GEOLOGIE EN MIJNBOUW VOLUME 55 (1-2), p. 51-60 1976

AN INEXPENSIVE INFINITE FLUME

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ABSTRACT

A new design is presented of an infinite flume. This flume has been specially developed to study equilibrium processes during transport and deposition of sand and the influence of time on these processes.

The flume-plan is oblong rectangular, the channel is 60 cm deep and 45 cm wide. In each corner reflexion blades are mounted, which are specially shaped to compensate for the increase in width in the bends.

The water drive is performed by means of paddles, hanging from two parallel chains which run over cog-wheels. The paddles move in a vertical position through the water. Due to a downcurrent inclination of the chains, the paddles are gradually lifted out of the water and are free of the surface whilst flipping round the cog-wheels, thus producing no extra turbulence.

Flow characteristic are shown for different discharge rates and peculiars of the flume are discussed.

INTRODUCTION

Sedimentary processes nearly always have an equilibrium aspect. After a change in conditions, it takes time before a system is adjusted to the new situation. E.g., when the current velocity is increased, material goes into transport. A layer of a certain thickness is eroded till the new capacity limit is reached. When this capacity is reached quantitatively, there can still occur exchange of particles in transport with bottom particles. Those particles that are least stable in the transport system, viz those with the highest settling velocities, are preferentially exchanged for more susceptible particles. In this way, the bottom population as well as the transport population become gradually better sorted. Such sorting processes take considerable time.

Another example is the formation of ripples. When in a flume of a certain dimension and with a certain bottom sediment, a certain water velocity is created, ripples may occur with a specific wave length and amplitude. Each time the experiment is repeated under identical conditions, identical ripples will occur, which suggests a physical law in which only the flume dimensions, the fluid properties and the particle parameters seem to be related to the ripple characteristic. However, when the experiment is extended in time, we see that the wave length of the ripples increases with time, all other conditions remaining equal.

To study the influence of time in sedimentological processes, extremely long flumes would be necessary, which are very expensive. Therefore, alternatives have been looked for, e.g. by making recirculating short flumes or by constructing infinite flumes.

Recirculating flumes have the disadvantage that the graded traction system is homogenised during recirculation. Often, these flumes are used by recirculating the water only and by adding new sediment in the upstream section.

Kuenen (1971) constructed a circular infinite flume, driven by rotating vertical paddles. A disadvantage was that spiral shaped flowlines developed and that, especially with high velocities, an unnatural sediment distribution was obtained due to centrifugal forces.

Another very ingenious circular infinite flume was demonstrated during the Euromech Colloquium 48 in the Institute of Hydrodynamics and Hydraulic Engineering in Copenhagen (1974). This flume is closed. It has no free water surface, but instead, the water drive is obtained by the shearing forces of a rotating ceiling which is pressed on top of the water surface. In this way, the water is prevented from standing higher-up against the outer wall and the development of spiral-shaped flowlines is suppressed. This flume has several advantages, e.g. the wet diameter is the same in every section and the flow pattern is very regular. Measuring and sampling during experiments ask for more sophisticated methods. Moreover, the particles in transport are subjected to centrifugal forces in the horizontal plane, which may be a complication whilst working with high current velocities.

After trying out several alternative possibilities, a new flume design is presented here, which, though still not ideal, fullfills many requirements to study processes in which equilibrium and time play a role and which is simple and inexpensive.

THE FLUME

The floor-plan of the flume is an oblong rectangle.

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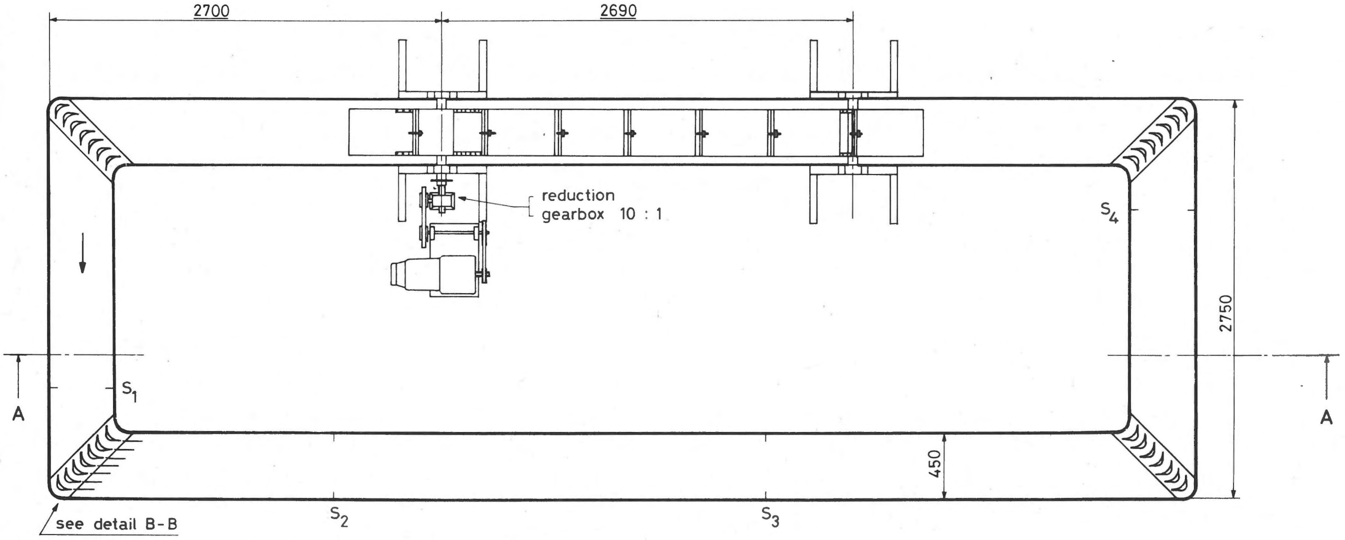


