CHAPTER 120

IOWA SEDIMENT CONCENTRATION MEASURING SYSTEM

by

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I. INTRODUCTION

The Iowa Sediment Concentration Measuring System (ISCMS) is an electro-optical instrument developed in 1969 (Glover, Bhattacharya, and Kennedy 1969) for measurement of suspended solid concentrations in unsteady solid-liquid flows. It has been used extensively in laboratory investigations to determine spatial and temporal variations of sediment concentration in a variety of steady, unsteady, uniform, and nonuniform flows (Bhattacharya 1971; Danushkodi 1974). Concurrent measurements of concentration and velocity fluctuations have been used together to obtain estimates of mass transfers in unsteady sediment-laden flows, with the goal of improving the understanding of the underlying mechanisms responsible for sediment entrainment and suspension (Nakato 1974). Interpretation of the data gathered in these experiments pointed out the need for a more thorough understanding of how the optical and electronic components of the ISCMS respond to the passage of individual sediment particles through the optical field of the transducer (Locher *et al.* 1974). An investigation was undertaken to determine the sensitivity of the ISCMS output to the position of a particle in the transducer field; the role of particle velocity in determining the ISCMS output; the effects of particle translucency and size on the output of the system; and the dependency of mean concentration estimates on integration time.

II. THE ISCMS PROBE FIELD

The transducer consists of a 1.55-mm diameter light source (P-N gallium arsenide, type TIL 24) and sensor (NPN planar silicon phototransistor, type TIL 604) separated by a distance of about 3.2 mm with their optical axes co-aligned, as shown in figure 1. Light from the source is attenuated by particles in the probe's optical field and the modulated light signal is transduced to an output voltage by the sensor and electronic circuits. Calculation of the average number of particles present in the transducer field in some wave-induced sediment entrainment studies at The University of Iowa demonstrated that often only one or two particles are present in the field, and highlighted the importance of knowing the effects of particle position and residence time in the space between the source and sensor on the system output.

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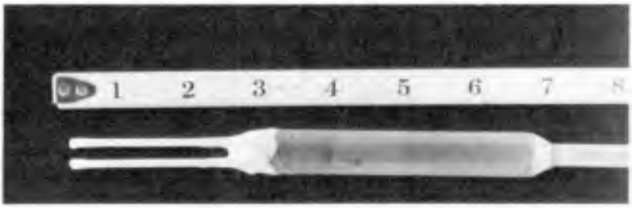

Figure 1. The ISCMS probe.

To investigate the ISCMS sensitivity to particle position, "artificial particles" were made by spattering India ink on a glass slide and then selecting several ink spots with the desired size and shape for detailed investigation. This approach was adopted because there is no means of supporting single glass bead or sand particle within the probe field without introducing additional refraction of the light. The slide with simulated particles was mounted on a microscope traversing mechanism, the ink spots were positioned at various locations along the optical axis of the source-sensor pair, and the corresponding ISCMS outputs were monitored. The results of tests with circular spots with diameters of 0.38, 0.25, and 0.12 mm are summarized in figure 2, in which the system output voltage normalized by the voltage obtained with the particle adjacent to the sensor is plotted versus spot distance from the sensor. It is seen that the ISCMS output voltage initially rises sharply with increasing distance, obtains a peak value at about 1.0 mm from the sensor, and then trails off monotonically until the spot is adjacent to the source where the output is only 50-60 percent as great as when it is adjacent to the sensor. In other words, the ISCMS response is strongly dependent on the position of the particle when traversed on the optical axis within the transducer field.

Tests also were conducted to ascertain the effect of the radial position of a "particle" in the probe field on the system response. These were realized by traversing a spot radially across the probe field in planes that were perpendicular to the optical axes and located at various distances from the sensor. The typical set of results shown in figure 3 depicts the variation in the ISCMS response as the 0.38 mm spot was traversed radially at several sections between the source and sensor. Note that the ISCMS output voltage for each location was normalized with the reading obtained with the particle adjacent to the sensor. These results show that the ISCMS output voltage varies continuously as the particle is moved radially through the optical field. It was found that the diameters of circular cylinders within which the normalized voltage is larger than approximately 0.5 are 0.6 and 1.0 mm for the 0.25 and 0.38 mm particles, respectively. The physical diameter of the source and sensor is 1.55 mm; therefore a substantial portion of the cross-sectional area of the probe field is not highly effective in sensing the particle.

