VARIATION OF THE CHARACTERISTICS OF DELTAIC AND STREAM BED DEPOSITS IN LABORATORY STUDIES

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ABSTRACT

This paper discusses the major processes that influence the distribution and characteristics of sedimentary deposits in deltaic systems (stream channel and delta). The distributions of the sediment sizes in the sedimentary deposits in several laboratory deltaic systems formed under steady-state conditions were determined. Statistical moments of the sediment size distribution were calculated and some explanations of their characteristics are given. Two size ranges of cohesionless sediments were used, along with several water discharges. The laboratory deltas were characterized by the classical top-, fore-, and bottom-set beds. Two- and three-dimensional deltas were analyzed and the relationships between the two are discussed. This paper should be of particular interest to the hydrologist, hydraulic engineer and sedimentologist whose interests include flow conditions that can be associated with a sedimentary deposit, rate of deposition in reservoirs, water resources development and sediment yield from rivers and river systems.

1/ Contribution from the Colorado Agricultural Experiment Station and the Northern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, Fort Collins, Colorado.

2/ Graduate Research Assistant, Civil Engineering Department, Colorado State University.

3/ Research Agricultural Engineer, USDA, Agricultural Research Service, Soil and Water Conservation Research Division.

4/ Professor of Civil Engineering and Associate Dean for Research, College of Engineering, Colorado State University.

Introduction

Most depositional processes are complex, involving the interaction of many variables and the simultaneous variation of all or most of them. These depositional processes cause a variation in the characteristics of delta and stream bed deposits. It is often desirable to relate depositional processes with deposit characteristics for which deposition has ceased. To do this, it is necessary to determine the characteristics of the deposit that can be associated with a set of depositional processes and to understand how a change in the depositional processes influences the characteristics of the deposit.

Objectives of the Study

The majority of the past studies on this subject has been two-dimensional and has emphasized the relation of laminae shape to the depositional processes. More realistic results can be obtained from a three-dimensional study. A better understanding of how the sediment sizes are distributed can aid in describing the flow conditions that existed when deposition occurred.

Hence the objectives are:

(1) to present the major conceptual processes that control the distribution of the sediments in the laboratory model;

(2) to present data collected from the laboratory model verifying the major conceptual processes;

(3) to determine to what extent a change in one of the processes influences the deposit characteristics.

Scope of the Study

The laboratory deltas were formed under steady-state conditions, i.e., the quantity and size of the sediment supplied, the discharge of water supplied at the head of the approach channel, and the level of the water in the stilling basin were held constant. The deltas were characterized by the classical top-, fore-, and bottom-set structures.

The several runs are summarized in Table 1. A schematic of the experimental equipment is shown in Figure 1. The flume is 30.5 m long, 7.32 m wide, and 0.61 m deep. The size distributions of the two cohesionless sediments that were used are shown in Figure 2.

Processes Acting in Laboratory Deltaic System

The processes that influence the distribution of sediment sizes in this laboratory deltaic system may be divided into three major groups: (1) those acting in the channel, (2) those acting on the delta surface, and (3) those acting on the foreset of the delta.

(1) Processes Acting in the Channel

In the natural streams, the average particle size normally decreases in the downstream direction as the result of hydraulic sorting and abrasion. This was not noted in this study, probably because of the short flume. The hydraulic measurements indicated that the flow was statistically uniform throughout the length of the rigid channel. Therefore, the power of the stream to move a certain size particle remained essentially constant. The region of gradually varied flow that existed over the horizontal beds on the delta did cause a noticeable reduction in the mean size in the downstream direction.

The size distribution of samples in the deltaic system depend largely on the aggradational and degradational history of the stream. With an aggrading stream, sediment introduced at the head of the channel will be deposited either on the channel bed, in the delta cross section, or on the