Section A - A

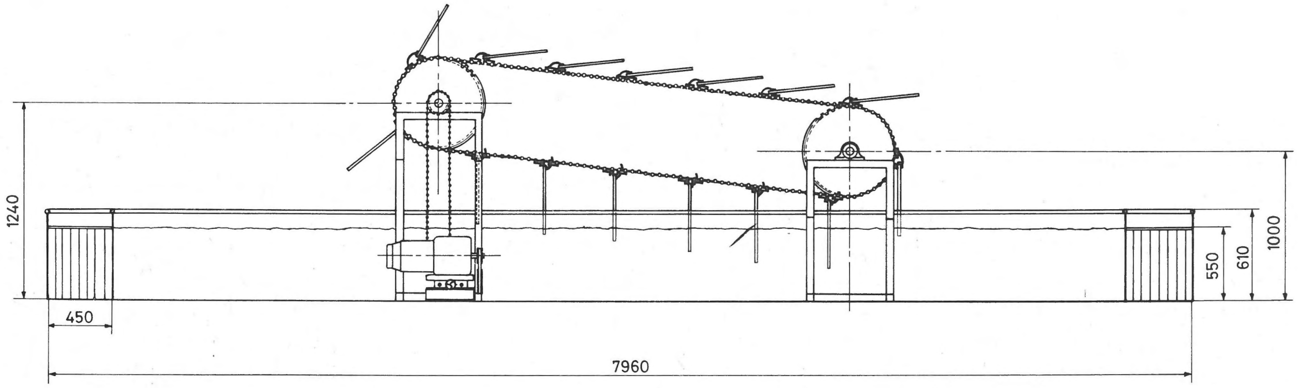


Fig. 1
Flume-plan and cross-section

(Fig. 1). The overall length is 790 cm, the width 275 cm. The channel is 60 cm high and 45 cm wide.

The flume is constructed of 3 mm thick grey P.V.C. plate. In the two long stretches, the outer wall is made of transparent P.V.C. to allow visual observations.

In each corner, 7 bended blades are mounted to deflect the current. The blades are made of 1 mm thick stainless steel and are hollow. They have a shape which compensates for the increase in width in the bends, i.e. at its thickest part, each blade has a thickness of $1/7 . (\sqrt{2} - 1) . 45$ cm (Fig. 2). In this way, the channel width remains constant everywhere and the streamlines pass practically undisturbed around the bends. This construction was copied from a flume developed by Shell E and P Lab, Rijswijk, Holland.

The waterdrive is performed by means of 16 paddles, which are mounted on two parallel bold-chains. The connection of the paddles to the chains is hinged (Fig. 3). The chains run over cogwheels. The downstream pair of cogwheels is mounted 25 cm higher than the upstream one, so that the chains make a small angle with the water surface. The pivot of the paddles is limited in such a way that, when they run through the water, they remain in a vertical position, making an angle of about 100° with the chains. Due to the slope of the chains, the paddles are gradually lifted out of the water during their downstream movement. Before they reach the downstream cogwheels, they are just free of the watersurface, but still in a vertical position. When they flip around the cogwheels, they do not disturb the watersurface

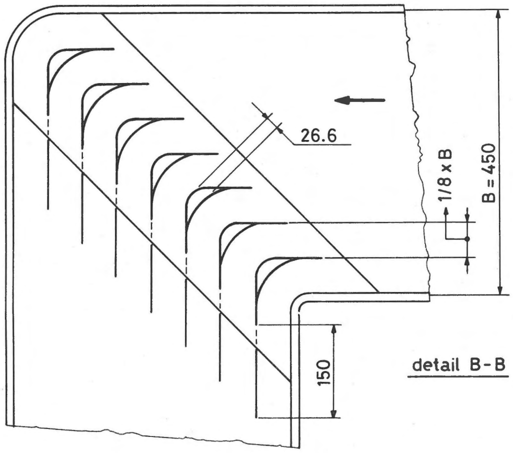


Fig. 2
Detail of corner

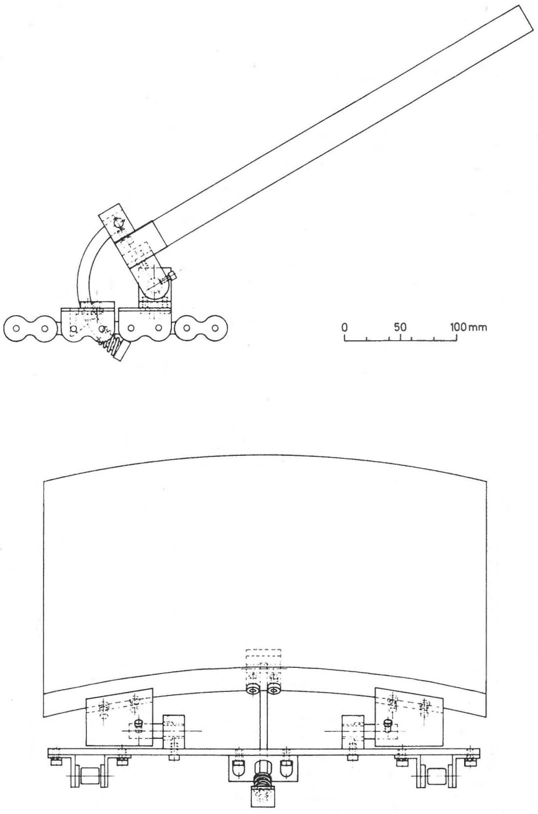


Fig. 3 Detail of paddle

anymore. During their travel upstream, they lay down in a horizontal position. When they go round the upstream cogwheels, they gradually hang down freely and when they touch the water surface, they are in a vertical position already, which they maintain during their further descent in the water. In this way, very little extra turbulence is added during the propulsion and the properties of the sediment distribution as grading etc. are disturbed as little as possible.

