# 2. EXPERIENCE WITH STRAIGHT FLUMES FOR MOVABLE BED EXPERIMENTS

by

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## 1. Introduction

Flume studies may increase the understanding of the interrelationship between the bed material and the sediment transport on the one hand and the hydraulic parameters on the other hand. During a flume experiment the conditions can be controlled and the relevant parameters can be measured with sufficient accuracy. Experiments in flumes, however, are influenced by the presence of the side-walls, which dissipate a part of the available flow energy. To reduce this effect, it may seem attractive to do experiments with relatively large width-depth ratios only. Under these conditions, however, three-dimensional bed form patterns and even alternate bars may occur. Although these phenomena are also present in nature, the ratio of the characteristic length of these macro-scale phenomena and the length of the average bed forms is much more unfavourable in flumes and therefore, the influence of the three-dimensional phenomena should be limited.

In this paper some of the experience gained at the Delft Hydraulics Laboratory is discussed concentrating mostly on the influence of the flume width on the bed forms. The implications of the observed phenomena are reviewed together with some preliminary results of presently on-going research.

## 2. Types of sediment flumes

Usually two types of flumes are being used for experiments with movable beds, viz. a sand-recirculation system and a sand-feed system:

| Sand-recirculation system | Sand-feed system |
|---|---|
| the sand particles are returned continuously (Figure 1) | the sand particles are separated from the flow and returned by means of some mechanical method (Figure 2) |
| advantages | advantages |
| * the system tends to act like an infinite flow (natural channels) | * possibility to impose a specific rate of sediment transport, |
| * applicable for fine sediments | * no limitations on flume dimensions |
| * relatively easy to operate | * accurate determination of sediment transport rate |
| * equilibrium conditions are established rapidly, if pre-set slope is correct | |
| imposed variables | imposed variables |
| * discharge | * discharge |
| * slope (tilting flume) | * sediment transport |
| adjusted variables | adjusted variables |
| * flow depth | * flow depth |
| * sediment transport | * slope |

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According to Guy et al (1967) the two systems do not show significant differences if the imposed boundary conditions are similar.

For experiments with a movable bed, presently two flumes are being used at the Delft Hydraulics Laboratory.
The smallest flume (test length = 10 m, width = 0.5 m and depth = 0.7 m, maximum discharge = 0.25 $m^3/s$) is mainly used for research in the field of suspended sediment transport. The largest flume (measuring length = 30 m, total length = 100 m, width variable between 0.3 and 1.5 m, depth = 1.0 m, maximum discharge = 0.8 $m^3/s$) has been built especially for fundamental research into bed-load transport.
The main features of the large flume are:

- the sediment transport is measured and regulated at the beginning and end of the flume by means of hydrocyclones enabling the determination of the submerged weight of the bed load (no influence of voids ratio), (Figure 3),
- longitudinal records of the sand-bed in three profiles (middle profile and two profiles on each side at one-sixth of the width) are measured by means of profile indicators, mounted on a measuring carriage; the measurements are made and stored automatically on pre-set hours,
- the discharge in the flume can vary in time according to a pre-set function by means of a computer programme.

Also the other relevant hydraulic and sediment parameters are sampled automatically. All collected data are stored on tape in a mini-computer, which also checks the collected data after each measurement. Next, the tapes are processed on a large computer system.
Originally, the large flume was built as a sand-feed system, but recently a slope-control system was installed to obtain the advantages of the sand-recirculation system. The slope-control system consists of regulating the height of the tailgate of the flume until the actual slope of the flume is equal to a pre-set value within narrow limits, while the sand particles are recirculated directly (see Figure 3).

## 3. Influence of the flume width

One of the problems in interpreting flume data is a correct elimination of the side-wall effects, because the side-walls influence both the bed-shear stress and the dimensions of the bed forms and hence the sediment transport.