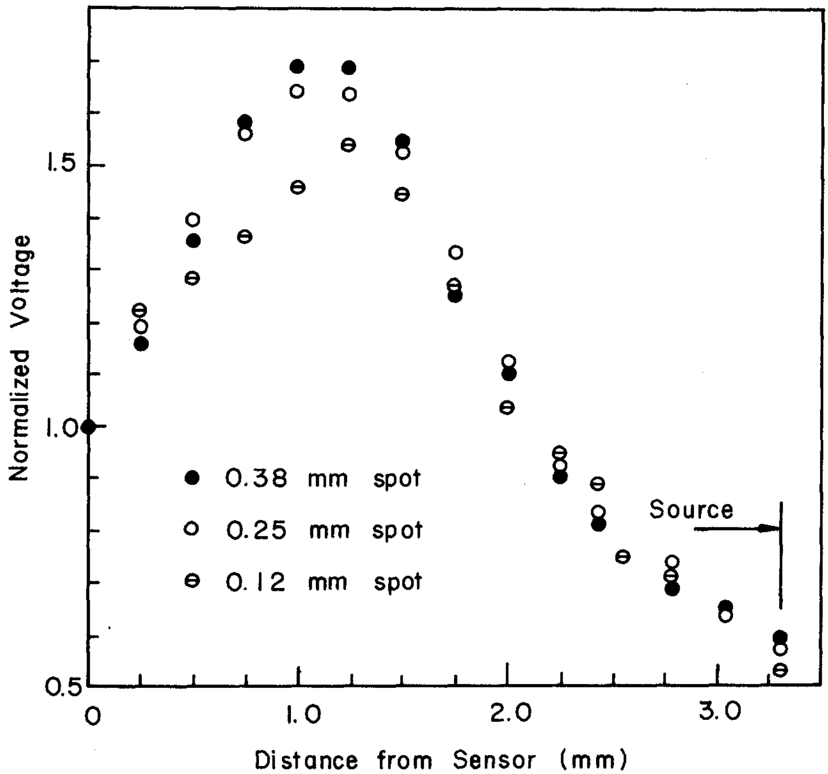

Figure 2. Variation of the ISCMS output for three "artificial particles" traversed along the optical axis of the transducer.

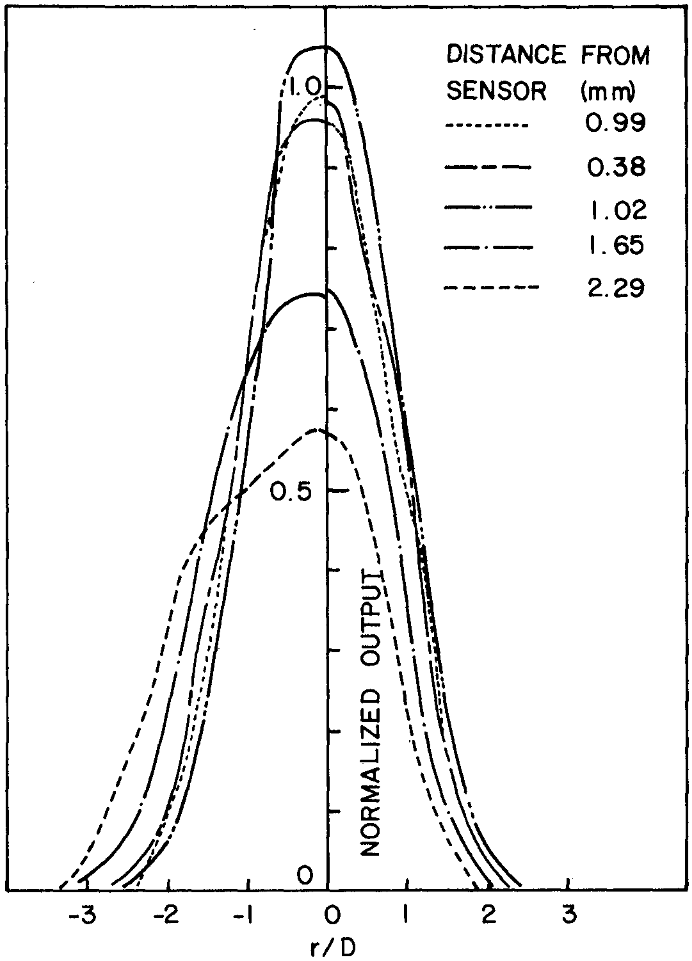

Figure 3. Variation of the ISCMS output along the radial axis of the transducer for the 0.38 mm "artificial particle".