The paddles are made of 1 mm thick stainless steel blade. They are slightly bended to increase their stiffness (Fig. 3). They are 39 cm broad and 42 cm long. When at their lowest point, the paddles leave 19 cm free from the bottom of the flume. This is to let the bottom sediments pass underneath and not to disturb too much the slower current near the bottom and near the walls. This implies a certain amount of slip between the paddles and the water.

For the propulsion, a 4 H.P. 3 phase electro-motor is used followed by a 10 : 1 reduction box. The rotation speed of the motor can be regulated stepless by means of a remote control. Average current velocities of 120 cm/sec can be reached easily. Above 100 cm/sec, there occur some spray and spill over round the cogwheels due to the increased centrifugal forces. If the flume is to be used regularly with high speeds, larger cogwheels should be used to reduce the angular speed.

The hinged connection of the paddles has the advantage, that when the speed is reduced suddenly or e.g. in case of motor failure, the paddles pivot freely in the current direction, offering hardly any resistance to the flow.

FURTHER DETAILS

To keep down the costs, only 3 mm thin P.V.C. plates have been used. This asked for special provisions to keep the flume rigid. Each 50 cm vertical P.V.C. ribbons of 1.5 cm thick are welded on the outer wall to prevent the formation of "cheeks". Furthermore, each 50 cm the flume walls are crossconnected with a P.V.C. rod. These rods are used to fix the different measuring tools as well. On the inner side, the rods are interconnected by an iron bar, which on its turn is fixed every meter to the concrete floor by means of L-shaped rectangular iron tubes.

THE EFFICIENCY OF THE PADDLE PROPULSION

Normally, the flume is used with a water depth of 45 cm. The maximum immersion of the paddles is then 26 cm. In Fig. 4 the paddle velocity is plotted against the water velocity measured at 35 cm from the bottom in the center of the channel. At all paddle velocities, the induced water velocity is about 73%. The paddle drive is thus rather efficient.

SPECIAL FLUME CHARACTERISTICS

One of the particulars of the flume is, that an artificial gradient is created. The water level downstream the paddle section is higher than upstream. A remarkable thing is, that this gradient is higher for the water near the inner wall than for the water near the outer wall, since a same difference in water level works over a longer distance near the outer wall. A consequence is that, at least with moderate speeds, the highest current velocities do not occur in the centre of the flume but a bit more towards the inner wall. At high velocities, the increased turbulence homogenises this effect.

Due to the gradient, the wet diameter decreases downstream and hence the current velocities increase a bit in downstream direction. This phenomenon becomes more pronounced with high velocities, since a steeper gradient works then over a same depth.

In the reach of the reach of the paddle propulsion, a paradoxal situation occurs, since this propulsion causes the water to flow slower again i.e. the wet diameter is increased here as the water gains potential energy. When the flume is used with sediment, the decrease in velocity will cause sedimentation and hence a decrease in wet diameter, balancing this effect.

