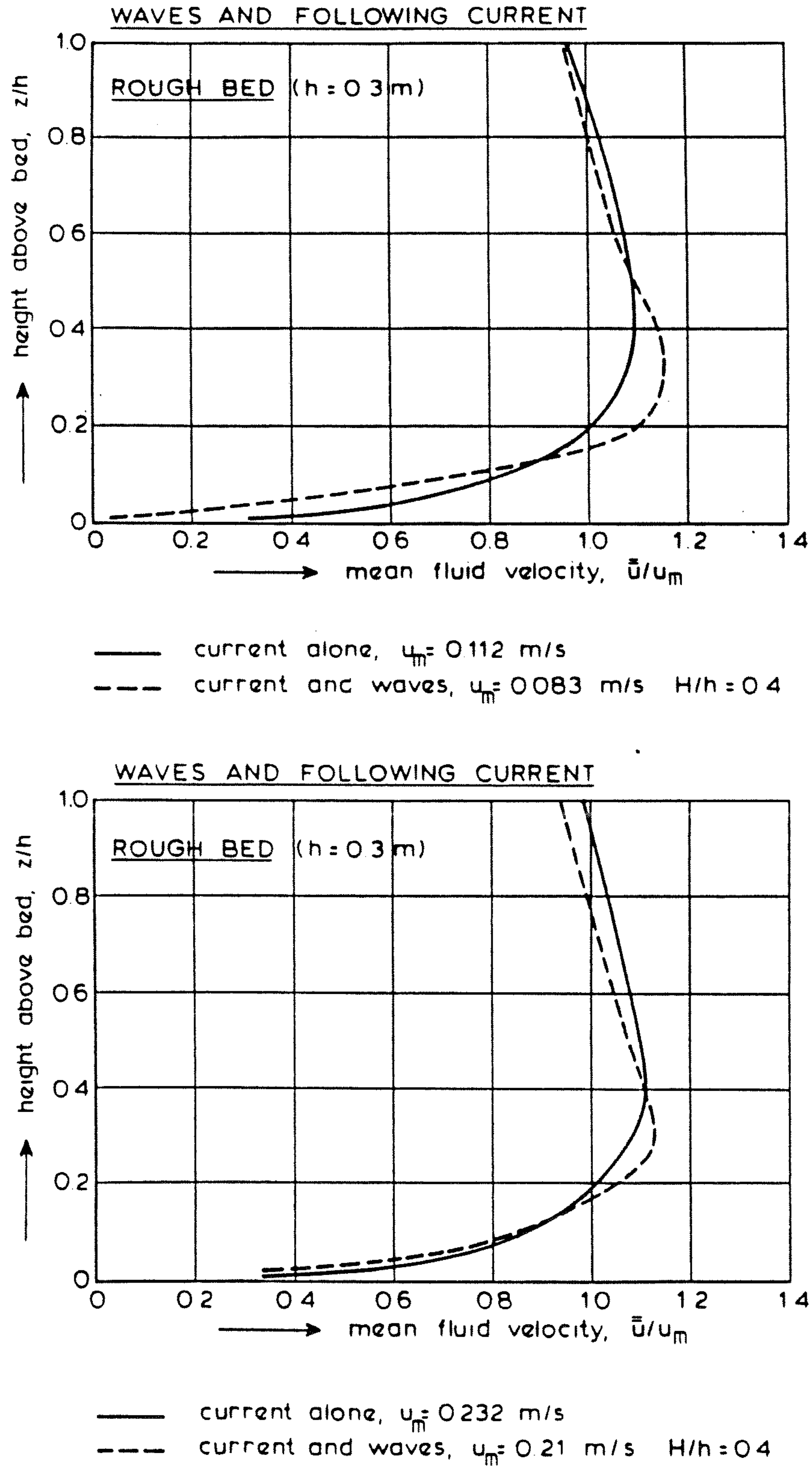

INFLUENCE OF WAVEHEIGHT ON VELOCITY DISTRIBUTION
FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.9 A



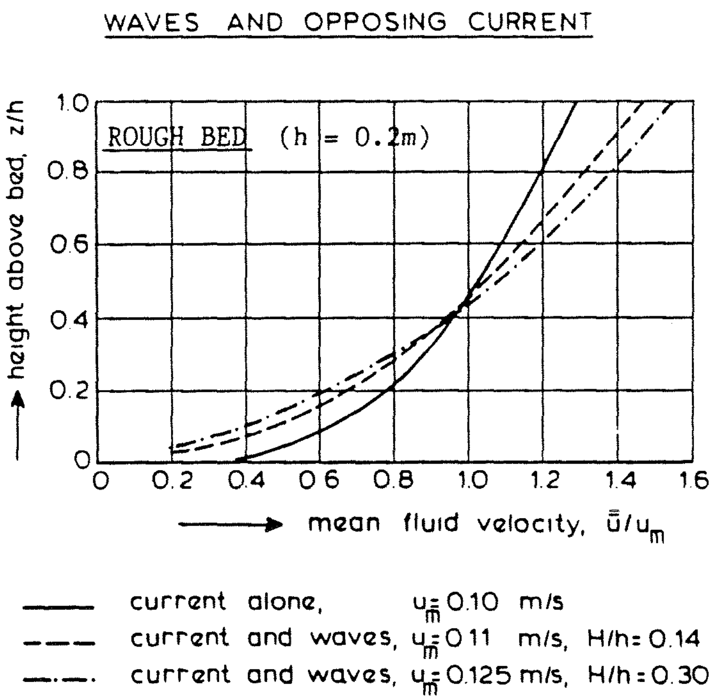

INFLUENCE OF WAVEHEIGHT ON VELOCITY DISTRIBUTION
FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.9 B



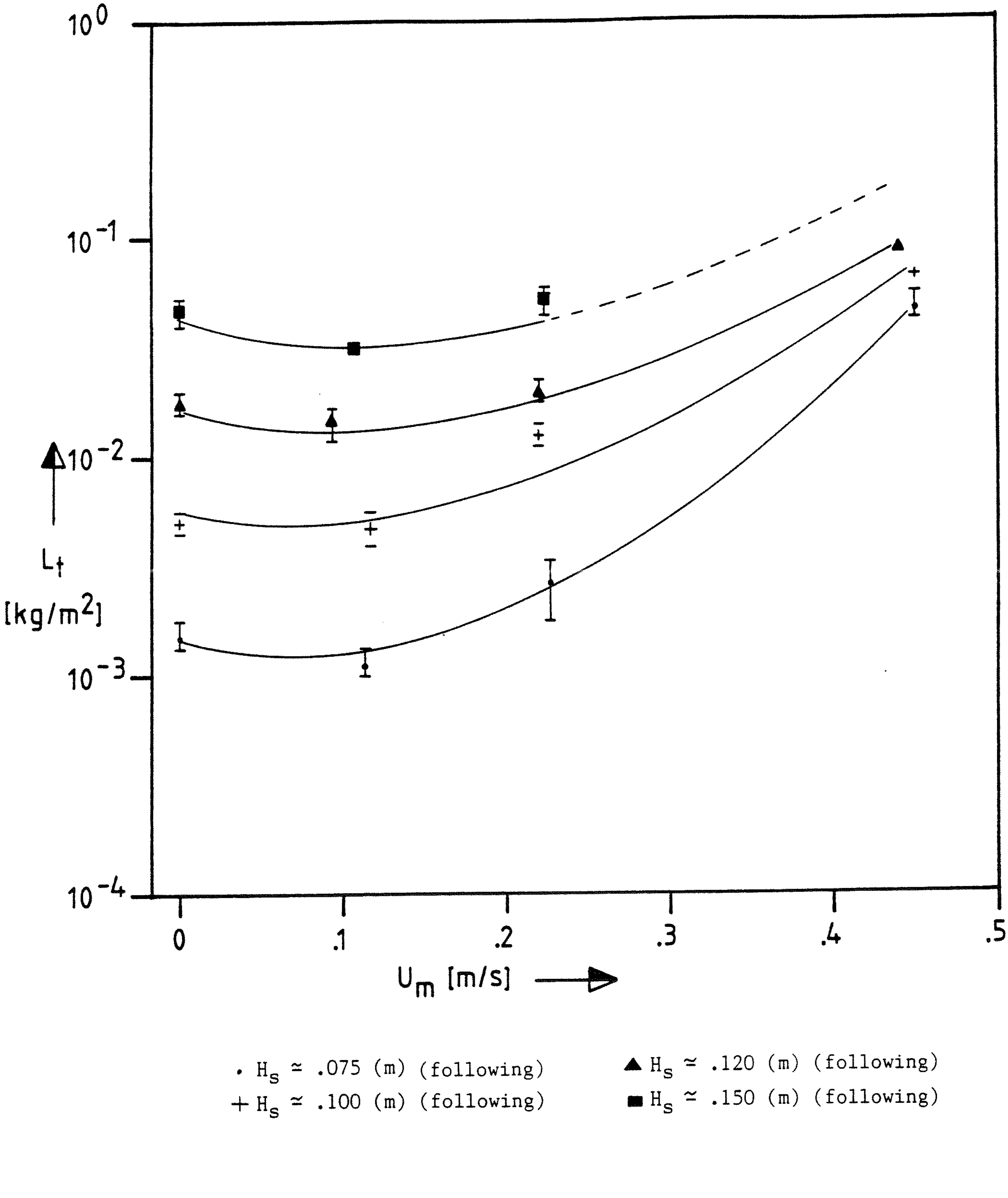

MEAN CURRENT VELOCITY PROFILES AS MODIFIED BY WAVES
ACCORDING TO BAKKER AND VAN DOORN (1980)
(DELFT HYDRAULICS LABORATORY, S 487)

FIG. 3.10 A



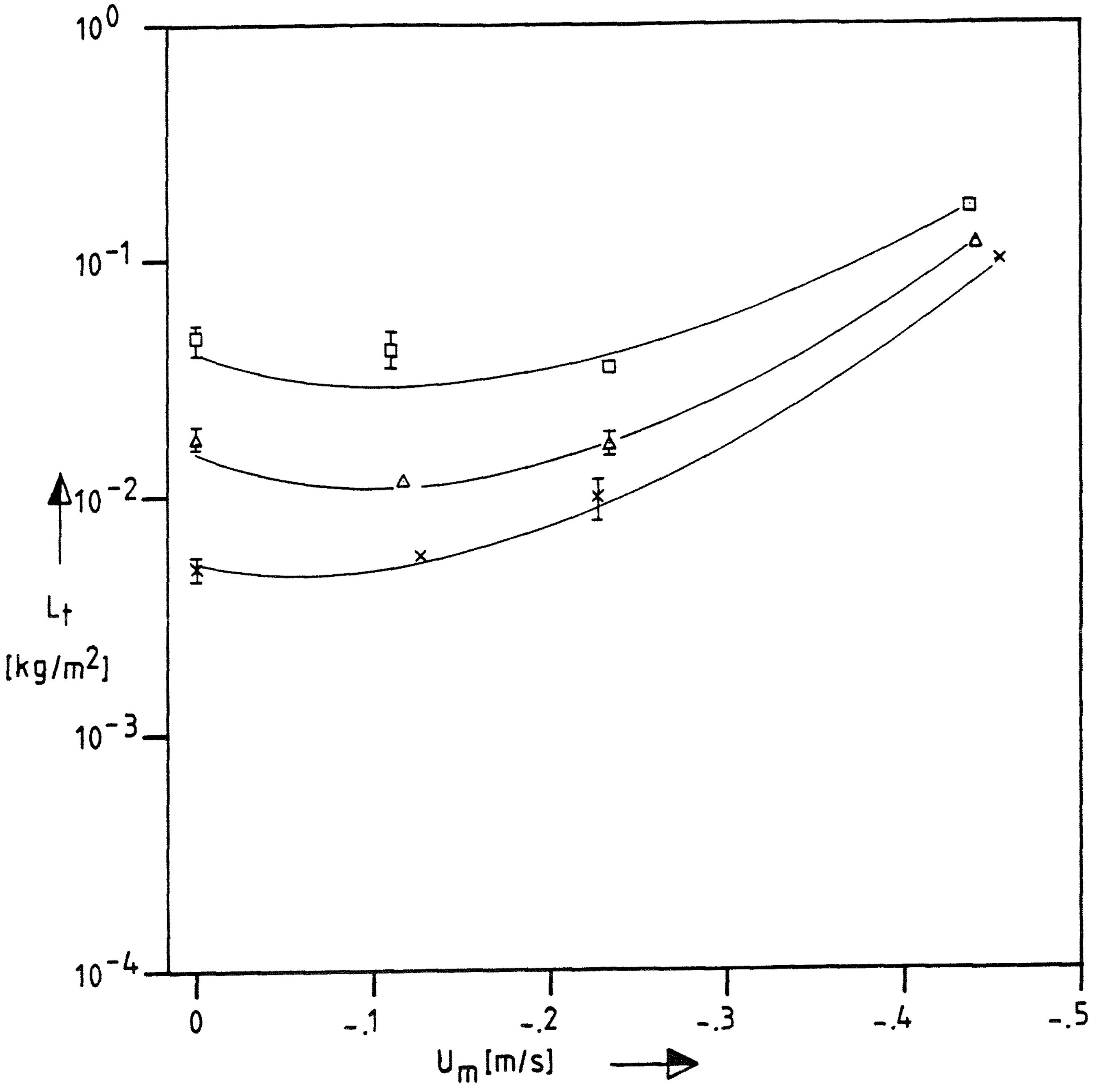

MEAN CURRENT VELOCITY PROFILES AS MODIFIED BY WAVES
ACCORDING TO KEMP AND SIMONS (1983)
(DELFT HYDRAULICS LABORATORY, S 487)

FIG. 3.10 B




TOTAL LOAD FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.11 A



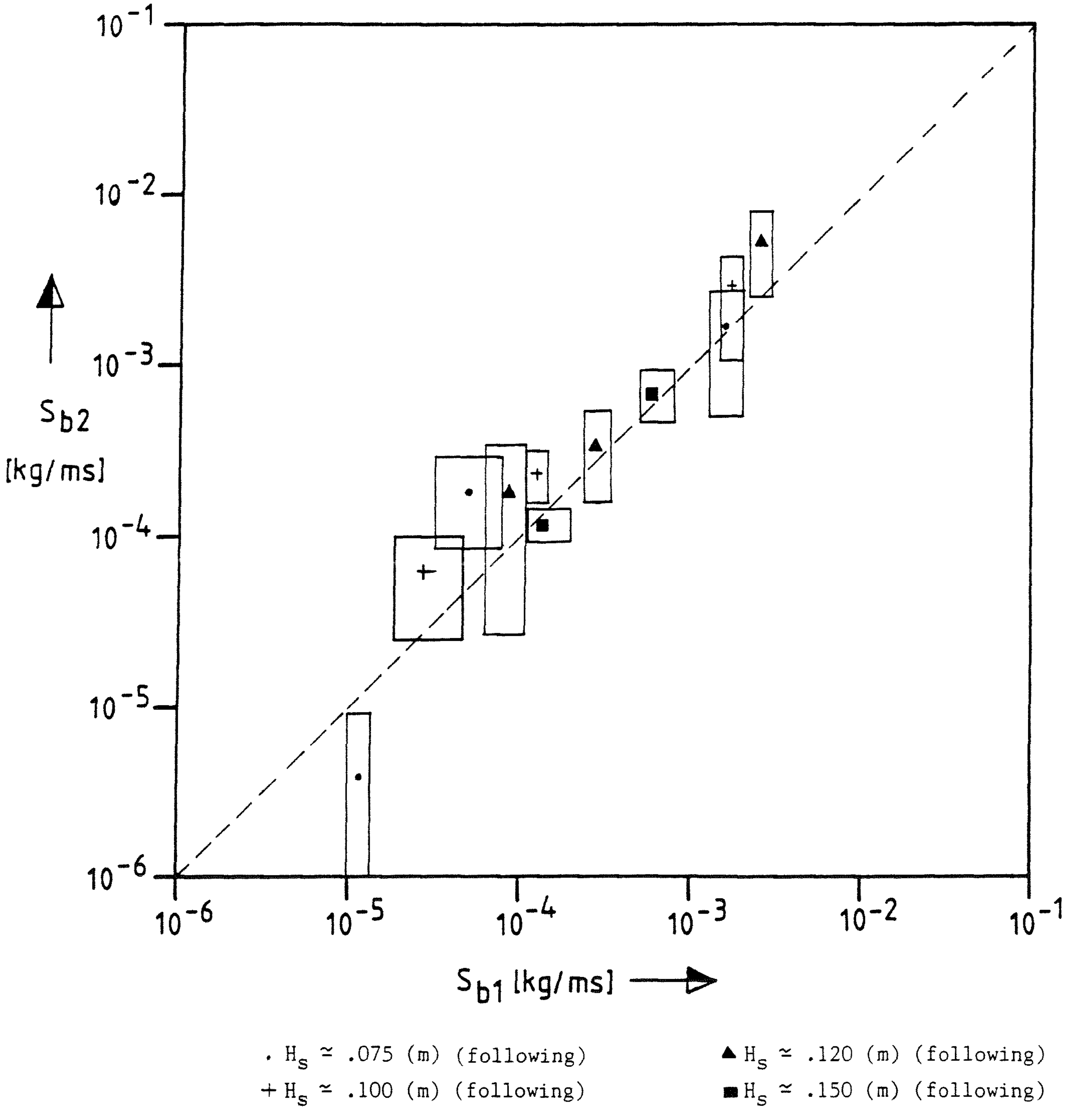

× $H_s \simeq$ .100 (m) (opposing)

△ $H_s \simeq$ .120 (m) (opposing)

□ $H_s \simeq$ .150 (m) (opposing)

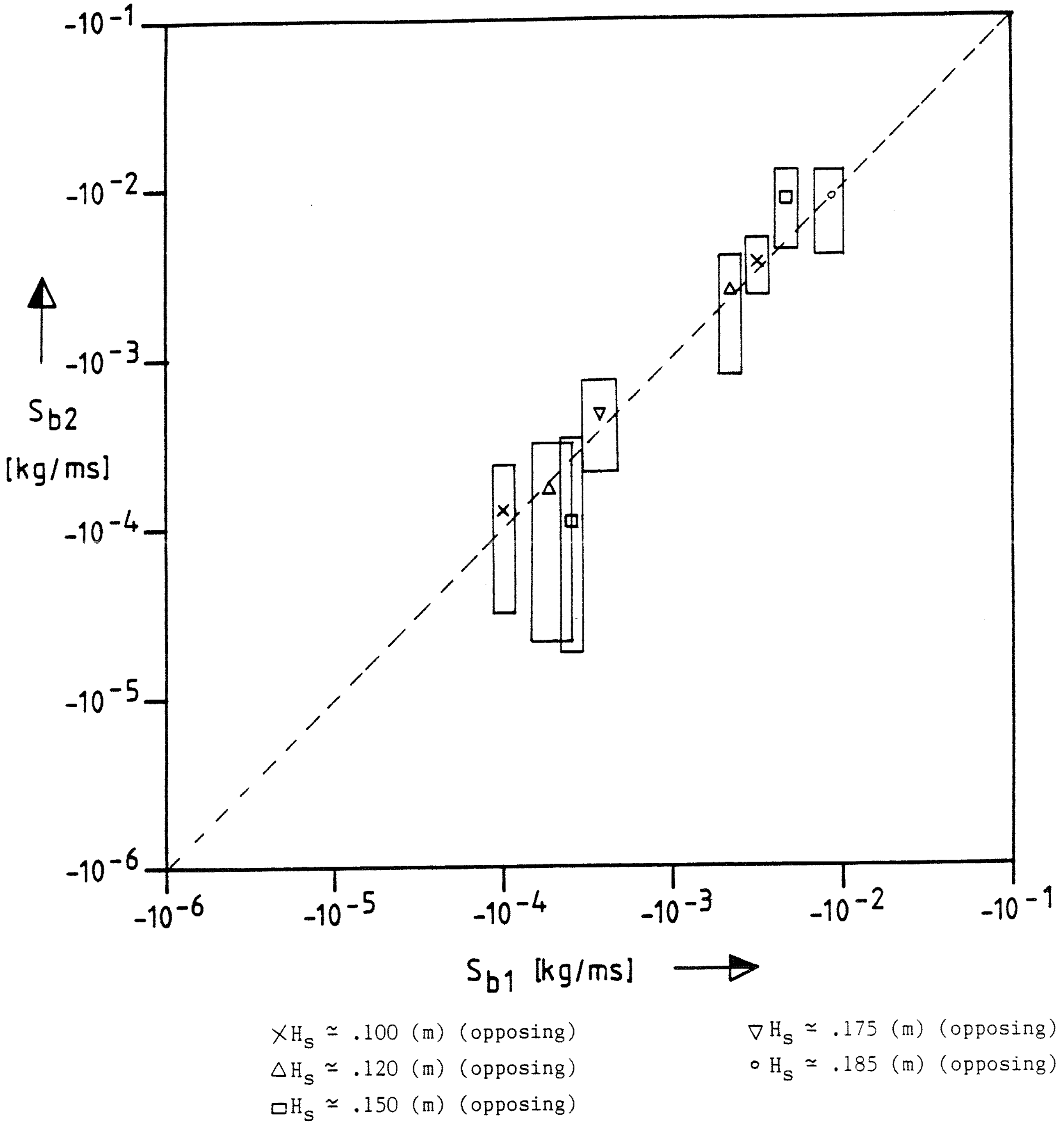
TOTAL LOAD FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.11 B



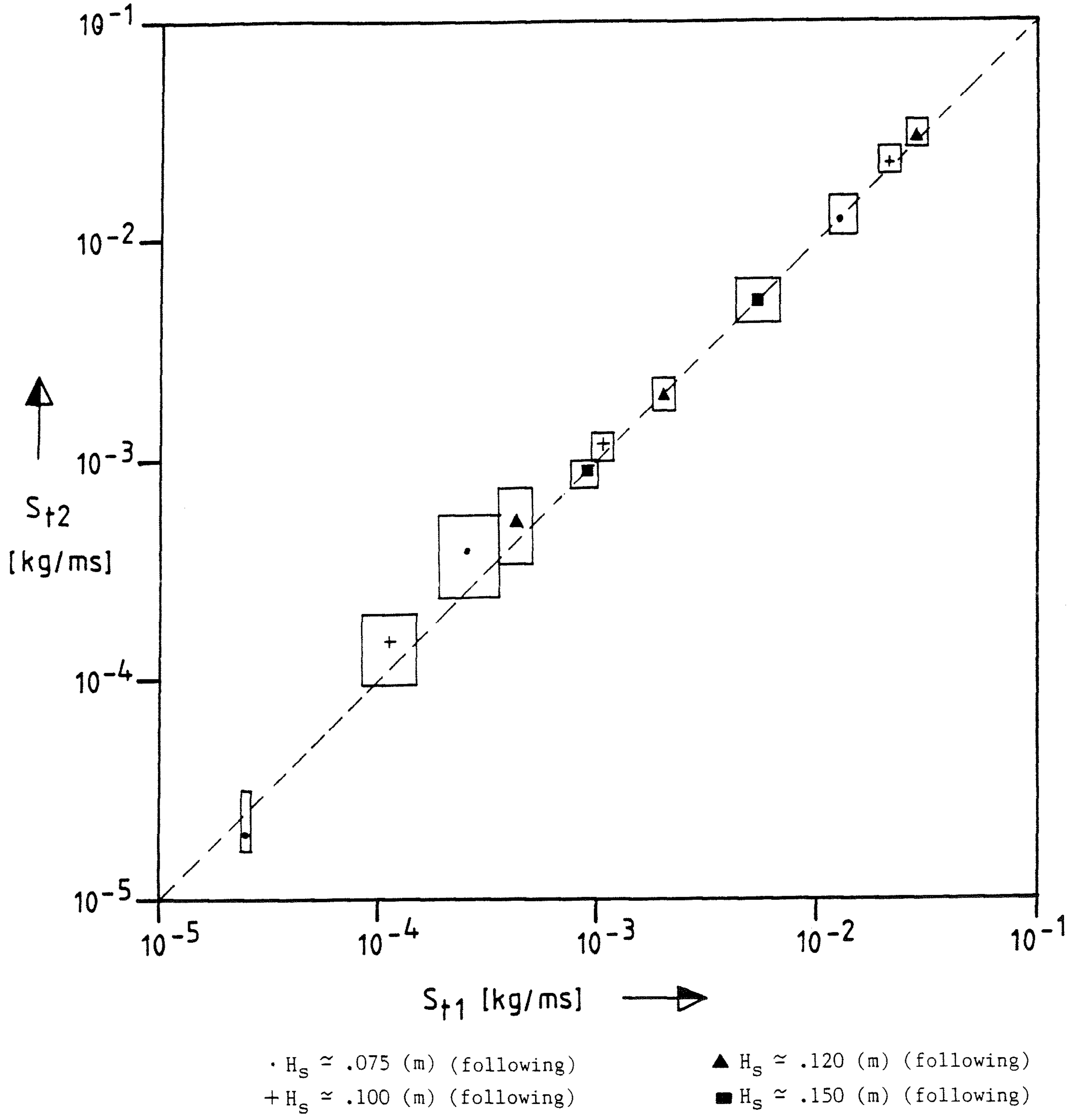

COMPARISON OF TWO CALCULATION METHODS FOR THE
BED LOAD TRANSPORT
FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.12 A



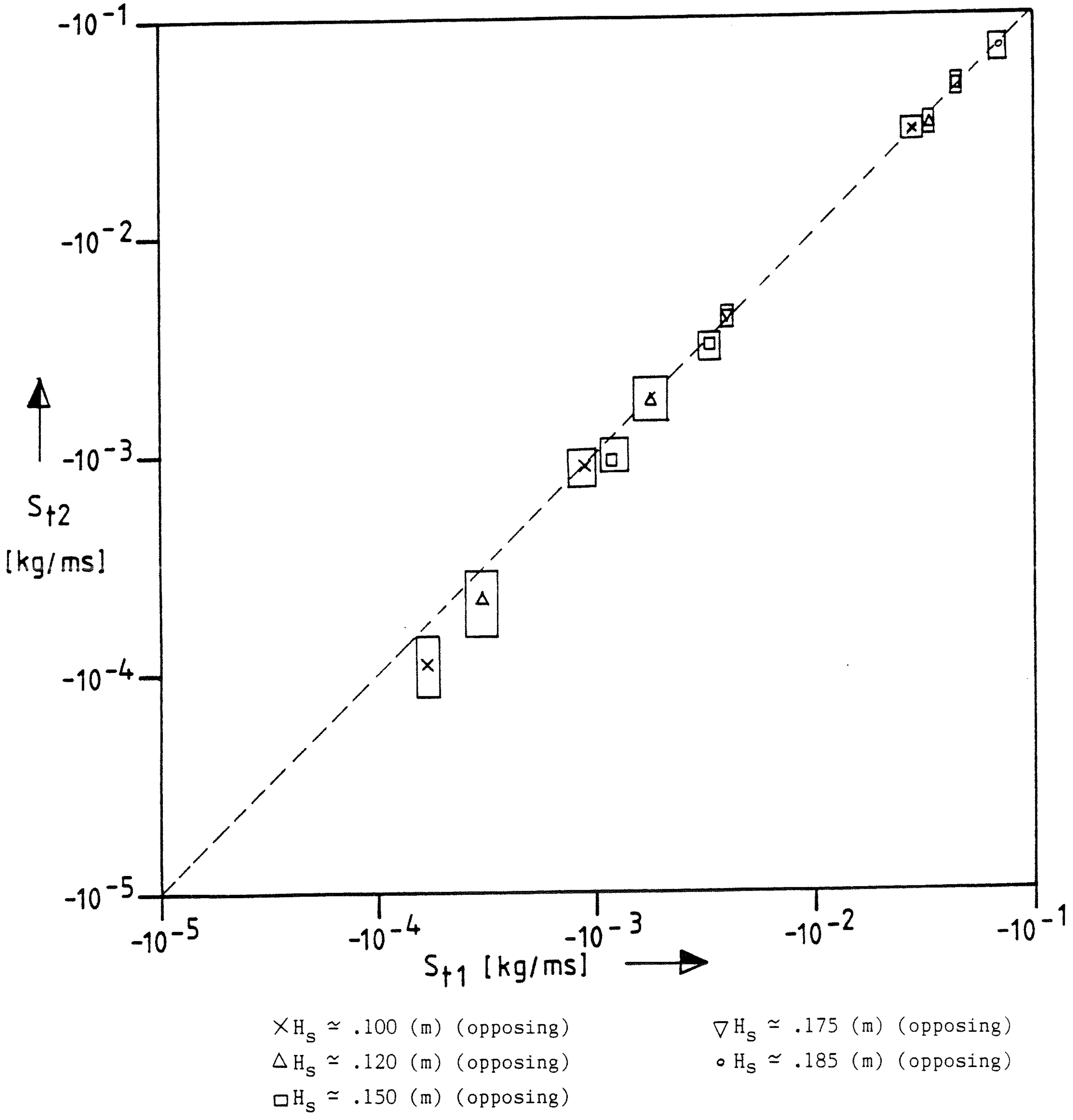

COMPARISON OF TWO CALCULATION METHODS FOR THE BED LOAD TRANSPORT FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.12 B



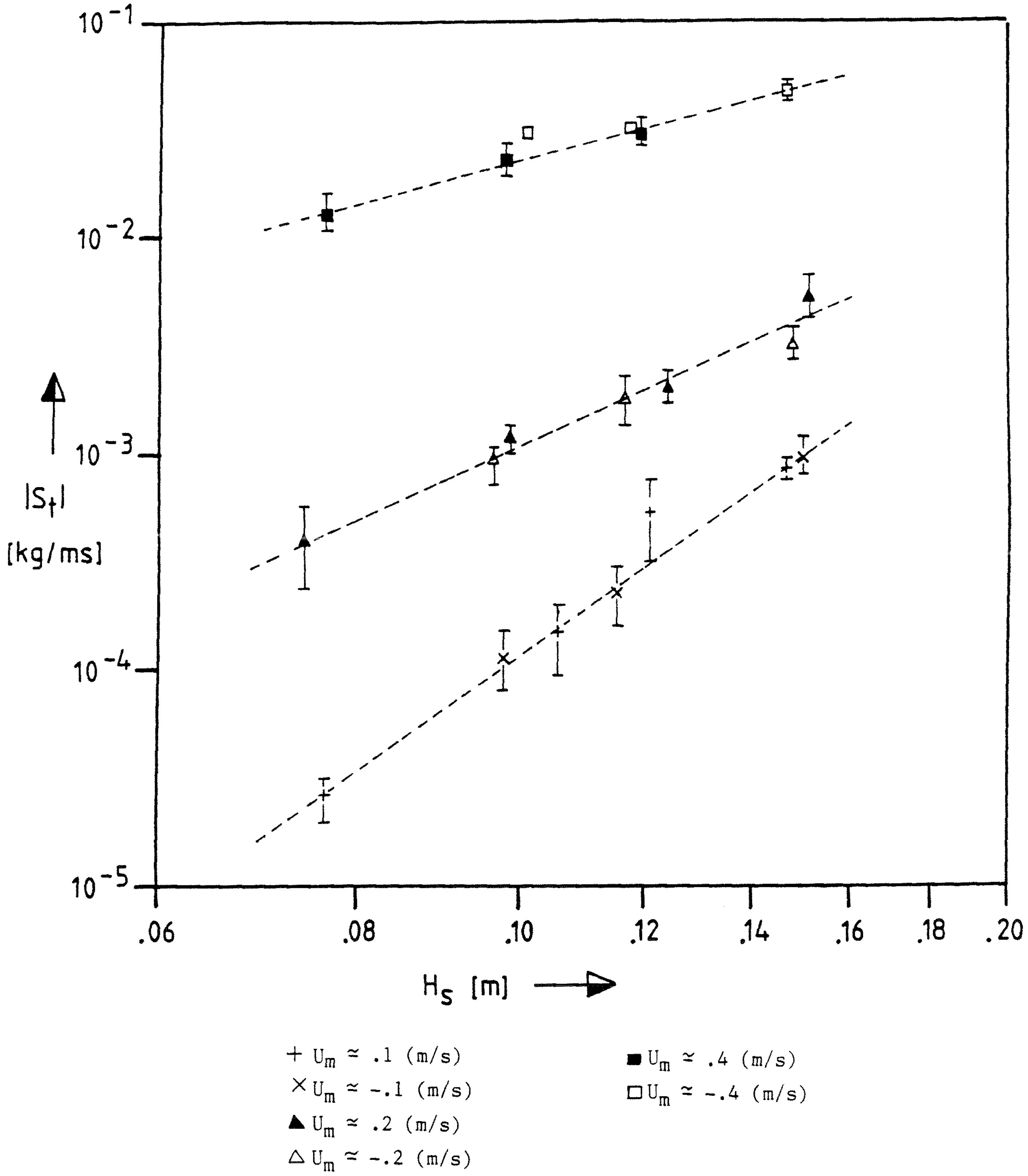

COMPARISON OF TWO CALCULATION METHODS FOR THE TOTAL LOAD TRANSPORT FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.13 A



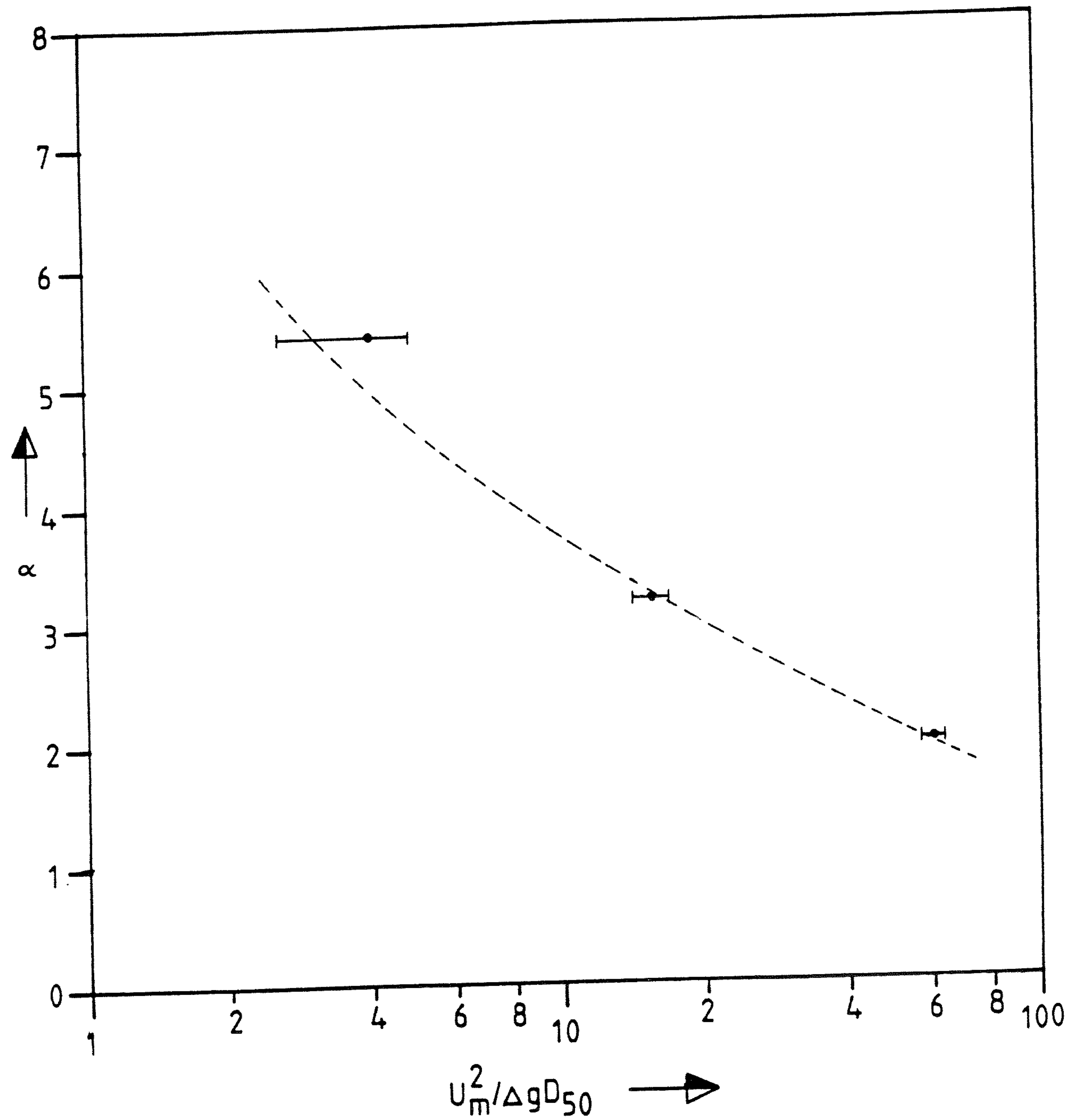

COMPARISON OF TWO CALCULATION METHODS FOR THE
TOTAL LOAD TRANSPORT
FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.13 B