The effects of particle velocity on the ISCMS response were investigated by passing a field of simulated particles through the transducer's sensing volume at different speeds. The "particle field" consisted of 120 0.127-mm diameter drilled holes equally spaced around the periphery of an 8.89-cm diameter circle on a lucite disk. The disk was rotated at various angular speeds about the center of the particle circle, with the simulated particles crossing the optical axis of the source-sensor pair. The rms of the ISCMS output voltage was recorded for several different angular speeds of the disk. The rms output voltages were normalized by the rms voltage obtained at a frequency of 100 particles per second or less; the results from several repetitions are plotted on figure 4. It is seen that there is no attenuation of the amplitude of the ISCMS voltage for frequencies under 100 Hz, but at higher speeds the signal is progressively diminished. This indicates that the upper limit of particle speed for which the instrument is able to measure the concentration corresponding to the passage of an individual particle through the transducer's field is approximately 23 cm/s. However, at a particle speed of 46 cm/s, the normalized rms voltage of the ISCMS output was reduced by only about 8 percent.

III. EVALUATION OF MEAN CONCENTRATION OF SUSPENDED SEDIMENT

To evaluate the effects of particle translucency on the ISCMS output, mean sediment concentrations were measured in suspensions of three different sediments: two quartz sands and crushed walnut shells with median diameters of 0.14, 0.25, and 0.20 mm, respectively. The specific weights of the two materials were 2.65 and 1.33 g/cm^3. These tests were conducted in a turbulence jar, in which each sediment was held in suspension in water by means of vertically oscillating grids. During calibrations, samples were withdrawn to obtain reference values of concentration, and the ISCMS output was recorded with the probe at several different elevations. The test results are plotted in figure 5 with $\Delta V/V_o$ presented as a function of $\bar{C}/\gamma D$, where ΔV is the net ISCMS output voltage; V_o is the output voltage with the light sensor shielded from the source light (approximately 12 volts); $\bar{C}$ is the measured mean concentration in ppm; D is the median diameter of the sediment; and γ is the specific weight of the sediment. It is seen in figure 5 that the calibration curves for the three samples are linear, and the data from the two quartz sands plot almost congruently. However, the slope of the calibration curve for the walnut shells is much larger than that for the quartz sands. This difference was attributed to variations in the opaqueness of the two materials. The walnut shells are less translucent than the quartz sand, and therefore produce stronger attenuation of the transmitted light and larger ISCMS output voltages. During the calibration, photographs of the ISCMS signals for each sample were obtained and their signal characteristics were compared. The results showed that there are far more voltage readings below the zero reference for the quartz sands than for the walnut shells. This effect is the results of light being reflected off the surface of the quartz particles into the sensor as the particle enters or leaves the probe field. The crushed walnut-shell surface does not reflect light as well as the quartz sand, and therefore drops below the reference voltage level were not so prominent. These negative voltages indicate light intensities above the ambient light