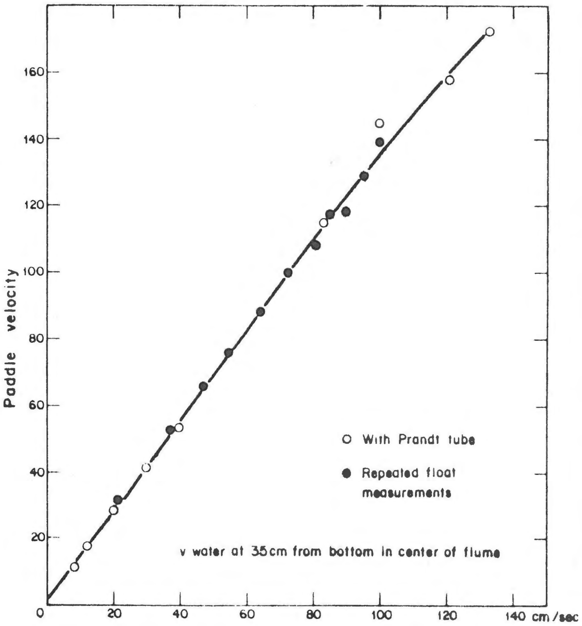
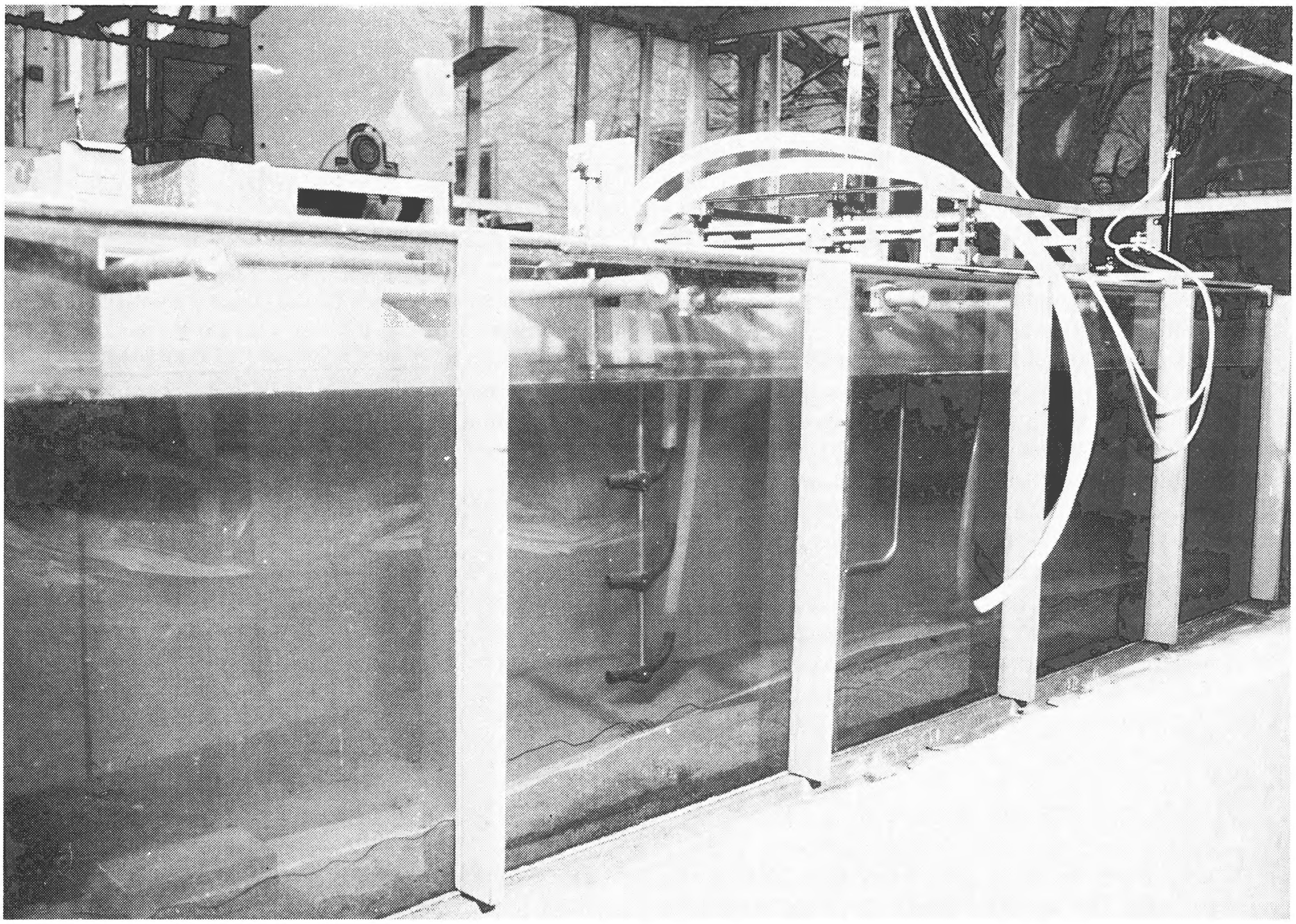


Fig. 4
Relation between paddle velocity and water velocity in flume

Fig. 5
Detail suspension sampler



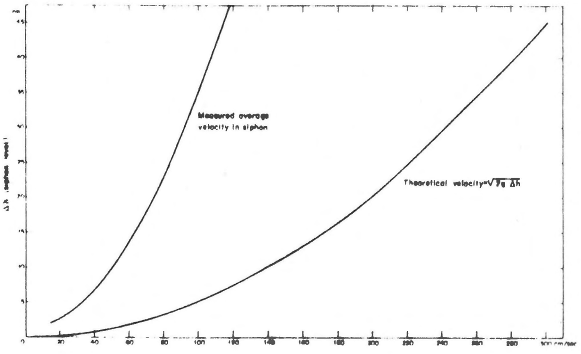


Fig. 6
Relation of siphon depth with average velocity in siphon hose, compared with the theoretical velocities

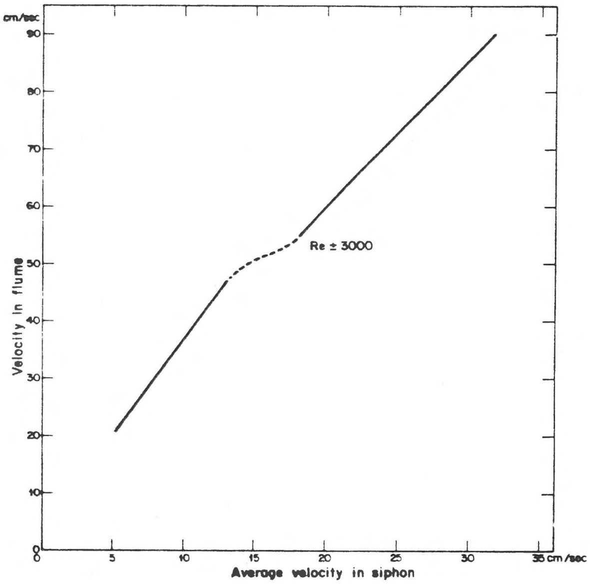


Fig. 7
Relation of water velocity in flume with average siphon velocity at siphon level zero

MEASURING TECHNIQUES

Velocity measurement

A Prandl static tube is used in connection with a manometer filled with CCL4, to which dye was added. CCL4 is very convenient due to its specific gravity of 1.594 and its good meniscus with water.

Especially with high velocities, the Prandl tube is not so convenient. Due to the turbulent gusts, the readings become increasingly inaccurate. Often, airbubbles enter or are formed in the tubes, so that the system has to be refilled. For velocity measurements during the experiments, another method is used therefore, which has been gauged with the Prandl tube. It works in combination with the suspension sampling.