TABLE 1

SUMMARIZATION OF THE RUNS

Run No.	Run Time	Q_w	Q_s	Sand No.	Average Channel Slope $\times 10^3$	Delta Height	Average Depth of Flow	Average Channel Vel.	F $\frac{\bar{U}}{\sqrt{g\bar{D}}}$	R $\frac{\bar{U}\,\bar{D}}{\nu}$	Rigid Channel Length	Sand Bed Length
	Hr.	$\frac{\text{Liters}}{\text{sec}}$	$\frac{\text{gm}}{\text{sec}}$	-	-	cm	cm	$\frac{\text{cm}}{\text{sec}}$	-	-	m	m
1												
2	91.0	5.00	7.4	1	-	41.08	-	-	-	-	-	17.80
3d												
4	101.8	.50	.31	1	-	102.00	2.34	42.1	0.88	11,600	3.05^{c}	3.05^{c}
5												
10	652.7	4.00	3.20^{a}	1	3.70	41.08	2.32	44.9	0.94	12,100	16.90	17.60
10b	288.7	5.00	3.20^{a}	1	-	41.08	2.32	44.9	0.94	12,100	16.90	17.60
17	47.8	6.31	8.8	1	5.20	7.36	2.44	53.8	1.10	15,200	16.20	16.20
17b	186.0	6.31	0.0	1	-	7.36	2.81	46.7	0.89	15,200	16.20	16.20
20	205.0	6.31	2.5	2	2.78	9.76	2.76	47.6	0.91	15,200	16.20	16.20
20a	57.2	6.31	5.0	2	3.86^{b}	9.76	2.56^{b}	51.3	1.02^{b}	15,200	16.20	16.20
20b	36.8	6.31	2.5	2	3.21^{b}	9.76	2.75^{b}	47.8	0.92^{b}	15,200	16.20	16.20
30	37.2	6.31	8.8	1	4.97	40.15	2.45	53.7	1.10	15,200	16.20	16.20

a -- average value b -- final value c -- initial channel length d -- narrow flume

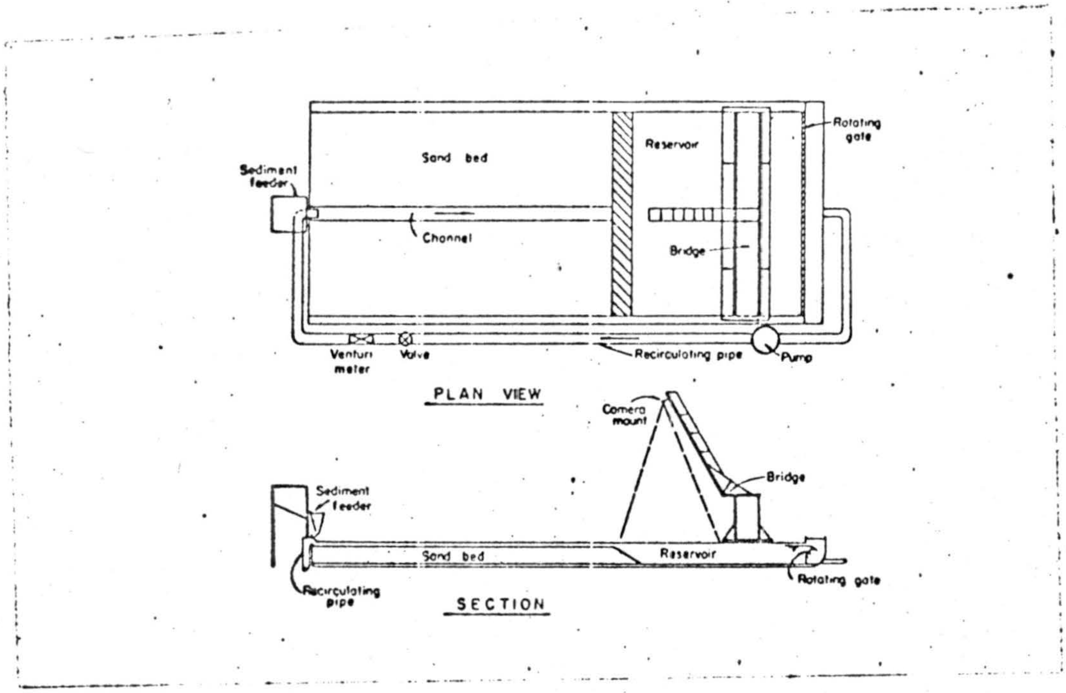

Figure 1. -- Schematic of experimental equipment.