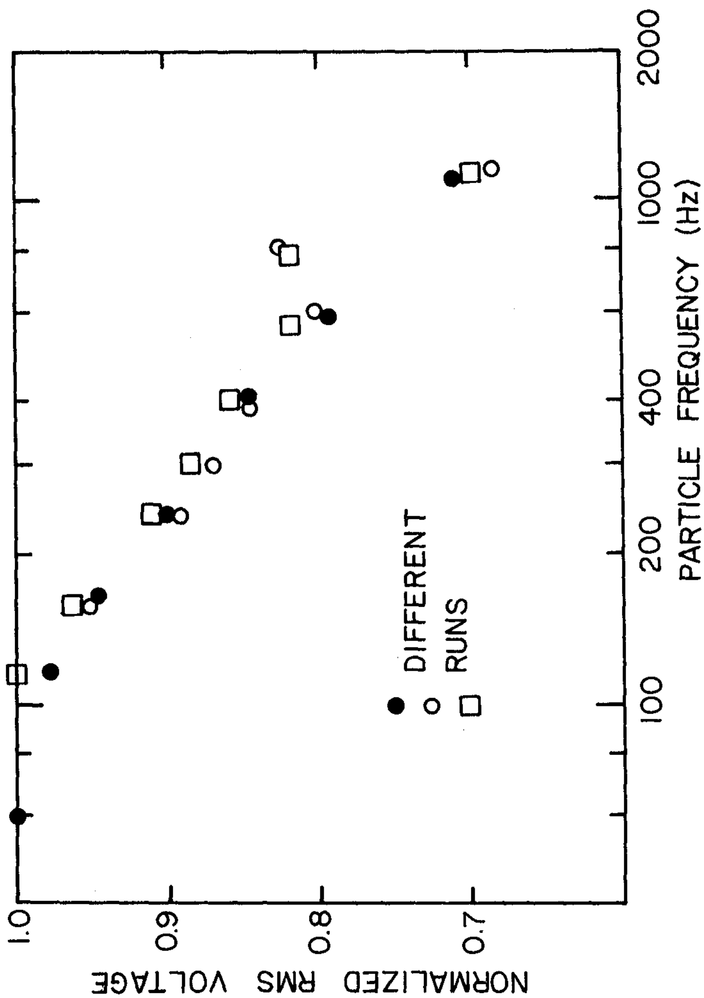

Figure 4. Attenuation of rms voltage as a function of particle frequency (rotating disk test).