SUSPENSION SAMPLING

To obtain a representative suspension sample at a certain point, it is necessary that the streamlines enter without deflection into the sampler.

For the sampling, thin-walled stainless steel tubes are used with an inside diameter of 15 mm. The tubes have a bend of 90° at their end. The vertical tubes are connected with plastic hoses of the same diameter. The total length of tube with hose is 150 cm. Three of these tubes are mounted on a vertical rod. The open ends stick out 10 cm to avoid influence of the rod. The sampling depth can be varied by means of screws. (Fig. 5). Once filled with water, the system can work as a siphon. The time is measured that it takes to siphon 10 l of water at different siphon levels in stagnant water. From the debit, the average velocity is calculated for each siphon level. Due to the friction in the system, these velocities are less than the theoretical frictionless velocity $v = \sqrt{2\ g.h.}$ From this difference, the resistance of the siphon can be calculated. Fig. 6 shows the relation of the siphon depth with the average velocity in the tube and with the theoretical frictionless velocities.

When the siphoning is done during experiments when the flume water has a certain velocity, the momentum of the water adds an extra pressure, which can be expressed as an excess static pressure ($\frac{1}{2}mv^2 = mgh.$). We can measure this momentum by using the siphon with a siphon depth of zero. With different flume velocities (which are measured with the Prandl tube), we measure the debit of the siphon and calculate the velocities in the siphon for the different flume velocities.

The results are plotted in Fig. 7. We see that the graph shows two straight stretches, connected with an irregular trajectory. Above 55 cm/sec flume velocity, the current is fully turbulent in the flume as well as in the siphon (Reynolds nr ± 3000).

Under such circumstances, the pressure excerted by the momentum of the flume water as well as the resistance in the siphon increase with the square of the velocity. With velocities between 45-55 cm/sec, the flume water is fully turbulent, whereas the current in the siphon is not. The coefficient of friction varies in this trajectory with the velocity. With still lower flume velocities, viscous shear forces become dominant in the flume as well as the siphon, giving rise again to a fixed coefficient of the friction, which is somewhat higher than during turbulent flow.

By measuring the debit of the siphon at siphon level zero, we can now measure the current velocity in the flume at every location, using Fig. 7.

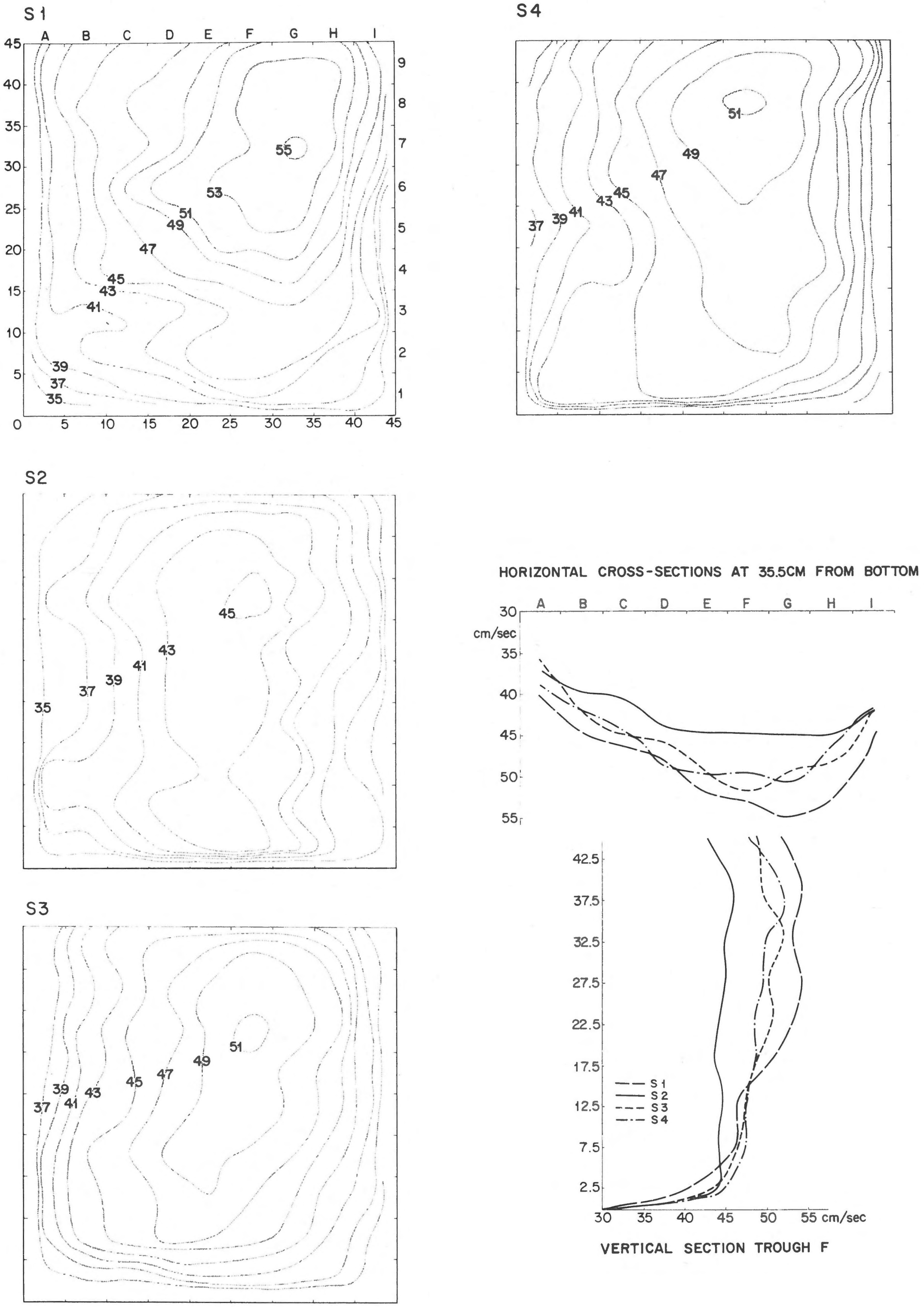


Fig. 8
Velocity distributions at about 45 cm/sec average velocity in different flume sections