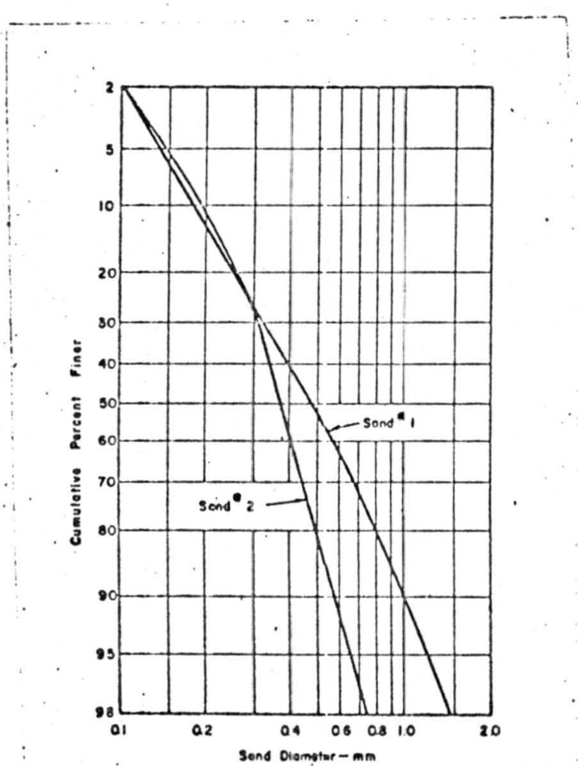

Figure 2. -- Size distribution of experimental sediments.

basin bottom. With a degrading stream, the sediment that is introduced will pass through the channel and additional material will be picked up from the bed. The two materials mix and both are deposited in the delta cross section or on the basin bottom. A certain amount of exchange of particles between the material in the bed and the material being transported can be expected with both aggradation and degradation.

The secondary currents, which result from the flow around alternate bars that form in channels with high width-depth ratios as were used in this study, cause a variation in the average sizes across the width of the channel. The boundary shear and the stream power decrease over the bar and are at their lowest values next to the wall. The smaller particles are picked up from the bars and are redeposited downstream. The larger particles are left in position near the wall to be eroded away after the bar moves downstream. Most of the movement of the sediment was in the form of bed load or saltation load. Actual measurements of the flow distribution around these alternate bars were not included as a part of this study.

(2) Process Acting on the Delta Surface

The processes that act on the sediments on the delta surface depend directly on the position of the channel. There are three major idealized paths possible: (1) straight, (2) split, and (3) curved.

A straight channel is simply an extension of the natural channel. On the delta there is a change in the cross section and a widening of the channel. This causes the alternate bars to flatten and spread out. It could, therefore, be expected that in a straight channel, the alternate bars would reach the lip of the delta with the same lateral distribution, but with a reduced average size.

A split channel exists on a delta surface for a short time after an avulsion (Riesen and Kuiper, 1955) has taken place. The older straight channel, being less efficient than the newer curved channel, soon fills with sediment. The division of the sediment between the two channels varies with the geometry, hydraulic and sediment variables of each channel.

When the alternate bars enter the sharp bend of the curved channel, the sediments are forced to the inside of the bend and are redistributed. The curved flow also erodes the outside of the bend and these sediments are carried to the inside of the bend or to the next crossing. The outside of the bend continues to erode until the channel is once again straight. This results in a mixing of two sediments with possibly different size characteristics. However, as the degree of curvature of the bend is reduced to a certain value, the alternate bars are no longer washed out by the vortical flow, but pass through the bend relatively unaffected. Because of this, the amount of mixing of the two sediments is probably a function of the degree of curvature of the bend.

(3) Processes Acting on the Foreset

As the sand bars reach the lip of the delta, the particles, because of the relatively low velocity, accumulate at the top of the foreset. The accumulation forms, in elevation, a wedge-shaped structure. When the angle of the front slope of the wedge structure exceeds the angle of internal friction, the wedge fails and the grains slip down the foreset. During this slip, the larger grains are pushed to the surface and because of the larger inertia effect slide further down the slope.

The distribution of grain sizes across the width of the channel causes different size particles to be deposited in these wedge structures in a single cross-section (parallel to the rigid channel) because of the sweeping of the jet. This results in a definite pattern of particle size variation in the horizontal direction of the cross-section for each depositional period. The depositional periods of a cross-section are those periods during which the sweeping channel is depositing sediments along the cross-section. Figure 3 shows that the assumed theoretical shape for the mean size in ϕ units (Krumbein 1936) increases along a length of the center line of the delta. Also shown are the average mean sizes of samples taken from several verticals in each of the depositional periods. The exact distribution curves were not determined because only a limited amount of data was collected. However, the limited data show a general agreement with the assumed theoretical curve.