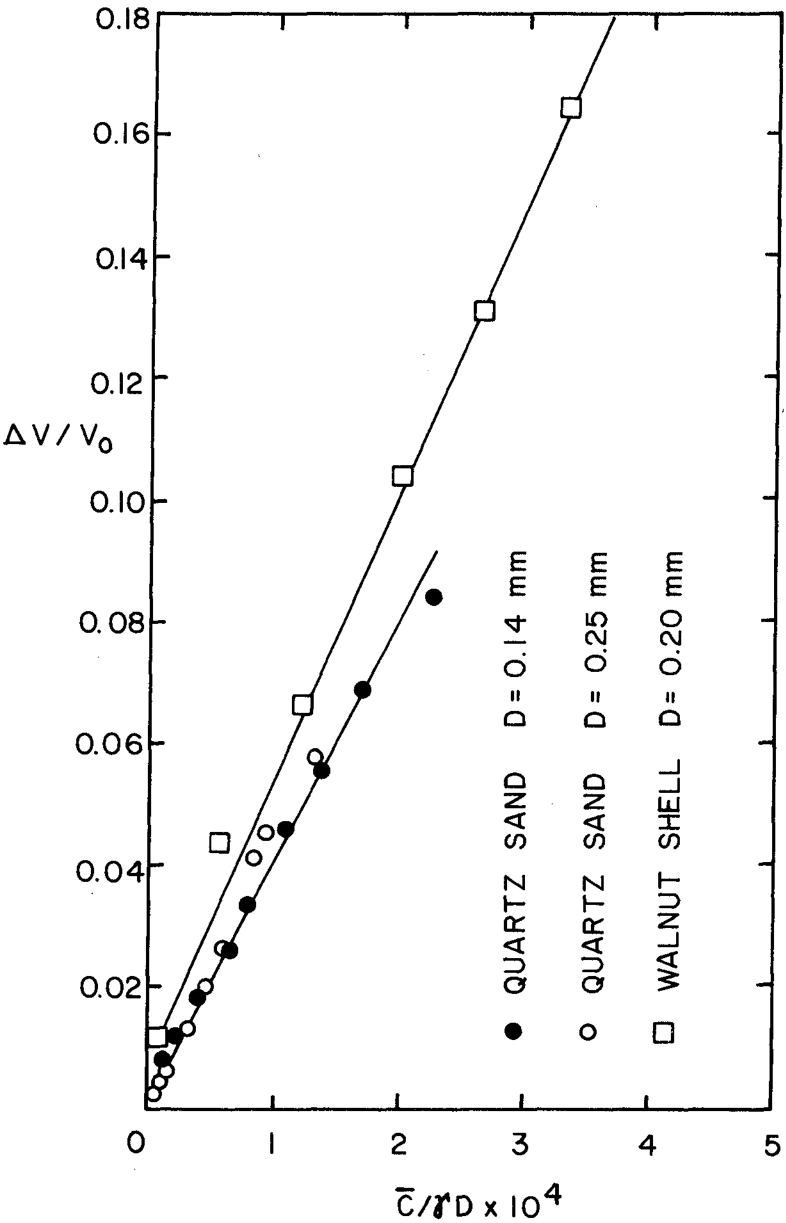

Figure 5. Calibration curve expressing $\Delta V/V_o$ as a function of $\bar{C}/\gamma D$ for quartz sand and walnut shells.

level with no particle in the probe field; therefore these negative voltages have to be discarded through a single polarity integrator in the instrument. The principal conclusion from this phase of the investigation was that the ISCMS must be calibrated for each different sediment material.

Tests to ascertain the sensitivity of the ISCMS to particle idameter also were conducted in the turbulence jar using four different glass beads with median diameters of 0.029, 0.062, 0.100, and 0.200 mm. Calibration data for the four samples are plotted in figure 6. The calibration curves are seen to be linear over the range of concentrations tested: 400 to 16,000 ppm. However, the slopes of the calibration curves are dependent on the diameter, with values of 3.62, 4.87, 7.96, and 12.35 ppm/mV, for the 0.029, 0.062, 0.100, and 0.200 mm beads, respectively. This dependency of calibration-curve slope on particle diameter can be explained as follows. For a fixed concentration, the number of particle present in the sensing volume of the probe increases with reduction in particle diameter. In the case of the finer sediments, some particles hide in the shadows of others, and are not detected by the light sensor. Therefore, at high concentrations the actual particle concentration in the probe field is higher than that indicated by the output.

Tests also were conducted in the turbulence jar to determine the effect of integration time on the measured estimate of mean sediment concentration for the two quartz sands and the walnut shells described above. A series of 200 sequential 10-sec averages of the ISCMS output voltage were obtained for each of these sediments at low, medium, and high mean concentrations ranging from 360 to 11,000 ppm. Successive 10-sec averages were combined to form sets of 20-sec and 50-sec averages, and the effects of averaging time of the confidence intervals of the mean concentration estimates were examined. It was found that increasing the averaging time above 10-sec does not have an appreciable effect on the confidence interval of the mean-concentration estiamtes. Similar tests also were made in the Iowa Oscillatory-Flow Water Tunnel (Nakato 1974; Locher *et al.* 1974). In these tests a signal-averaging technique (Trimble 1968) was employed to decompose the analog concentration signal into its mean, periodic, and random components. Although the ISCMS response is dependent on the position of the sediment particle in the probe's sensing volume, for a completely random sediment motion the trajectories along which the particles traverse the field tend to be uniformly distributed over the sensing volume. Therefore, the effect of particle position on probe response described above averages out over time, and the signal-averaged measurements of $\bar{C} + C_p$, where $\bar{C}$ and C_p are respectively, the mean and periodic components of the sediment concentration, were judged to be accurate. The period of the oscillatory fluid motion, T, over the 0.14 mm quartz sand bed was 1.8 sec, and the piston stroke was 15.2 cm. The ripples produced on the bed had a mean wavelength of 8.5 cm and a mean height of 1.2 cm. With the probe over the ripple crest, data from 200 wave cycles were obtained, with a sampling interval of 18 milliseconds, and analyzed in groups of 20, 50, and 100 wave cycles. The value of $\bar{C}$ for the data from 200 wave cycles was 3,094 ppm, while the mean concentrations for the data from the first and second 100 cycles were 3,096 and 3,092 ppm, respectively. The values of $\bar{C} + C_p$