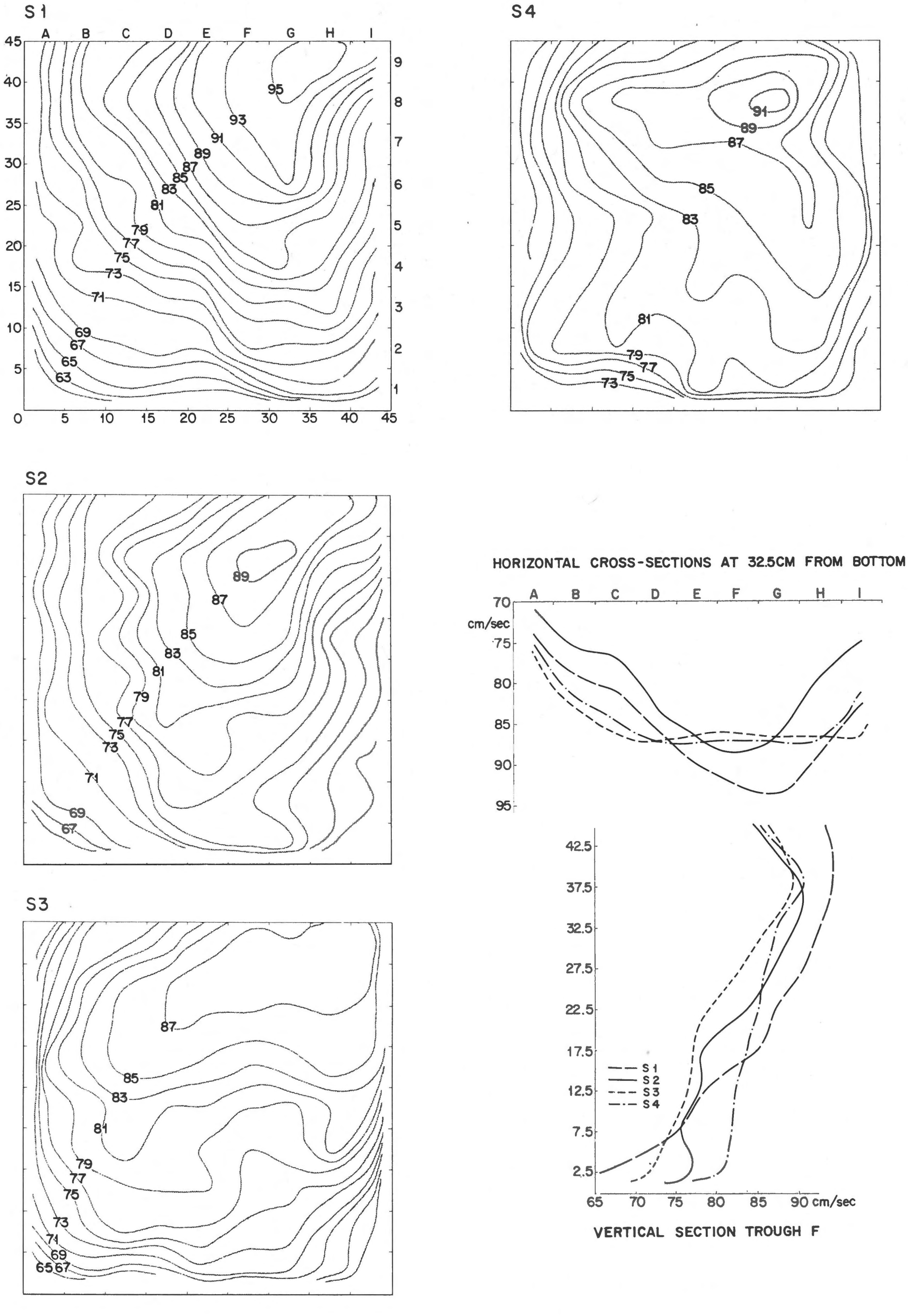


Fig. 9
Velocity distributions at about 80 cm/sec average velocity in different flume sections

