CHAPTER 58

MEASUREMENT OF SEDIMENT SUSPENSION IN COMBINATIONS OF WAVES AND CURRENTS

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ABSTRACT

The paper describes a procedure for obtaining field data on the mean concentration of sediments in combination of waves and currents outside the breaker zone, as well as some results of such measurements. It is assumed that the current turbulence alone is responsible for the maintenance of the concentration profile above a thin layer close to the bottom, in which pick-up of sediments due to wave agitation takes place. This assumption gives a good agreement between field data and calculated concentration profiles.

1. INTRODUCTION

An extensive investigation programme was carried out in 1971 to predict the sedimentation in a proposed dredged entrance channel to the Port of Karachi. During the summer the area is exposed to monsoon waves and to tidal currents.

The programme involved both field and laboratory measurements of concentrations of suspended sediment, and the results were interpreted on the basis of simultaneous recordings of waves and currents. This paper deals with the determination of concentration profiles in the region outside the breaker zone.

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2. NOTATION

c - Concentration

c_r - Concentration at a reference level

D - Water depth

u - Maximum orbital velocity of wave movement at the bottom

U_f - Friction velocity

w - Settling velocity of suspended grains

y - Vertical coordinate

z - $w/\kappa \cdot U_f$

ε_s - Diffusion coefficient for suspended sediment

κ - v. Karman's constant

3. THEORETICAL CONSIDERATIONS

In a turbulent flow, the concentrations of suspended sediments are determined by an equilibrium between settling of sediments, due to gravity, and diffusion of sediment grains towards levels with lower concentrations. This mechanism may be described by the equation:

$$c \cdot w = -\varepsilon_s \frac{\partial c}{\partial y} \qquad (1)$$

In a fully turbulent two-dimensional steady and uniform flow, this equation may be integrated to yield

$$c = c_r \left(\frac{D - y}{y}\right)^z \qquad (2)$$

in which

$$z = \frac{w}{\kappa \cdot U_f}$$

if ε_s is assumed to be equal to the eddy viscosity of the flow. The concentration c_r at a reference level has to be determined by measurements.

In pure sinusoidal waves, sediment suspension occurs only within a thin turbulent layer near the bottom. It is known from several investigations that the thickness of the wave boundary layer is of the order of magnitude of a few centimetres. However, suspended sediments have been found above this layer in a number of tests. The suspension mechanism under such circumstances cannot yet be described mathematically, which means that in neither of the cases, pure wave motion and wave motion combined with currents, can equation (1) be integrated in this region.

For the present purposes, it is assumed that the wave motion provides a boundary condition, from which a c_r in equation (2) may be found. This boundary condition is assumed to be related only to the wave conditions whereas the profile above the level of this c_r is calculated by equation (2), and is thus assumed not to be influenced by the presence of waves.

4. FIELD MEASUREMENTS

4.1 Hydrographic Conditions

Measurements of concentration profiles were carried out at 11 m water depth off Karachi during the southwest monsoon season of 1971. During this season the coast is constantly exposed to high waves. Wave measurements performed with a Waverider system simultaneously with the water sampling showed significant heights of 1.4-2.7 m, and zero-crossing periods of 7-9 s. The currents generated by the predominantly semidiurnal tide of maximum range 3.5 m reached a maximum velocity of 0.5 m/s at the sampling position.

The bottom sediments are silt and fine sand with a median diameter of 0.08 mm.

4.2 Measuring Technique

The main problem of these measurements was to establish a fixed location of the sampling levels relative to the bottom. This is very critical, especially when sampling from levels close to the bottom, because the concentration gradient is very large.

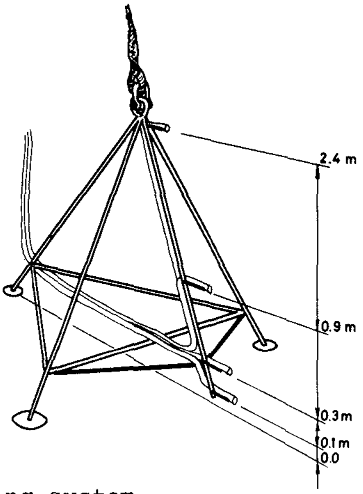

Fig. 1 - Sampling system

The sampling system was constructed as a tripod frame of steel bars, figure 1, which was lowered to the bottom from a vessel anchored at the sampling position. The frame was supported on feet shaped as part of a sphere to reduce scouring around the feet. Four suction hoses were attached to intake nozzles mounted on this frame and a fifth hose was lowered with a sinker for sampling at mid depth.

Every 45 minutes, two 1 litre samples from each of the five levels, were pumped on board the vessel, each sample representing an average over 30 s. The sediment concentrations of these routine samples were determined by filtration. In addition to this 20 l samples were taken for determination of the settling velocity distribution by the hydrometer method.

In order to investigate the relationship between wave conditions and the concentrations near the bottom, samplings were carried out during eight periods, each of them covering one half tidal cycle.

4.3 Results

Figure 2 presents the results of measurements during one flood tide. The results did not show any systematic variation of the concentrations arising from the variation of the tidal current velocity. Therefore, the measurements are correlated with the average characteristics of the tidal current over the flood tide. The calculated mean profile is based on the settling velocity distribution as determined in the boundary layer 0.05 m above the bottom, and the average concentration of the 12 samples from the 0.3 m level. The friction velocity in equation (2), could not be determined by the current measurements performed. Hence, an approximate value of 0.05 times the average velocity over depth was used.