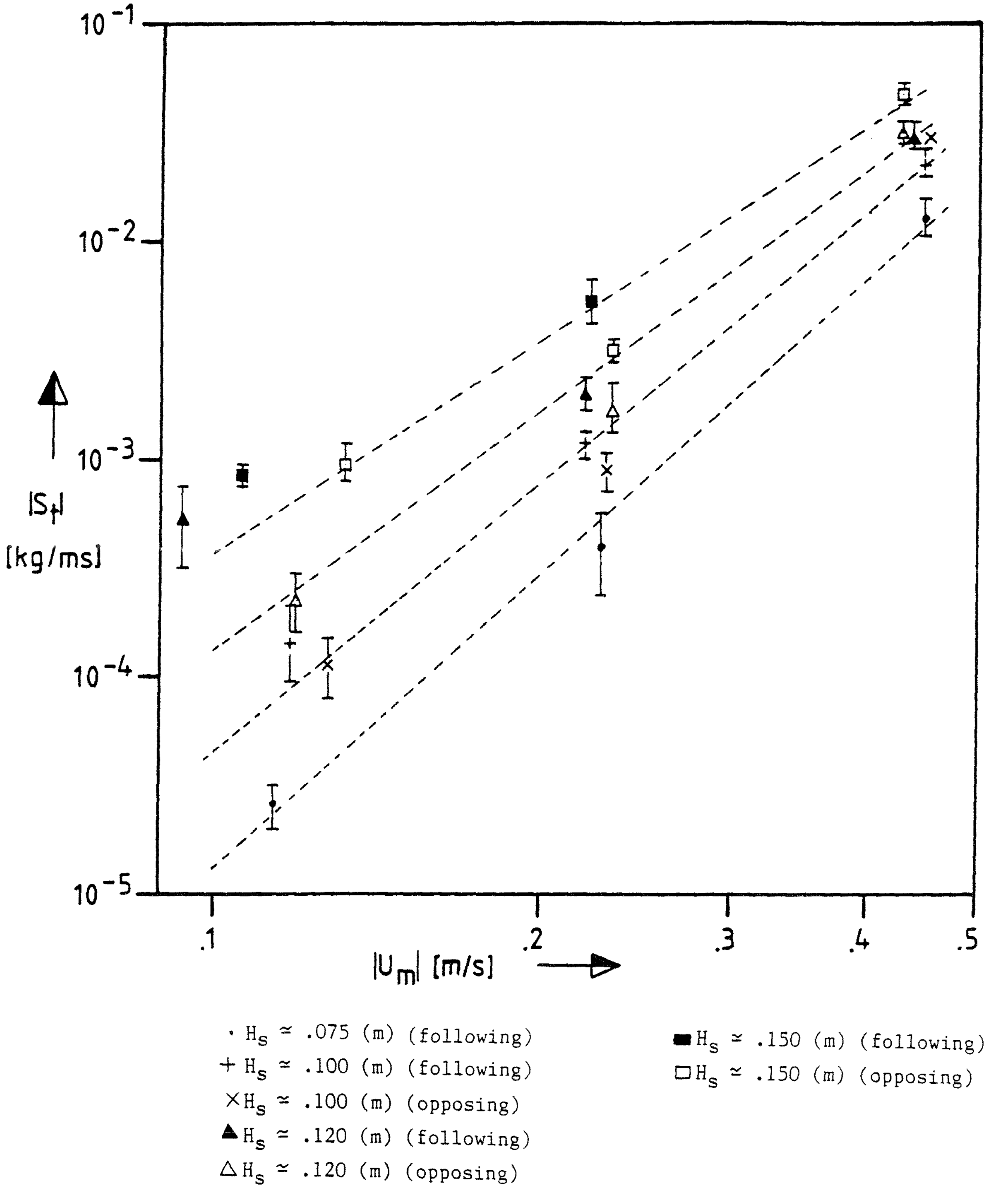

DEPENDENCE OF TOTAL LOAD TRANSPORT ON WAVEHEIGHT

FIG. 3.14

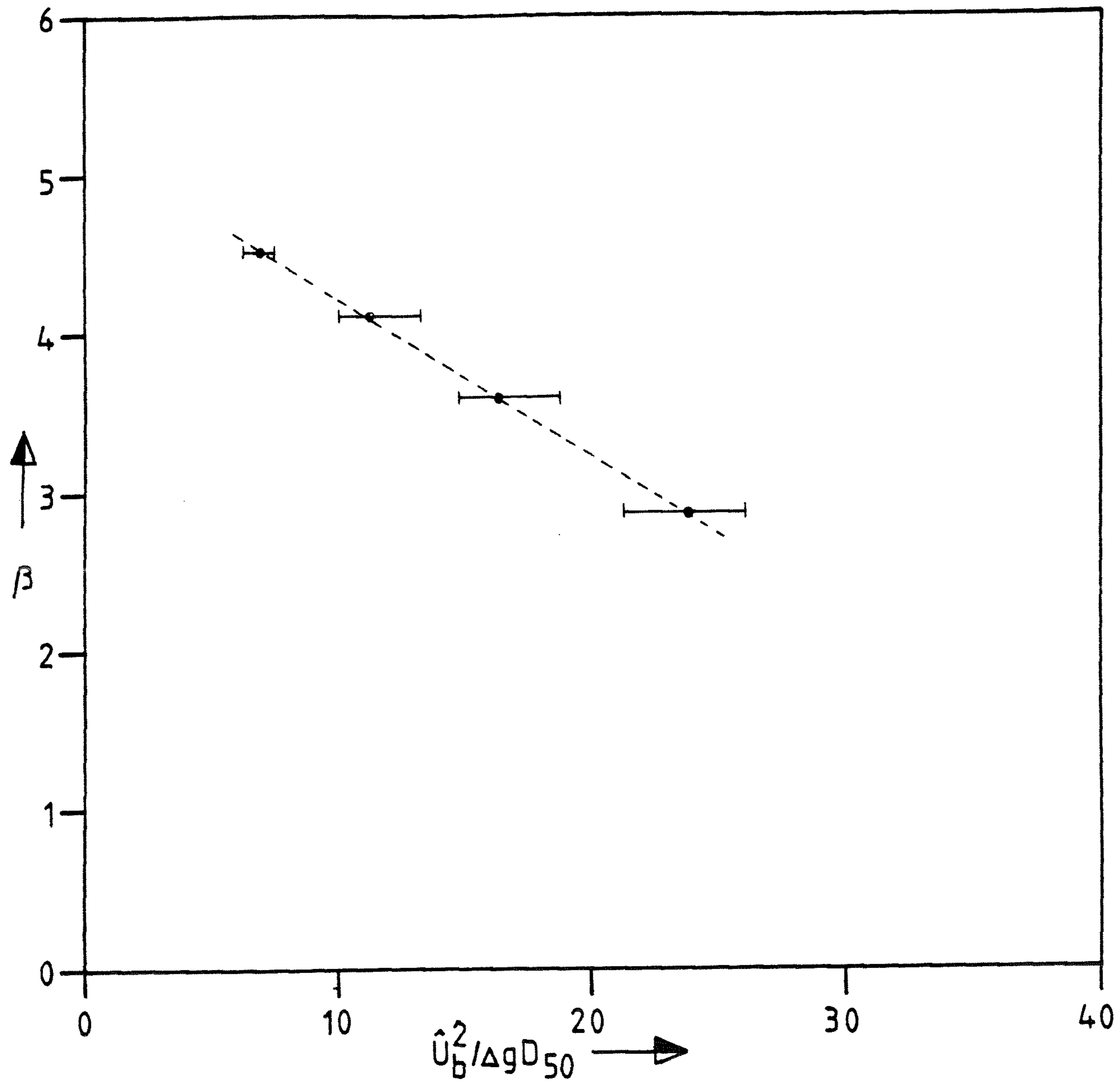



INFLUENCE OF DEPTH AVERAGED VELOCITY ON WAVEHEIGHT PROPORTION FACTOR

FIG. 3.15

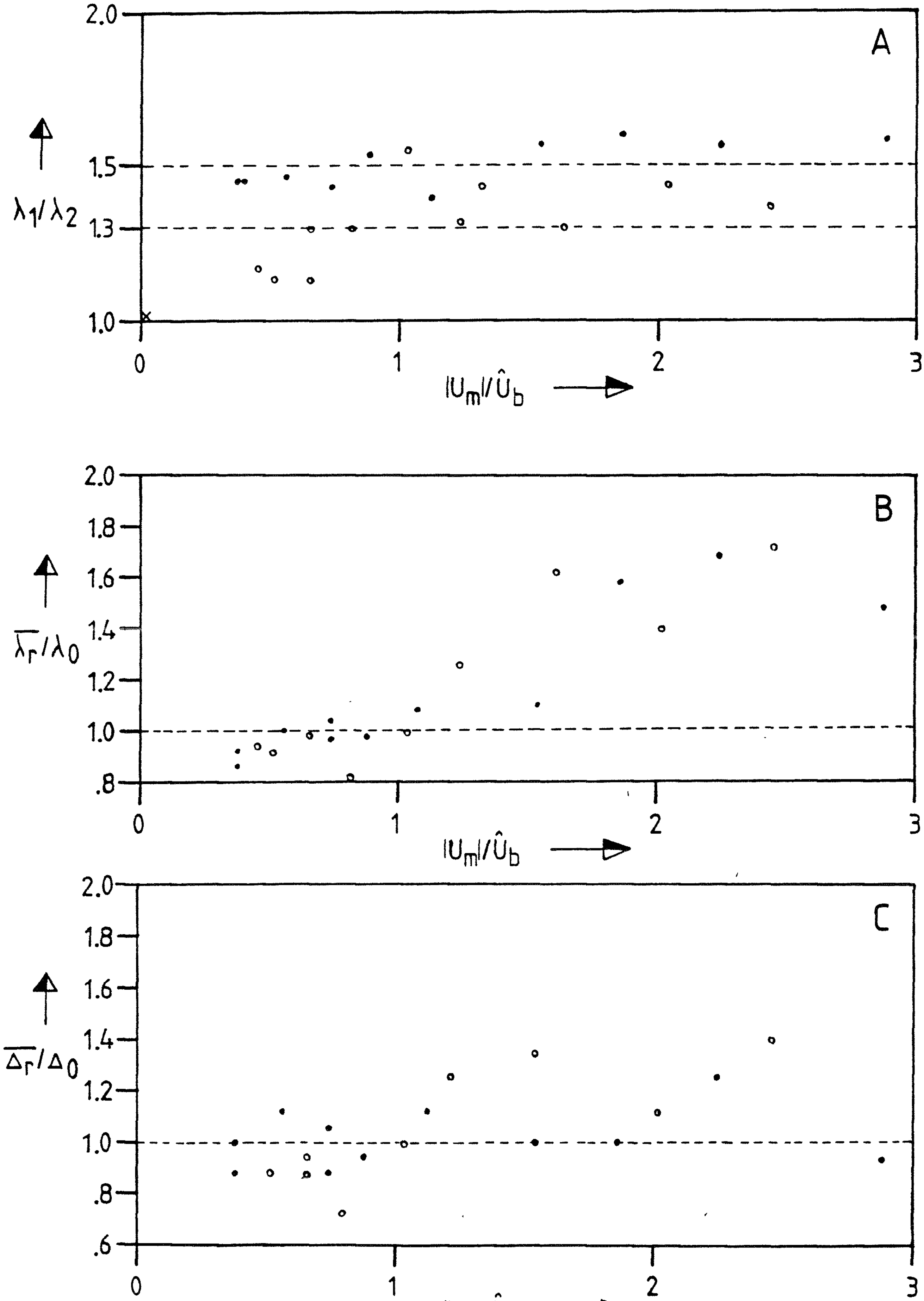



DEPENDENCE OF TOTAL LOAD TRANSPORT ON DEPTH AVERAGED VELOCITY | FIG. 3.16




INFLUENCE OF WAVEHEIGHT ON DEPTH AVERAGED VELOCITY PROPORTION FACTOR

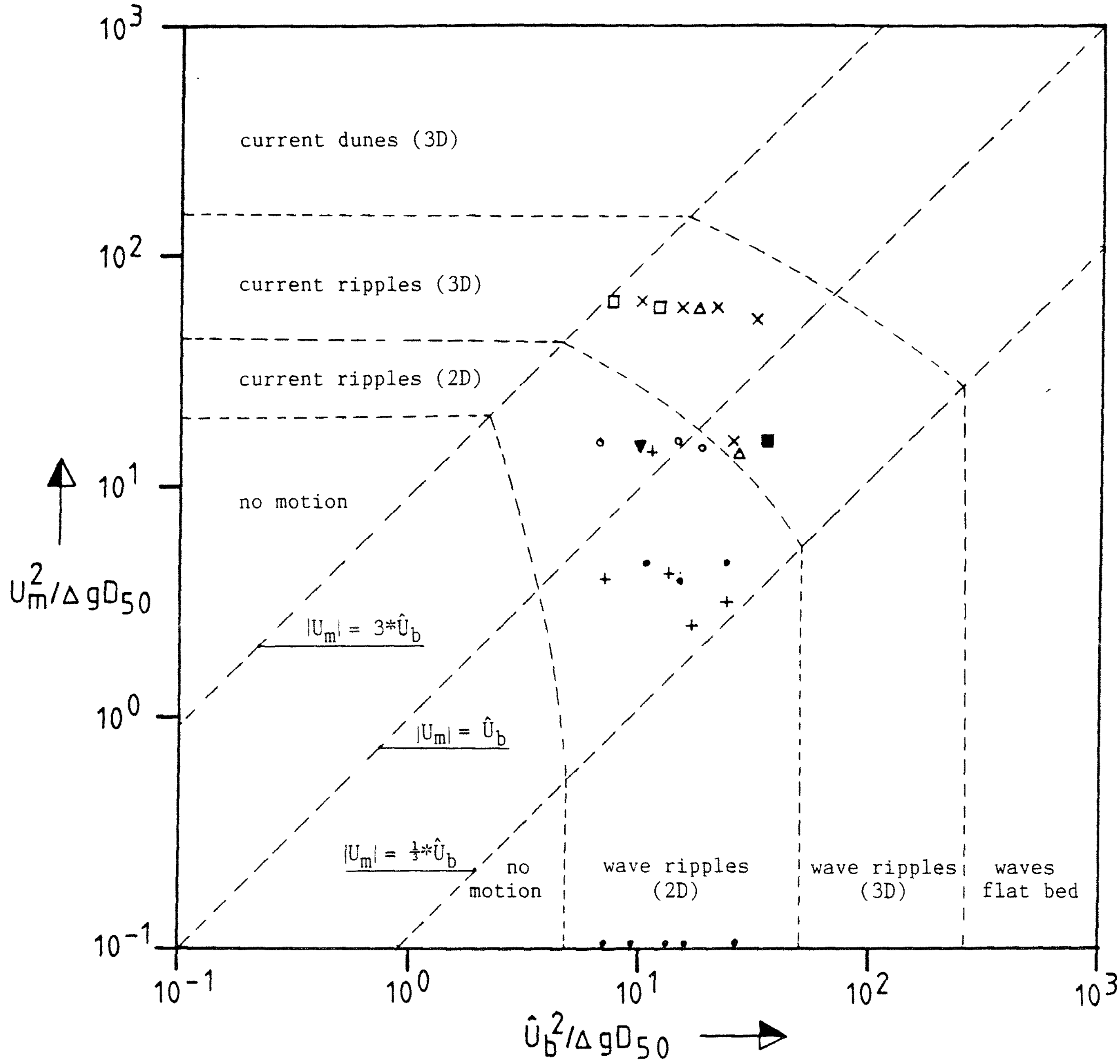
FIG. 3.17




• following current  ∘ opposing current  × no current

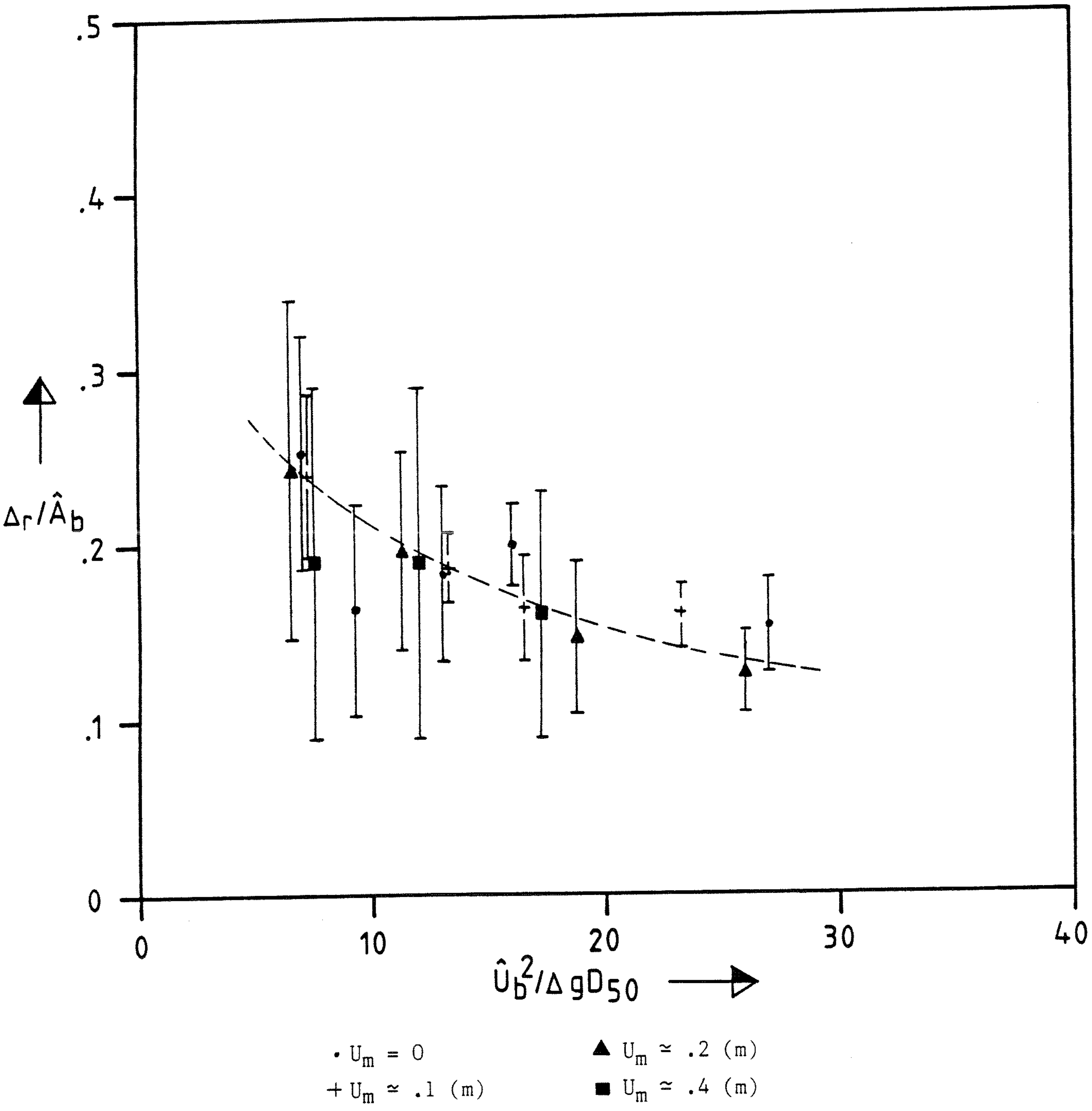
RIPPLE CHARACTERISTICS

FIG. 3.18
A–C



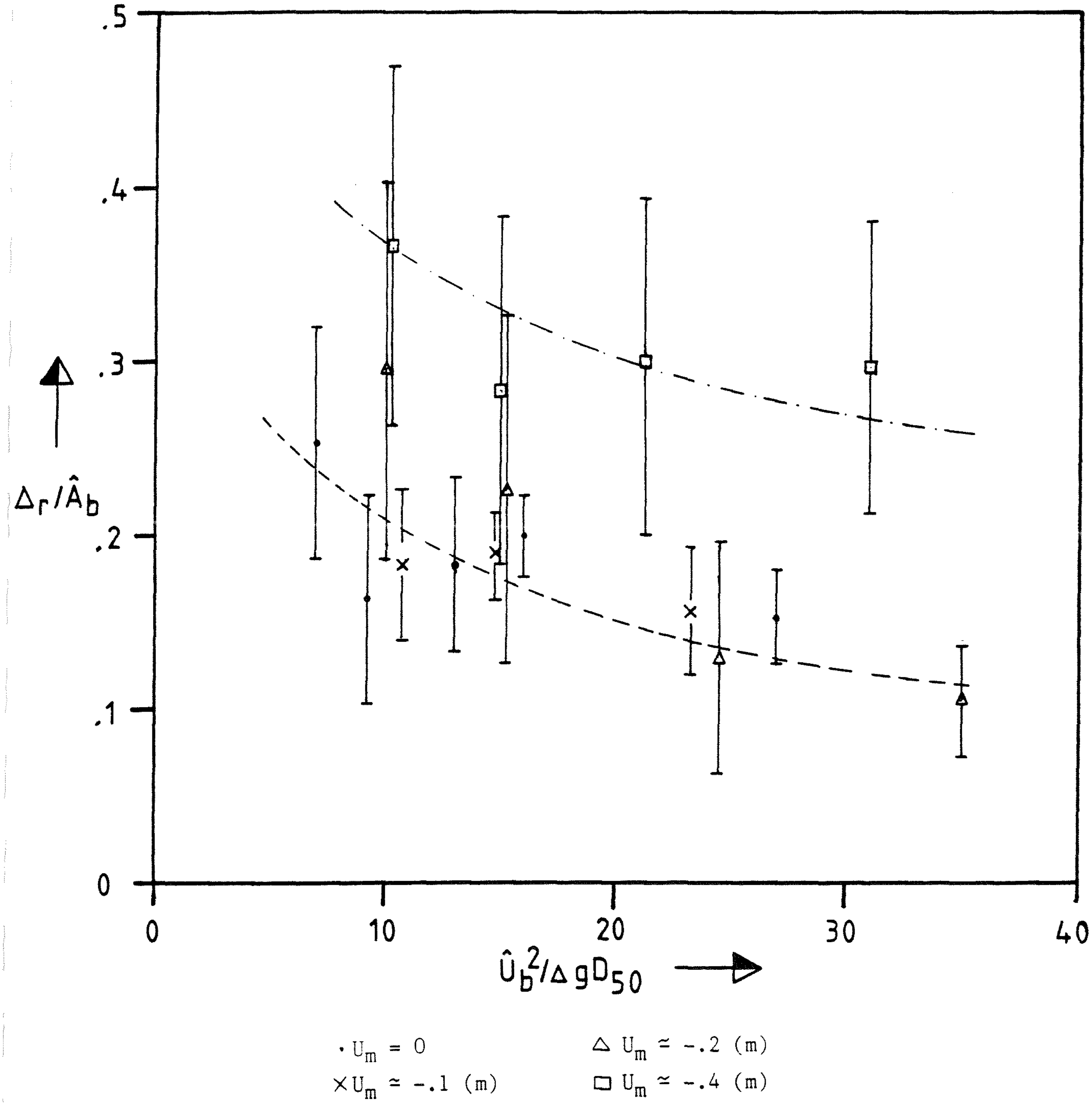

• 2 dimensional/wave dominated
▲ 2½ dimensional/wave dominated
■ 3 dimensional/wave dominated
+2 dimensional/transition
▼2½ dimensional/transition
×3 dimensional/transition
∘2 dimensional/current dominated
△2½ dimensional/current dominated
□3 dimensional/current dominated