### Bed-shear stress

For large values of the width-depth ratio the influence of the side-walls can be neglected and the bed-shear stress can be assumed to be equal to the value $\rho ghi$ ($\rho$ = density of fluid, g = acceleration of gravity, h = flow depth, i = slope).
Some insight in the value of the bed-shear stress for small width-depth ratios can be obtained from the experiments of Knight and Macdonald (1979), who determined the bed-shear stresses from special Pitot-tube measurements for different bed roughnesses. Figure 4 shows values of $\tau_{bed}/\rho ghi$ ($\tau_{bed}$ = bed-shear stress) as a function of the width-depth ratio and the bed roughness.
Assuming a rough bed for experiments with a mobile bed, a width-depth ratio larger than 3 should be taken to reduce the side-wall influence to less than about 20%. This is in accordance with the observations of Williams (1970), that at the same flow conditions the energy gradient remains nearly constant for a width-depth ratio larger than 3 indicating a vanishing influence of the side walls (Figure 5).
Initially the design of the large flume in the Delft Hydraulics Laboratory was based on a minimum width-depth ratio of 4 (Struiksma et al, 1971); lateron also tests with smaller ratios were carried out.

## Bed-form dimensions

Experiments have shown that the flume width also influences the dimensions of the bed forms. Crickmore (1970) and Williams (1970) reported an increase of both the length and height of the bed forms for increasing values of the width-depth ratio at the same flow conditions (discharge per unit width).
Statistical analysis of the sand waves measured in the large flume of the Delft Hydraulics Laboratory (Bogirski, 1977) and some tests with reduced widths in a flume of the Delft University of Technology (Vermaas, 1980) show similar results. For each experiment the bed was sounded in 3 longitudinal profiles at regular time intervals of 2 hours (to ensure statistical independent measurements). In all about 400 bed forms for each profile were analyzed. The data were used to compute the average bed slope of each profile, the bed form lengths defined as the distance between two successive zero-upcrossings with the average bed slope, and the bed form heights defined as the distance between the highest and lowest point between two successive zero-upcrossings.
Figure 6 shows the average bed form length and height (in the middle profile) as a function of the width-depth ratio for the same flow depth and discharge per unit width.
Clearly, an increase of the bed form dimensions for increasing values of the width-depth ratio can be observed, while both the value of the energy-gradient and the Chézy-coefficient show a decrease. Figure 7 represents the probability density function of the bed form length which shows a shift to the larger bed-forms for larger width-depth ratios, while also the variation in the bed form length shows an increase.

## 4. Three-dimensional effects

Three-dimensional bed forms have been reported by Guy et al (1966), who carried out a series of experiments in a 8-foot wide flume in the years 1956-1961. They described the development of alternate bars in some runs which caused the flow to meander. Also Williams (1970) reported three-dimensionals bed forms for a widht-depth ratio larger than about 3.
Statistical analysis of sand waves measured in three longitudinal profiles in the large flume of the Delft Hydraulics Laboratory also show the existence of predominantly three-dimensional bed forms for large width-depth ratios. Figure 8 represents the ratio of the bed form dimensions in the side profiles and the middle profile as a function of the width-depth ratio (same run as in Figure 6). As can be observed, the length and height of the bed forms in the side profiles are considerably larger than the values in the middle profile. Particularly, the ratio of the bed-form length in the side profiles and the middle profile seems to increase with the width-depth ratio.
It should be stressed that the present results relate to average values obtained from 15 to 20 independent soundings of the bed profiles. Individual measurements show considerable scatter in the observed energy gradients, Chézy-coefficients and bed form dimensions. This may, at least partly, be caused by the presence of three-dimensional phenomena, which may migrate in downward direction thereby causing a continuous change in the flow conditions in the flume.

## Present research

At present, research is carried out at the Delft Hydraulics Laboratory into these three-dimensional phenomena. The purpose of this research is to establish criterions for the selection of an optimal flume width for particular tests conditions, taking into account the effect of both the wall roughness and the occurence of three-dimensional phenomena. Within this frame-work, methods are studied to eliminate the effect of the latter phenomena from the bed-level recordings.