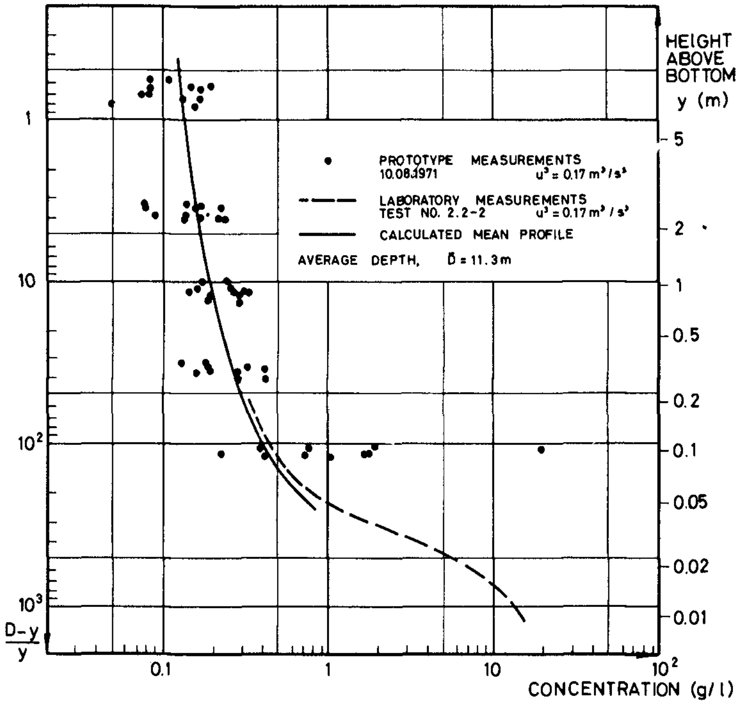

Fig. 2 - Sediment concentration profiles

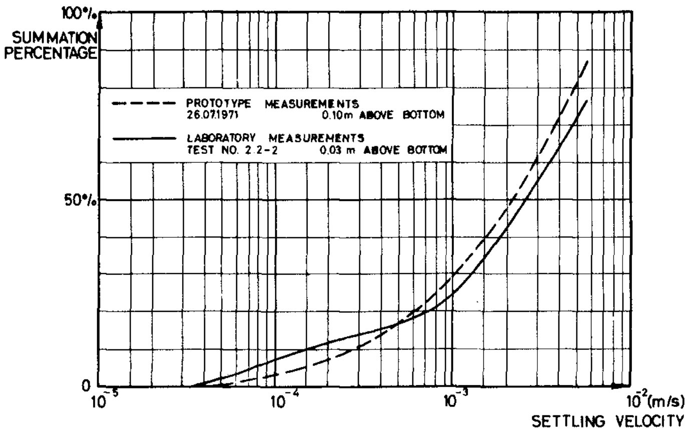

Fig. 3 - Settling velocity distributions

The agreement between the calculated profile, shown by a solid curve in figure 2, and the averages of measured sediment concentration is demonstrated by the following table:

Height above bottom	Concentrations measured	Concentrations calculated
5.5 m	0.122 g/l	0.12 g/l
2.4 m	0.154 g/l	0.15 g/l
0.9 m	0.238 g/l	0.20 g/l
0.3 m	0.265 g/l	0.265g/l
0.1 m	0.282 g/l	0.40 g/l

Except for the level closest to the bottom, the agreement appears to be very good. Close to the bottom, however, the measurements show considerably higher sediment concentration than the calculated profile.

The most likely explanation of this discrepancy is that the frame does not fulfil the requirement of being a fixed reference system, but sinks a little into the bed, so that the lowermost nozzle is, in fact nearer to the bottom than assumed. This explanation is supported by the fact that in many cases the concentration close to the bed increased with time after placing the frame on the bed. Another explanation could be the existence of bed undulations of a size comparable to the size of the frame.

Sometimes during the samplings very sudden, bursts of exceptionally high concentration were observed. This could be the effect of eddies separated from the bottom, either associated with the orbital movements or with scouring around the feet of the frame.

5. LABORATORY MEASUREMENTS

In nature it appears to be very difficult to obtain sufficiently accurate results close to the sea bed, as appears from the concentrations obtained at the 0.1 m level. Therefore, supplementary tests were carried out in the Institute's oscillating water tunnel. In this device orbital motions of the water particles near the bed, as generated by regular waves can be reproduced to the scale 1:1.

A number of tests at various periods and amplitudes were performed on bottom material recovered from the site. A concentration profile obtained in the water tunnel at conditions similar to the prototype condition is presented in figure 2.

Figure 3 shows settling velocity distributions of suspended sediment samples taken close to the bottom as determined from samples taken in the laboratory as well as the field.

For comparison of conditions in the oscillating water tunnel and in the nature it has been assumed that the height of regular waves creating the orbital motion simulated in the water tunnel corresponds to the RMS wave height of the prototype wave train.

In figure 2 the wave conditions are represented by the parameter u^3, as the data both from the prototype and from laboratory measurements suggested a proportionality between the concentration near the bed and u^3. The validity of this relationship could, however, not be satisfactorily confirmed on the basis of the present measurements.

6. CONCLUSIONS

The following conclusions may be drawn from the work described in this paper:

1. The field measuring procedure used is satisfactory at levels not too close to the bottom (from 0.3 m and upwards). However, improvements are required in order to obtain reliable field data closer to the bottom than 0.3 m. The procedure described appears to be satisfactory in principle, when the transported sediments are predominantly silt and finer grains.

2. In a combination of waves and currents the concentration profile may be divided in an upper part where the characteristics of the current determine the profile, and a boundary layer, in which the wave motion determines the rate of pick-up of sediments from the bottom. The boundary layer in this respect is not well defined, and further investigations in this region are urgently required.

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