| REGIME | FIG. 3.19 |
|---|---|



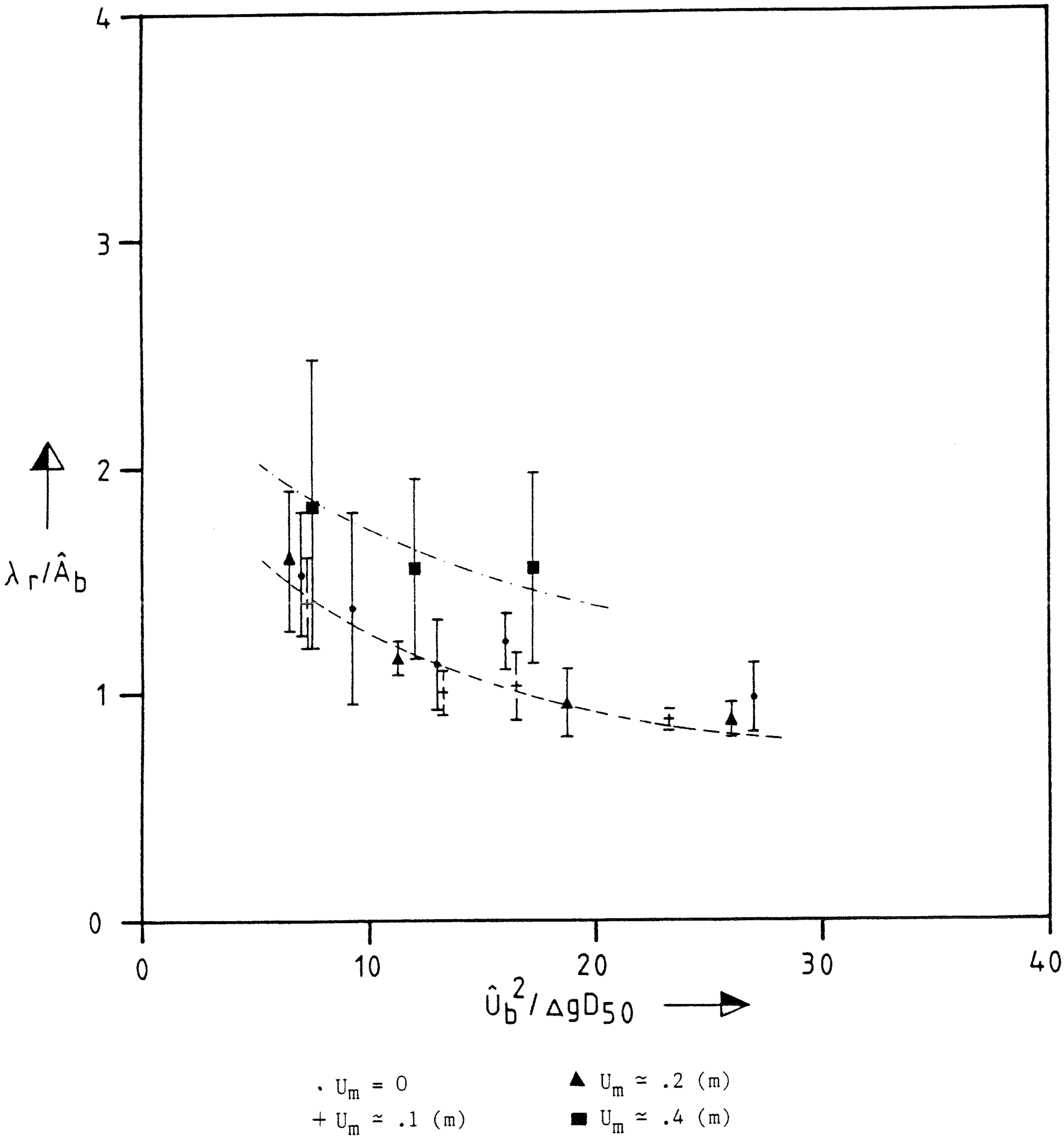

DEPENDENCE RIPPLE HEIGHT ON WAVEHEIGHT
FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.20 A



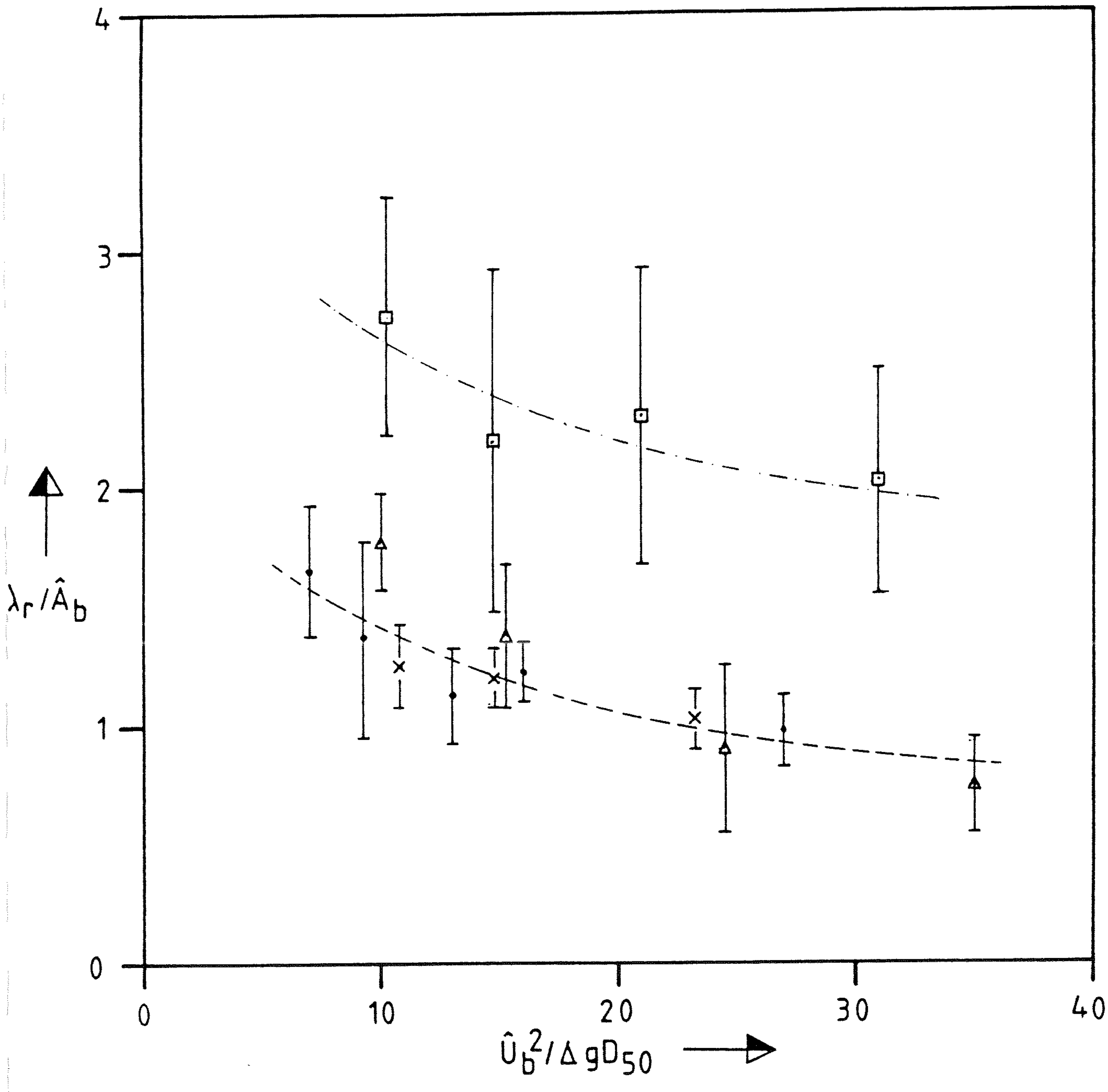

DEPENDENCE RIPPLE HEIGHT ON WAVEHEIGHT
FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.20 B



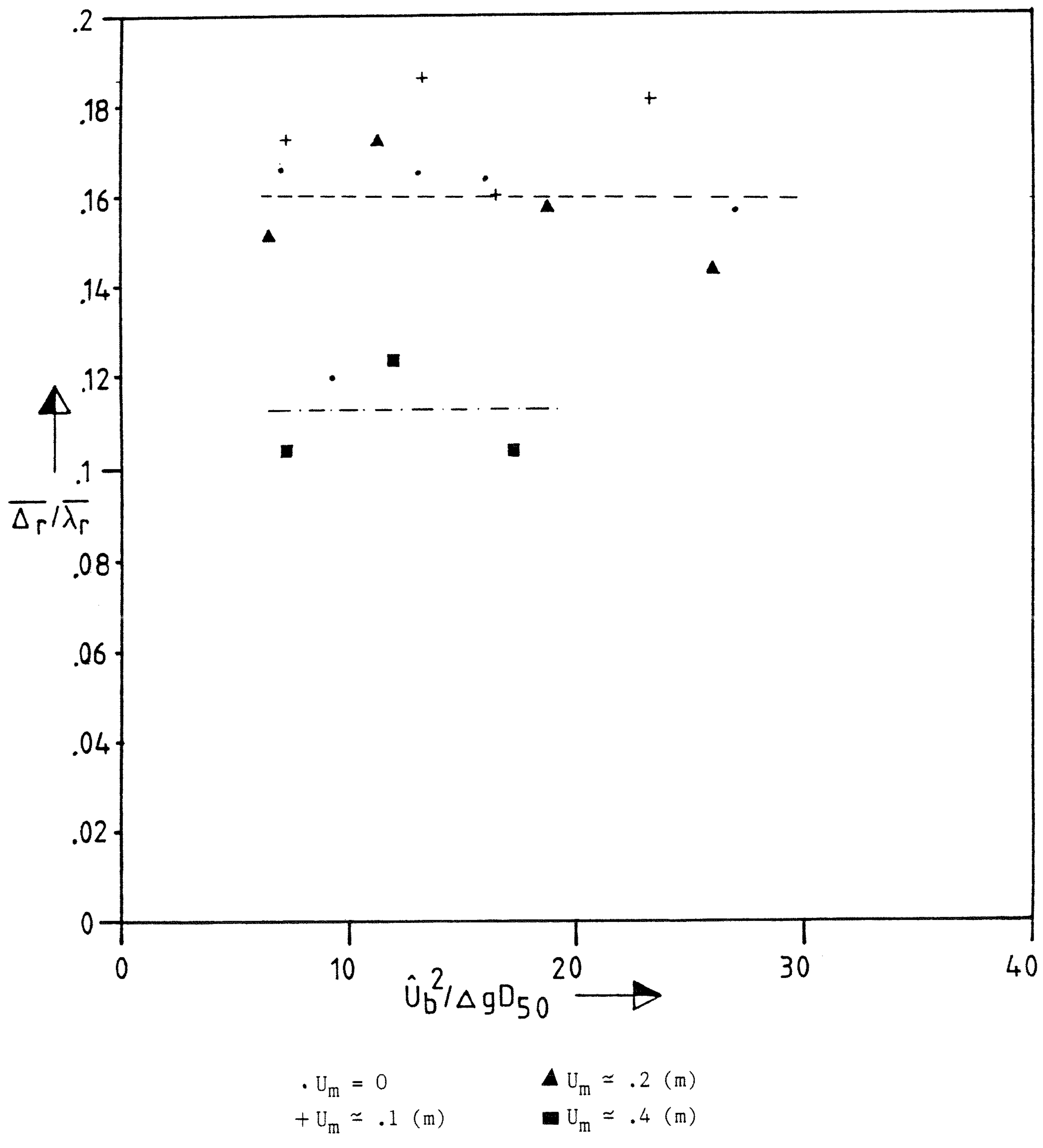

DEPENDENCE RIPPLE LENGTH ON WAVEHEIGHT
FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.21 A



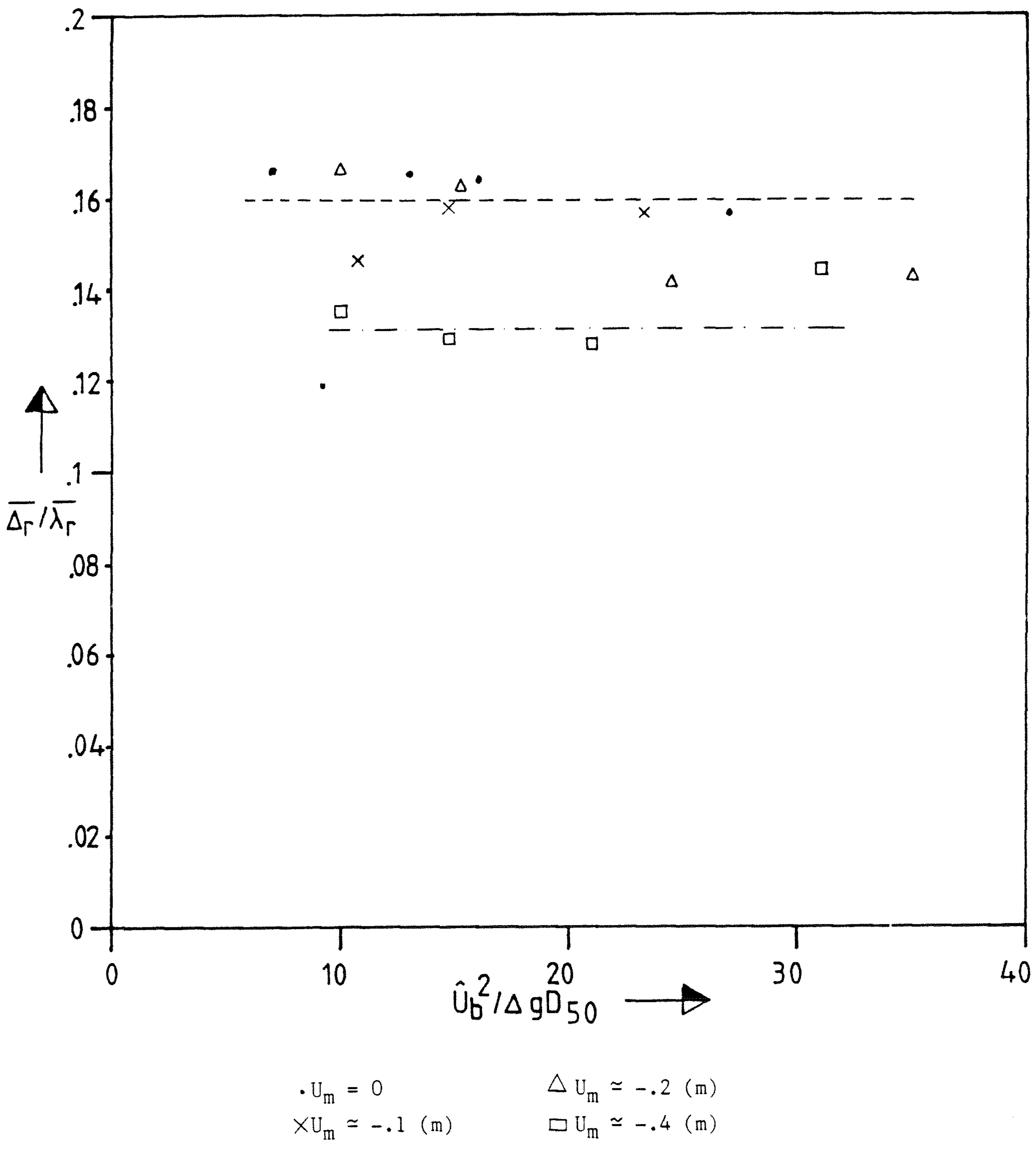

DEPENDENCE RIPPLE LENGTH ON WAVEHEIGHT
FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.21 B



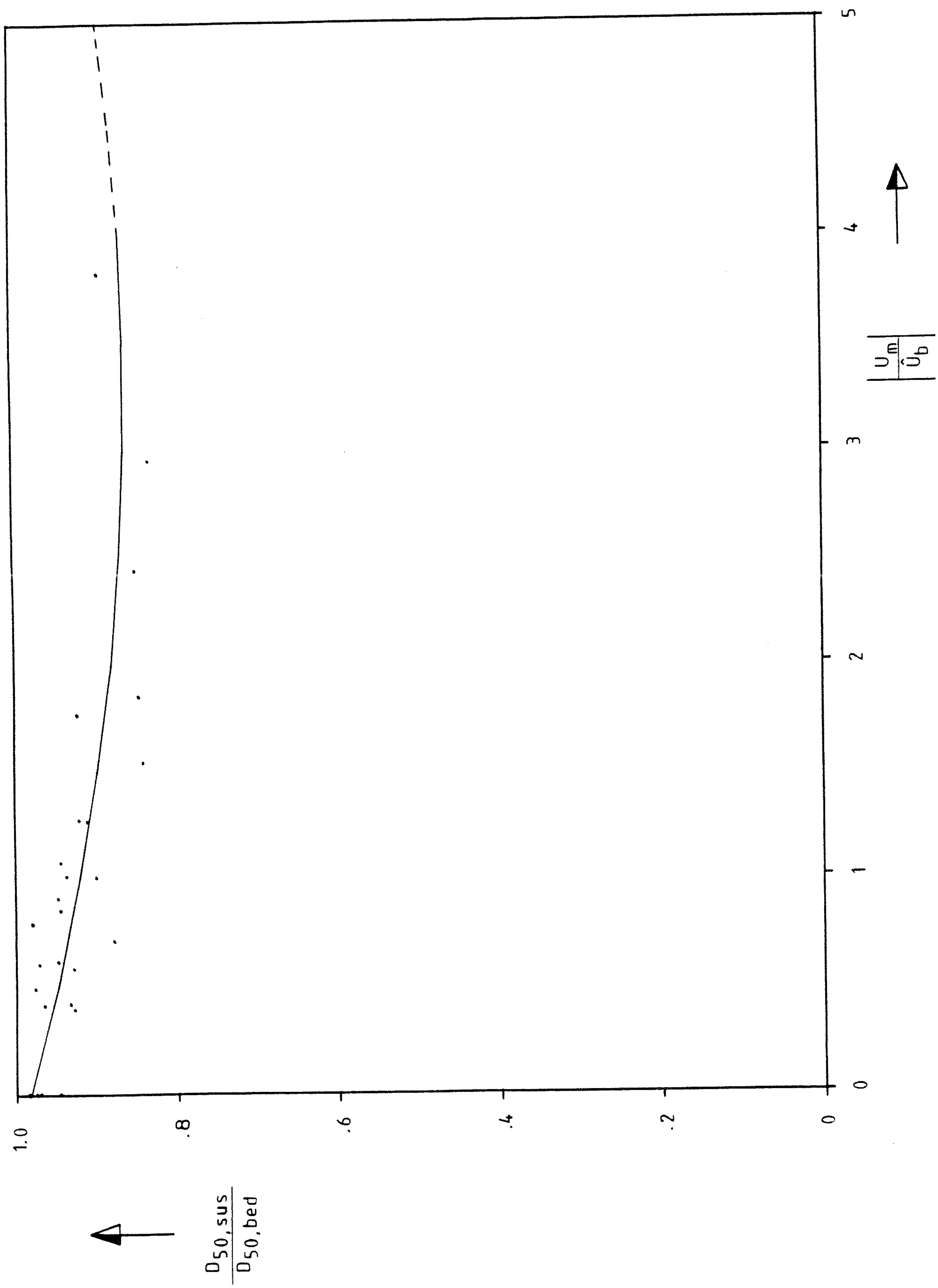

DEPENDENCE RIPPLE STEEPNESS ON WAVEHEIGHT
FOR WAVES PROPAGATING WITH THE CURRENT

FIG. 3.22 A



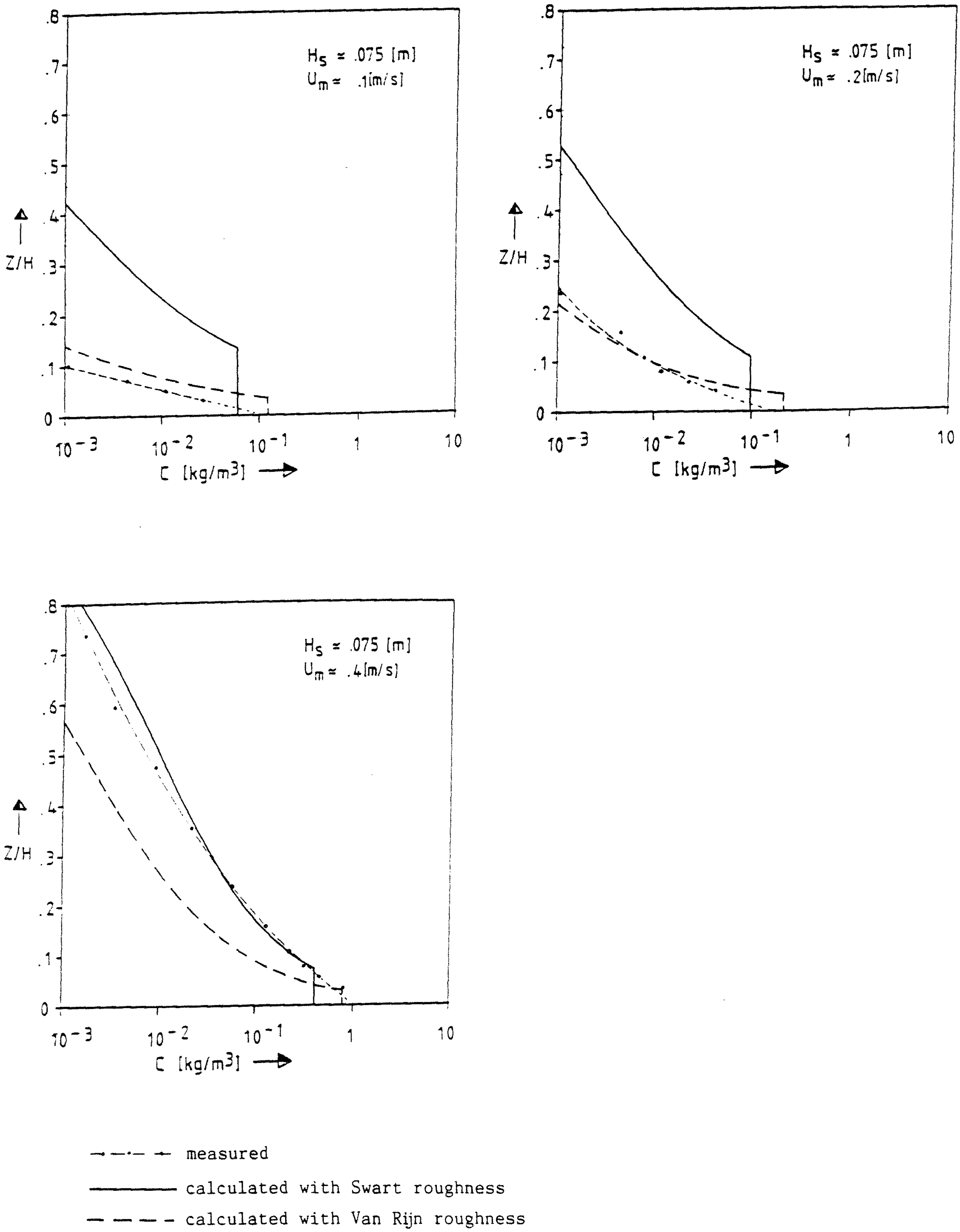

DEPENDENCE RIPPLE STEEPNESS ON WAVEHEIGHT
FOR WAVES PROPAGATING AGAINST THE CURRENT

FIG. 3.22 B



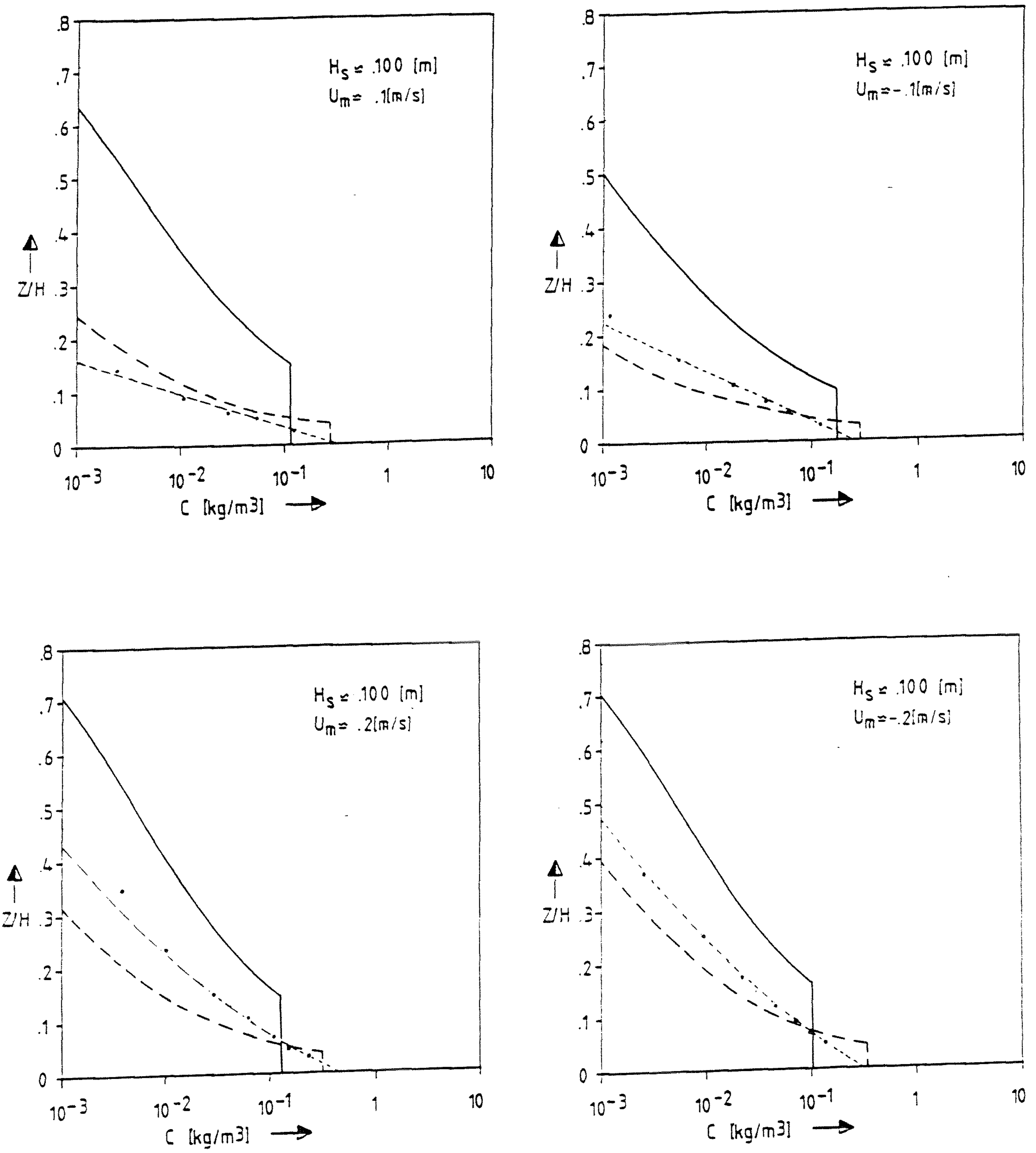

DEPENDENCE OF SUSPENDED SEDIMENT SIZE ON WAVEHEIGHT AND ON DEPTH AVERAGED VELOCITY

FIG. 3.23




CONCENTRATIONS CALCULATED WITH THE BIJKER METHOD

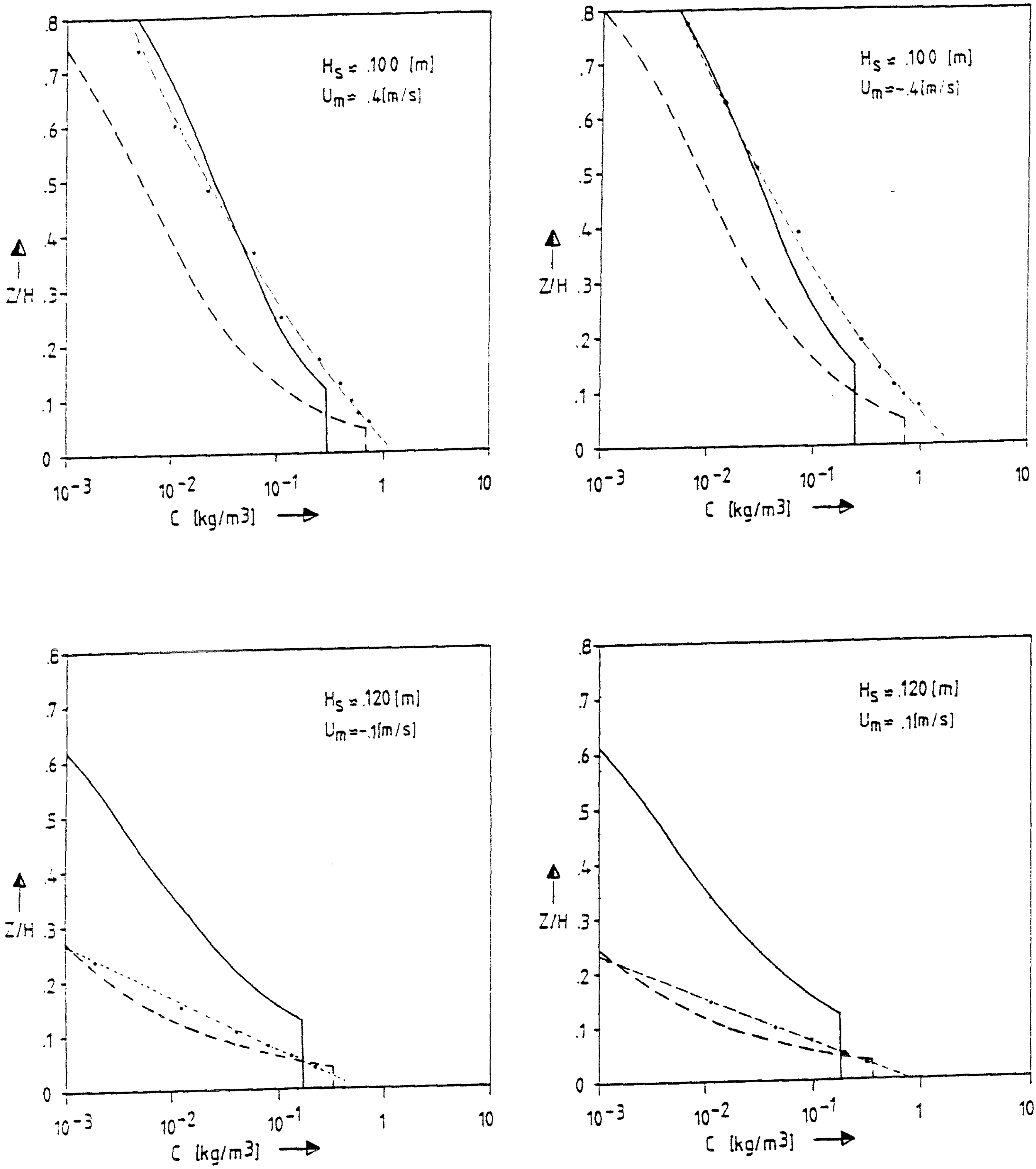
FIG. 4.1 A




- · — — · — — measured
- ———— calculated with Swart roughness
- — — — — calculated with Van Rijn roughness

CONCENTRATIONS CALCULATED WITH THE BIJKER METHOD

FIG. 4.1 B



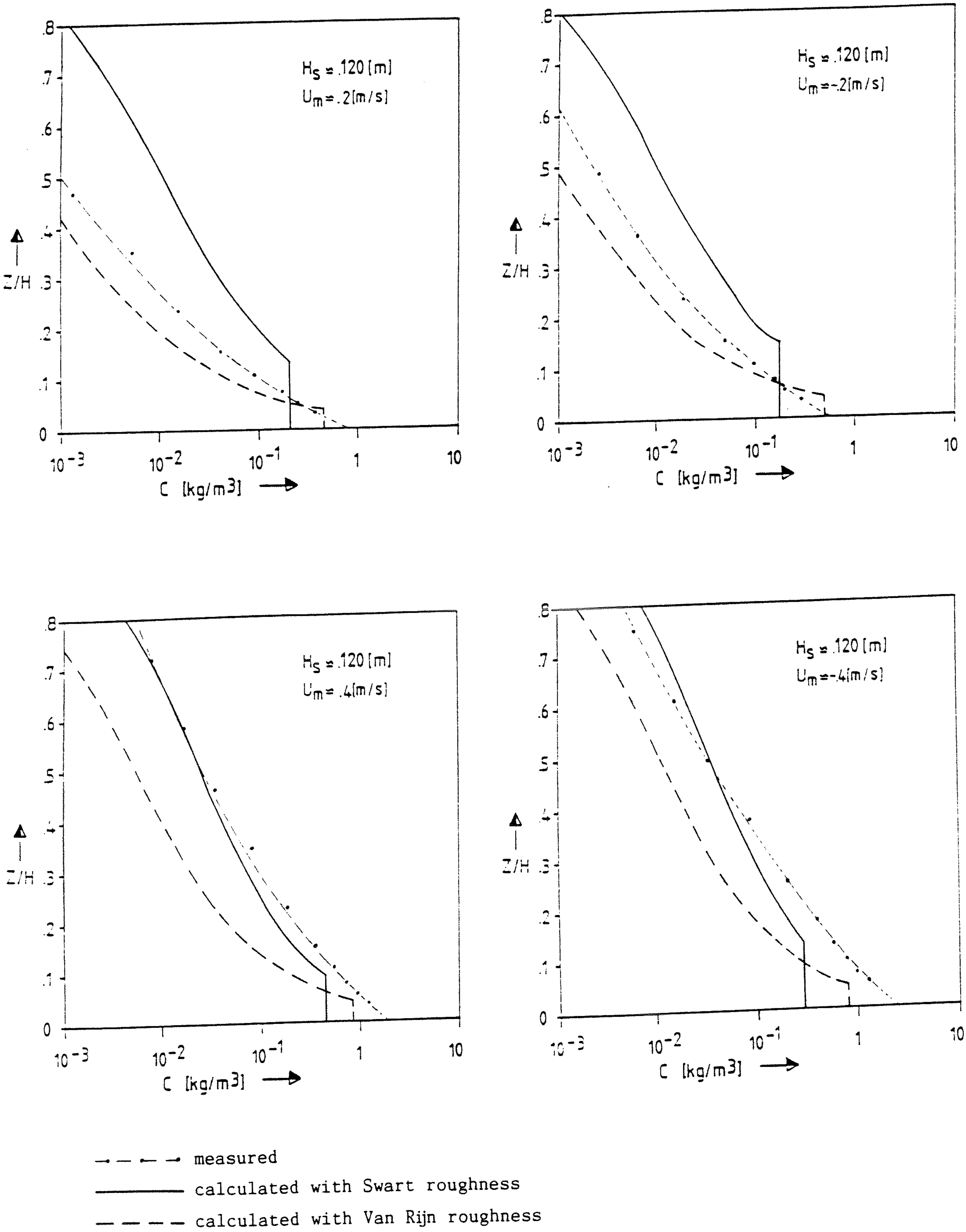

- - - - measured

——— calculated with Swart roughness

— — — calculated with Van Rijn roughness

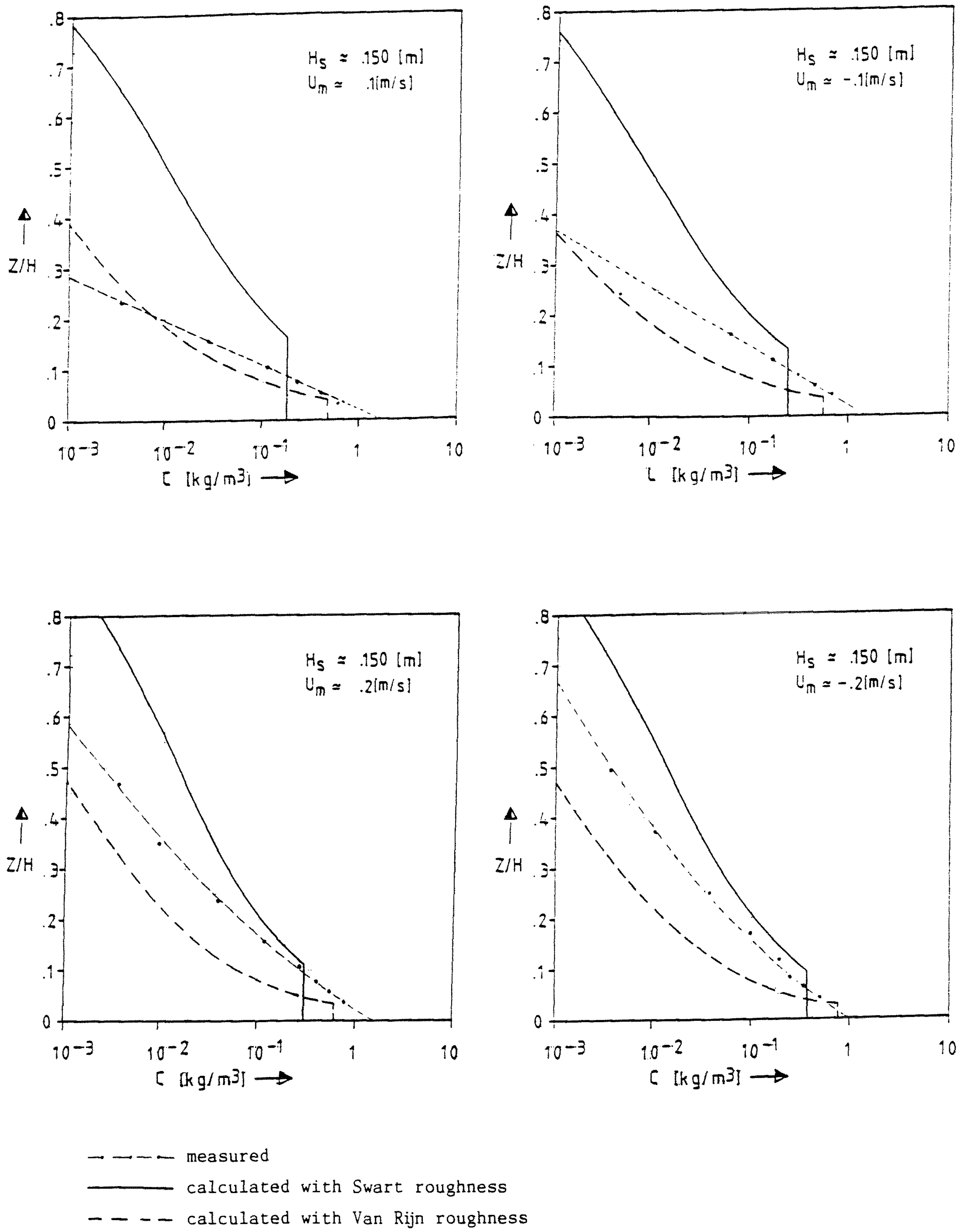
CONCENTRATIONS CALCULATED WITH THE BIJKER METHOD

FIG. 4.1 C



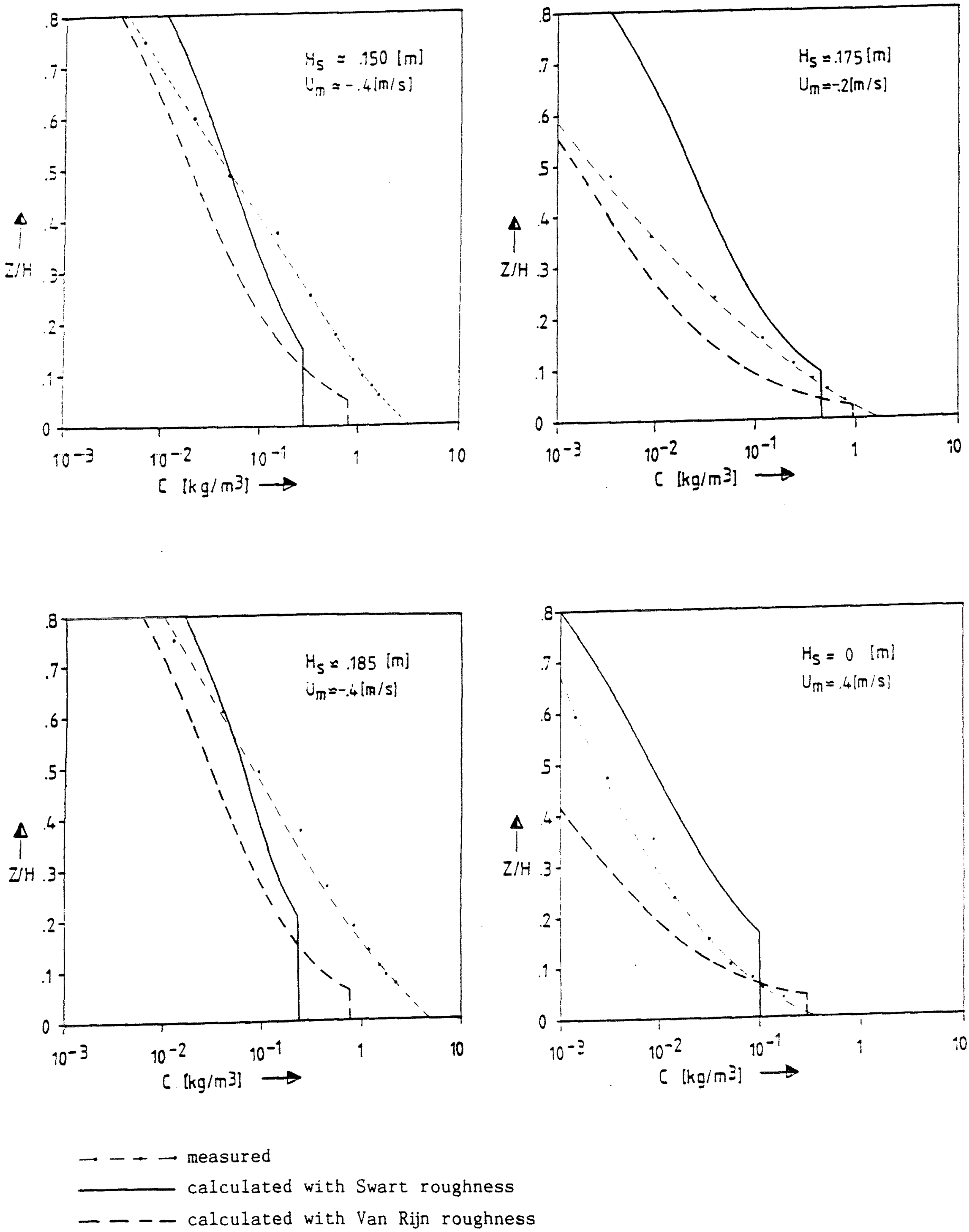

CONCENTRATIONS CALCULATED WITH THE BIJKER METHOD

FIG. 4.1 D



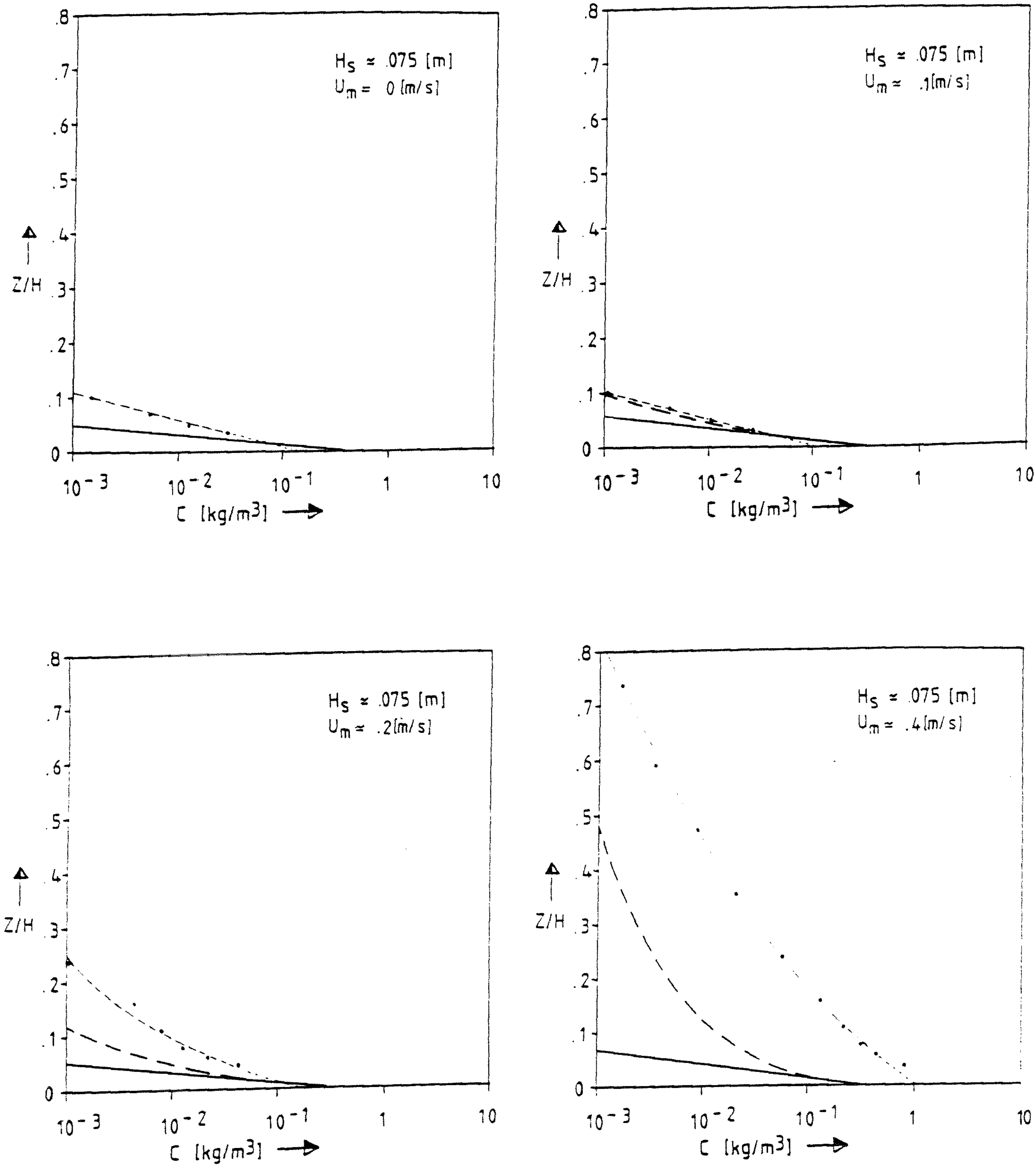

CONCENTRATIONS CALCULATED WITH THE BIJKER METHOD

FIG. 4.1 E




CONCENTRATIONS CALCULATED WITH THE BIJKER METHOD

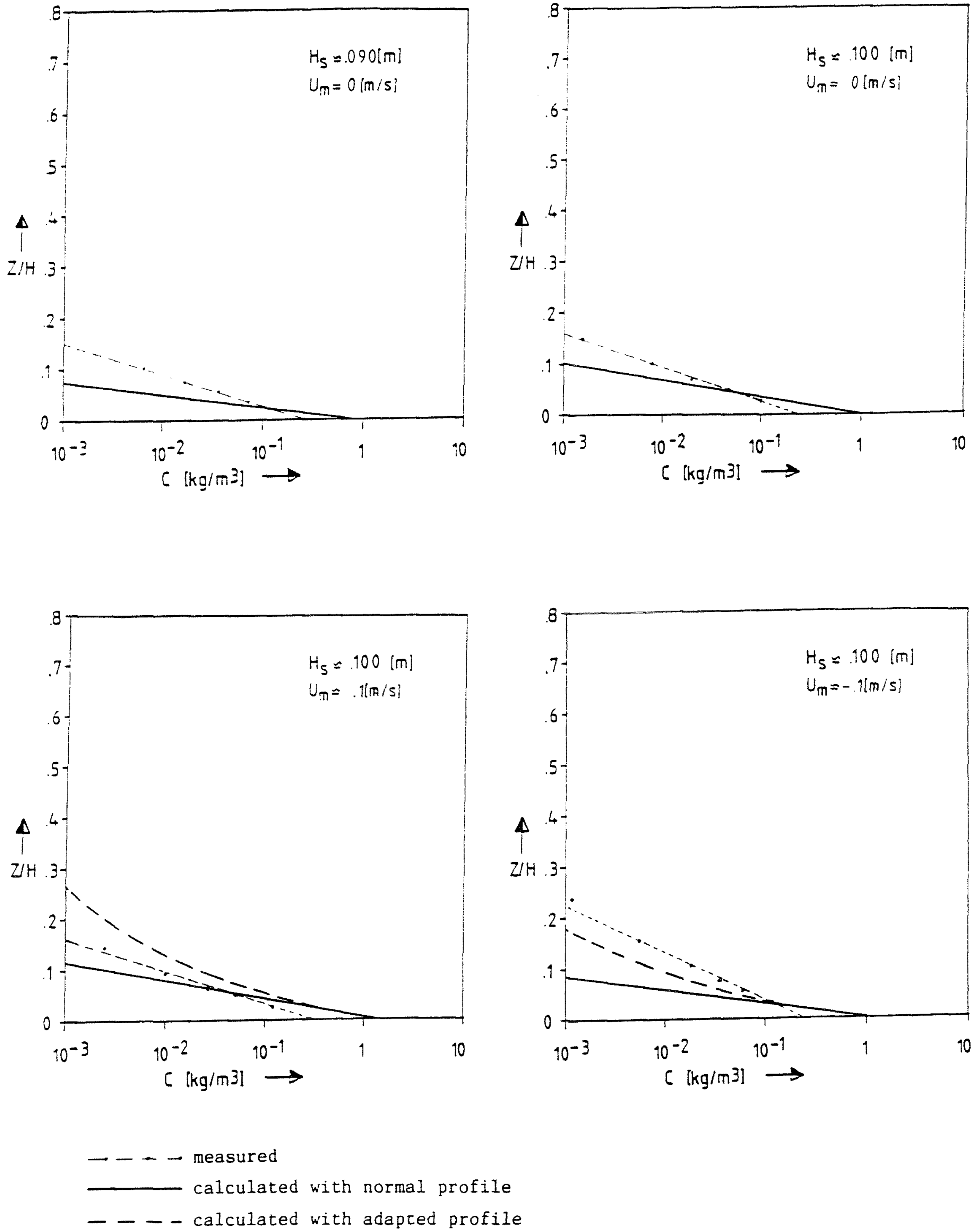
FIG. 4.1 F



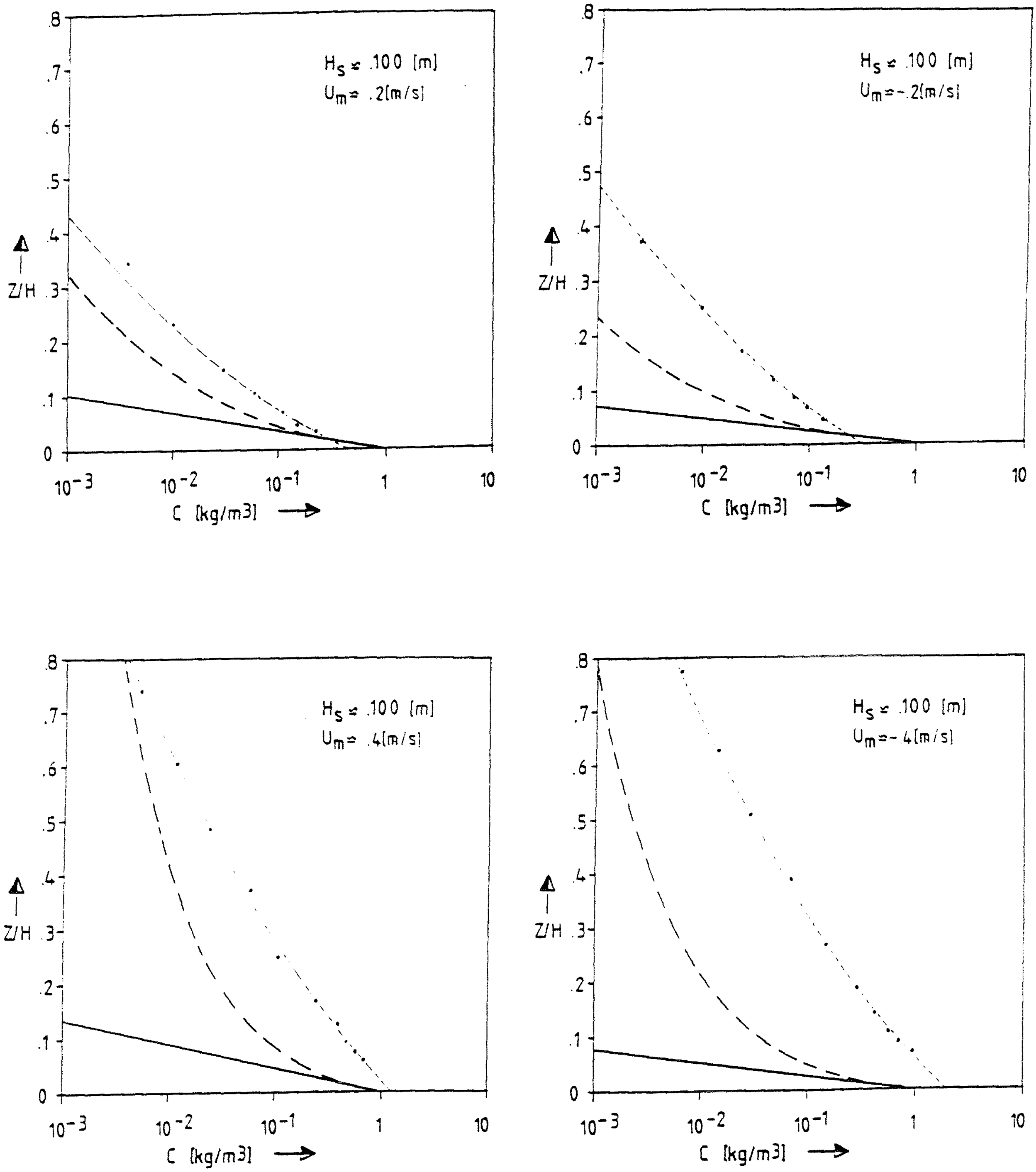

- - - measured
——— calculated with normal profile
— — — calculated with adapted profile

CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 A



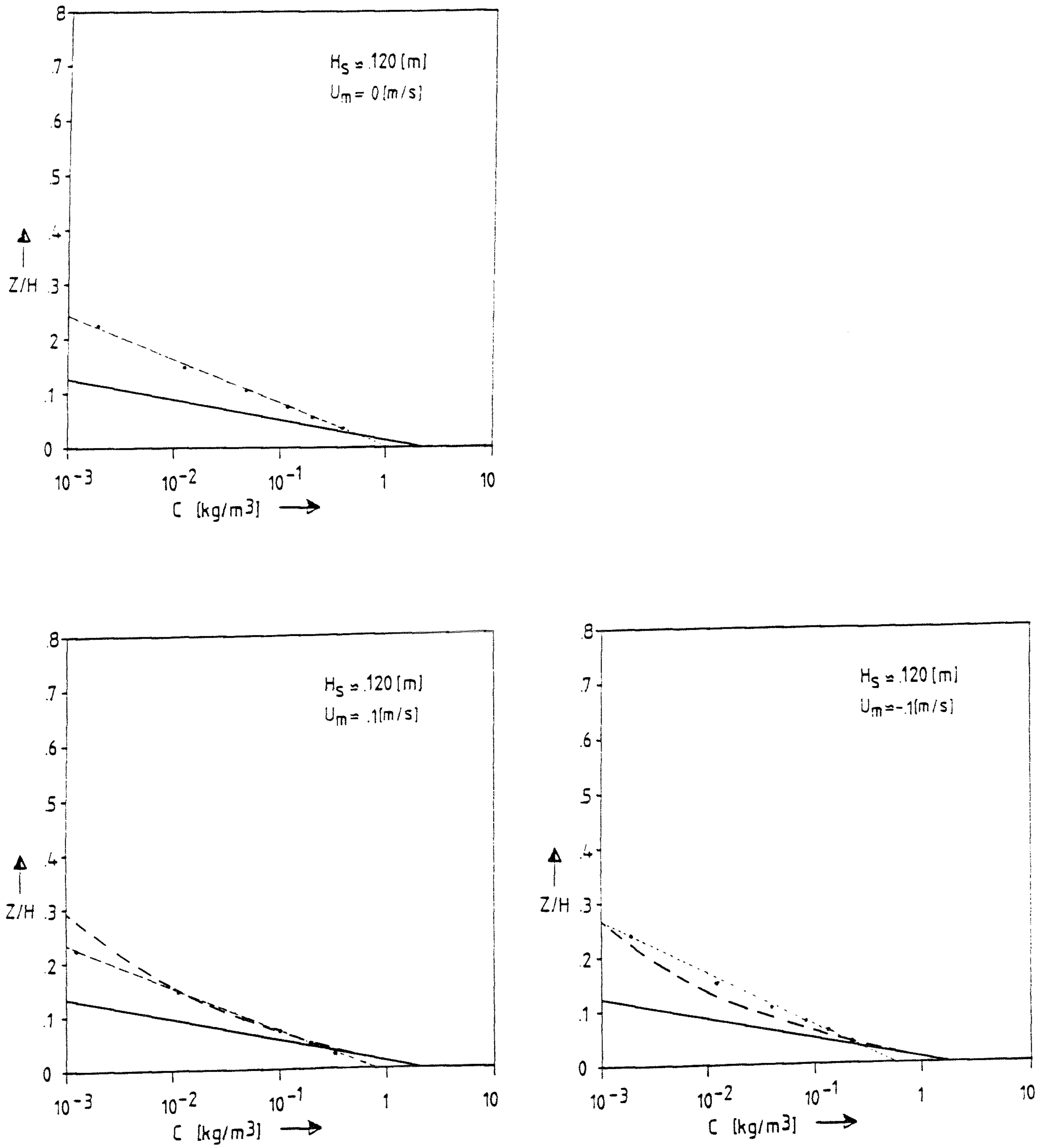

CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD | FIG. 4.2 B




- - - measured
—— calculated with normal profile
— — — calculated with adapted profile

CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 C



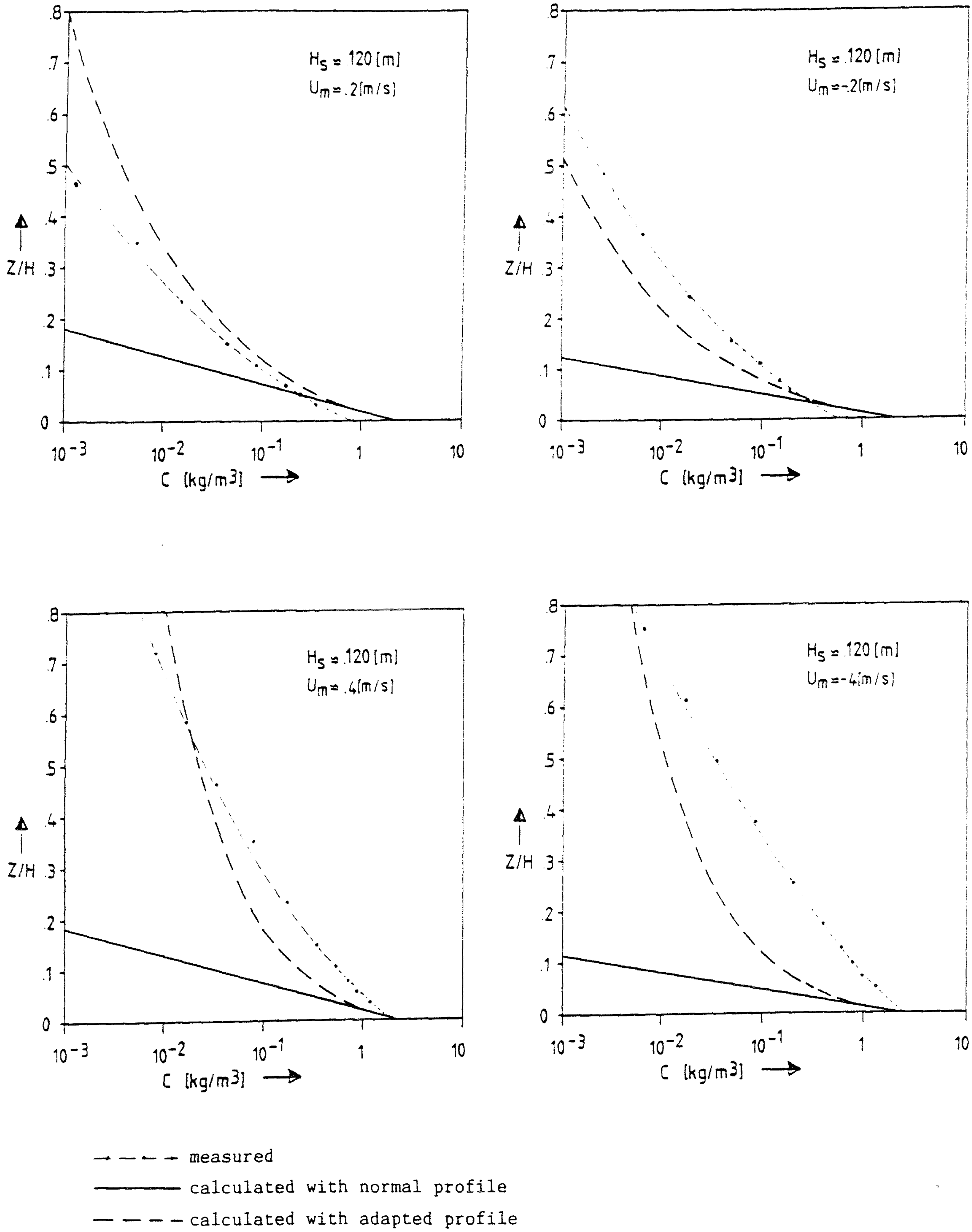

— —·— — measured

——— calculated with normal profile

— — — — calculated with adapted profile

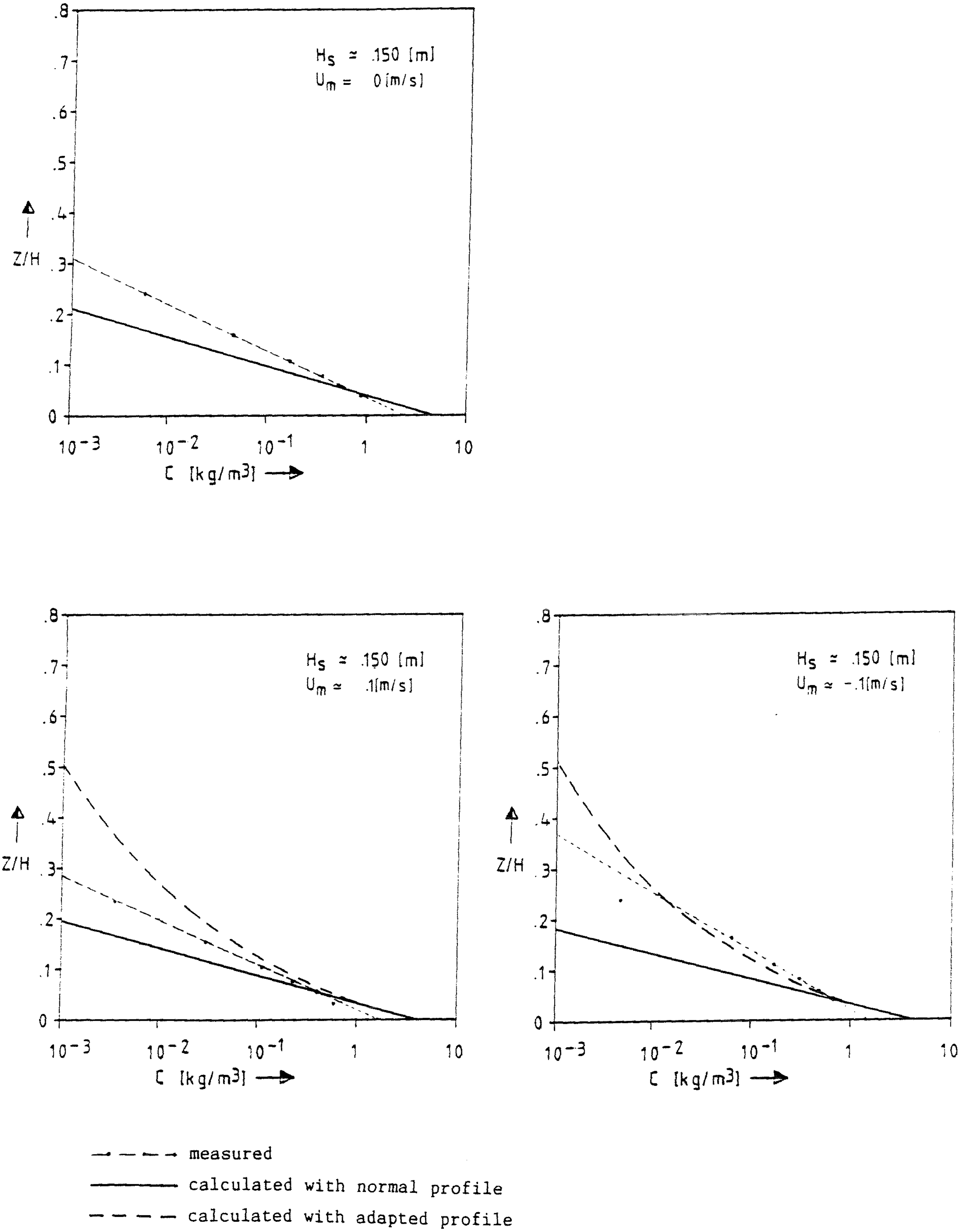
CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 D