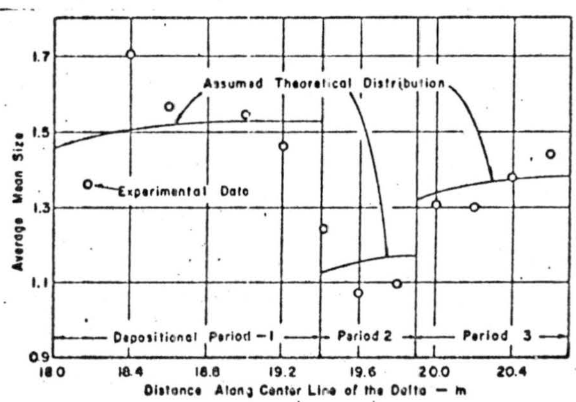

Figure 3. -- Variation of the average mean size in the vertical with distance along the center line of the delta.

Discussion of the Results

The characteristics of the final response are affected by different sets of processes. A change in the set of processes studied can be made most easily by changing the delta height. As the height is increased, a single slide may not reach the bottom. The material will be deposited along the slope and a wedge-shaped structure will form on the foreset that will eventually slide. More of these failures are possible with increasing height. If the delta is extremely thin the flow of particles will be stopped by the bottom of the basin before the slide is completed.

The results of this study on the influence of the change in the delta height have been divided into two major sections: (1) the relationships, for various delta heights, of the first four graphical statistical moments that were computed for each sample with the equations suggested by Folk and Ward (1957); and (2) the vertical distribution of the sediments in sizes in the delta cross-section. A total of 546 samples were analyzed from the several deltas that were all deposited under aggrading conditions.

(1) Relationships of the Graphical Statistical Moments

Plots of the standard deviation, skewness, and kurtosis as functions of the mean size for each of the runs have been summarized in Figures 4, 5 and 6 (Reid, 1967). All the moments are for the ϕ size distribution. Close examination of these figures reveals several relationships.

As the height of the delta varies, the curves shift position. The plot of the standard deviation against mean size, Figure 4, shows that as the height of the delta is decreased, the standard deviation against mean size, Figure 4, shows that as the height of the delta is decreased, the standard deviation for a given mean size increases. As the height is decreased, the length of the foreset, over which the sorting can take place by the sliding, is reduced, thus, there is an increase in the range of sizes in any sample. The plots of skewness and kurtosis as a function of mean size, Figure 5 and

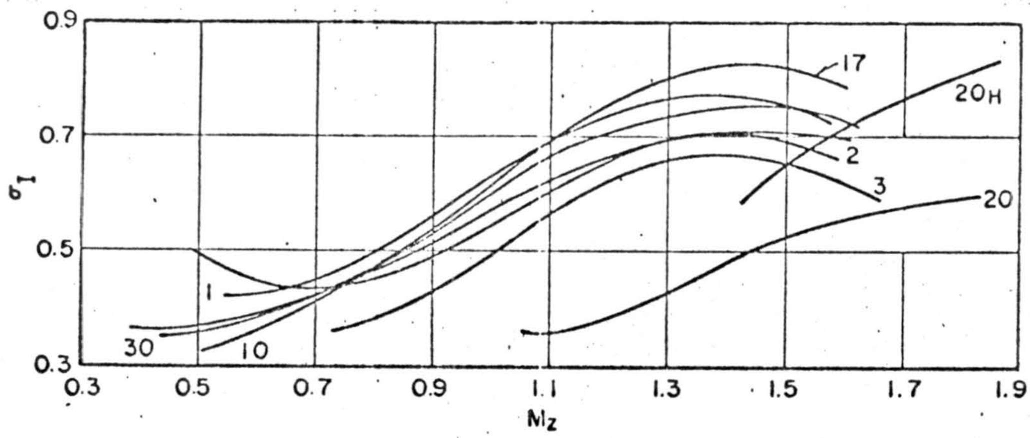

Figure 4. -- Standard Deviation as a function of Mean Size.