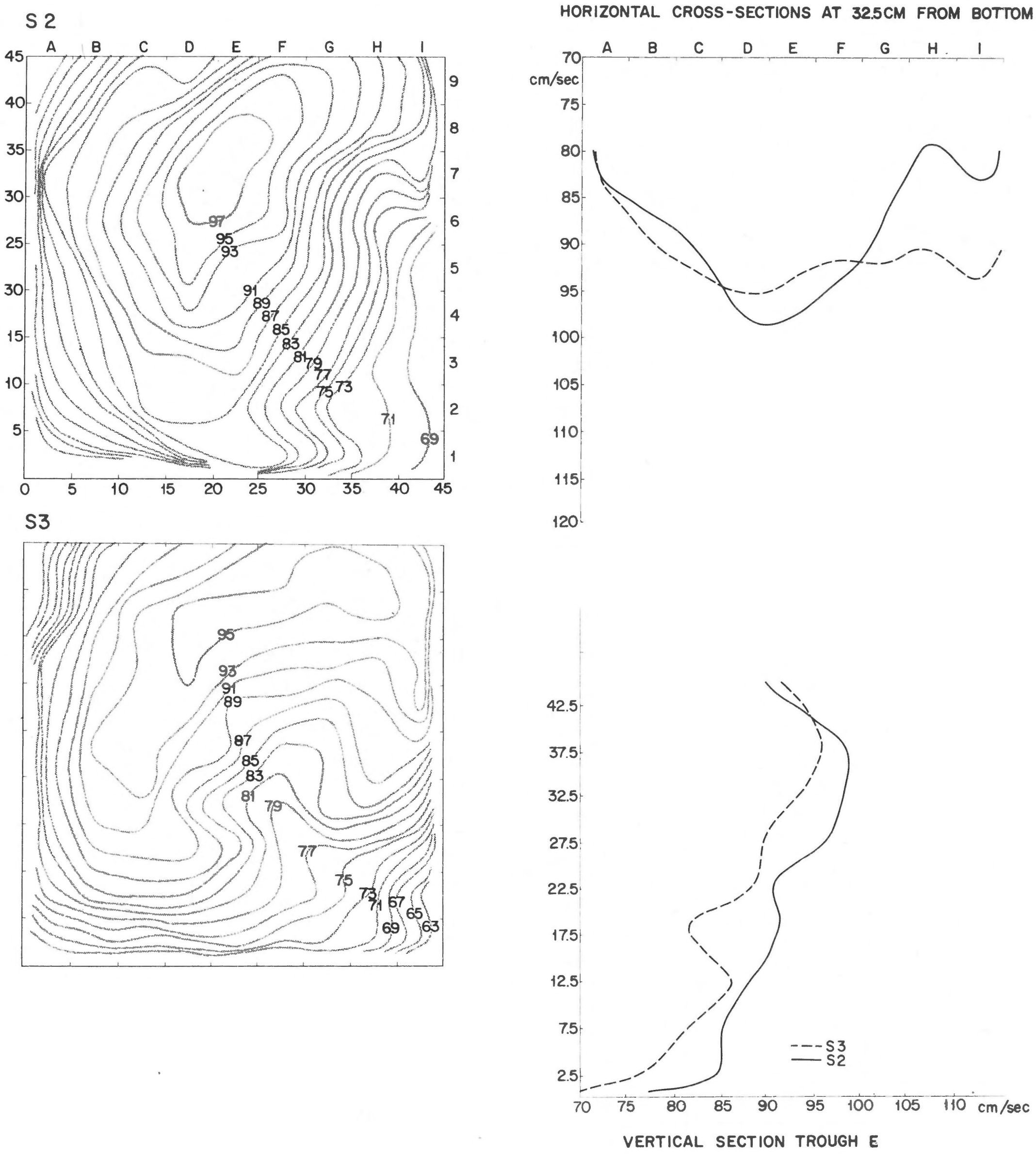


Fig. 10
Velocity distributions at about 85 cm/sec average velocity in different flume sections

To take accurate suspension samples, it is desired that the velocity in the measuring point is equal to the velocity in the siphon, so that the streamlines go straight through. After having measured the flume velocity, we read from Fig. 6 which siphon level is needed to achieve this velocity in the tube. From this siphon level, we must subtract the momentum of the flume water converted to potential energy expressed as height. This is the height the Pitot tube manometer indicates when water were used as manometer liquid, and can be read from Fig. 6. Detailed conversion tables for $\sqrt{2g.h}$ to $\triangle h$ are available in literature, e.g. Hendry (1971).

N.B. The method described above is only approximate, but good enough for accurate sampling. Several side effects occur. E.g. the siphon diameter is too large. The water velocity only exerts its maximum pressure in the stagnation point. More peripheral streamlines produce only a component of this pressure. On the other hand, turbulent currents always produce a pressure, which is higher than that belonging to the average velocity because velocity peaks increase this pressure squared. Errors due to these effects act in opposite direction.