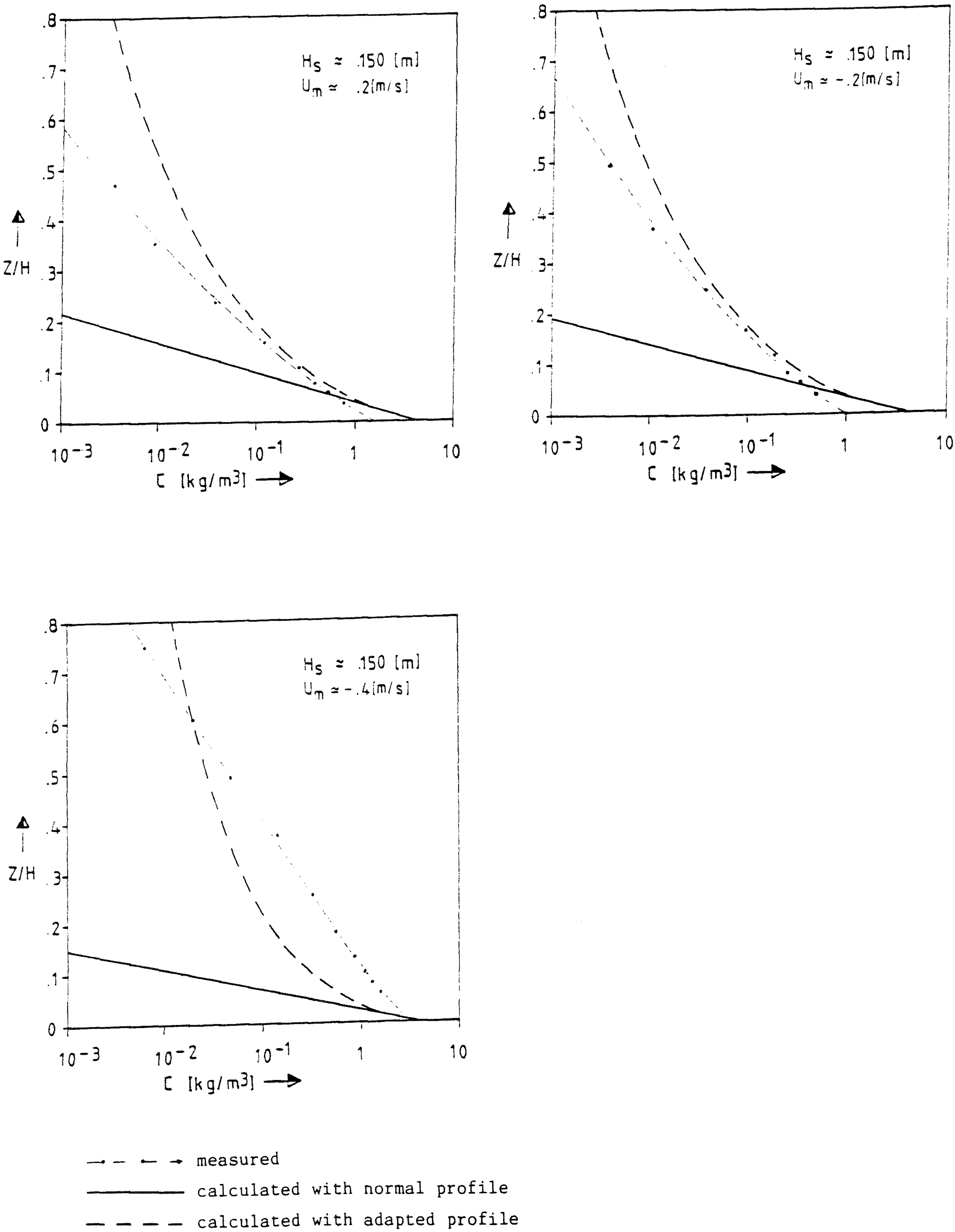

CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 E



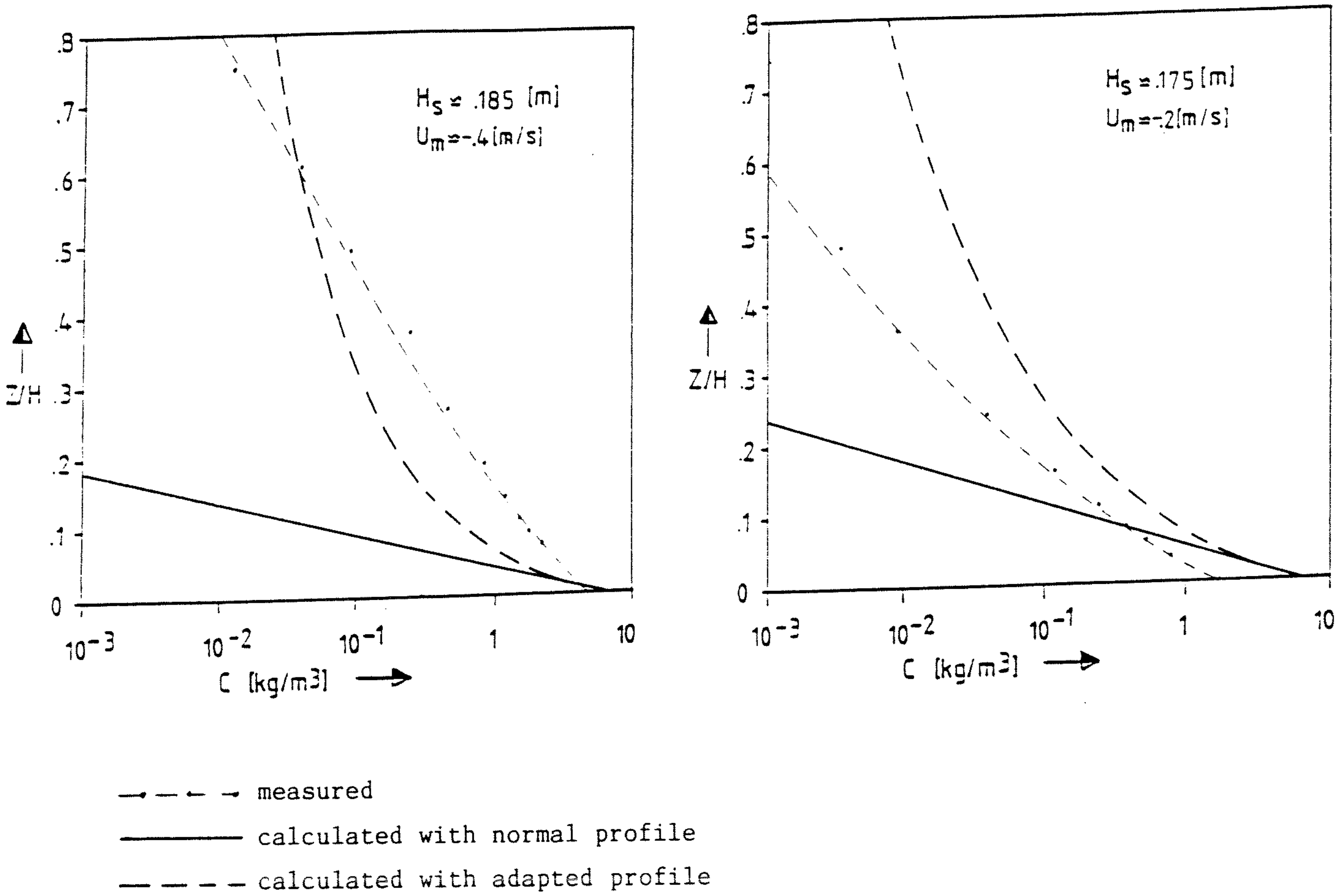

CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 F



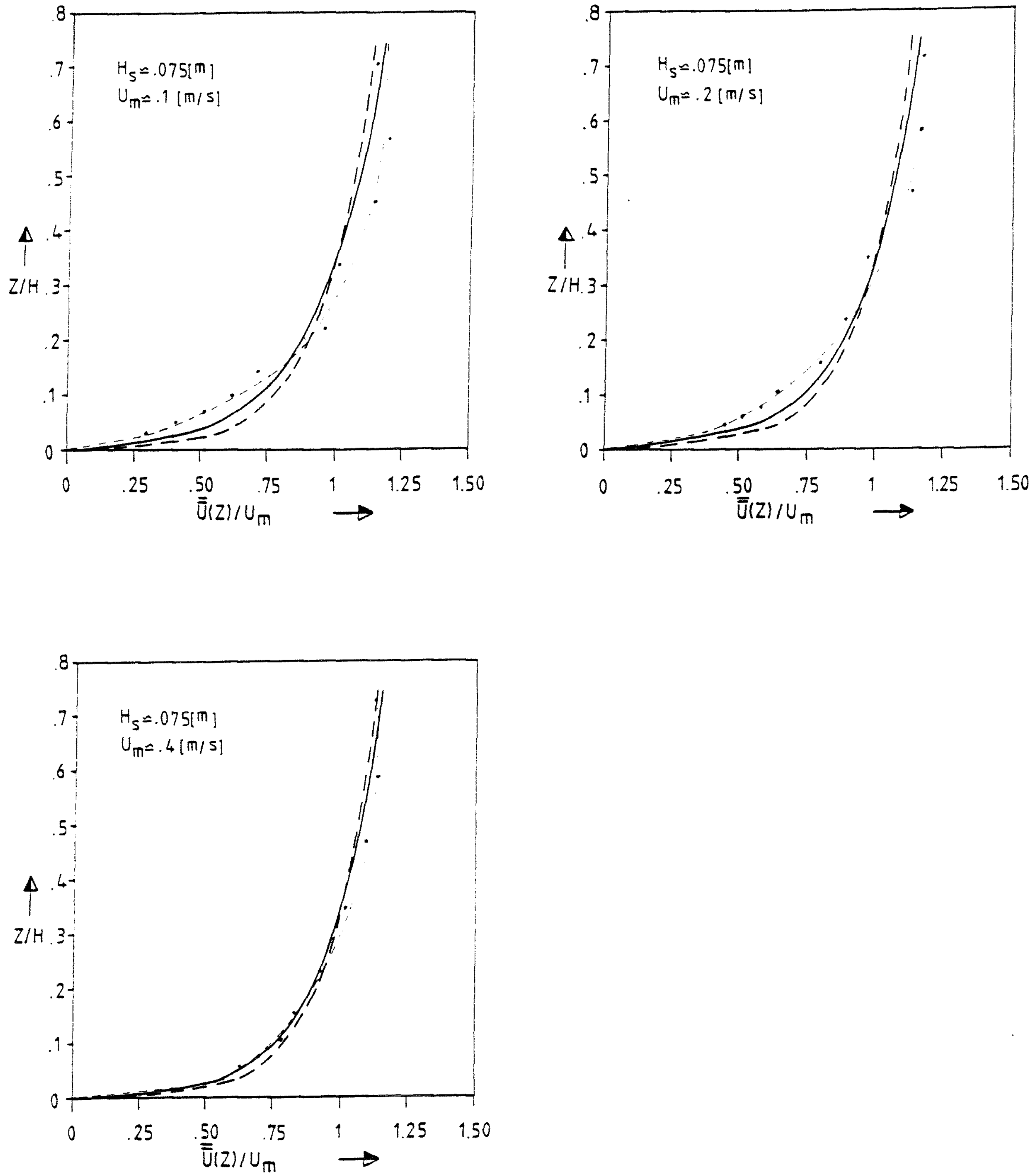

CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 G




CONCENTRATIONS CALCULATED WITH THE NIELSEN METHOD

FIG. 4.2 H



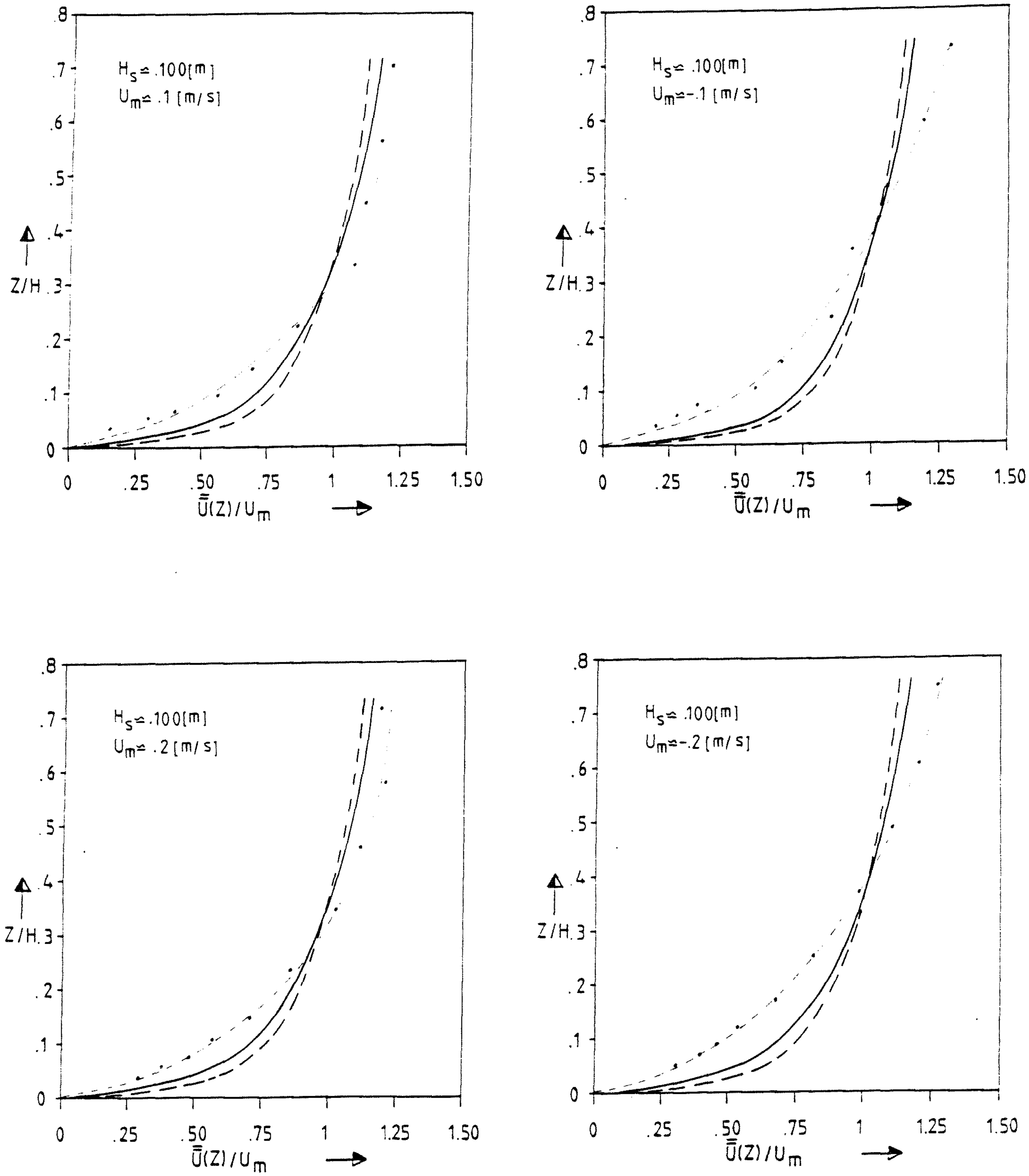

— — measured

——— calculated with Swart roughness

— — — calculated with Van Rijn roughness

VELOCITIES CALCULATED WITH THE BIJKER METHOD

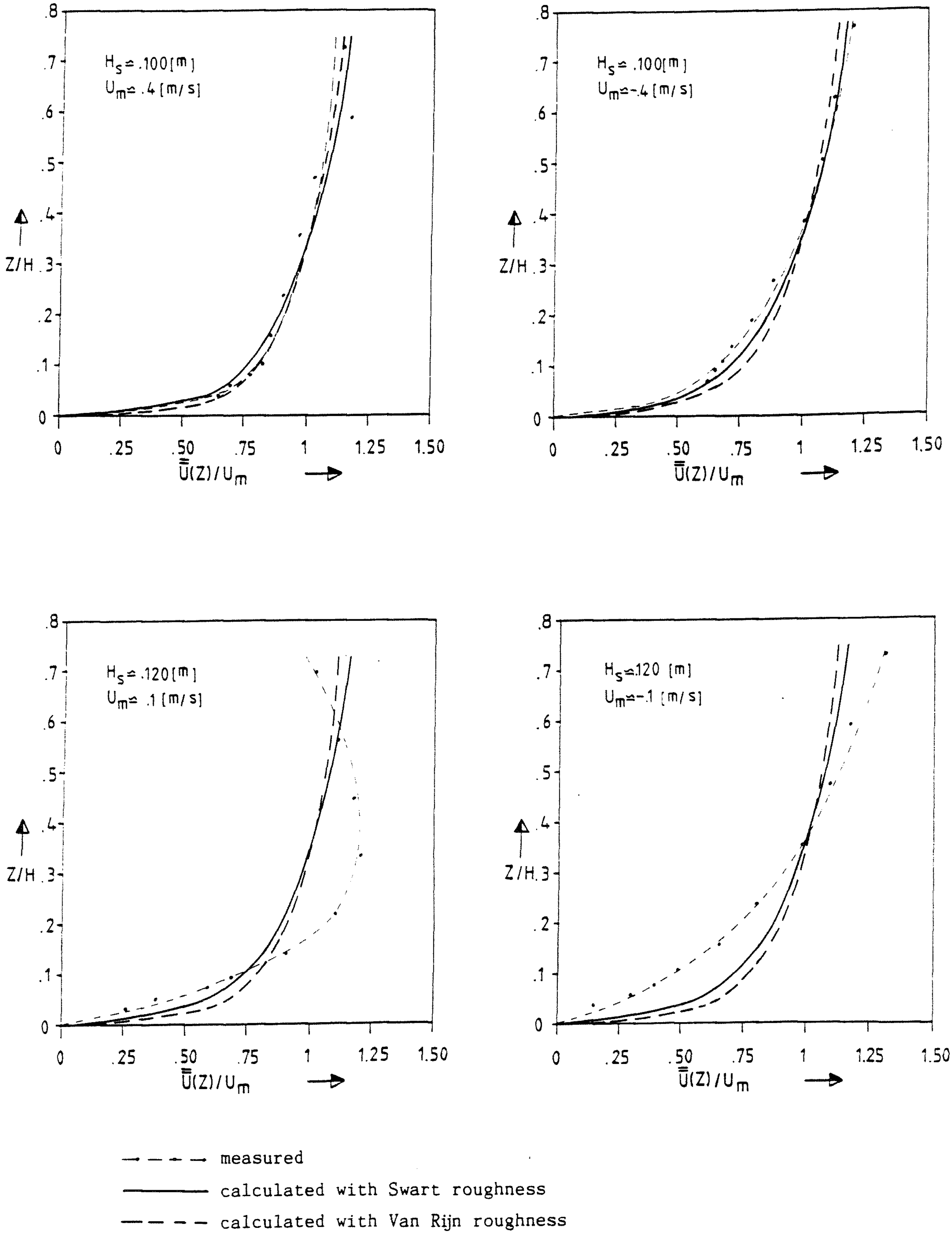
FIG. 4.3 A




— · — · measured

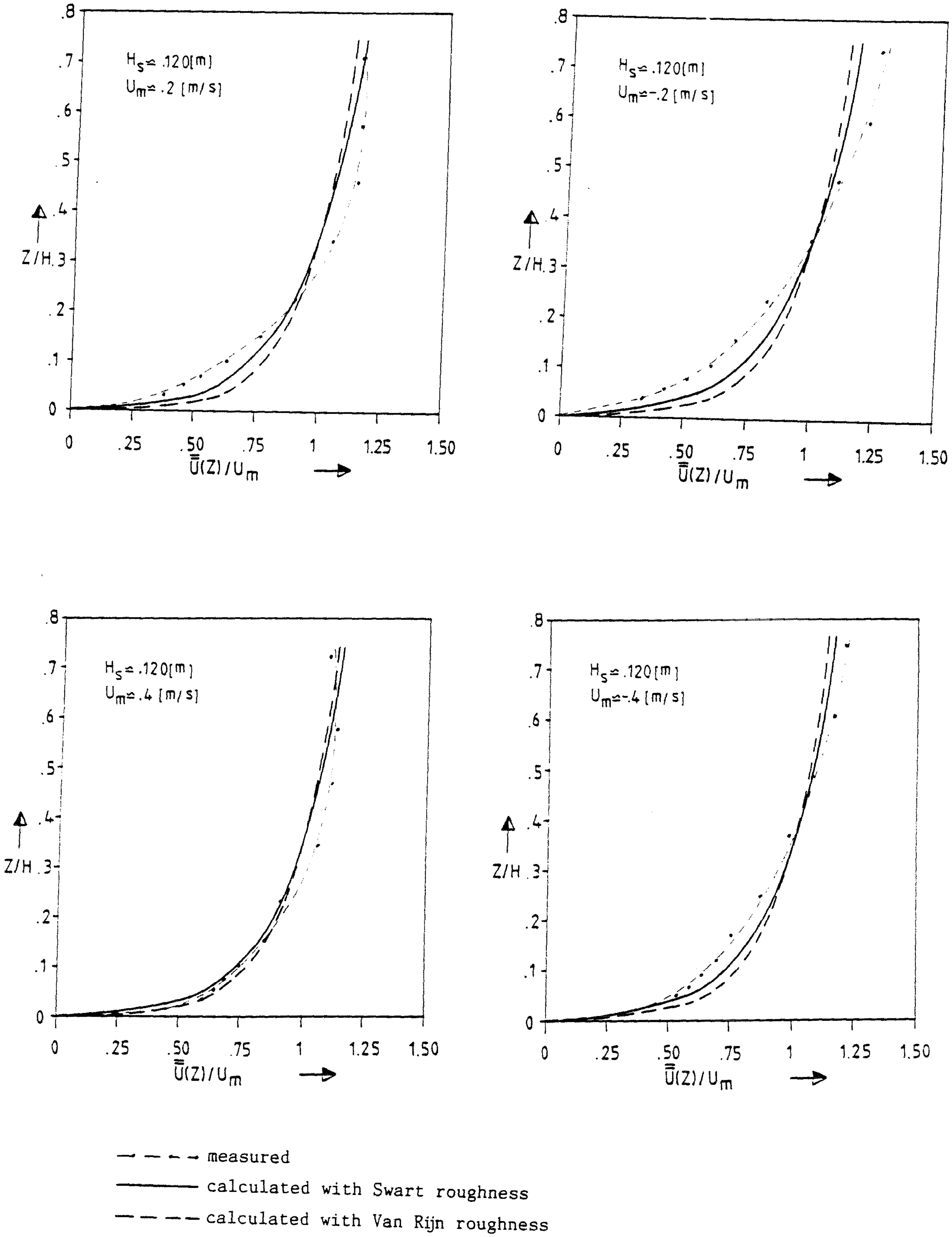
——— calculated with Swart roughness

— — — calculated with Van Rijn roughness



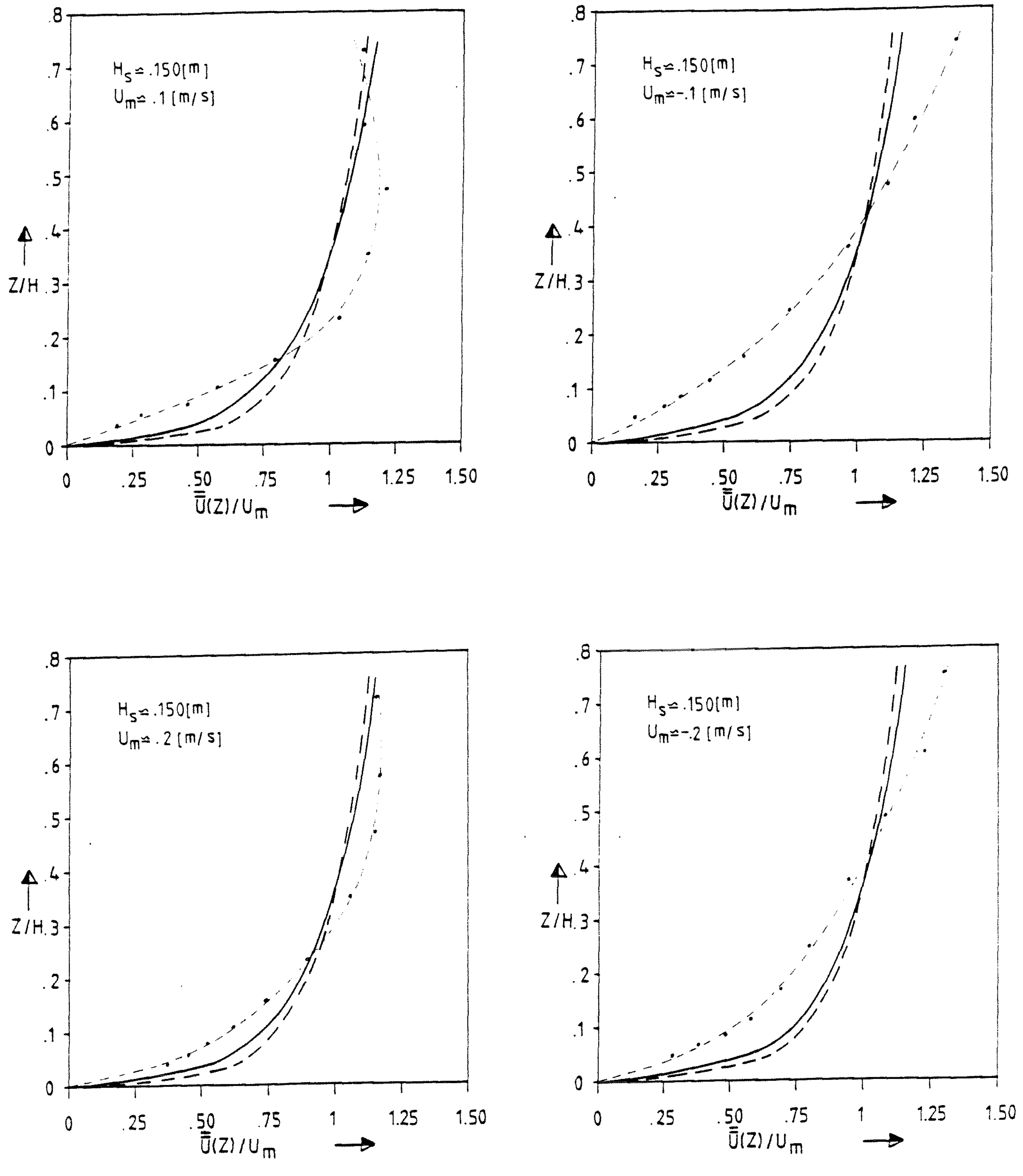

VELOCITIES CALCULATED WITH THE BIJKER METHOD

FIG. 4.3 C




VELOCITIES CALCULATED WITH THE BIJKER METHOD

FIG. 4.3 D



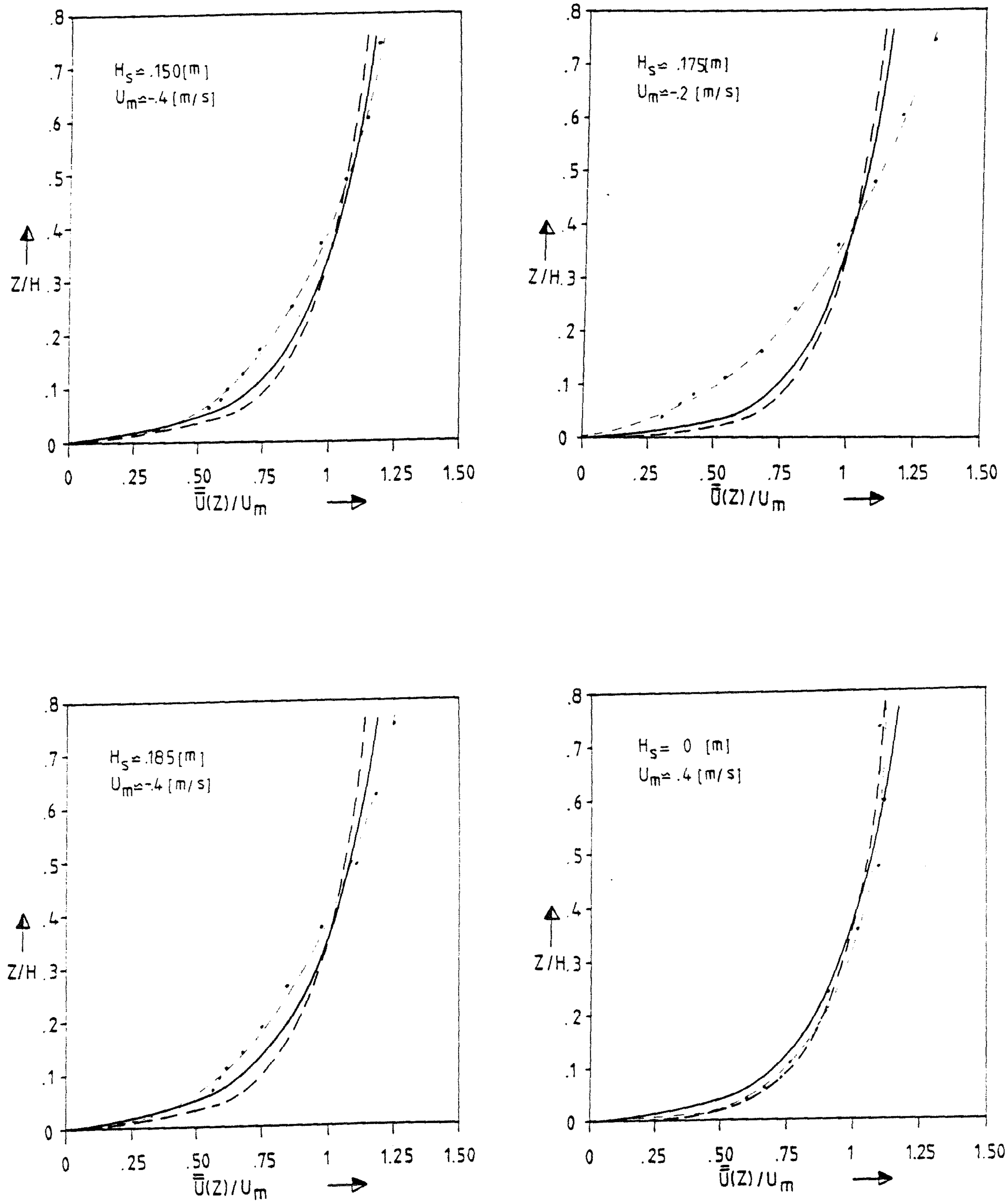

measured

calculated with Swart roughness

calculated with Van Rijn roughness

VELOCITIES CALCULATED WITH THE BIJKER METHOD

FIG. 4.3 E



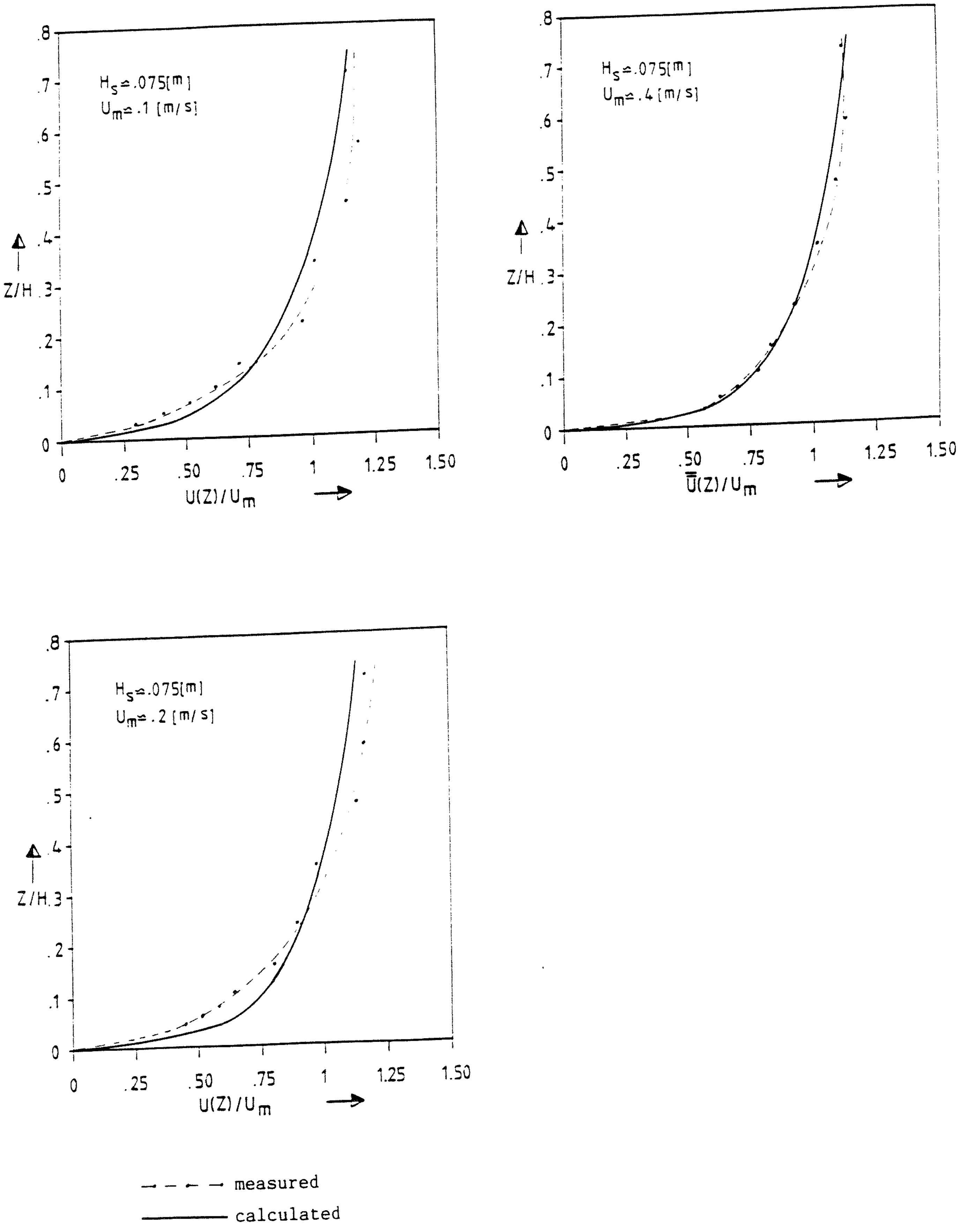

measured

calculated with Swart roughness

calculated with Van Rijn roughness

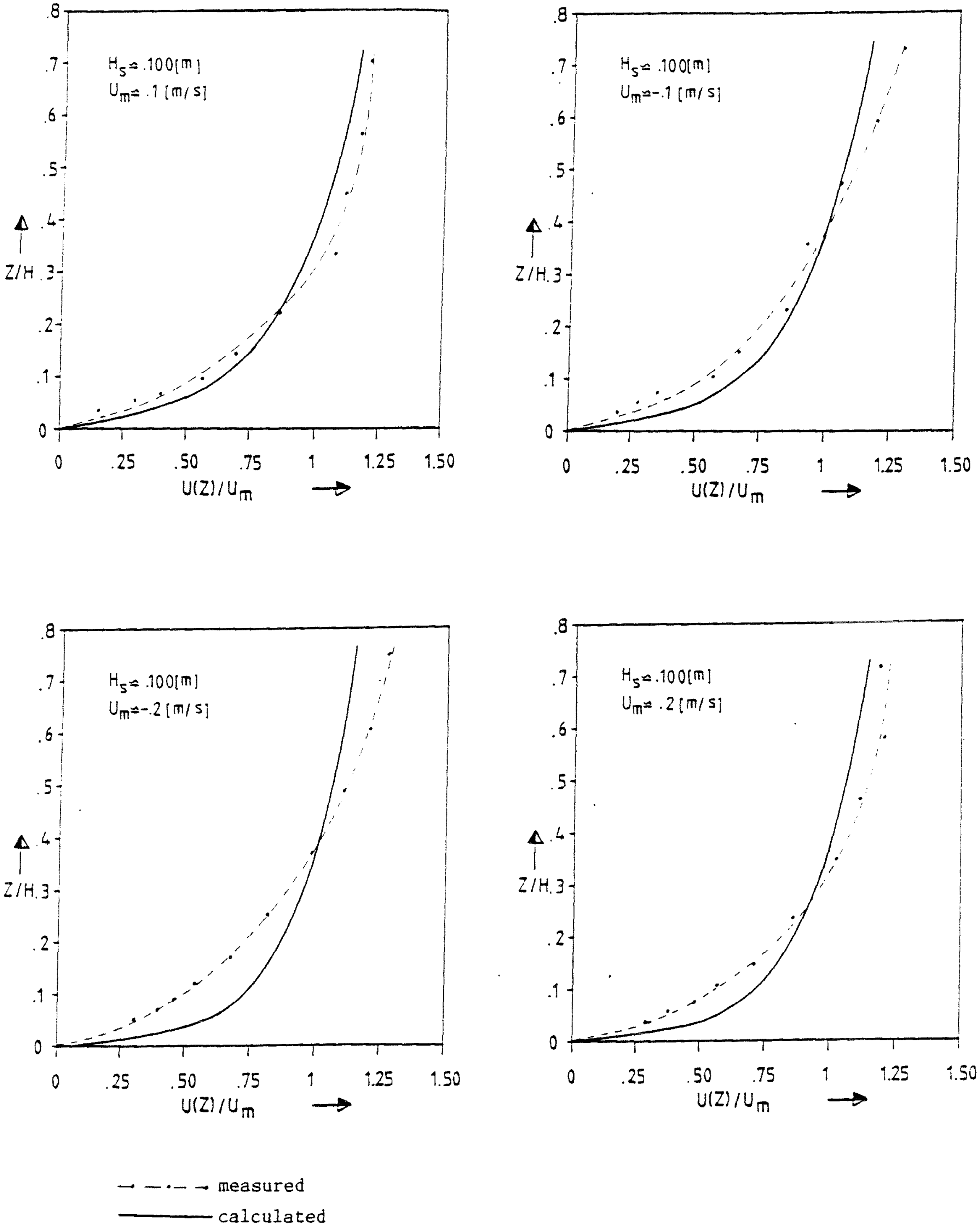
VELOCITIES CALCULATED WITH THE BIJKER METHOD

FIG. 4.3 F



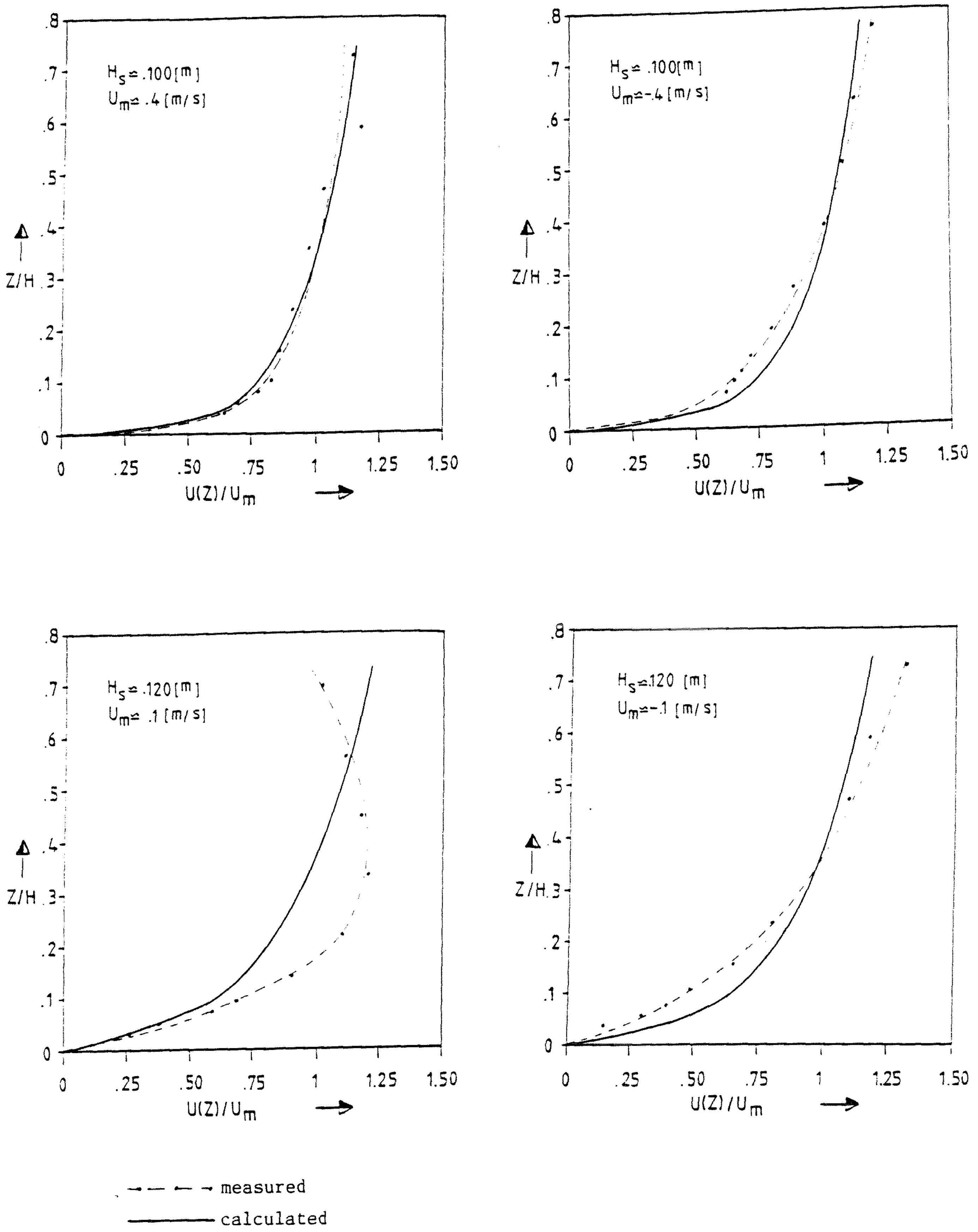

VELOCITIES CALCULATED WITH THE NIELSEN METHOD

FIG. 4.4 A



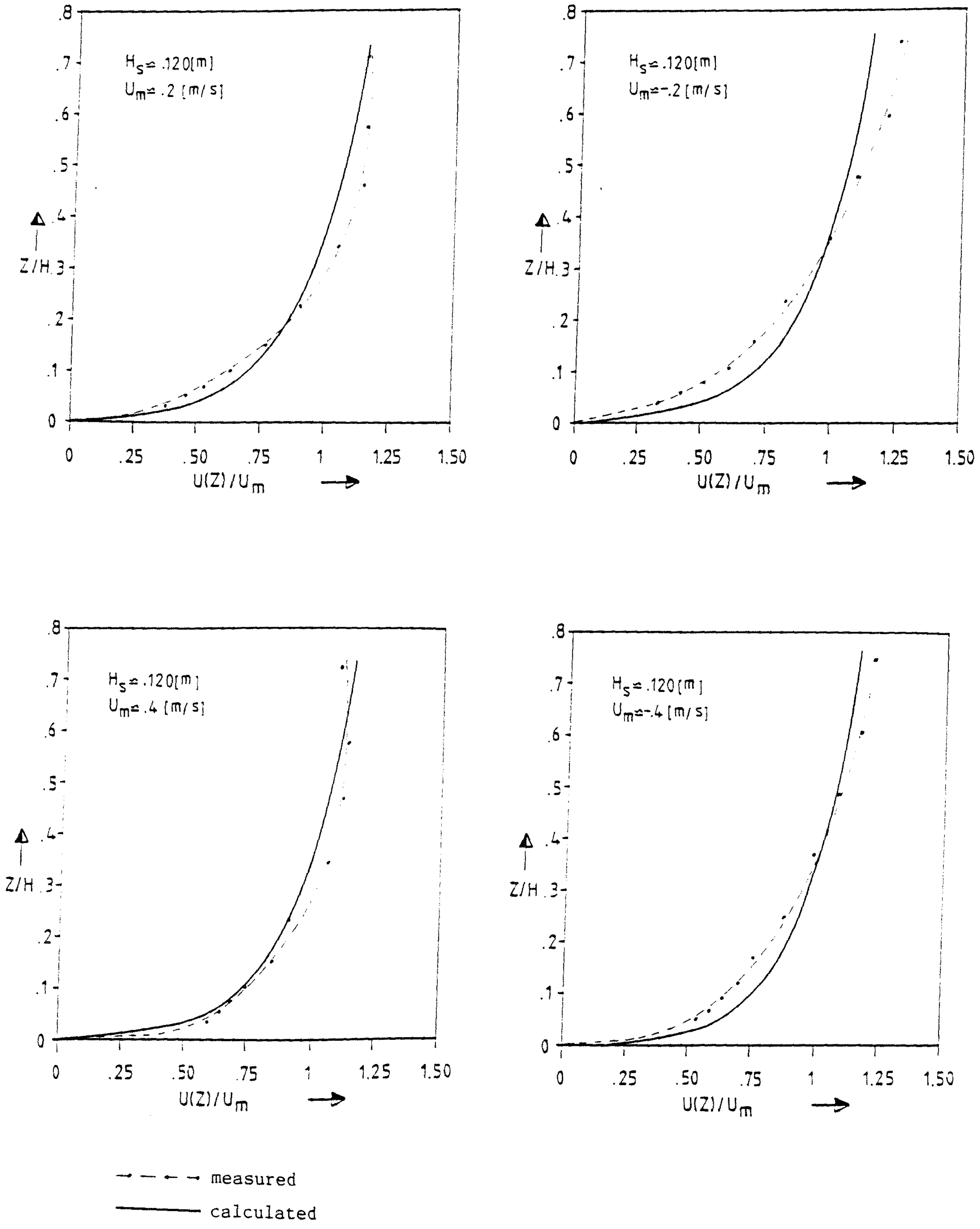

VELOCITIES CALCULATED WITH THE NIELSEN METHOD

FIG. 4.4 B



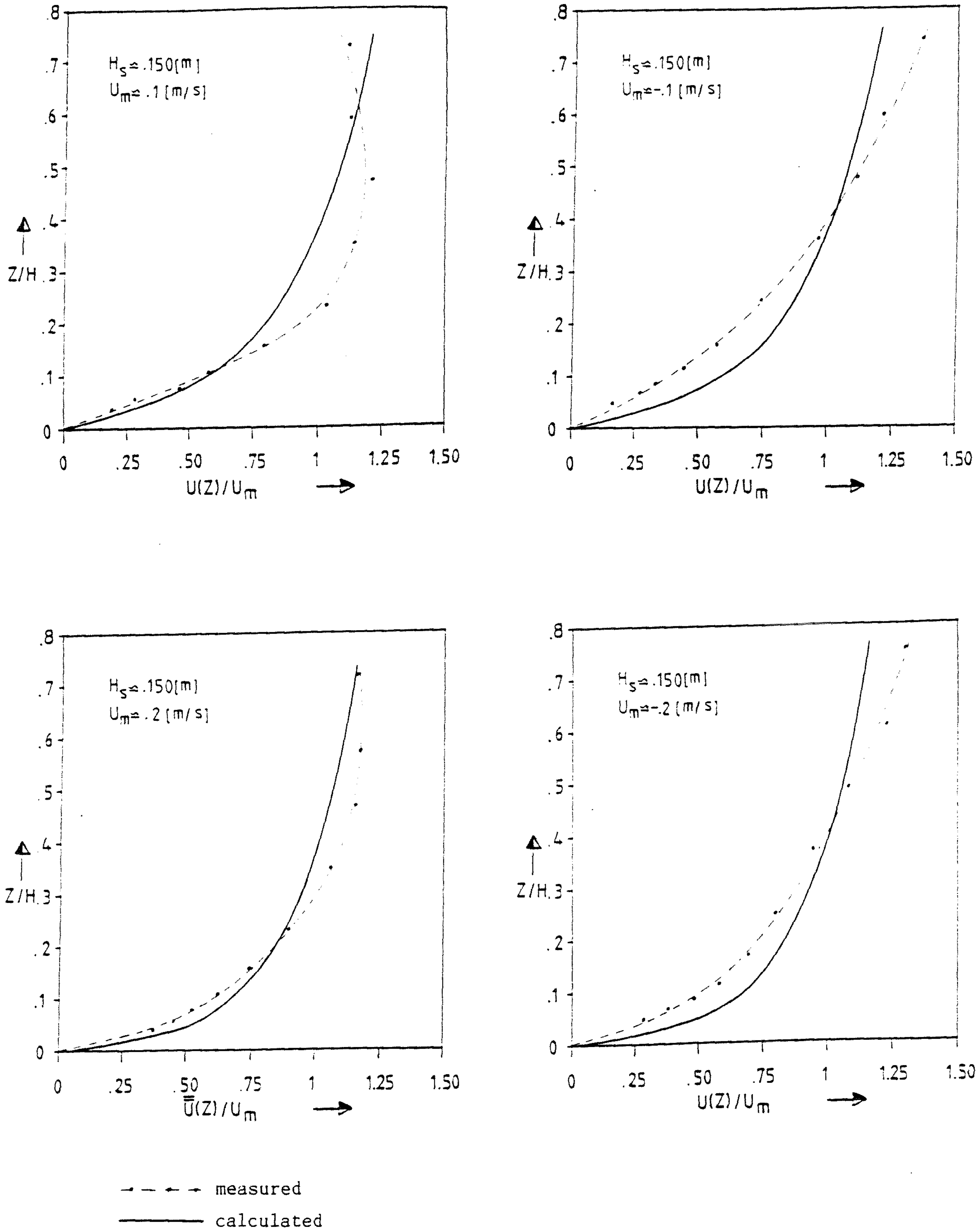

VELOCITIES CALCULATED WITH THE NIELSEN METHOD

FIG. 4.4 C



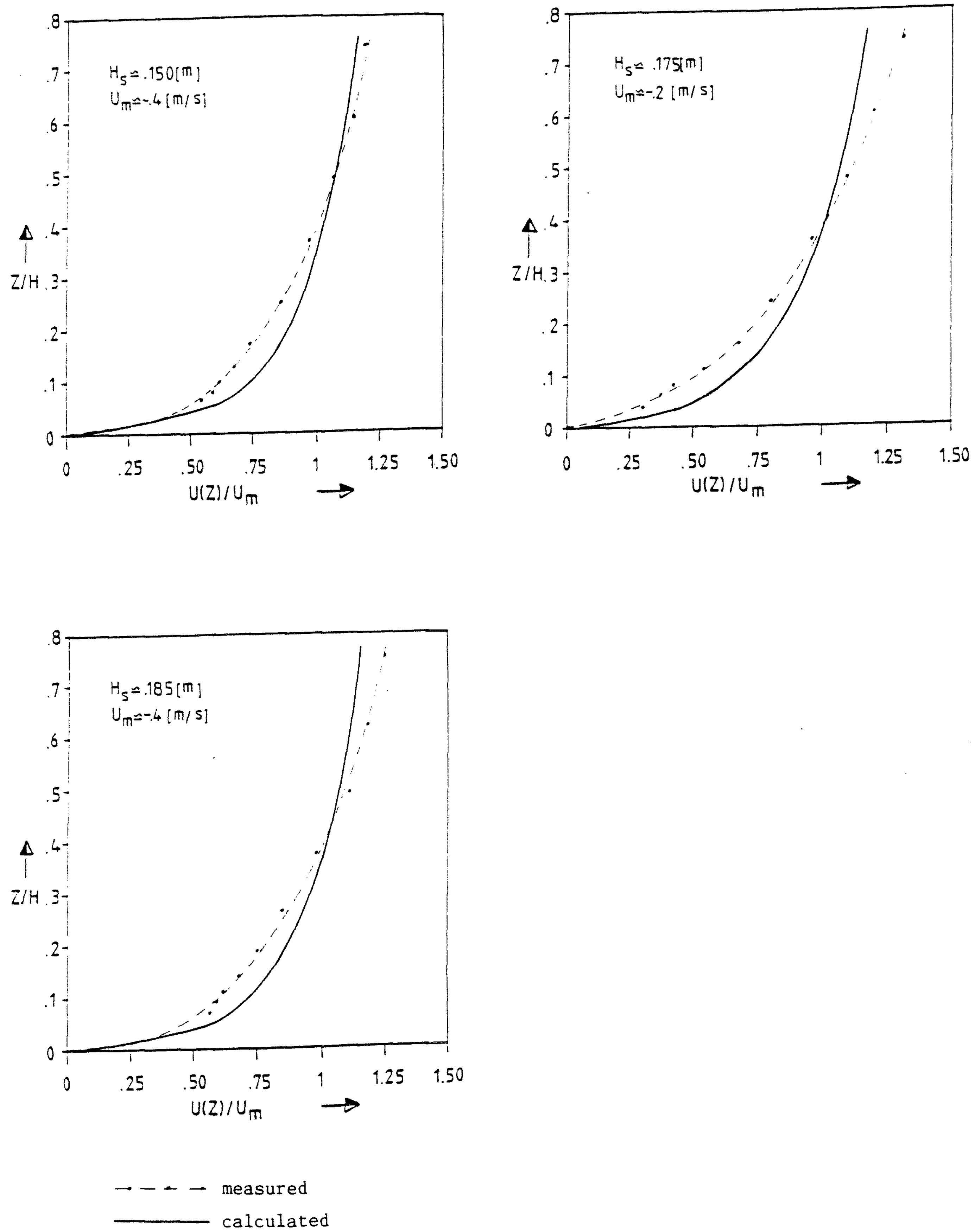

VELOCITIES CALCULATED WITH THE NIELSEN METHOD

FIG. 4.4 D



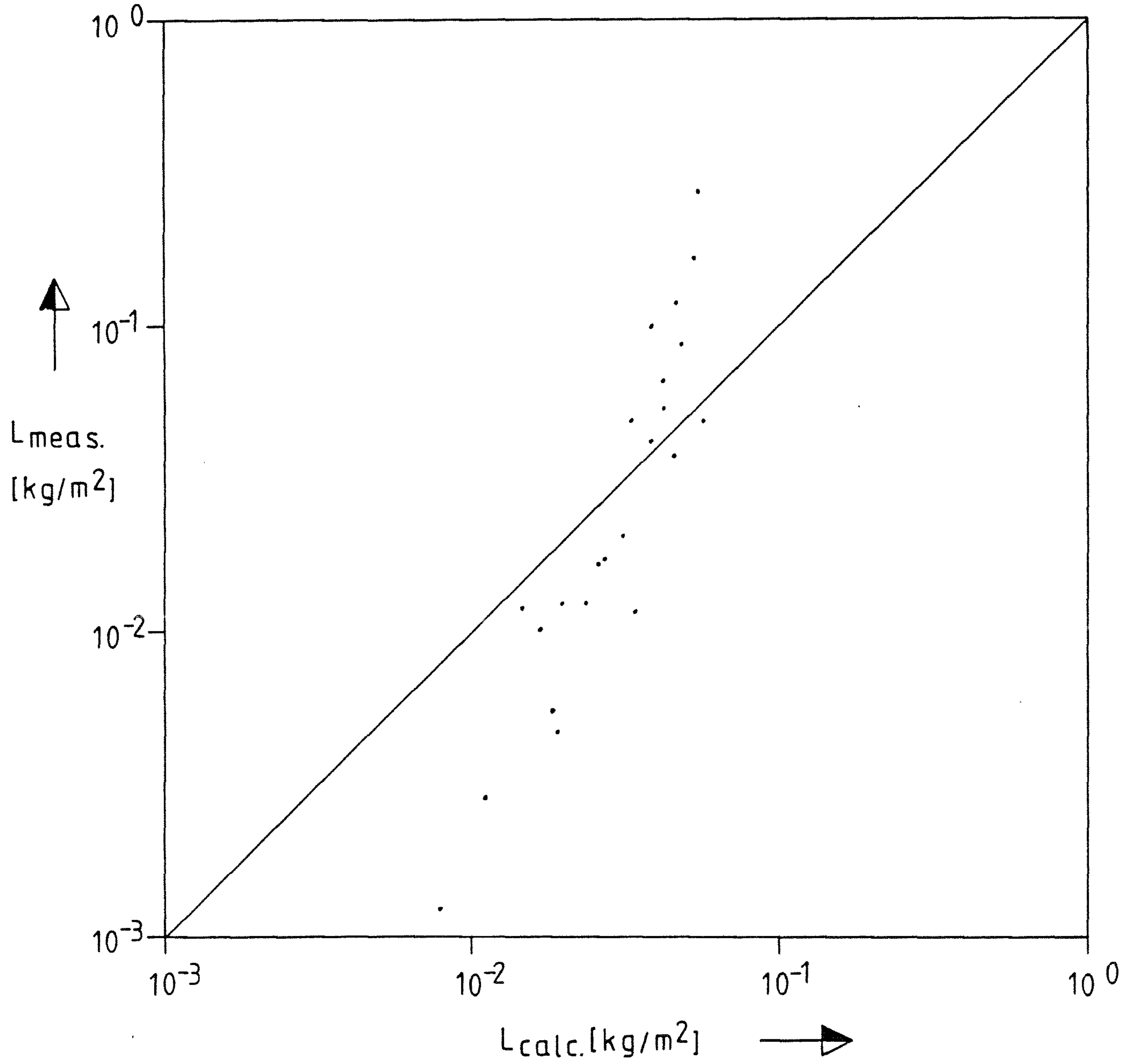

VELOCITIES CALCULATED WITH THE NIELSEN METHOD

FIG. 4.4 E



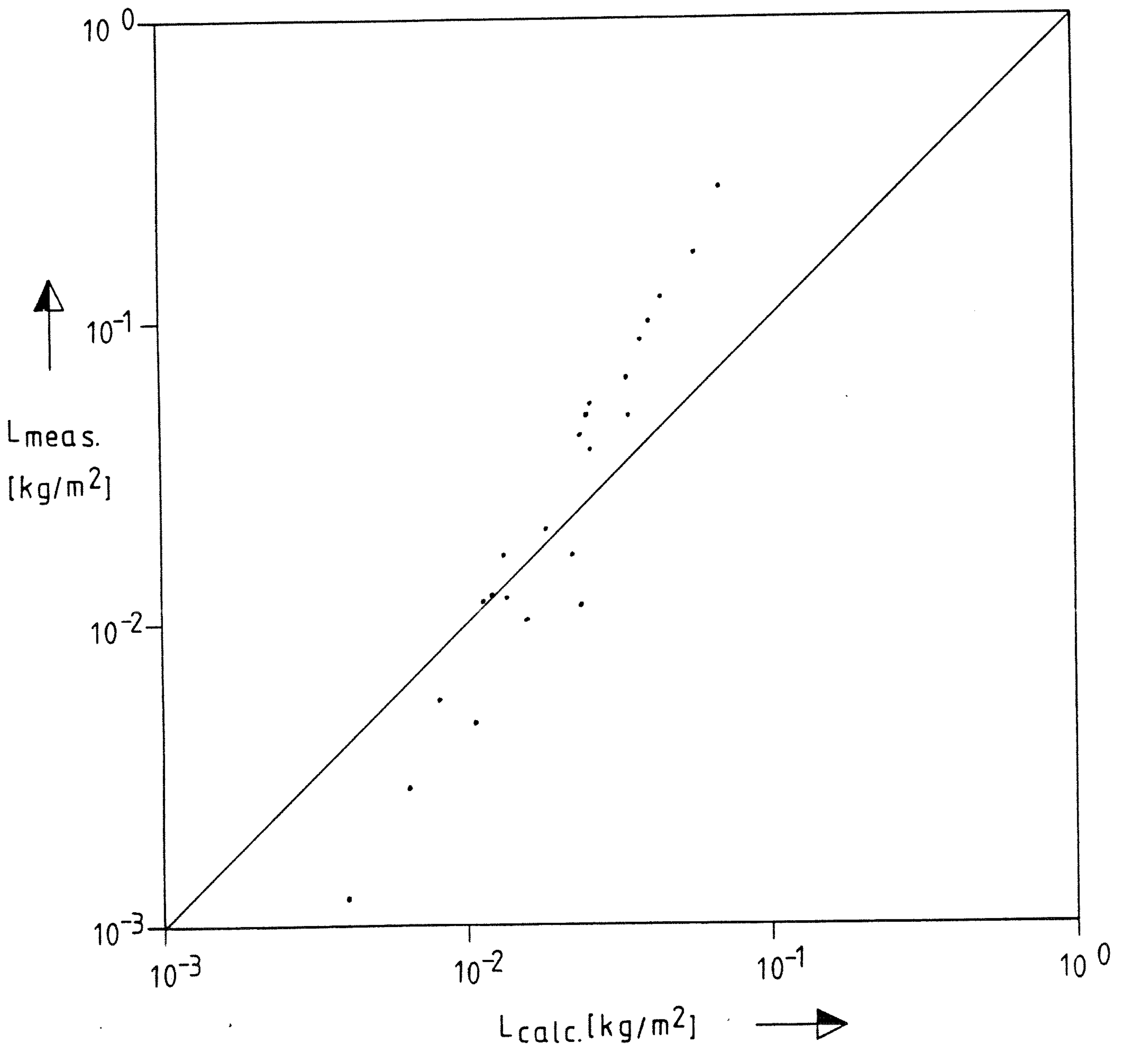