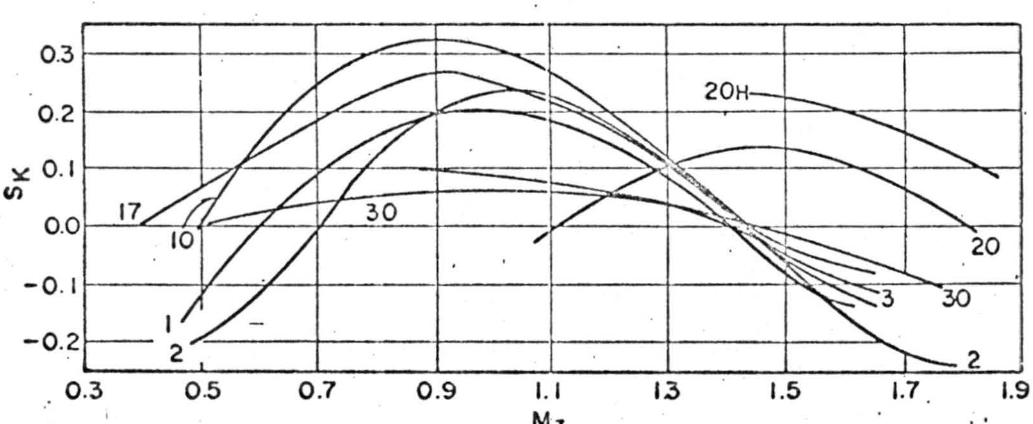

Figure 5. -- Skewness, as a function of Mean Size.

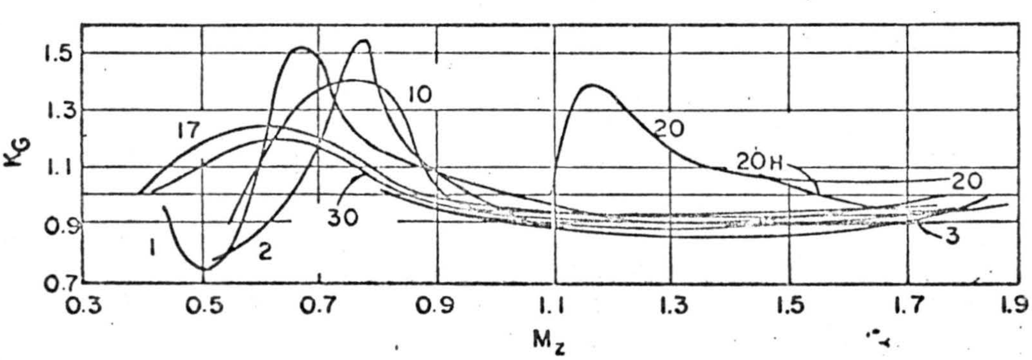

Figure 6. -- Kurtosis as a function of Mean Size.

Figure 6, respectively, show similar trends, but they are not as consistent as the standard deviation against mean size. The exception is Run 17 where the peak appears to drop; however, data in this region may not completely define the curve. The period for all the curves appears to be relatively constant. This would be expected because the modes of the material being introduced should not change appreciably.

Runs 1, 2, 10 and 30 were with the same height of delta, but there were some differences in the runs or in the location of the samples which appear to be reflected in the curves. Runs 1 and 2 were from the same delta. Data for Run 2 were taken along the centerline of the delta, and those for Run 1 were taken parallel to, but at a distance of 1.15 m from, the centerline. For a given mean size, the standard deviation for Run 1 is greater than for Run 2. The samples in Run 1 were deposited under curved flow conditions. The mixing action associated with curved flow could cause a greater range of sizes in any sample. There does not appear to be a significant increase in the amplitude of the curves of skewness and kurtosis as a function of mean size. Runs 1 and 2 were the most complex of the group, having both an unconfined channel and delta. Run 30 was an extra wide two-dimensional model with straight flow. Remarkably close agreement between the plots of standard deviations as a function of mean size was obtained for Run 2 and Run 30. These two sets of samples came from the centerline of the two deltas. For Run 30, the amplitudes of the skewness and kurtosis curves as a function of mean size are significantly reduced as compared with those of a three-dimensional model. These changes can probably be explained by the more confined flow condition of the two-dimensional model.