Some preliminary results of the application of a high-pass digital filter to the recordings is presented in Figure 9. This figure is related to a test with a width-depth ratio of about 15. The mean waterdepth is about 0.10 m. In the figure the original signal, the removed trend and the resulting signal are shown for the middle profile and the side-profiles. The filter characteristics are such that all wave-lengths larger than 3 m have been removed from the signal. From the results it can be concluded that for this particular test a definite alternate bar pattern is present. After filtering, the ratio of the dune-length of the side and the middle profile decreased from 1.56 to 1.04.

The research programme will be continued (i) by selecting the most appropriate filter, (ii) by applying the filtering method to other tests with smaller width-depth ratios, (iii) by estimating the effects of the three-dimensional bed-level pattern on hydraulic roughness and sediment transport.

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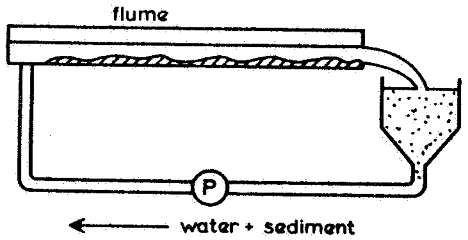



FIG. 1 SAND-RECIRCULATION SYSTEM

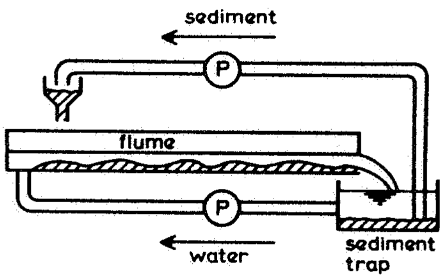



FIG. 2 SAND-FEED SYSTEM

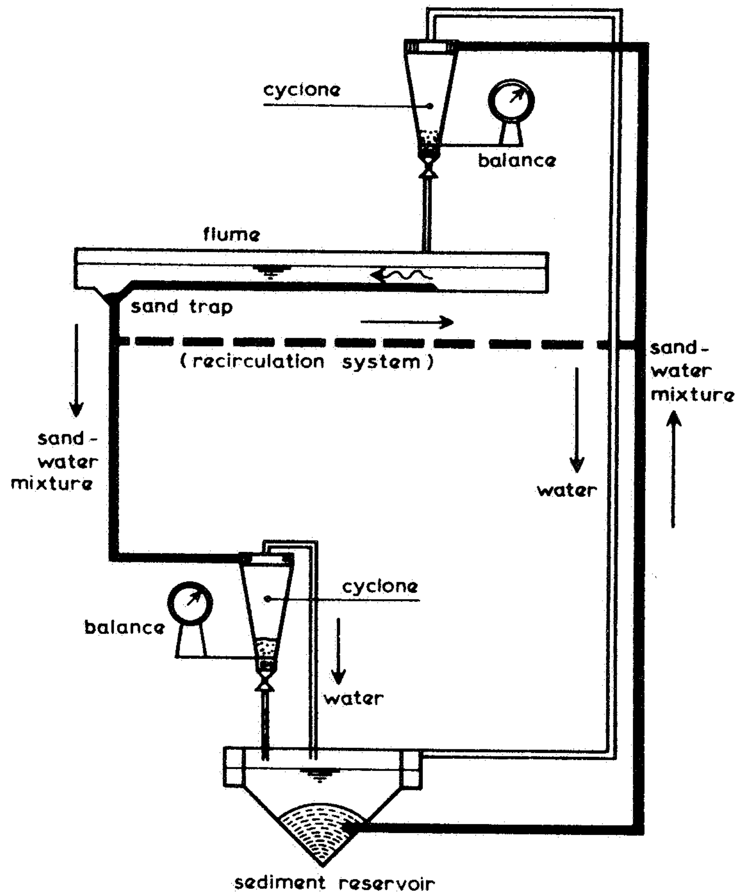



FIG. 3 SAND-FEED SYSTEM OF THE LARGE FLUME AT THE DELFT HYDRAULICS LABORATORY

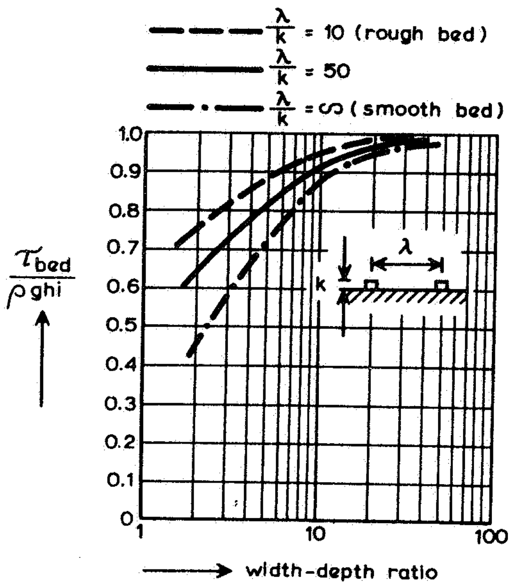



FIG. 4 BED-SHEAR STRESS AS A FUNCTION OF FLUME WIDTH AND BED-ROUGHNESS (KNIGHT ET AL., 1979)

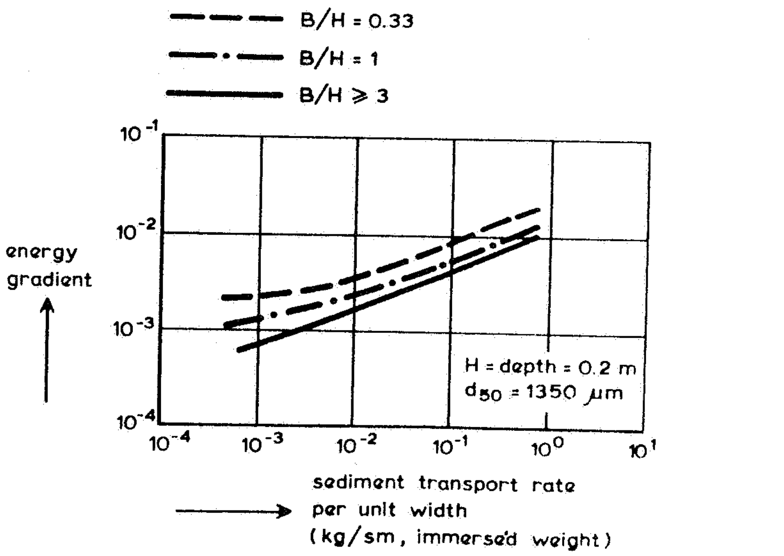
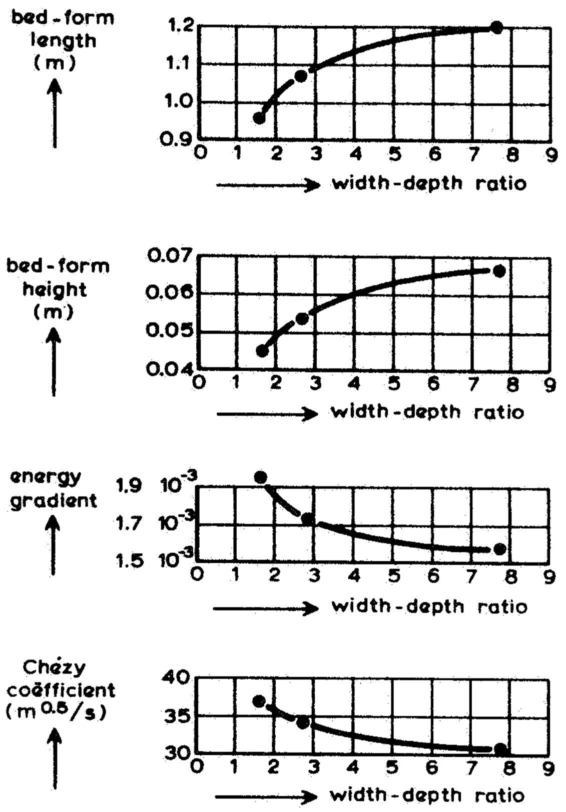
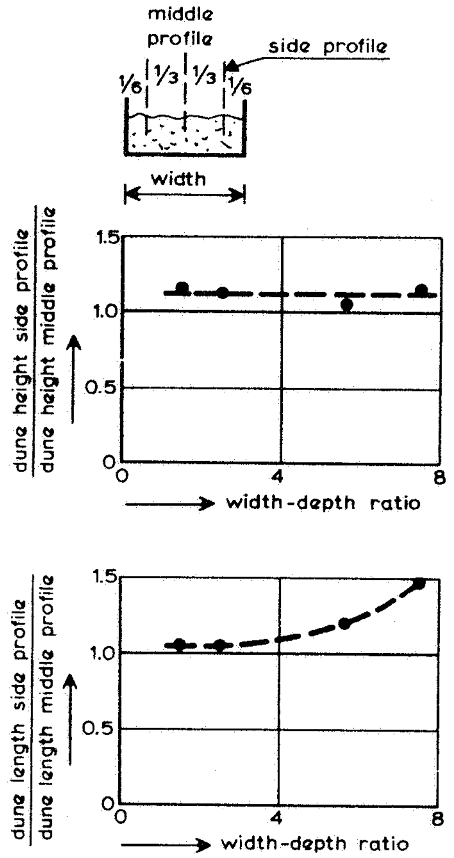