VELOCITIES CALCULATED WITH THE NIELSEN METHOD

FIG. 4.4 F



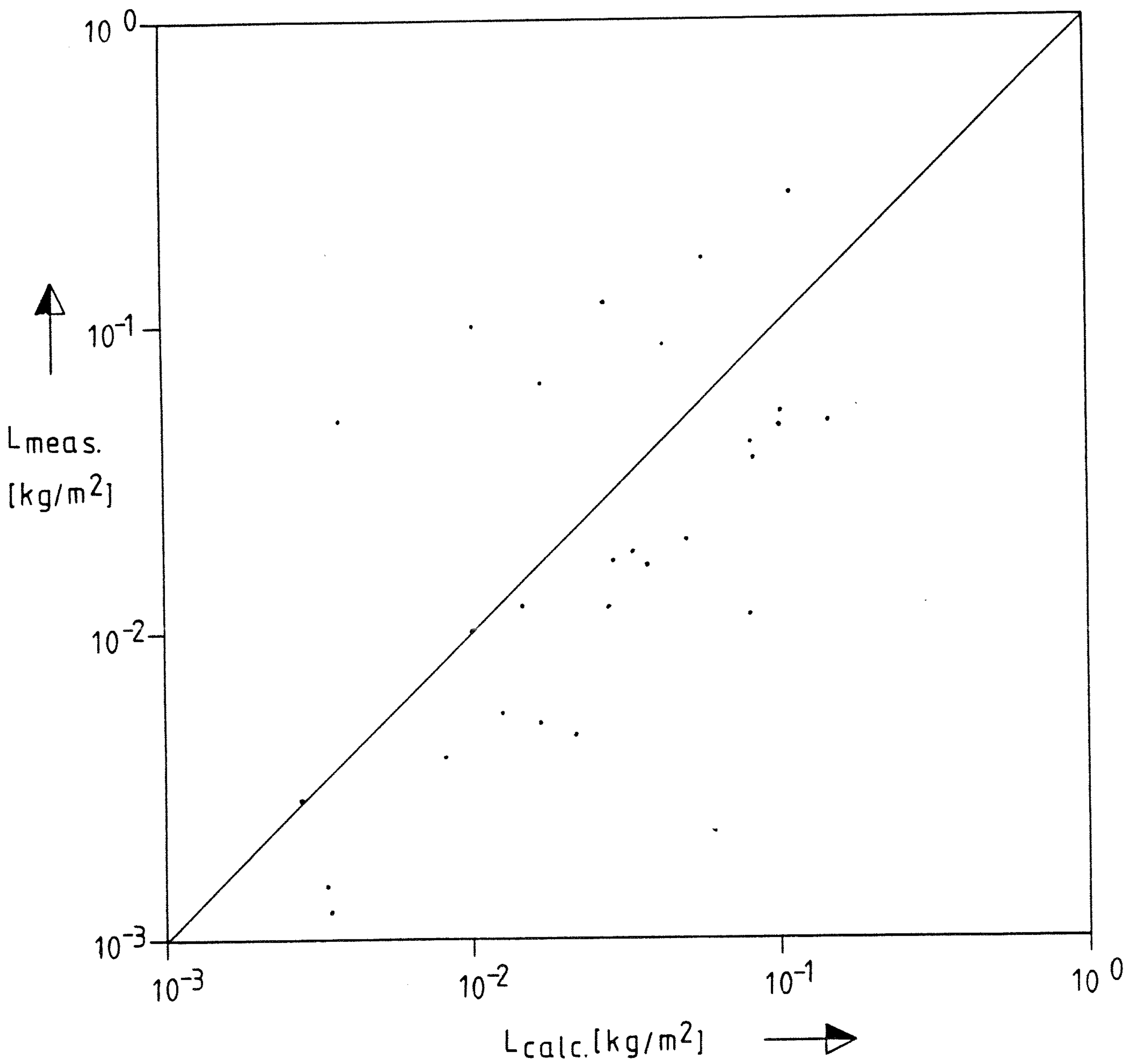

COMPARISON OF MEASURED TOTAL LOAD AND TOTAL LOAD CALCULATED
WITH THE BIJKER METHOD USING THE SWART ROUGHNESS

FIG. 4.5 A



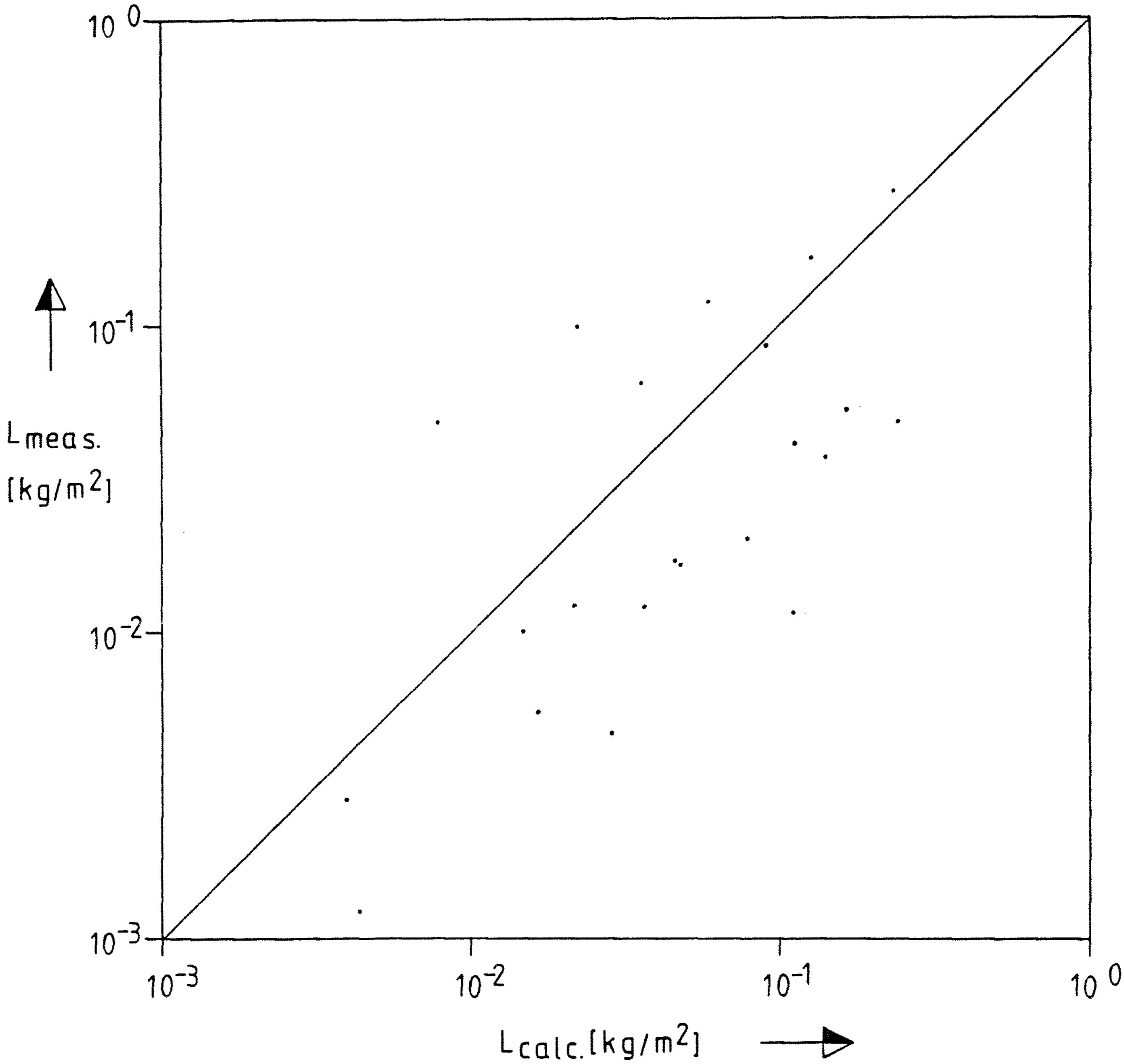

COMPARISON OF MEASURED TOTAL LOAD AND TOTAL LOAD CALCULATED WITH THE BIJKER METHOD USING THE VAN RIJN ROUGHNESS

FIG. 4.5 B

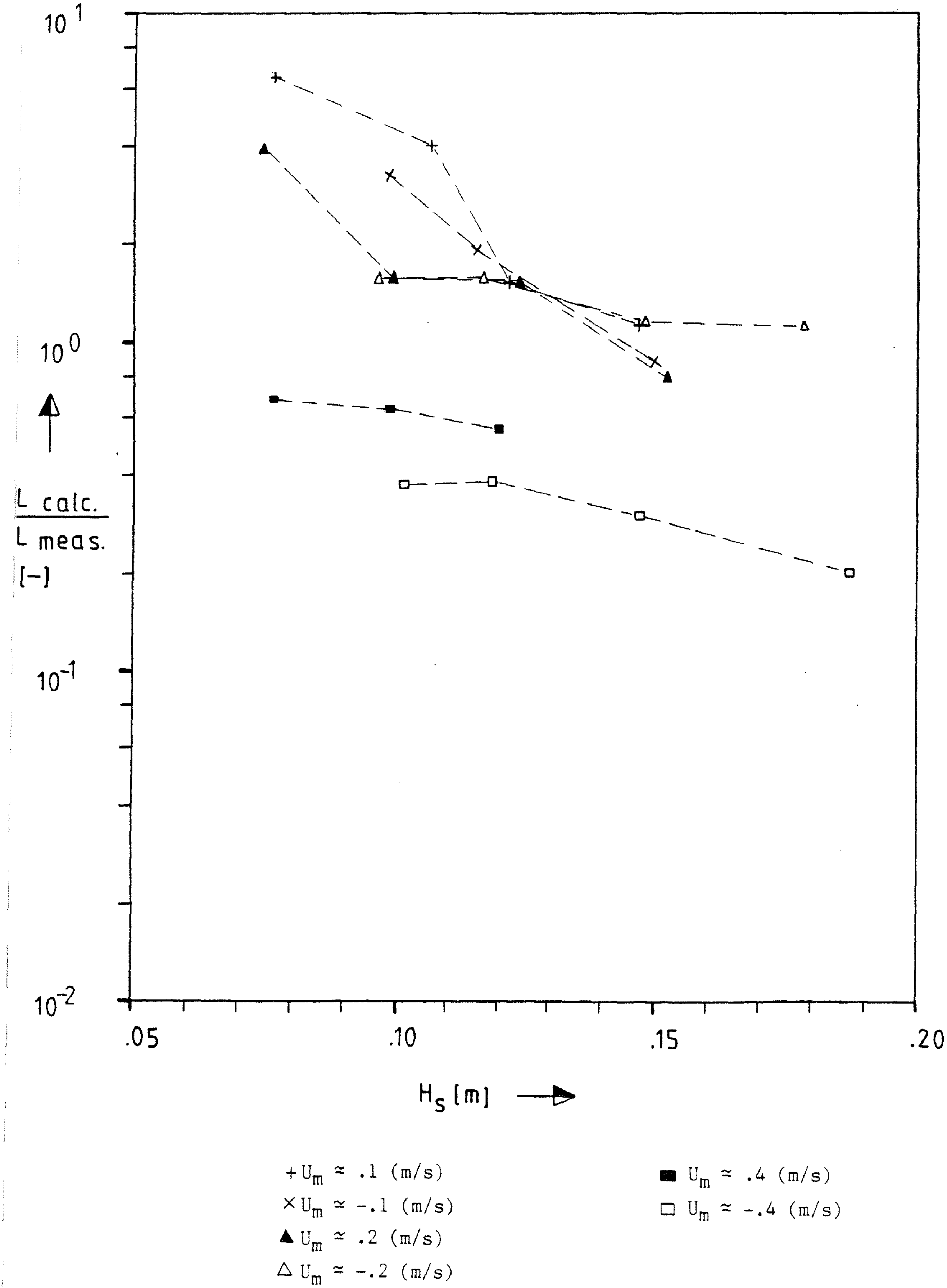



COMPARISON OF MEASURED TOTAL LOAD AND TOTAL LOAD CALCULATED WITH THE NIELSEN METHOD USING THE NORMAL CONCENTRATION PROFILE

FIG. 4.5 C

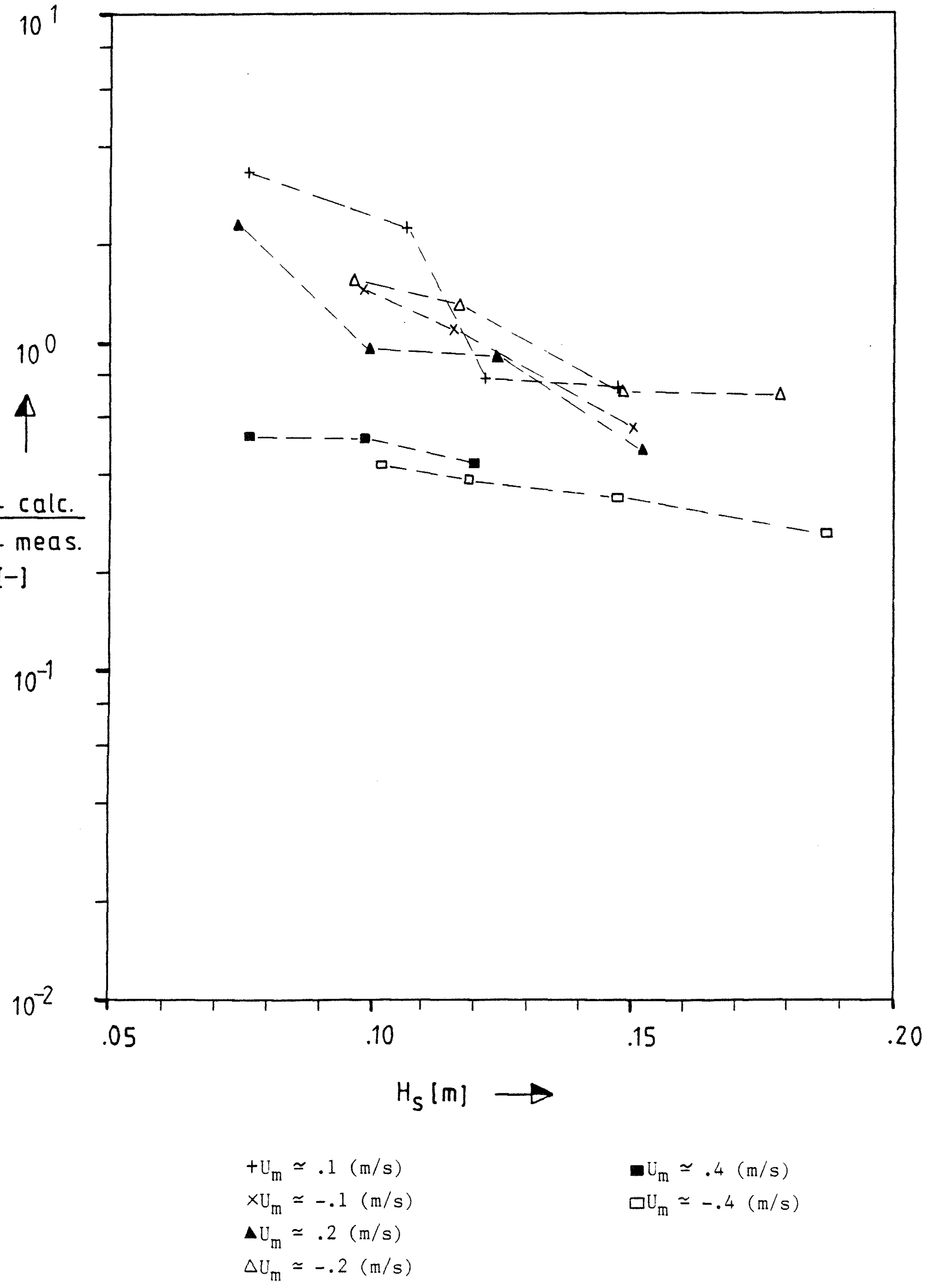



| | |
|---|---|
| COMPARISON OF MEASURED TOTAL LOAD AND TOTAL LOAD CALCULATED WITH THE NIELSEN METHOD USING THE ADAPTED CONCENTRATION PROFILE | FIG. 4.5 D |



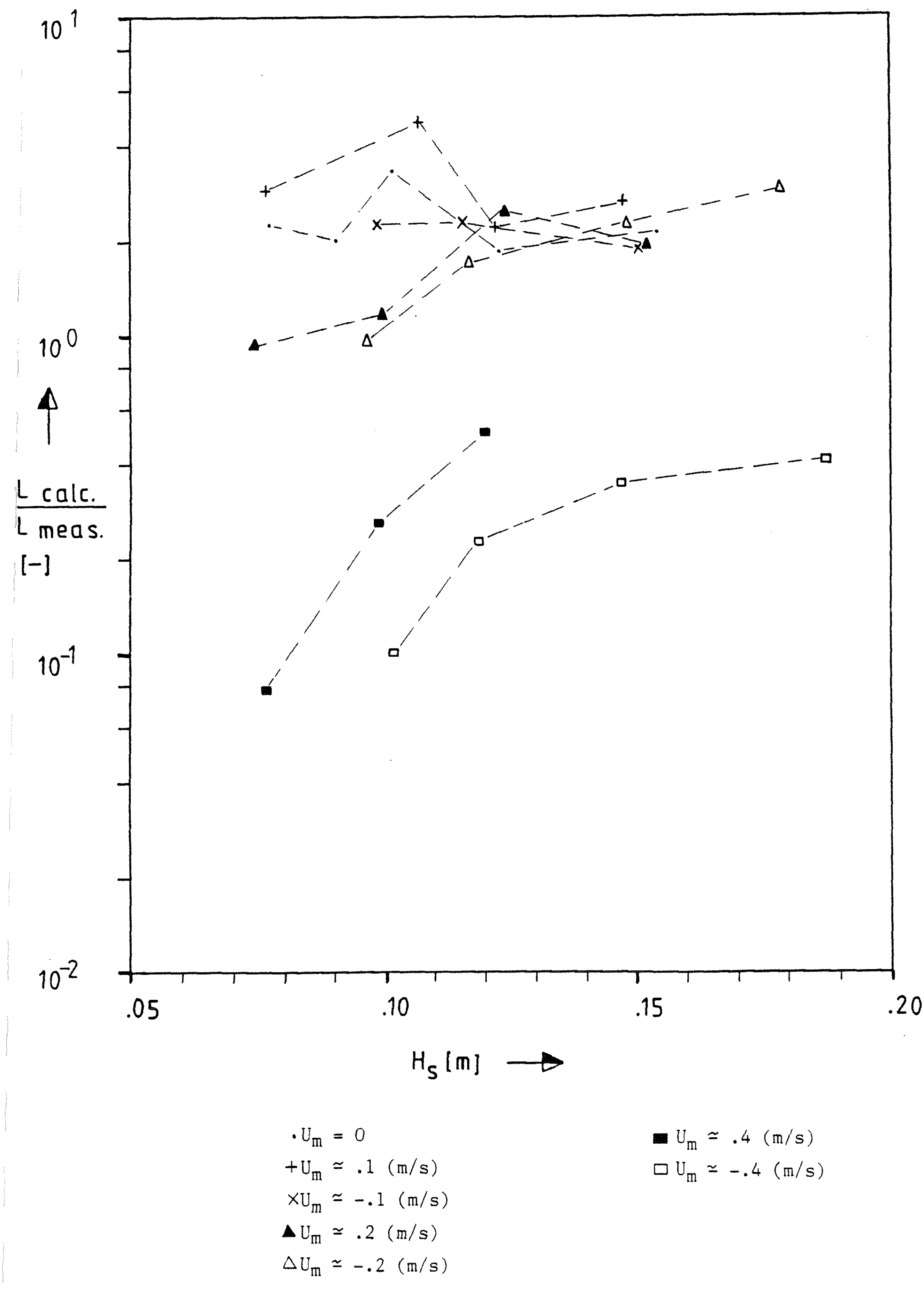

RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR BIJKER METHOD (APPLYING SWART ROUGHNESS)

FIG. 4.6 A



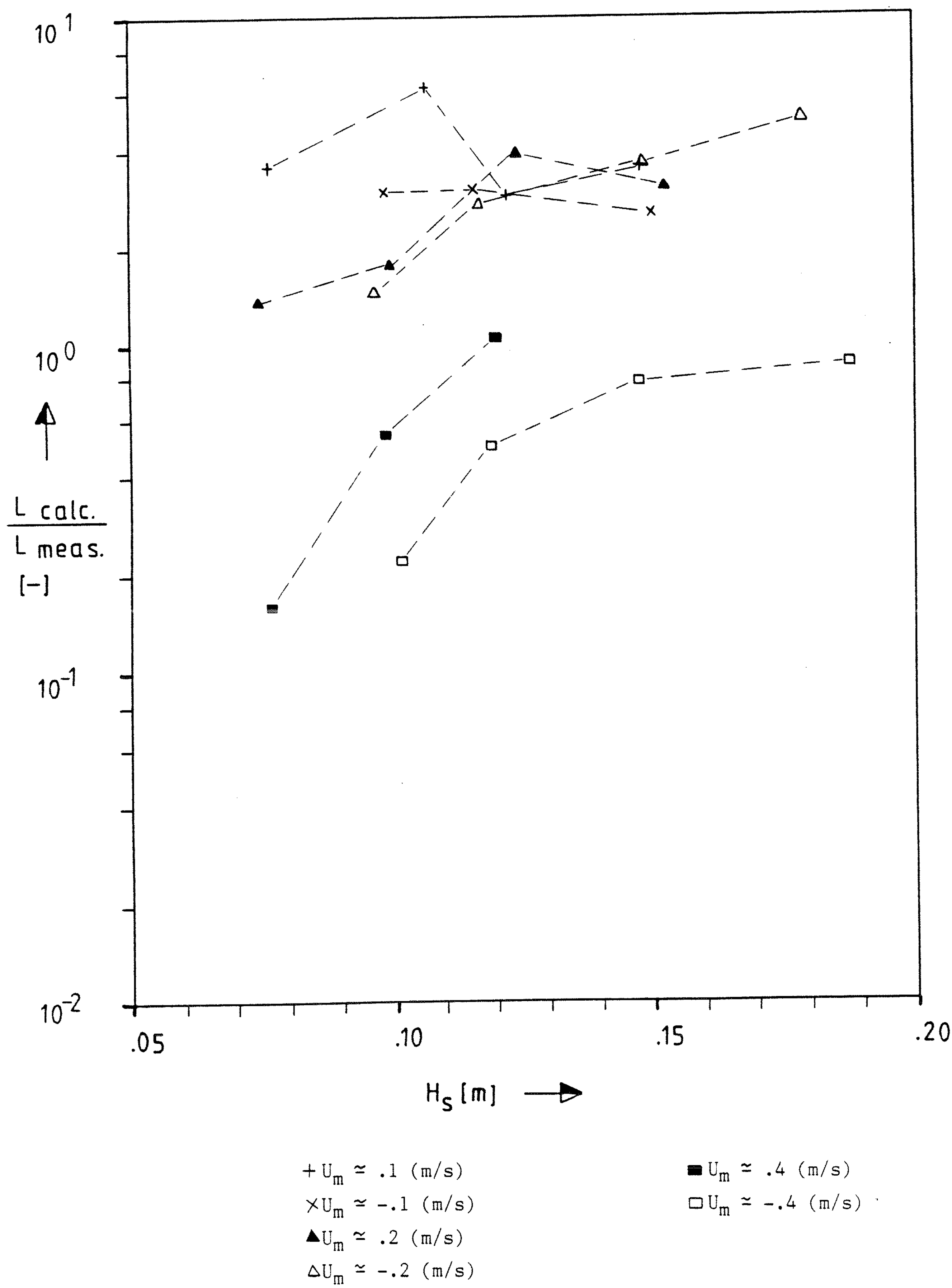

RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR BIJKER METHOD (APPLYING VAN RIJN ROUGHNESS)

FIG. 4.6 B



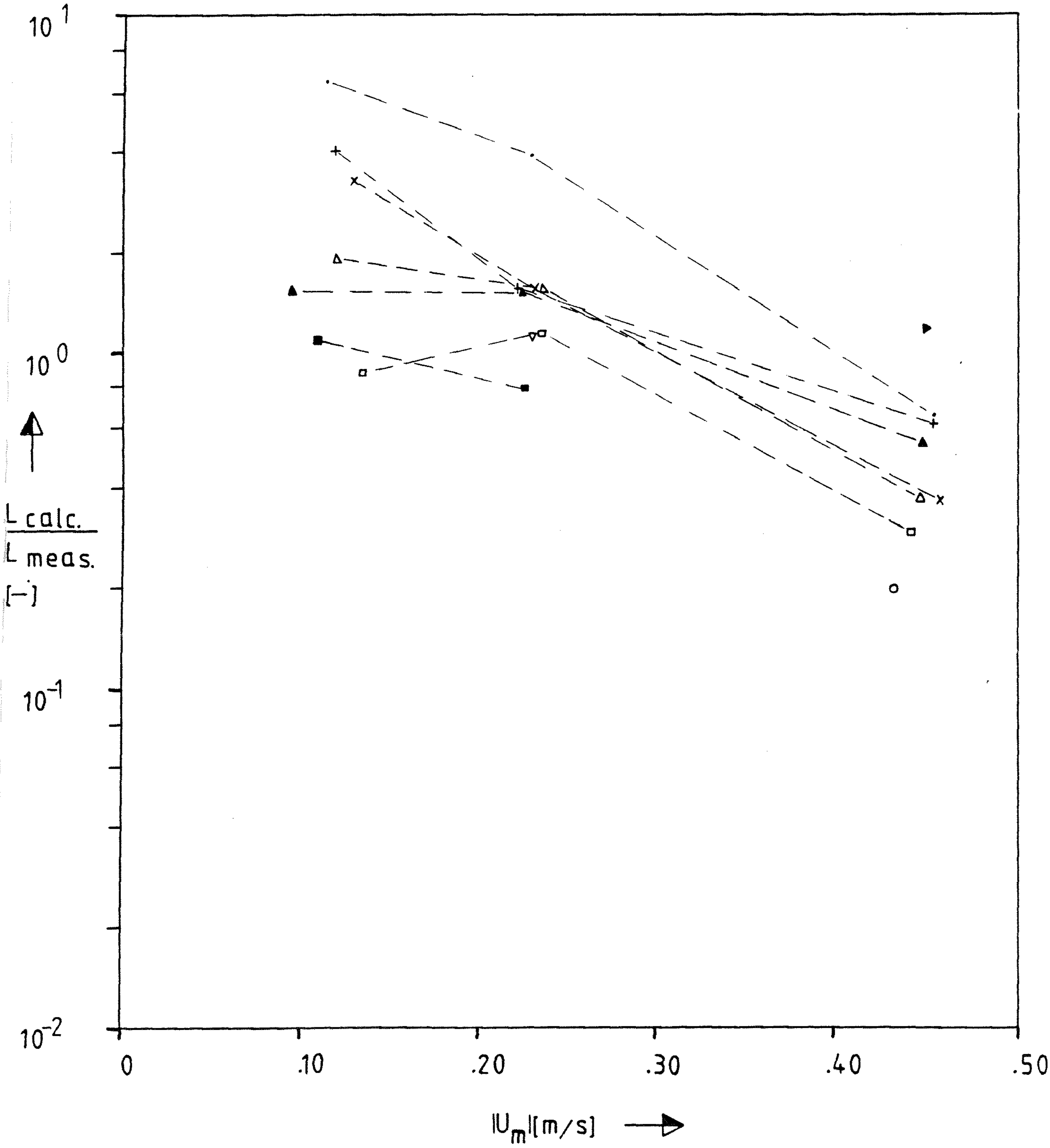

RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR NIELSEN METHOD (APPLYING NORMAL CONCENTRATION PROFILE)

FIG. 4.6 C




RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR NIELSEN METHOD (APPLYING ADAPTED CONCENTRATION PROFILE)

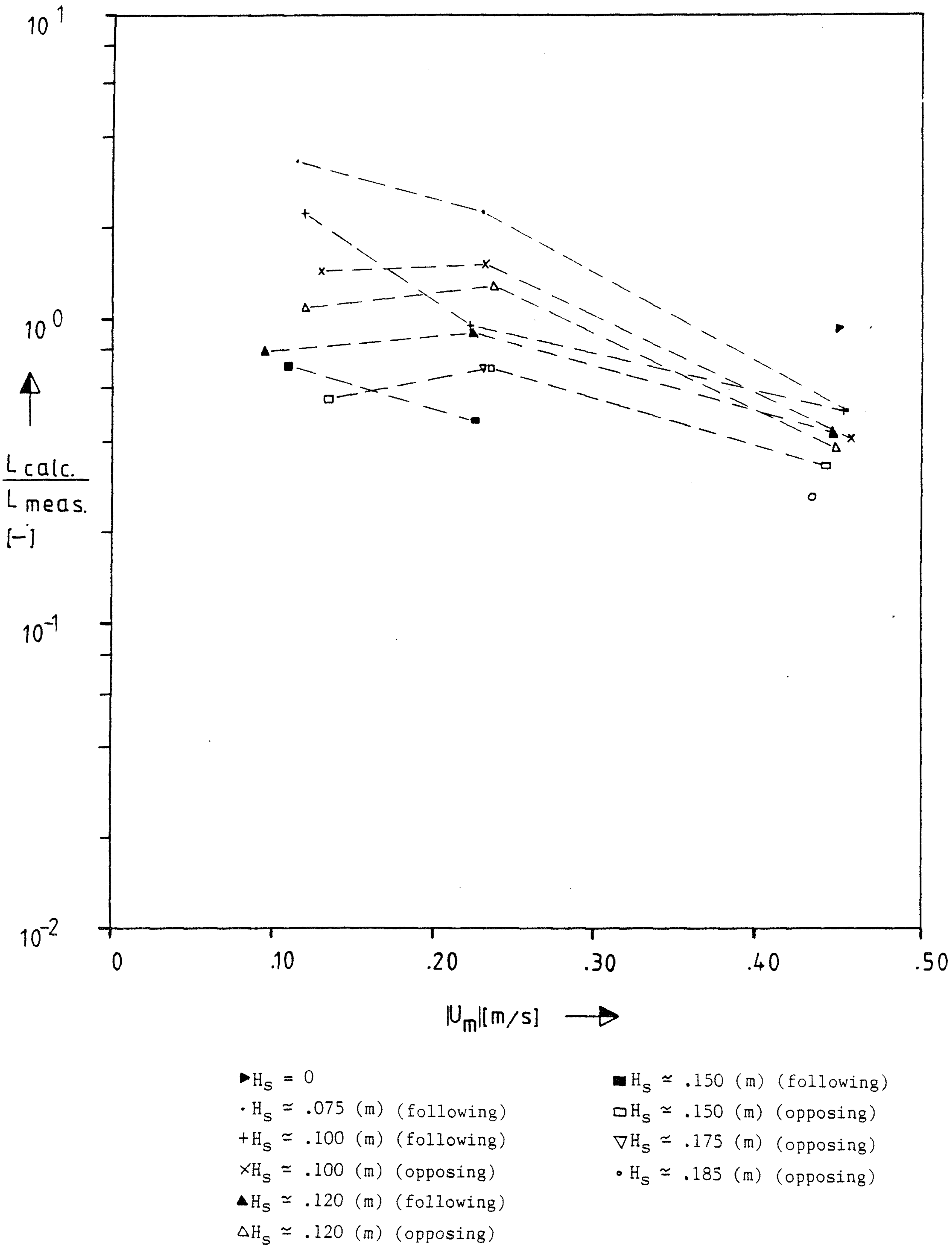
FIG. 4.6 D




▶ $H_s = 0$
· $H_s \simeq .075$ (m) (following)
+ $H_s \simeq .100$ (m) (following)
× $H_s \simeq .100$ (m) (opposing)
▲ $H_s \simeq .120$ (m) (following)
△ $H_s \simeq .120$ (m) (opposing)
■ $H_s \simeq .150$ (m) (following)
□ $H_s \simeq .150$ (m) (opposing)
▽ $H_s \simeq .175$ (m) (opposing)
○ $H_s \simeq .185$ (m) (opposing)

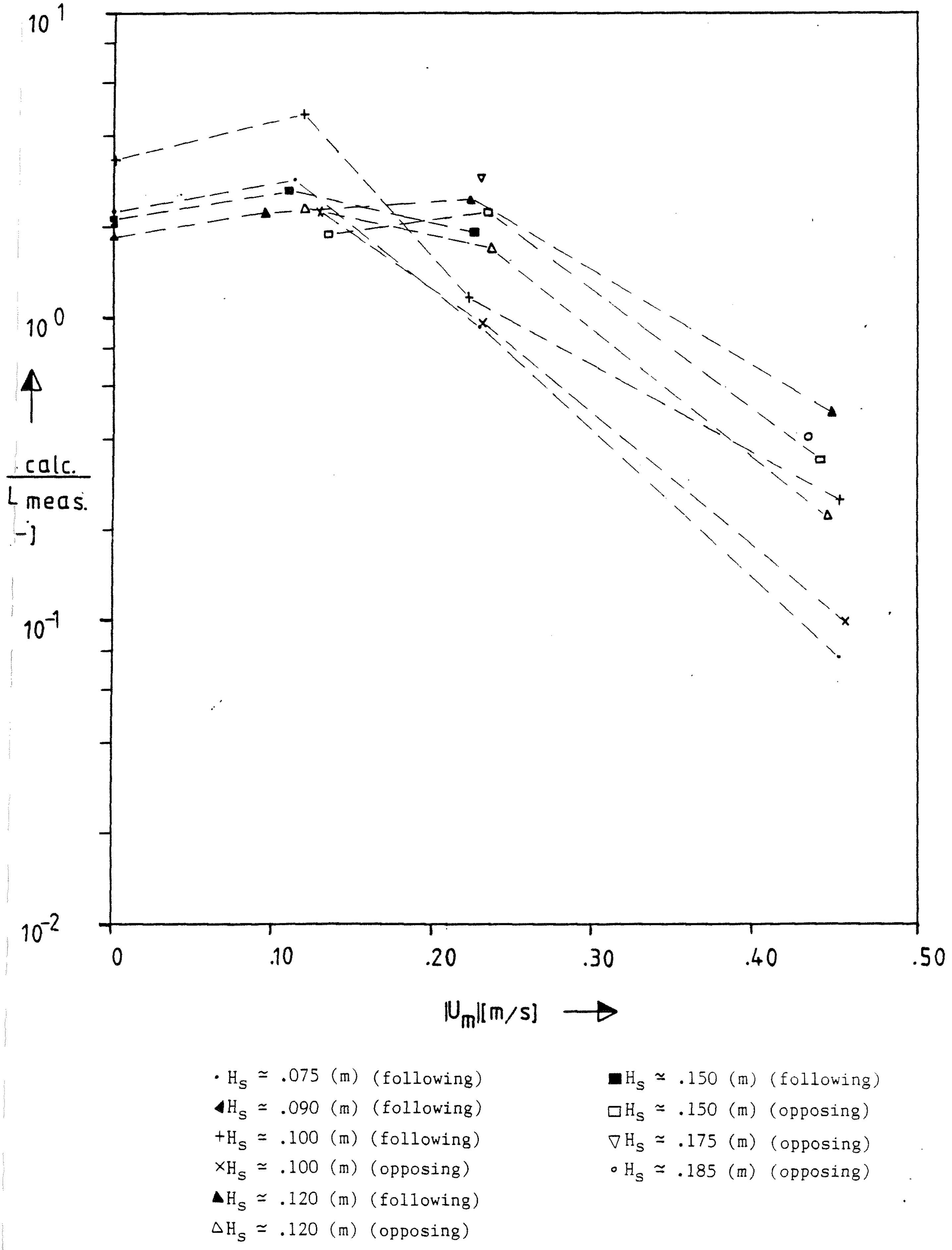
RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR BIJKER METHOD (APPLYING SWART ROUGHNESS)