Run 20 was performed with the smaller material, which accounts for the shift in the curves to the larger mean sizes. Samples were taken from the cross-bedding of the delta (curve 20) and from the horizontal bed that was deposited on the crossbedding (curve Run 20H). The average mean size of the bed material from the horizontal bed is larger than the average mean size from the cross-bedding. It is normally thought that the larger particles will be deposited in the channel first. This would mean a smaller mean size of bed material in the channel and in the horizontal bedding than in the cross-bedding, but this is opposite from what was found. From a study of the gradation curve, the maximum size of bed material in the top layers of the horizontal bed was as large as that in the cross-bedding. The samples from the horizontal bed had a greater and more positive skewness (tail caused by fine sediment) than those in the cross-bedding. This resulted from the smaller particles hiding behind and between the larger particles. Also, the horizontal bed samples had not been subjected to the sorting process associated with the sliding of particles down the foreset.

(2) Vertical Size Distribution

The sorting process associated with the sliding of particles down the foreset results in a vertical size distribution change in the statistical moments. The slides in this study may be thought of as small-scale turbidity currents. Scheidegger and Potter (1965) suggested that for turbidity currents the curve of particle size as a function of depth may be concave upward, uniform, or convex upward with the larger particles at the bottom. In this study, concave upward curves were obtained for thick deltas and convex upward curves were obtained for thin deltas. Scheidegger and Potter obtained the same results in their work. Apparently, the curve changes from concave to convex as the thickness of a deposit increases, and the curve would be uniform at some particular thickness.

Conclusions

The following general conclusions may be drawn:

(a) Three-dimensional models provide much better conditions for studying internal structure of sedimentary deposits than two-dimensional models.

(b) There is a cyclic change in particle size along a given cross-section during a depositional period. This cyclic change depends on the lateral distribution of the sediments in the channel.

(c) The curves of standard deviation, skewness, and kurtosis as a function of mean size fit the shape of the theoretical curves suggested by Folk and Ward (1957) quite well. The period of the curves appears to be constant. The amplitude varies as a function of delta geometry and location of samples; increases as the height of the delta decreases or as the distance from the centerline increases.

(d) A two-dimensional model cannot, in general, be used to determine the relationships of the statistical parameters for samples from three-dimensional models. The only exception is that the standard deviation, as a function of the mean size for the centerline of a delta, may be determined in a two-dimensional model.

(e) The particles increase in size down the foreset under the flow conditions studies. The curves of grain size as a function of depth may be concave upward, uniform, or convex upward. The curves change from concave upward to convex upward at the height of the delta is increased.

In summary, minor changes in the flow process are reflected by changes in the characteristics of the size distribution of the sediments. These minor changes are detectable with the present method of measurement and analysis. This means that the sediment size distribution of samples from a delta cross-section, with additional refinement, can be used as a factor in estimating flow conditions associated with ancient deposits.

Practical Application

When developing a reservoir, it is necessary to determine the rate at which the sediment will accumulate in the reservoir. The sediment discharge is normally measured on the larger streams and the rate of accumulation can be determined. On the smaller streams where stock watering ponds, small reservoirs, and flow retention structures are often built, the sediment discharge is not available and other means of estimating the rate of accumulation must be used.

Based on the results of this study, one procedure would be to determine the relationship of sediment yield to various combinations of hydrologic, watershed, and channel conditions. The volume of sediment discharged from each event could be determined by examining the internal structure of the deltaic system. This required that the relationships between the flow conditions and the internal structure be known. These relationships could be determined from controlled laboratory studies for steady and unsteady flow, fluctuating basin level, and other variables. Then, controlled detailed studies in which the important variables that influence the rate of erosion and sediment accumulation are measured, should be performed on small watersheds on which a reservoir has been built. After a period of time the internal structure of the deltaic system could be examined. Using the relationships established in the laboratory studies, the volume of sediment accumulation for the various combinations of the recorded hydrologic, watershed, and channel conditions could be determined. Additional information could be obtained from other watersheds with a small reservoir for which the required factors have been recorded. Once the necessary relationships were established, it would be possible to estimate the rate of sediment accumulation based on the recorded or estimated hydrologic events and watershed conditions. These estimates would be approximate because of the nature of the problem. However, for small reservoirs on streams with no sediment discharge measurements, they would probably be sufficient for most purposes.

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