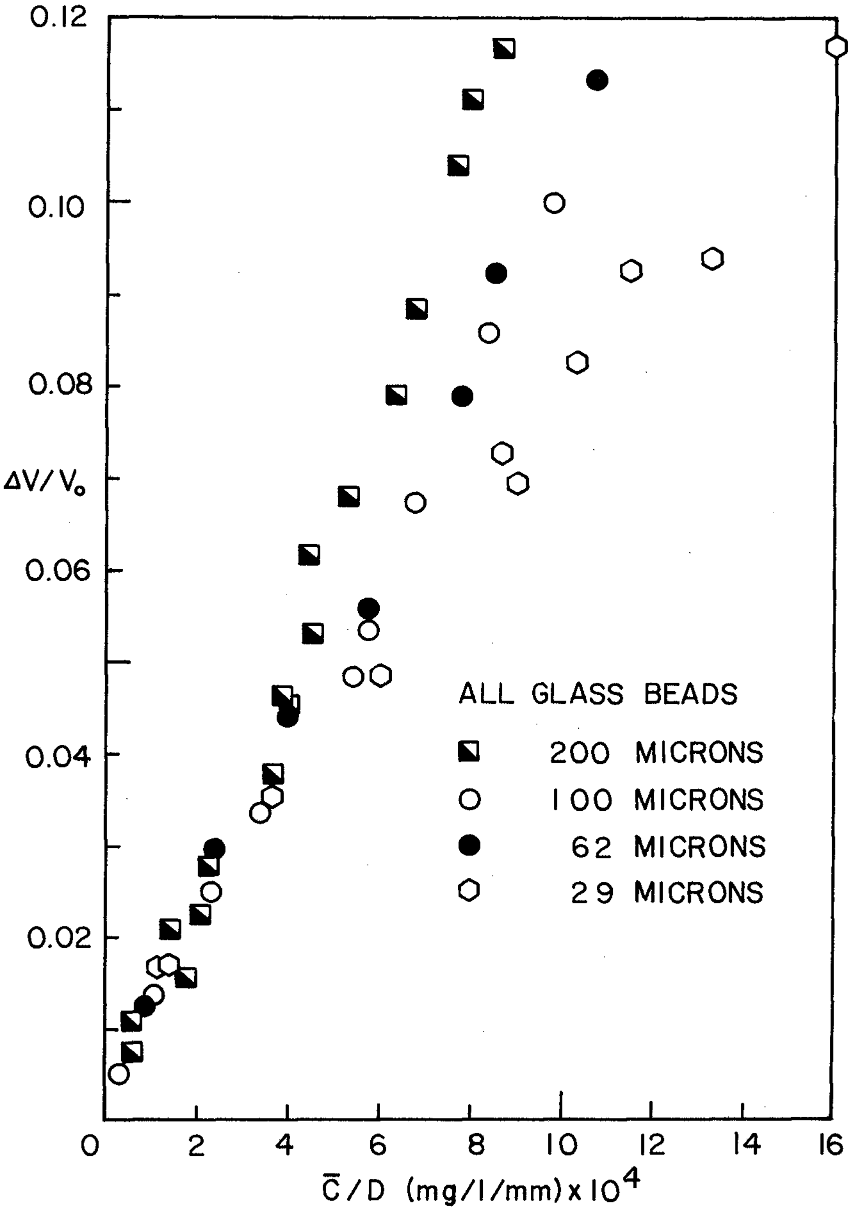

Figure 6. Calibration curve expressing $\Delta V/V_o$ as a function of $\bar{C}/D$ for glass beads.