FIG. 4.7 A



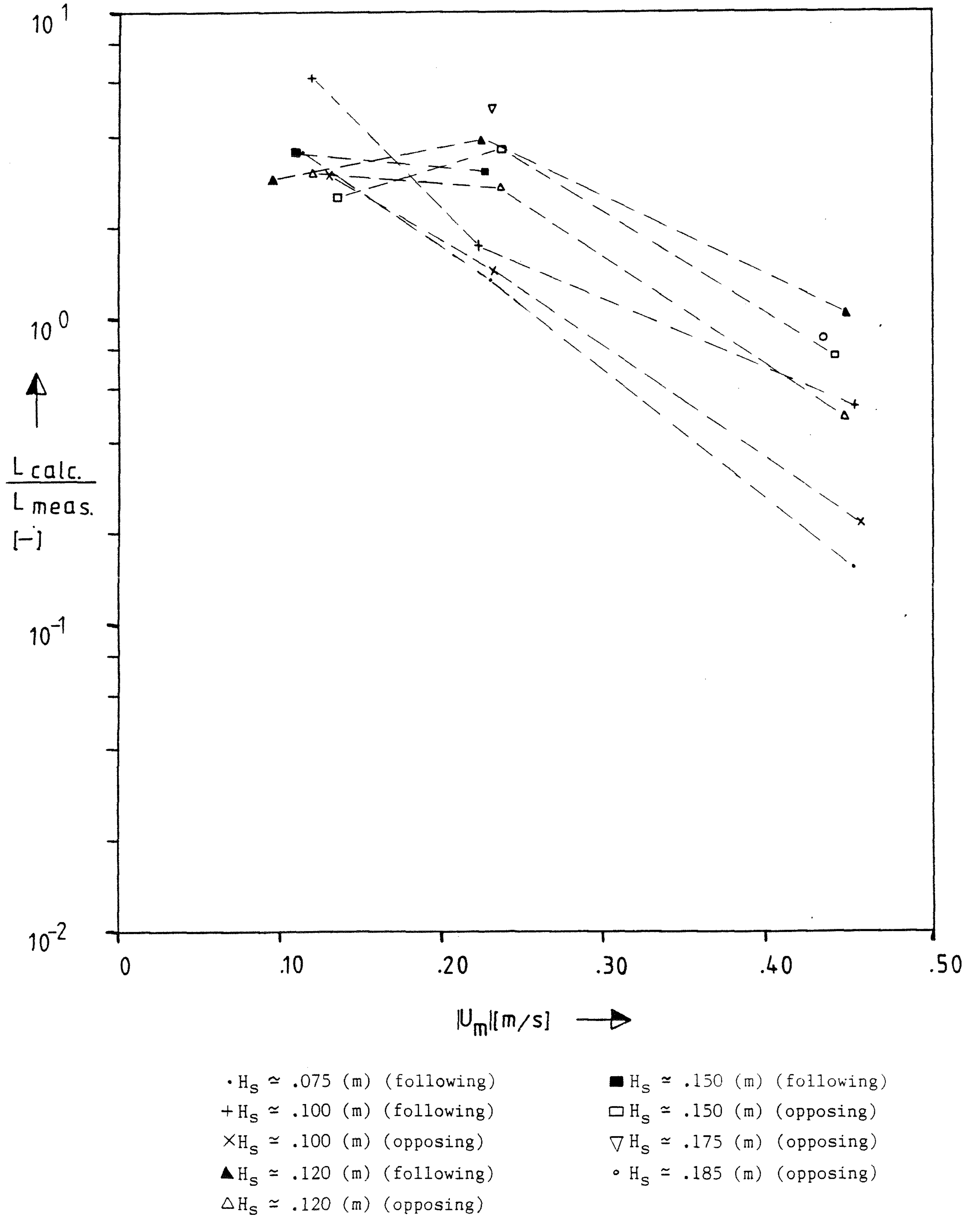

RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR BIJKER METHOD (APPLYING VAN RIJN ROUGHNESS)

FIG. 4.7 B



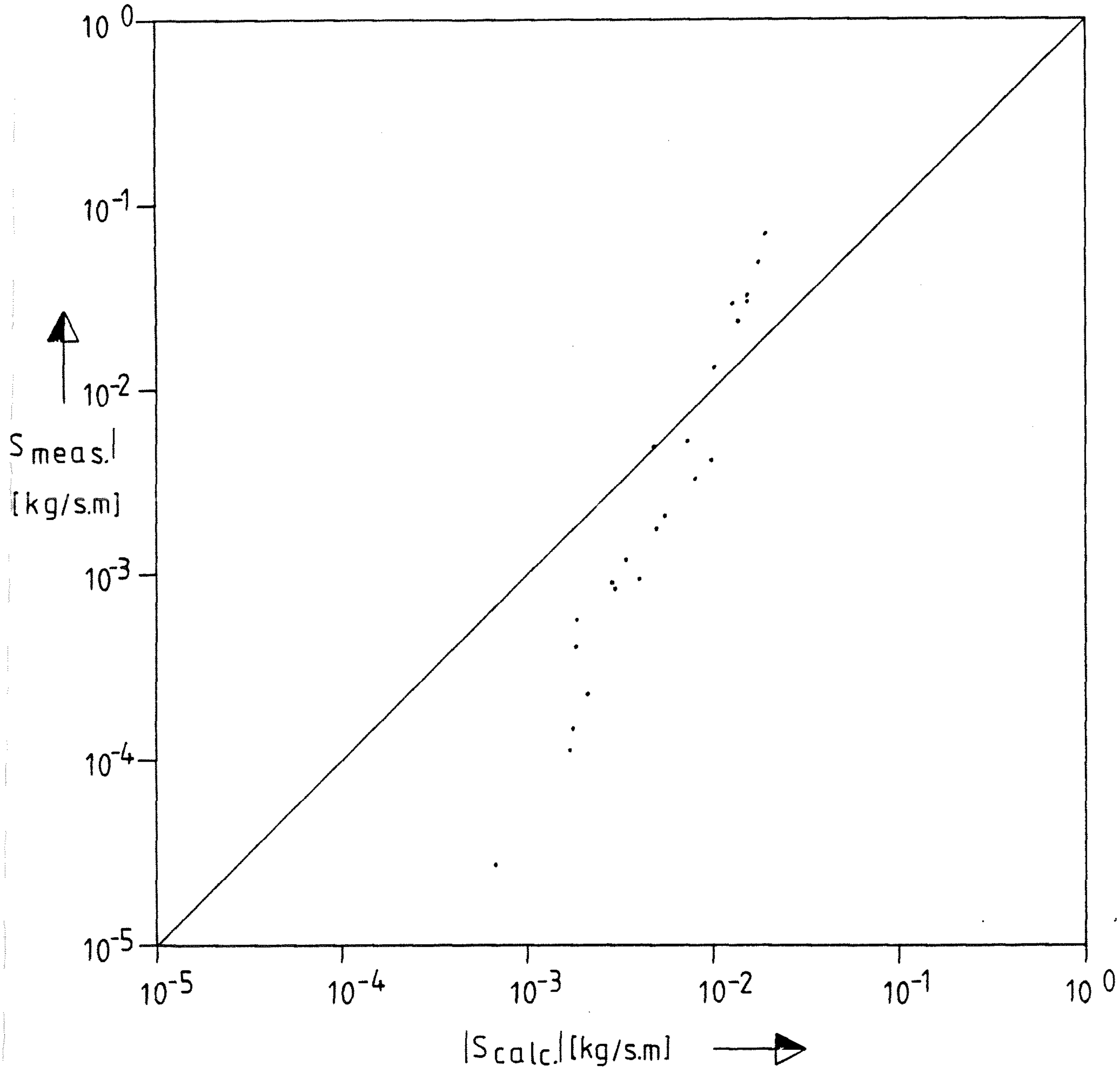

RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR NIELSEN METHOD (APPLYING NORMAL CONCENTRATION PROFILE)

FIG. 4.7 C



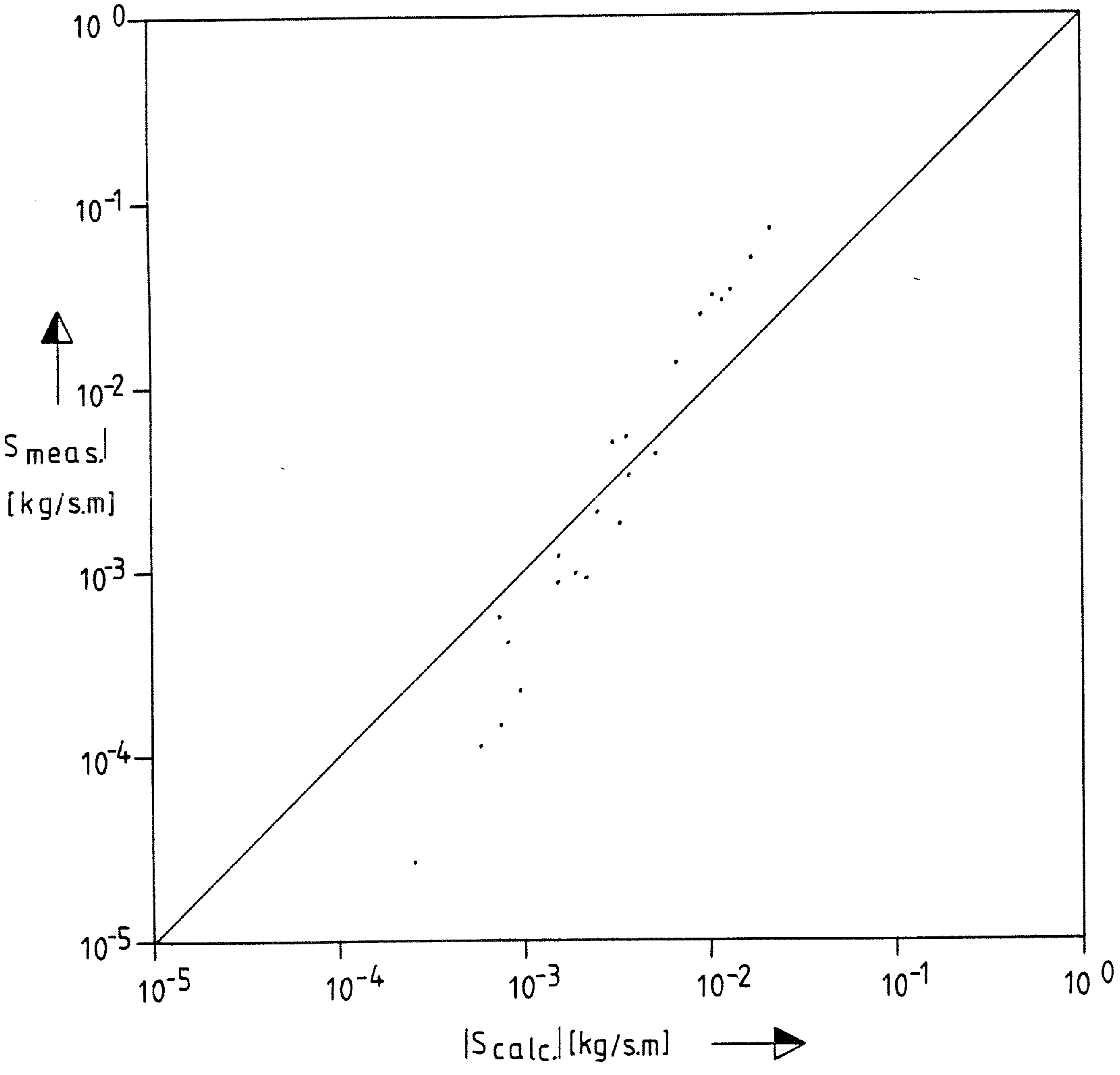

RATIO OF CALCULATED AND MEASURED TOTAL LOAD AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR NIELSEN METHOD (APPLYING ADAPTED CONCENTRATION PROFILE)

FIG. 4.7 D



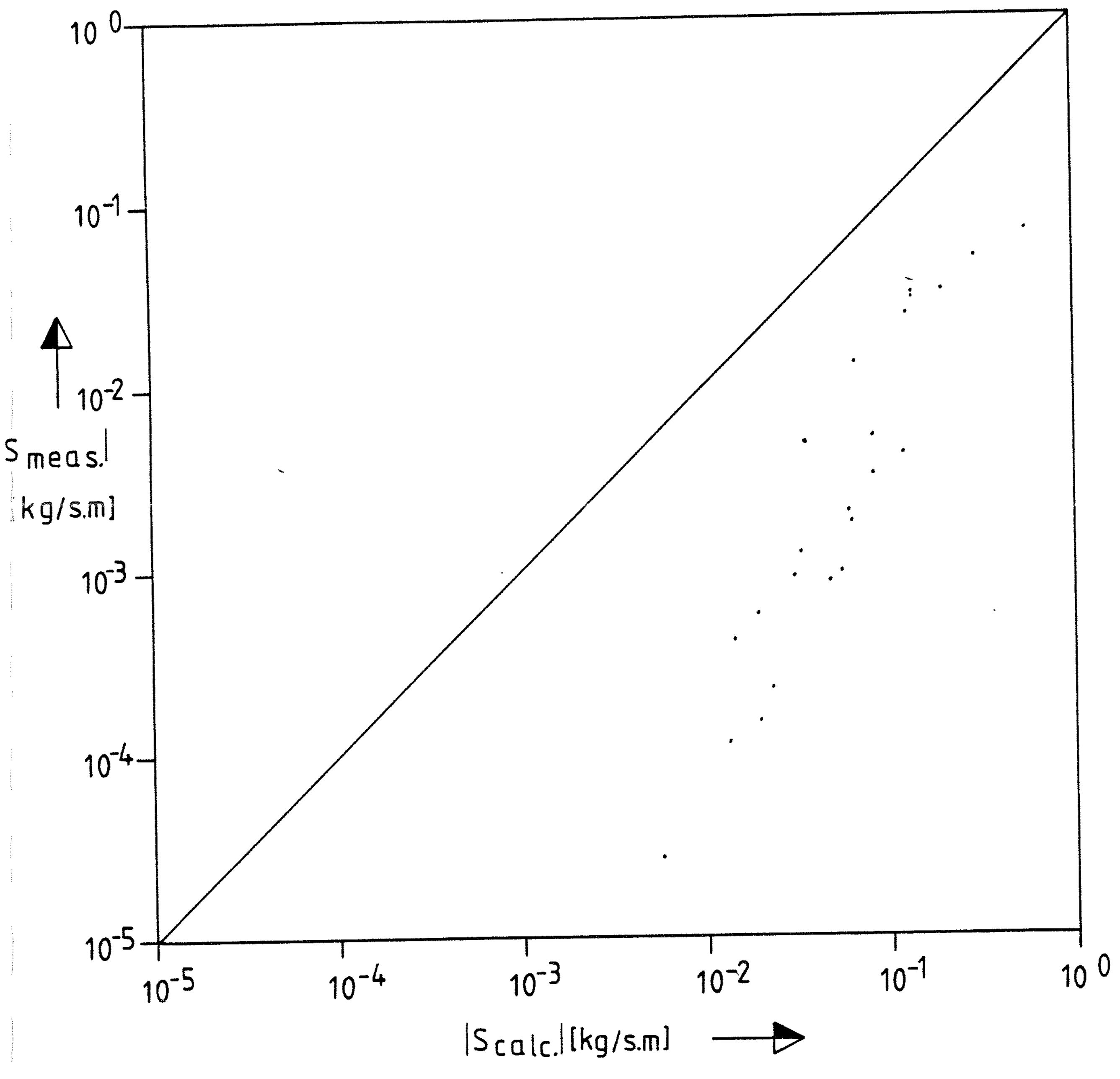

COMPARISON OF MEASURED TOTAL LOAD TRANSPORT AND TOTAL LOAD TRANSPORT CALCULATED WITH THE BIJKER METHOD USING THE SWART ROUGHNESS

FIG. 4.8 A



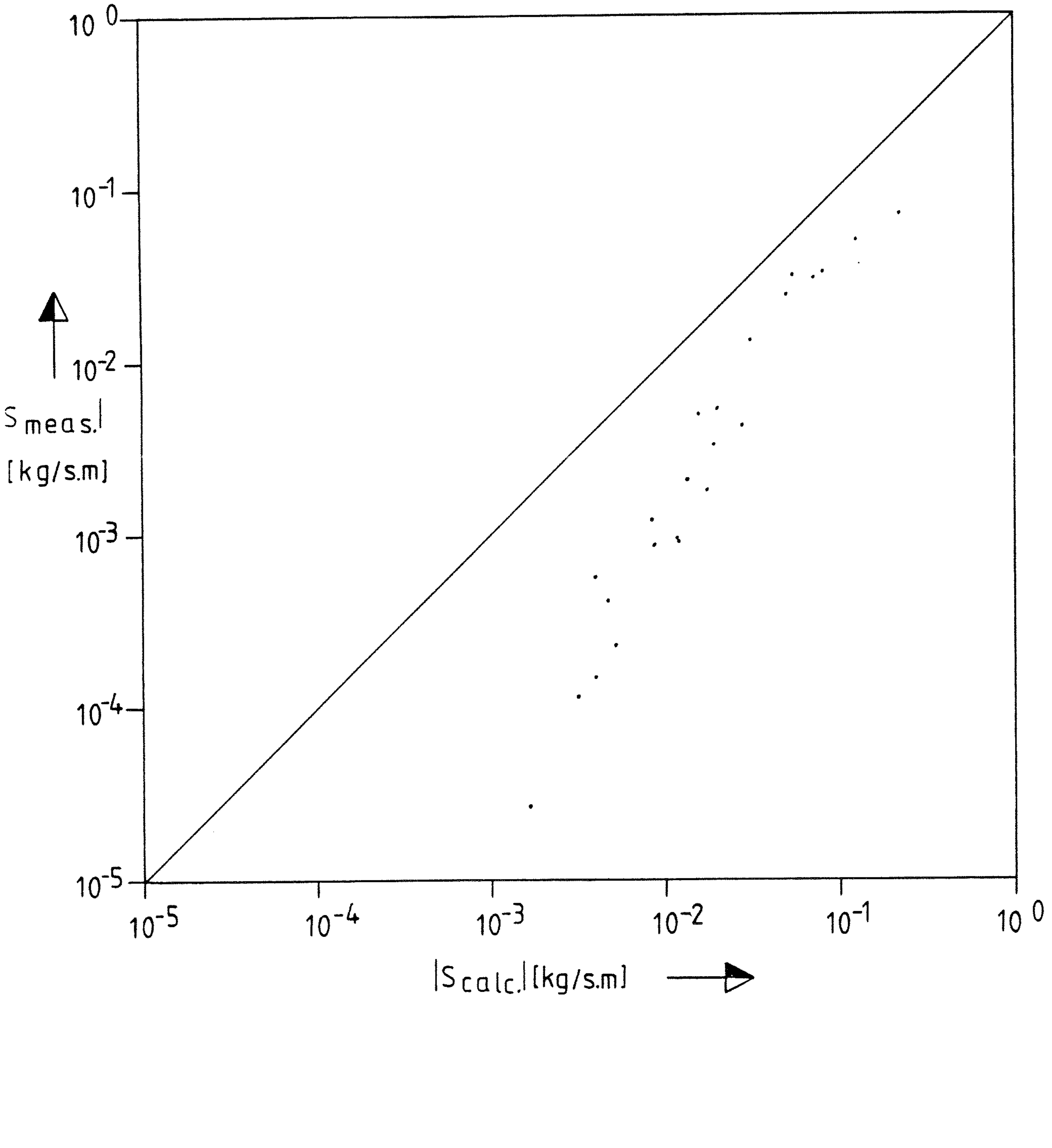

COMPARISON OF MEASURED TOTAL LOAD TRANSPORT AND TOTAL LOAD TRANSPORT CALCULATED WITH THE BIJKER METHOD USING THE VAN RIJN ROUGHNESS

FIG. 4.8 B



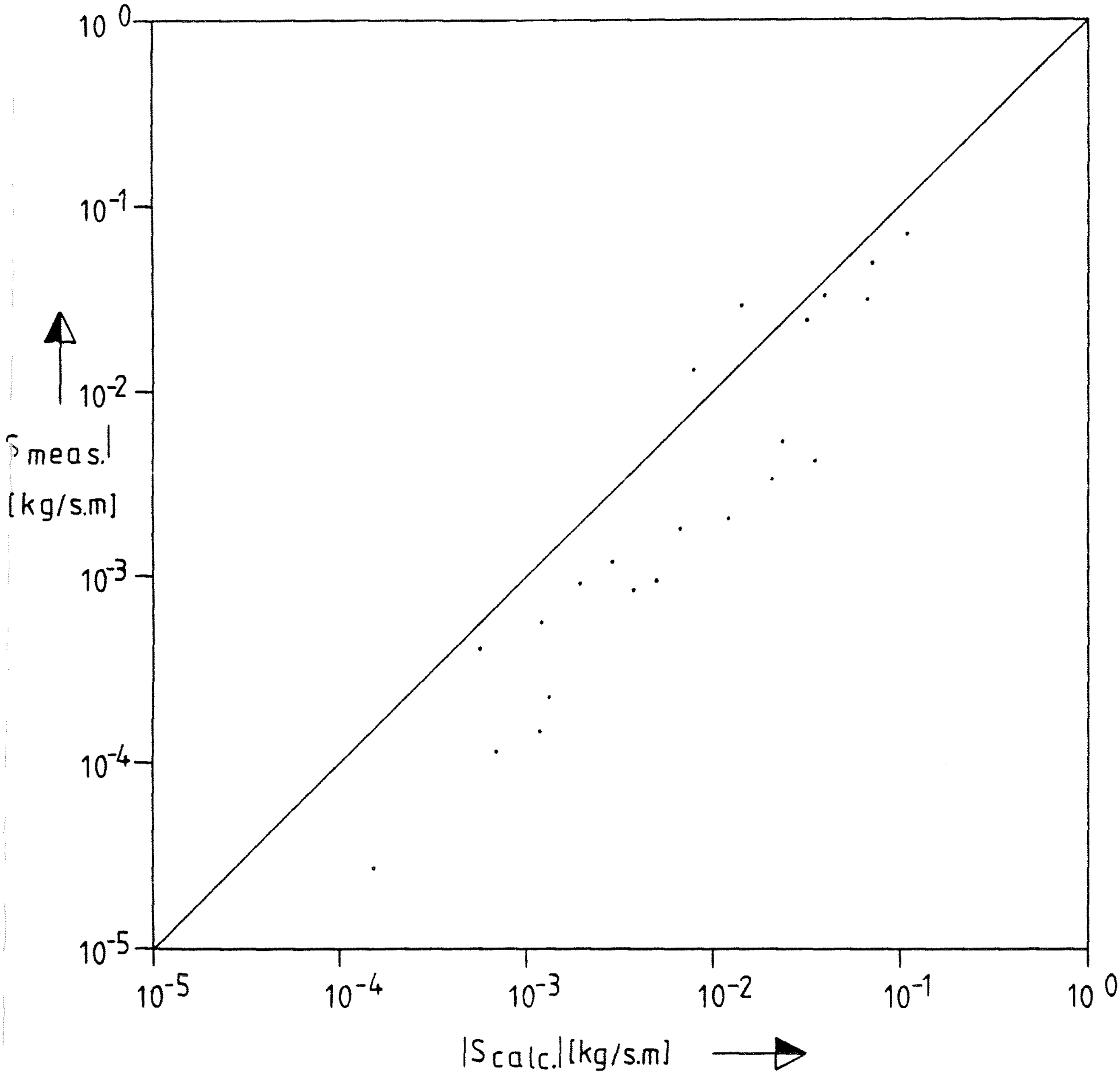

COMPARISON OF MEASURED TOTAL LOAD TRANSPORT AND TOTAL LOAD TRANSPORT CALCULATED WITH THE ADAPTED ENGELUND-HANSEN METHOD USING THE SWART ROUGHNESS

FIG. 4.8 C



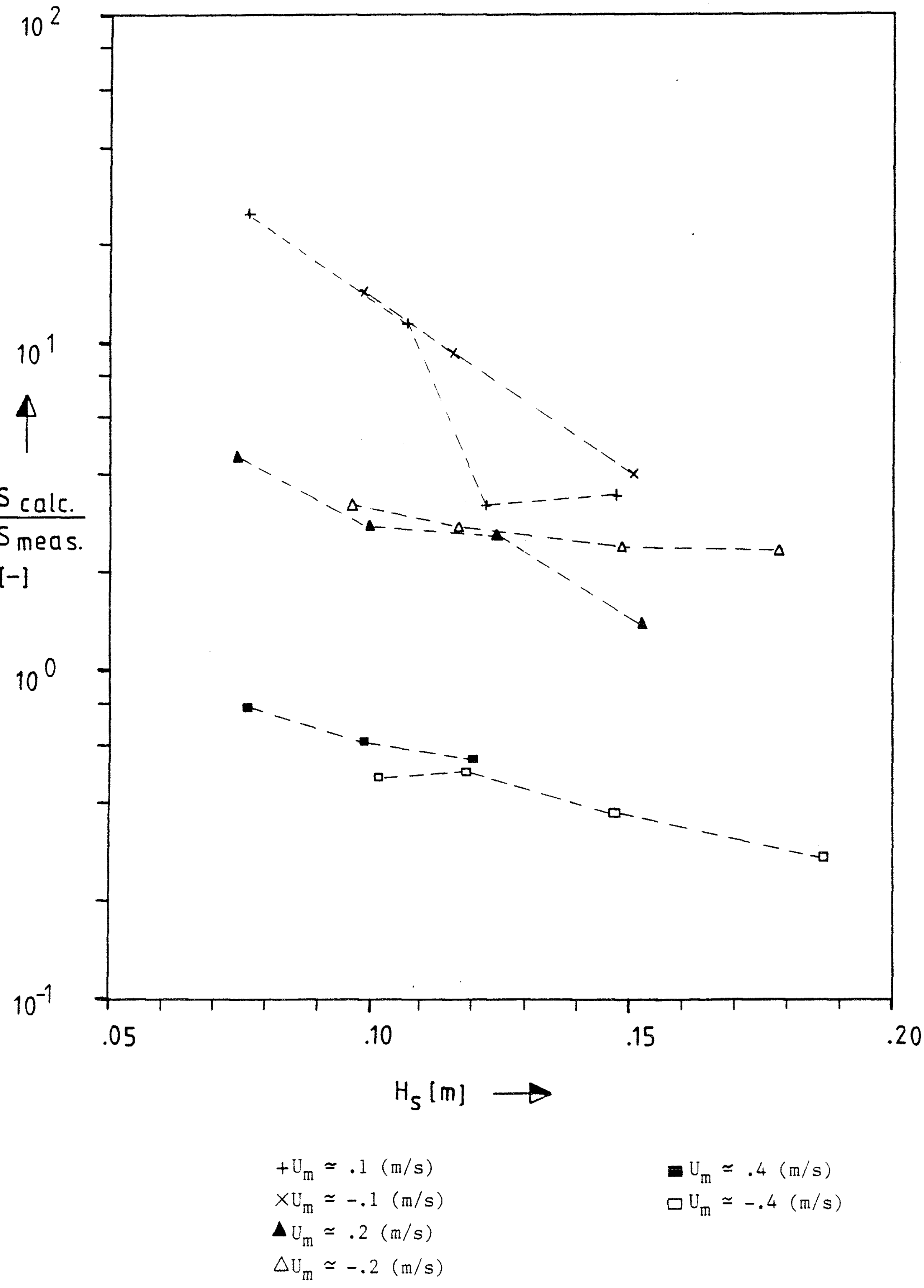

COMPARISON OF MEASURED TOTAL LOAD TRANSPORT AND TOTAL LOAD TRANSPORT CALCULATED WITH THE ADAPTED ENGELUND-HANSEN METHOD USING THE VAN RIJN ROUGHNESS

FIG. 4.8 I

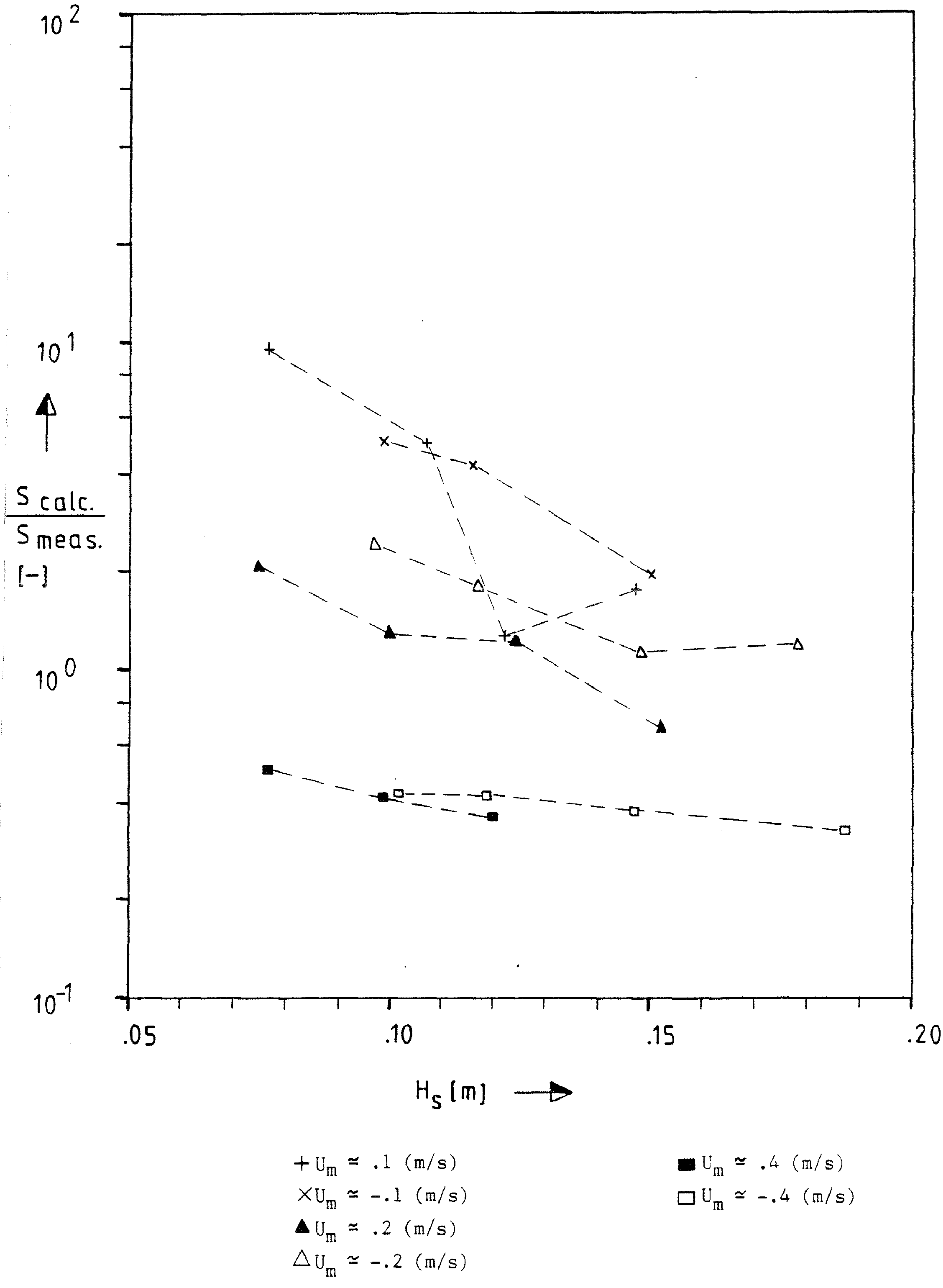



COMPARISON OF MEASURED TOTAL LOAD TRANSPORT AND TOTAL LOAD TRANSPORT CALCULATED WITH THE NIELSEN METHOD

FIG. 4.8 E

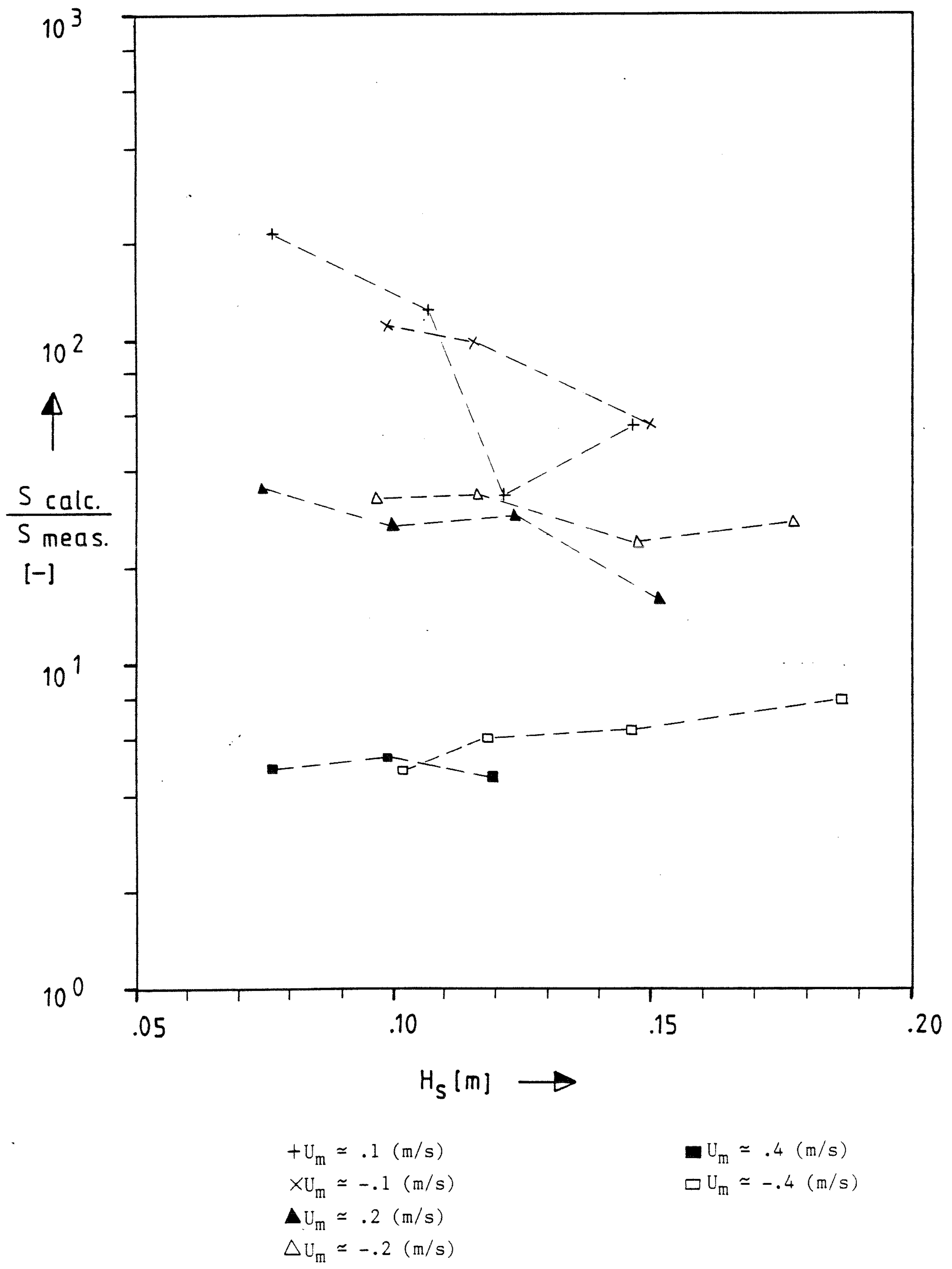



| | |
|---|---|
| RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR BIJKER METHOD (APPLYING SWART ROUGHNESS) | FIG. 4.9 A |



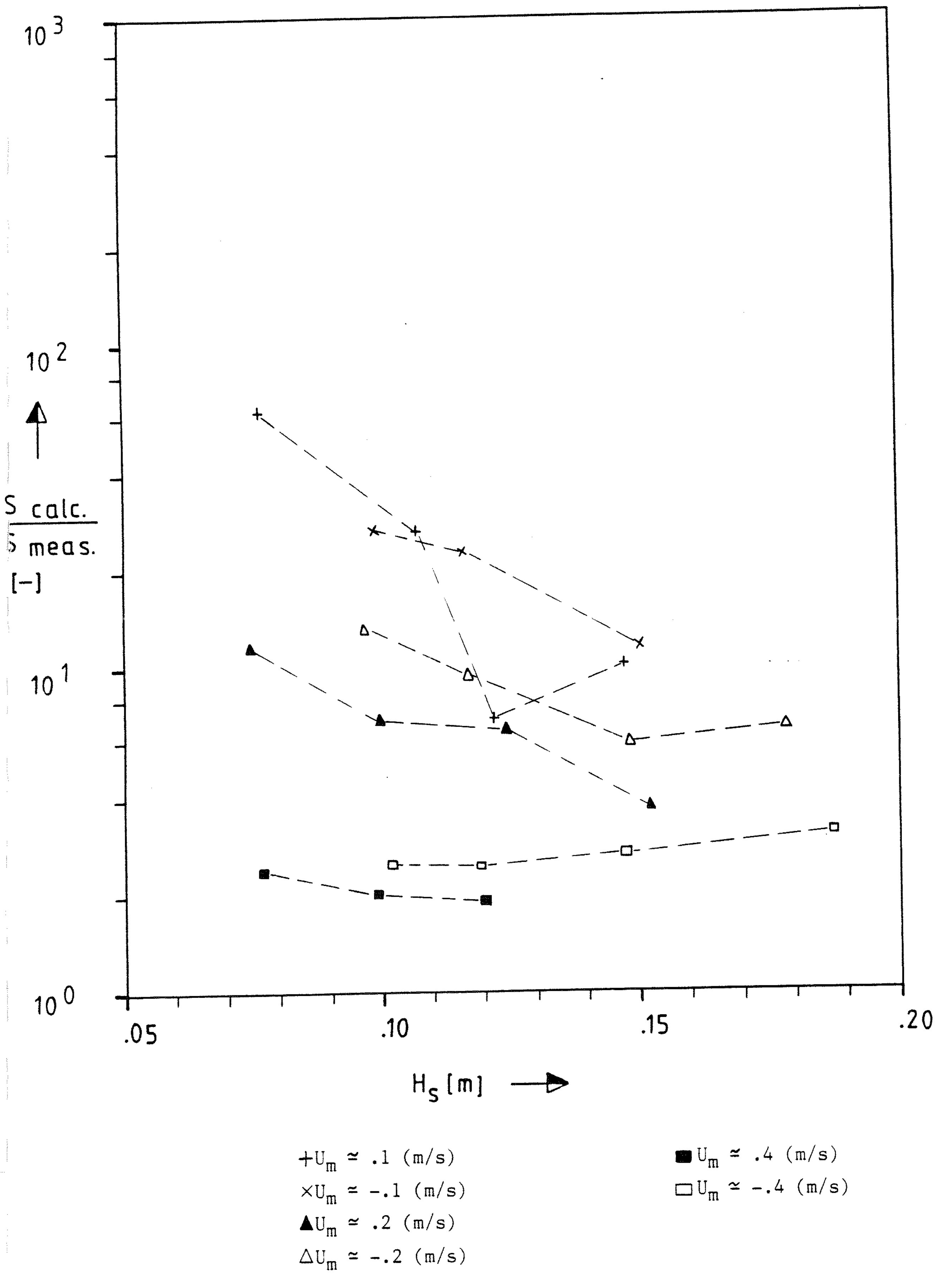

RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR BIJKER METHOD (APPLYING VAN RIJN ROUGHNESS)