FIG. 5 ENERGY GRADIENT AS A FUNCTION OF THE FLUME WIDTH AND SEDIMENT TRANSPORT RATE (WILLIAMS, 1970)



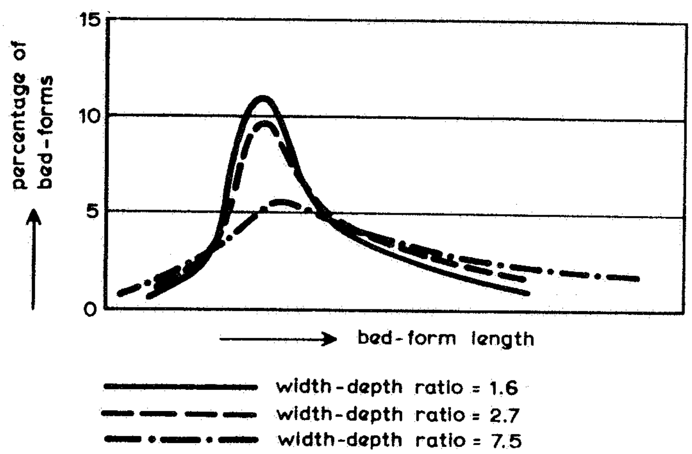

q = water discharge = 0.1 $m^2/s$
s = sand discharge = 0.0122 $10^{-3}$ $m^2/s$
H = flow depth = 0.19 m
$D_m$ = sand diameter = 770 $\mu m$