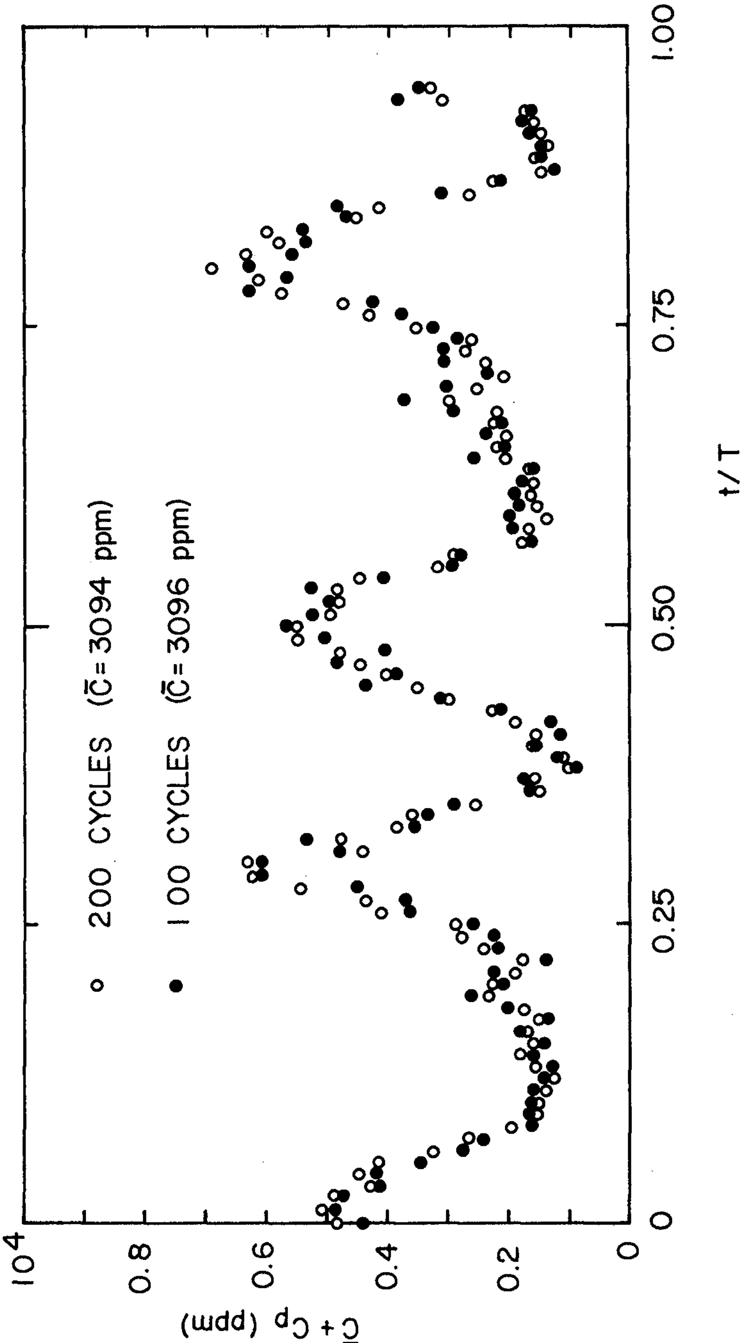

Figure 7. Comparison of estimates of $\bar{C} + C_p$ with 100- and 200-cycle wave data.

calculated from the set of 200-cycle data and the first 100-cycle data are plotted in figure 7. It is seen that there is not much difference in the estimates of $\bar{C} + C_p$ between two sets of data. However, the mean concentrations as well as the periodic components C_p obtained from the sets of 50- and 20-cycle data varied somewhat from that yielded by the 100-cycle data sets. The variations in the $\bar{C}$ estimates were found to be between 2,867 ppm and 3,317 ppm, and 2,746 ppm and 3,521 ppm for the 50- and 20-cycle data, respectively. The plots of $\bar{C}$ and C_p values from the 50- and 20-cycle data also were found to scatter much more widely than those of 100-cycle data. It was concluded, therefore, that at least 100 wave cycles of data are necessary to obtain meaningful estimates of the mean and periodic components of sediment concentration in the suspended sediment field produced by oscillatory motion over a rippled sand bed investigated in this study.

IV. SUMMARY OF RESULTS

The principal results of this investigation may be summarized as follows:

1. The ISCMS response to the single particle depends strongly on the particle position within the probe field. Therefore, the instantaneous output voltage of the ISCMS cannot be correlated with the instantaneous suspended sediment concentration within the probe position.

2. The frequency response of the instrument limits the use of the ISCMS to flows with mean velocities less than approximately 23 cm/s. At a particle velocity of 46 cm/s the rms output is down approximately 8 percent.

3. The ISCMS output voltage varies linearly with mean sediment concentration. However a separate calibration must be obtained for each sediment.

4. An integration time of at least 10 seconds is necessary to obtain reliable estimates of mean sediment concentration when calibrating the ISCMS probe in a turbulent jar. This appears to be a reasonable lower time limit also when the ISCMS is used in steady uniform flows.

5. Approximately 100-cycle wave data are sufficient to obtain quantitative estimates of $\bar{C} + C_p$ in the oscillatory flume used in the present study.

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