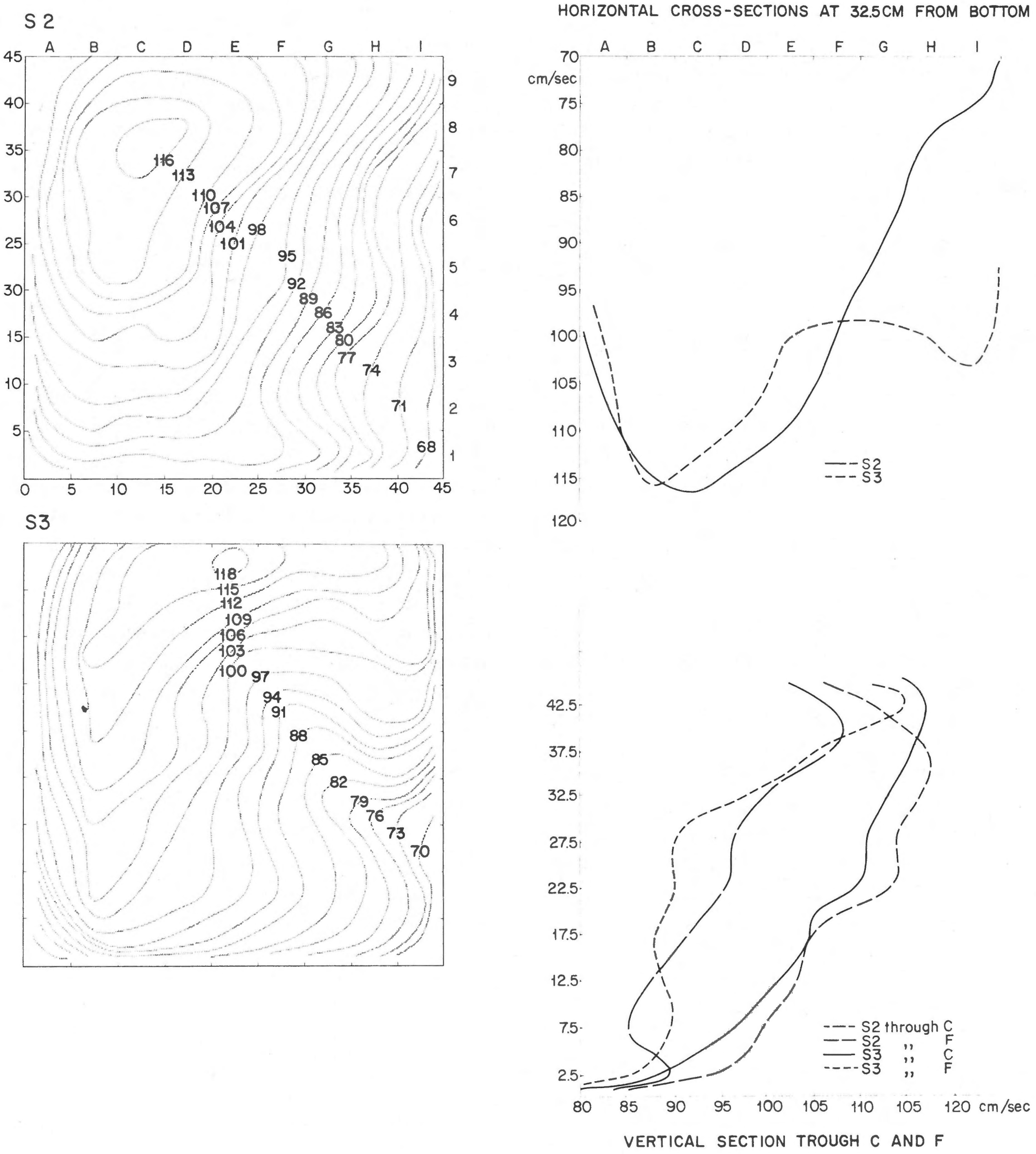


Fig. 11
Velocity distributions at about 100 cm/sec average velocity in different flume sections.

FLOW CHARACTERISTICS

To obtain a detailed insight into the flow characteristics of the flume, velocity measurements were carried out in four sections S1-S4, which are indicated in Fig. 1. Each section has been subdivided into nine horizontal and nine vertical parts and in the center of each block of 5 cm velocity measurements were performed with a Prandl tube at different discharges. Per section, 81 velocity values are thus obtained, from which rather detailed velocity distribution pictures can be plotted (Fig. 8–11).

Fig. 8 shows the distribution at an average speed of about 46 cm/sec. Section 1 (highest upstream) is clearly a-symmetrical. The highest velocities occur at about 1/3rd from the inner wall. In the long straight stretch opposite the paddle section, the pictures become gradually more symmetric (S2→S3). Where the water approaches the paddle section again, the maximum current velocities shift again towards the inner wall (S4). In the whole flume, the current is very regular with these low velocities. There is a steep velocity gradient near the bottom. At 5 cm depth, the average velocity is reached already.

In Fig. 9, the situation is shown for an average velocity of about 80 cm/sec. The maximum velocities still occur near the inner wall. In the region of S3, opposite the paddle section, the flow tends towards symmetry, but further down stream (S4) the a-symmetry increases again. The vertical profiles show that the velocities increase more gradual from the bottom to top.

At a bit higher velocities of about 85 cm/sec (Fig. 10), the maxima occur in the center of the flume. However, the tendency to flow faster near the inner wall can still be noted in the cross-sections. The vertical velocity gradient is more gradual. There is a tendency to form an inflexion at half the water depth.

With still higher velocities of about 100 cm/sec average (Fig. 11), the maximum velocities occur nearer to the outer wall. From the vertical cross-sections it can be seen that the profiles show a more pronounced inflexion at about half the water depth.

To understand this, we must consider the situation just after the paddles. The water is piled up here and tends to flow out in all directions. In the upper half of the water, backflow is prohibited due to the steadily advancing paddles. Below the paddles, the water can react with the flowing water and slow down the current which comes from underneath the paddles. In this way a shear plane is created, which continues for some distance in down stream direction, the more so for higher velocities. In Fig. 9 e.g. it can be seen that this shear plane is present in S1 and 2 but not anymore in S3 further downstream, where the current is fully homogenised by the turbulence. In Fig. 8, only the most upstream sections shows this shear plane, whereas at 85 cm/sec (Fig. 10) it proceeds further than S3.

STANDING WAVES

A particular of infinite flumes is that they always have a very distinct own wave length. Since the paddle propulsion induces a very regular impact frequency, interference phenomena easily occur. At some velocities, a standing wave is created with an amplitude of about 2 cm. Since the total depth of the water is about 45 cm, such waves cause velocity fluctuations of about 5%, which is not too serious. When the paddles were placed at somewhat irregular distances on the chains, this phenomenon could probably be suppressed.

FINAL REMARKS

The first rectangular flume I saw in the Shell Lab. in Rijswijk had the peculiarity, that both long stretches shared the inner wall, the overall width being thus only twice the width of the channel. Such a design is cheaper in material and takes less space. I choose for the "court-yard" type, because in the central space the motor unit is safest and sand can be stored there close at hand.

Our flume is resting directly on the concrete floor. An observation pit is spared out alongside the outer wall of the long flume stretch. The pit is 90 cm deep, 150 cm wide and 5 meter long and is very convenient for observations, measurements, sampling etc.

A disadvantage of the paddle propulsion is the high noise level at high velocities.

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