FIG. 6 BED-FORM DIMENSIONS IN MIDDLE PROFILE, ENERGY GRADIENT AND CHÉZY - COËFFICIENT AS A FUNCTION OF FLUME WIDTH




q = 0.1 $m^2/s$
s = 0.0122 $10^{-3}$ $m^2/s$
H = 0.19 m
$D_m$ = 770 $\mu m$

FIG. 8 RATIOS OF BED FORM LENGTH AND HEIGHT IN MIDDLE AND SIDE PROFILES AS A FUNCTION OF FLUME WIDTH




q = 0.1 $m^2/s$
s = 0.0122 $10^{-3}$ $m^2/s$
H = 0.19 m

FIG. 7 PROBABILITY DENSITY FUNCTION OF THE BED-FORM LENGTH IN MIDDLE PROFILE

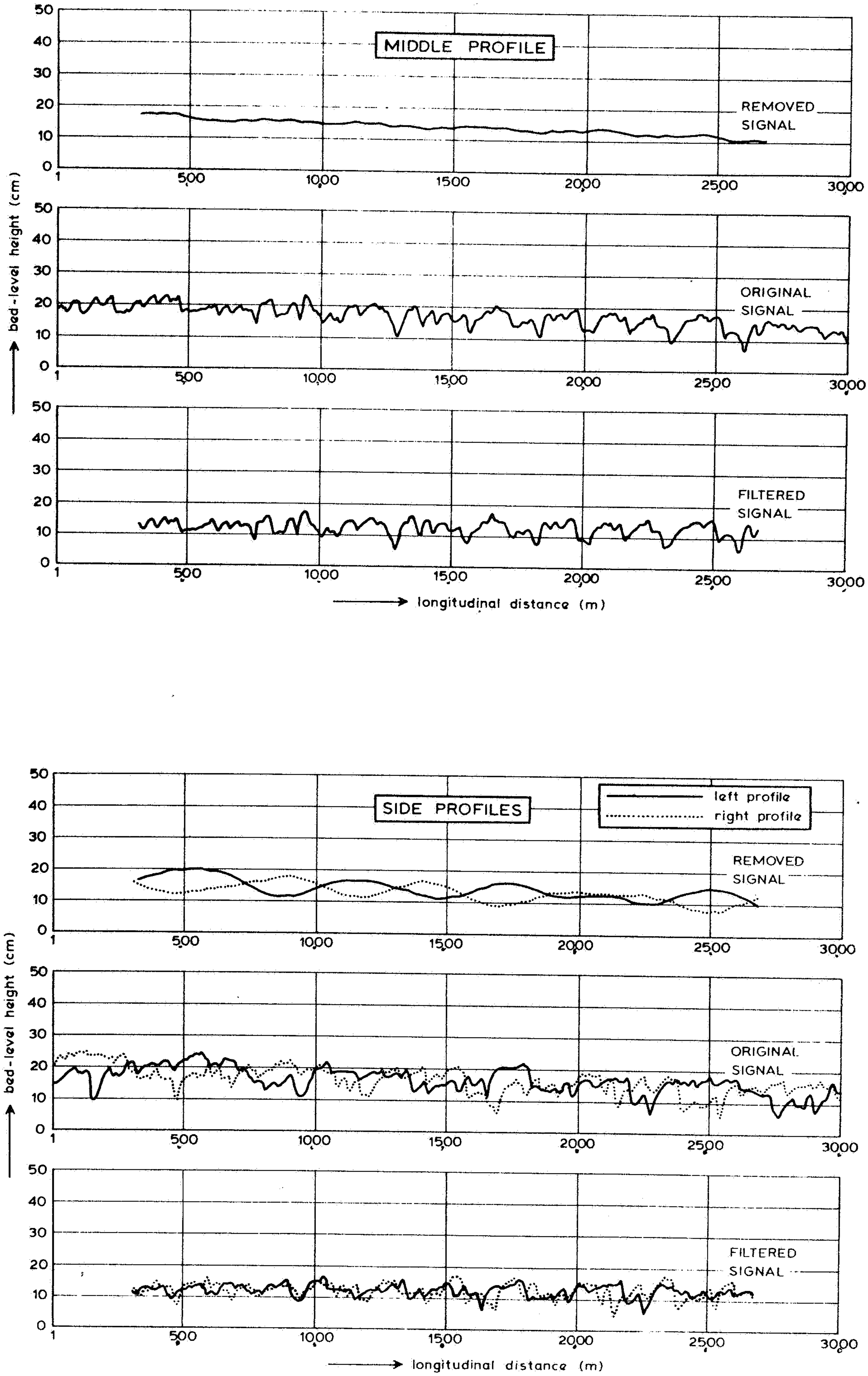



FIG. 9 BED LEVEL RECORDINGS