FIG. 4.9 B



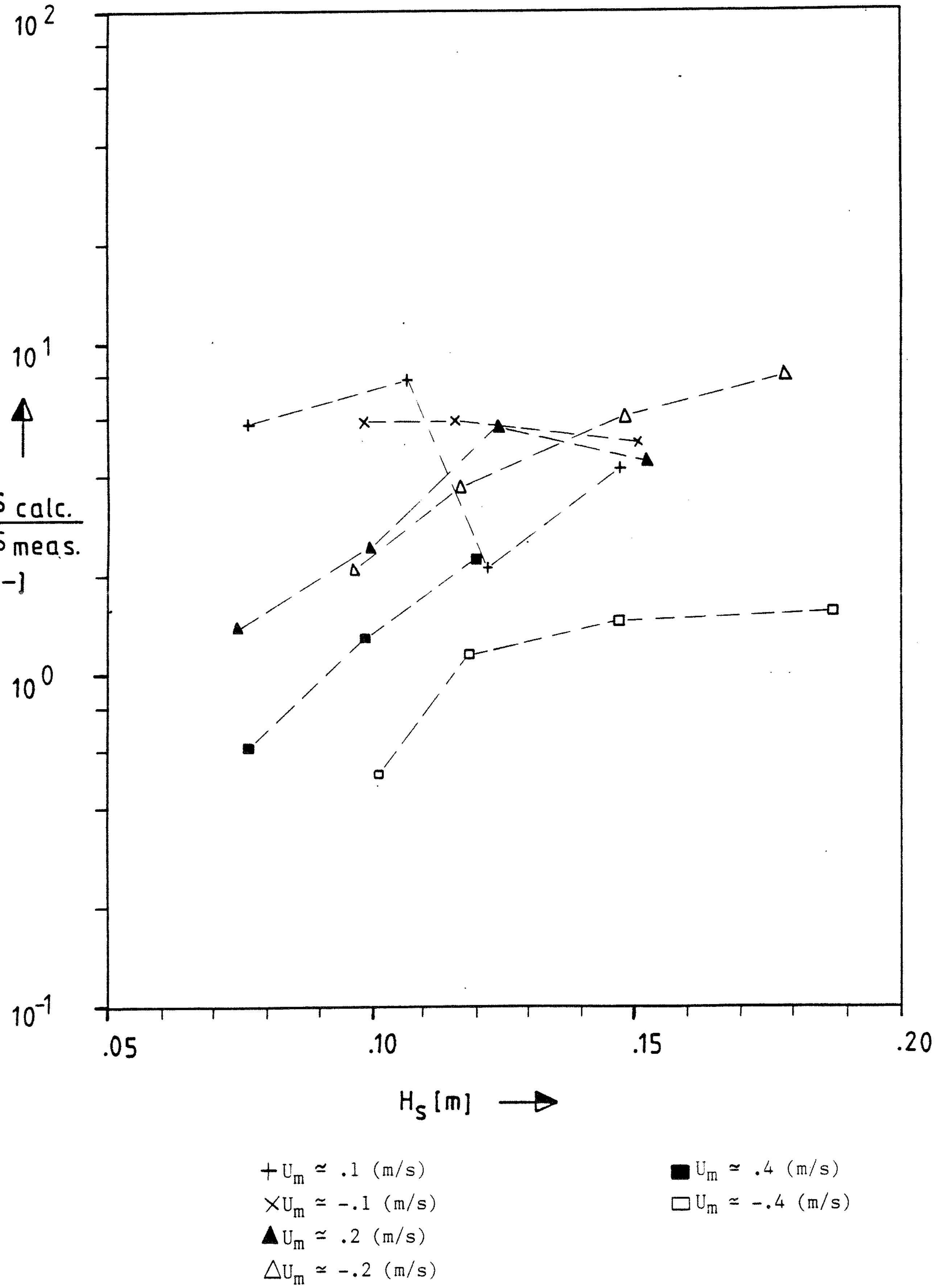

RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR ADAPTED ENGELUND-HANSEN METHOD (APPLYING SWART ROUGHNESS)

FIG. 4.9 C



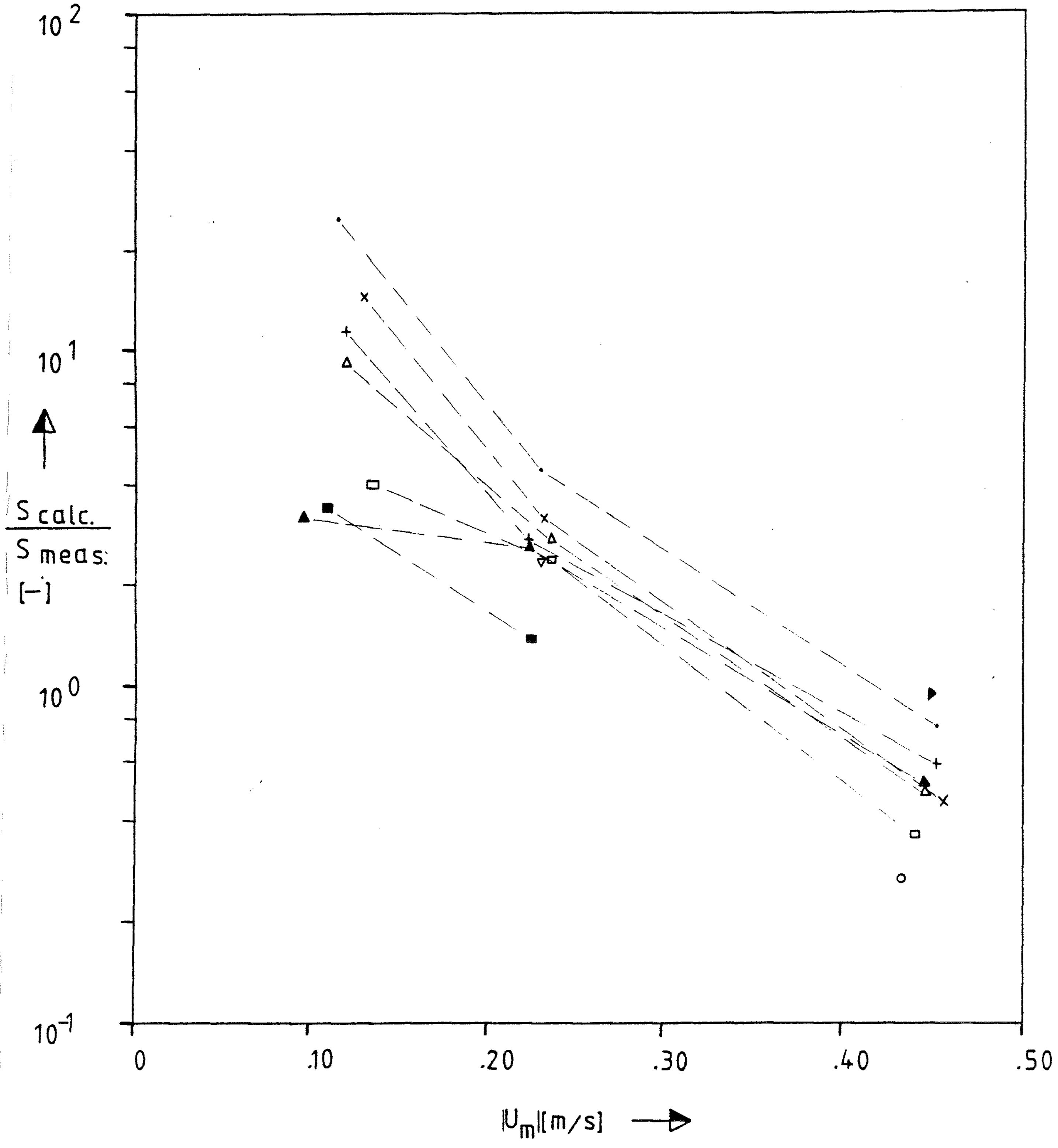

RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR ADAPTED ENGELUND-HANSEN METHOD (APPLYING VAN RIJN ROUGHNESS)

FIG. 4.9 D



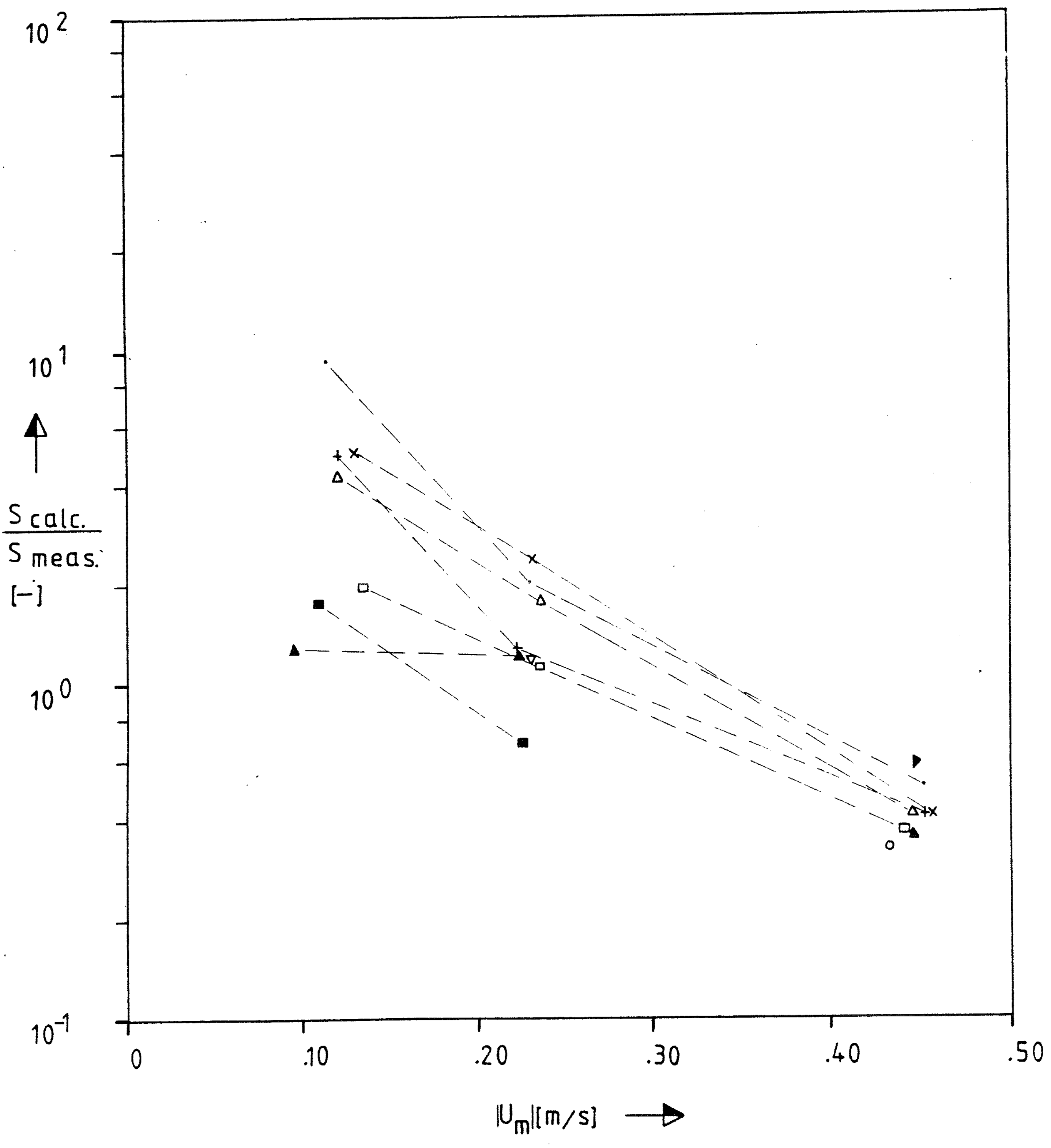

RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF SIGNIFICANT WAVEHEIGHT FOR NIELSEN METHOD

FIG. 4.9 E




▶ $H_s = 0$
· $H_s \simeq .075$ (m) (following)
+ $H_s \simeq .100$ (m) (following)
× $H_s \simeq .100$ (m) (opposing)
▲ $H_s \simeq .120$ (m) (following)
△ $H_s \simeq .120$ (m) (opposing)
■ $H_s \simeq .150$ (m) (following)
□ $H_s \simeq .150$ (m) (opposing)
▽ $H_s \simeq .175$ (m) (opposing)
○ $H_s \simeq .185$ (m) (opposing)

| | |
|---|---|
| RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR BIJKER METHOD (APPLYING SWART ROUGHNESS) | FIG. 4.10 A |




▶ $H_s = 0$

· $H_s \simeq .075$ (m) (following)

+ $H_s \simeq .100$ (m) (following)

× $H_s \simeq .100$ (m) (opposing)

▲ $H_s \simeq .120$ (m) (following)

△ $H_s \simeq .120$ (m) (opposing)

■ $H_s \simeq .150$ (m) (following)

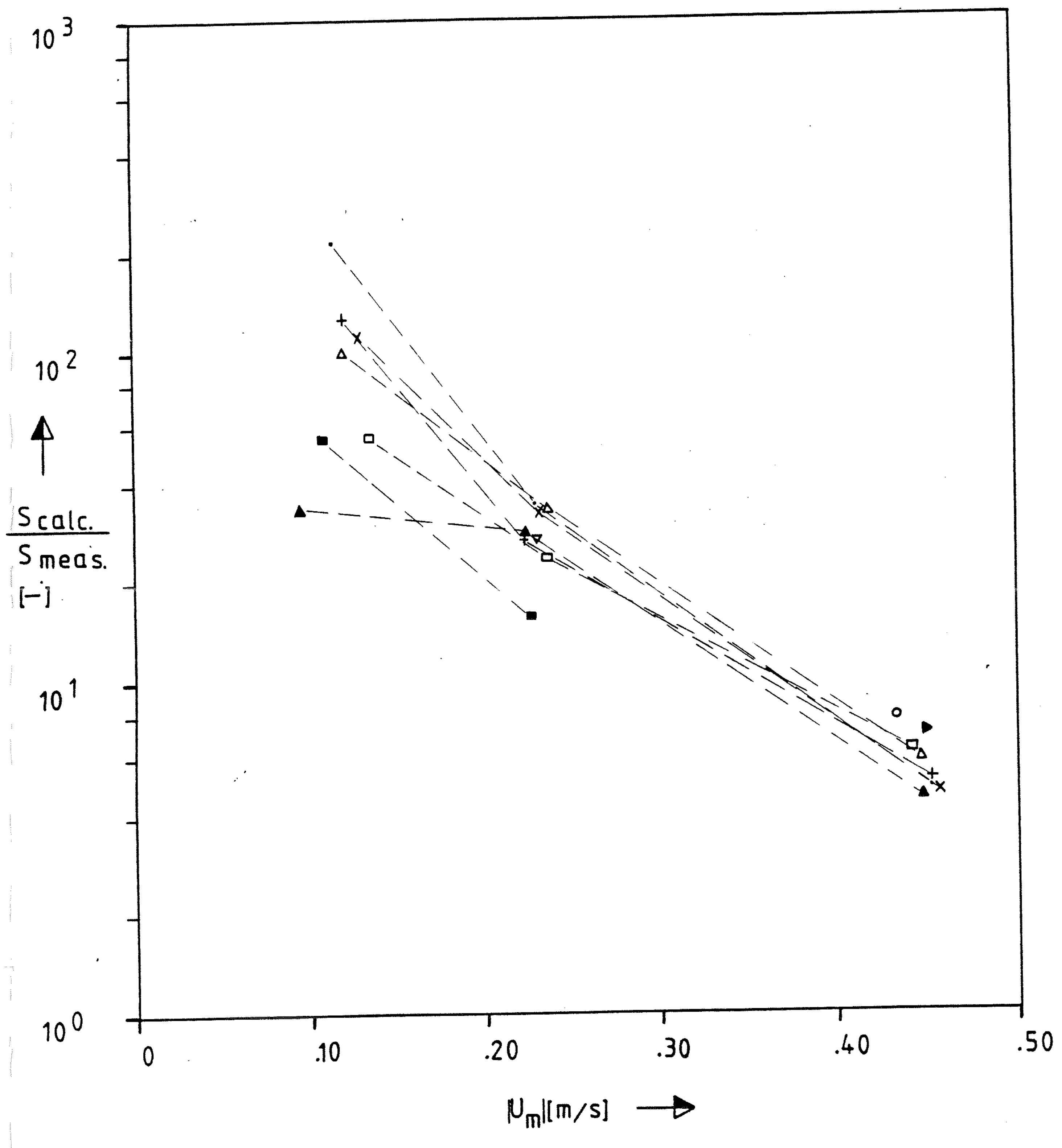
□ $H_s \simeq .150$ (m) (opposing)

▽ $H_s \simeq .175$ (m) (opposing)

∘ $H_s \simeq .185$ (m) (opposing)

RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR BIJKER METHOD (APPLYING VAN RIJN ROUGHNESS)

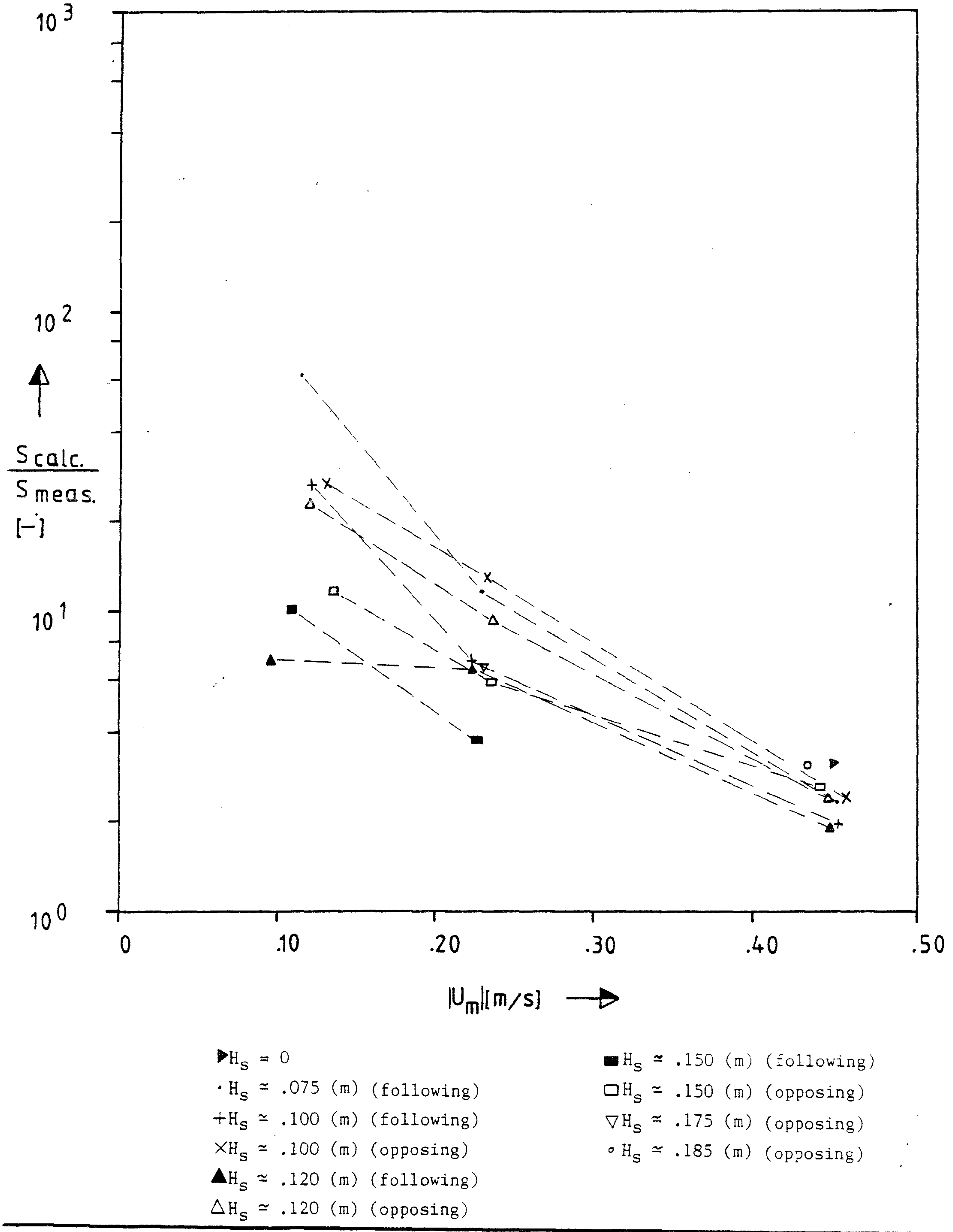
FIG. 4.10 B



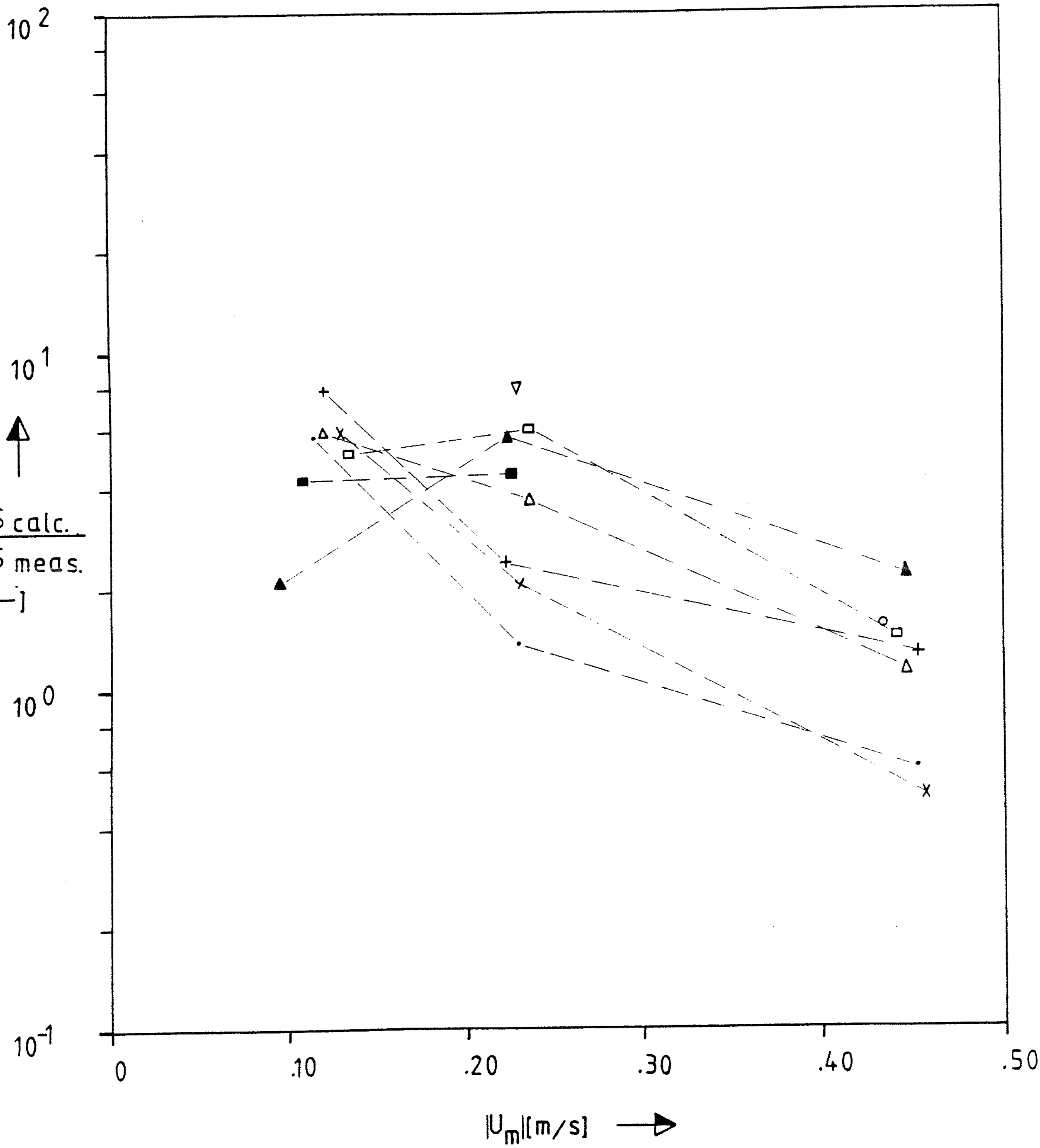

▶$H_s$ = 0
· $H_s$ ≃ .075 (m) (following)
+$H_s$ ≃ .100 (m) (following)
×$H_s$ ≃ .100 (m) (opposing)
▲$H_s$ ≃ .120 (m) (following)
△$H_s$ ≃ .120 (m) (opposing)
■$H_s$ ≃ .150 (m) (following)
□$H_s$ ≃ .150 (m) (opposing)
▽$H_s$ ≃ .175 (m) (opposing)
∘ $H_s$ ≃ .185 (m) (opposing)

RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR ADAPTED ENGELUND-HANSEN METHOD (APPLYING SWART ROUGHNESS)

FIG. 4.10 C



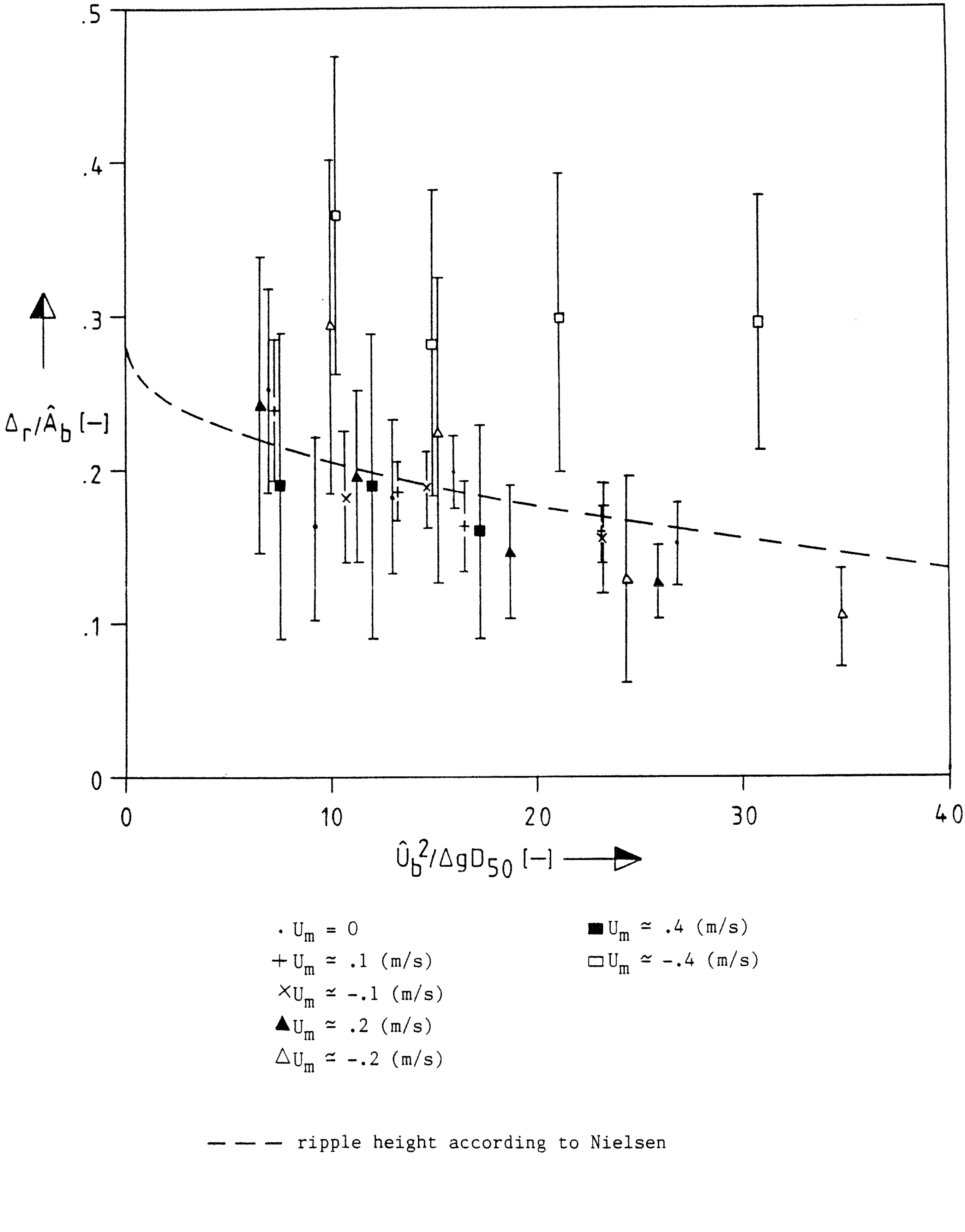

| RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR ADAPTED ENGELUND-HANSEN METHOD (APPLYING VAN RIJN ROUGHNESS) | FIG. 4.10 D |
|---|---|




· $H_s$ ≃ .075 (m) (following)
+ $H_s$ ≃ .100 (m) (following)
× $H_s$ ≃ .100 (m) (opposing)
▲ $H_s$ ≃ .120 (m) (following)
△ $H_s$ ≃ .120 (m) (opposing)
■ $H_s$ ≃ .150 (m) (following)
□ $H_s$ ≃ .150 (m) (opposing)
▽ $H_s$ ≃ .175 (m) (opposing)
∘ $H_s$ ≃ .185 (m) (opposing)

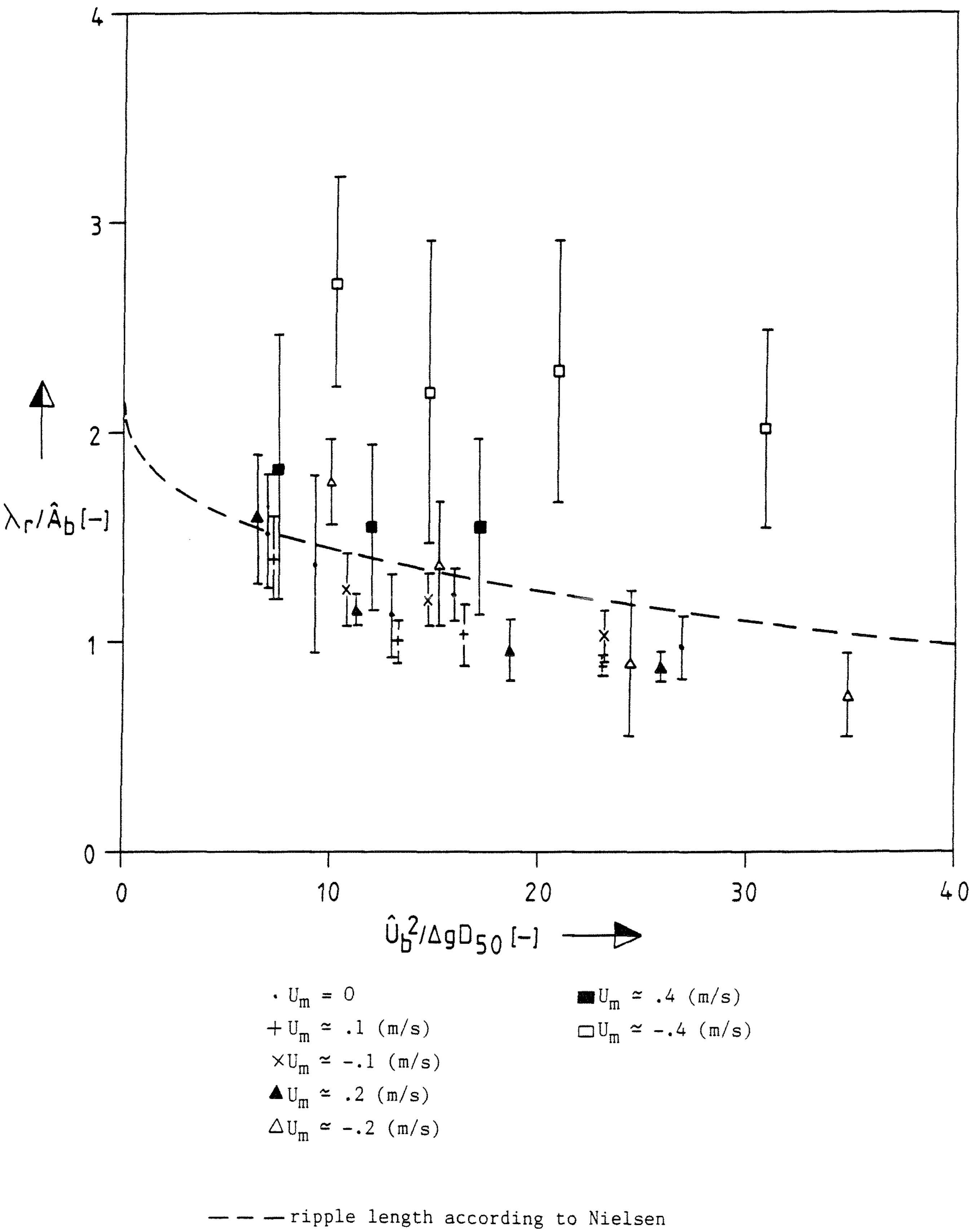
RATIO OF CALCULATED AND MEASURED TOTAL LOAD TRANSPORT AS A FUNCTION OF DEPTH AVERAGED VELOCITY FOR NIELSEN METHOD

FIG. 4.10 E



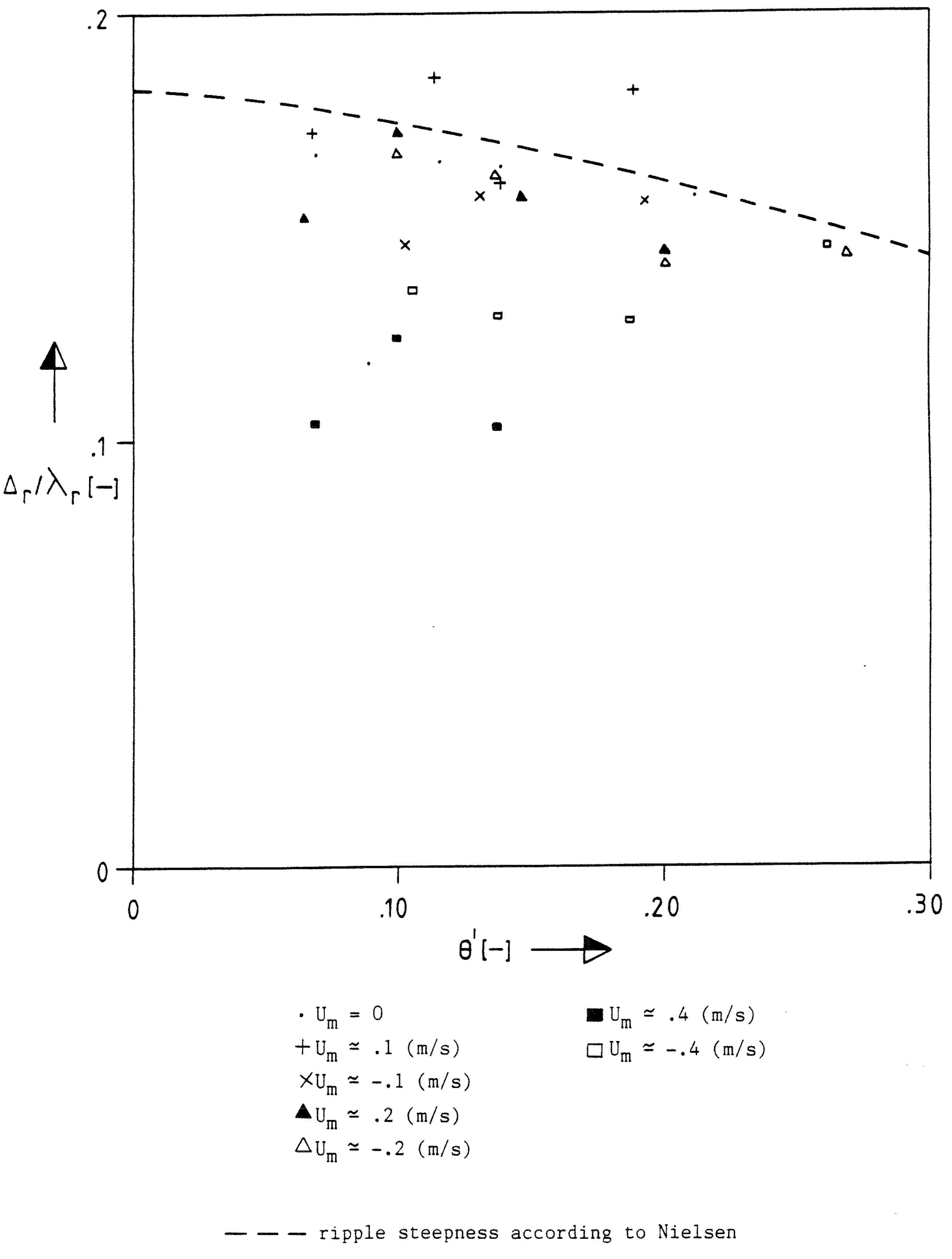

MEASURED RIPPLE HEIGHTS COMPARED WITH THE RIPPLE HEIGHTS ACCORDING TO NIELSEN

FIG. 4.11




MEASURED RIPPLE LENGTHS COMPARED WITH THE RIPPLE LENGTHS ACCORDING TO NIELSEN

FIG. 4.12




| | |
|---|---|
| MEASURED RIPPLE STEEPNESS COMPARED WITH THE RIPPLE STEEPNESS ACCORDING TO NIELSEN | FIG. 4.13 |