tion of the samples. The shear strength, s, as determined by direct shear tests, was found to approximate closely one-half the unconfined compression, $qu/2$.

Samples were segregated into six groups according to grain size, Group 1 having a range in median diameter between 1 and 2 μ, Group 2, between 2 and 4 μ, and so on, in geometric intervals to Group 6, which ranged between 32 and 64 μ. The strengths of all samples were then plotted against water content for each grain-size group. A definite relationship was found within each group, as illustrated by Fig. 1, which shows the data for Group 4, in which D_{50} ranged between 8 μ and 16 μ. The slopes of the curves for all six grain-size groups varied in a very regular manner. The over-all relationship between strength, water content, and grain size is expressed by the following equation:

$$s = \mathrm{Log}_{10}^{-1}\left(\frac{7.5 - 3w - 4\mathrm{Log}_{10}D_{50}}{1.8 - \mathrm{Log}_{10}D_{50}}\right)$$

where s is the shear strength in lb/sq ft, as determined from measurements of unconfined compression, $qu/2$, w is the water content expressed as the ratio of the weight of water to the weight of solid constituents, and D_{50} is the median diameter in microns.

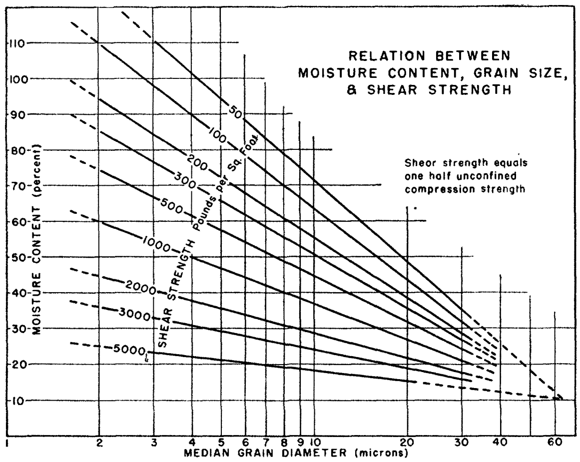

FIG. 2.

The equation is expressed graphically by the family of curves shown in Fig. 2. The reliability of the equation was substantiated by comparing, for 100 random samples, the strength as computed from the equation with the strength as measured in the laboratory. The average observed strength was found to be within 5% of the computed strength. The deviations between observed and computed strength are distributed according to a symmetrical bell-shaped probability curve. The relationship does not hold well for grain size in excess of 32 μ.

Strength naturally is influenced by factors other than water content and grain size. Among these other factors the mineral content, particularly the type of clay minerals, conceivably could be significant. However, in a restricted area such as San Francisco Bay, the newly deposited sediments could be presumed to be relatively similar in mineral and clay composition. This inference is supported by the fact that when the Atterberg limits are plotted on the plasticity chart (*1*), the points lie in a straight and narrow band parallel to and slightly above the "A" line. Apparently, clay and other minerals would have relatively little effect upon the over-all relationships between strength, water content, and grain size in the samples studied.

Factors affecting strength to some extent are mutually interrelated. Water content of sediments varies inversely with grain size (*2*). Also, the plasticity index of the samples from San Francisco Bay varies inversely with grain size. The equation for the relationship is:

$$I_w = 23\,(2 - \mathrm{Log}_{10}D_{50})$$

where I_w is the plasticity index and D_{50} is the median diameter expressed in microns. Consequently, it follows that in the sediments studied, the three principal variables affecting strength—water content, grain size, and mineral composition—are not completely independent variables.

Further study, particularly of sediments in other areas, is needed in order to appraise the significance of the relationship between strength, water content, and grain size, as observed in sediments of San Francisco Bay. The data obtained thus far, however, indicate that the comparison of unconfined compression with both water content and grain size may give a better understanding of the strength of sediments than comparison with water content alone.

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Interchangeable Pencil-Type Micromanipulator[1]

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The author is engaged in performing operations on the cochlear partition of the inner ear, a working area of less than 1 sq mm. Because the area is so small and speed is so essential in operations on living tissue, most available micromanipulators have proved unsuitable for this work, even though they are quite adequate for anatomical dissection. They are too large and clumsy, require too many complicated adjustments, and do not permit quick interchange of surgical instruments.

An ideal solution would be to have several small, pencil-like micromanipulators, one for each of the necessary surgical instruments. The movements of a handle would be transmitted to the tip, but greatly reduced in magnitude. The carrier for the manipulators should be simple enough to permit quick and easy interchange of manipulators. Thus the instruments could be brought to the

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operative field in the same way as ordinary surgical instruments. Such a micromanipulator has been developed with an over-all length of 15 cm and a greatest diam of 2 cm.

Observation of a freehand operation under the microscope reveals two difficulties: (1) it is difficult to bring the instrument into the microscope field, and (2) the involuntary vibrations of the hand can destroy the tissue around the point of operation. The first difficulty can be overcome by having an adequate guide for the manipulator, but the second is much more complicated. Involuntary movements of the point of a pencil held in a comfortable position, with the hand supported by the little finger, while the experimenter tried to keep the tip of the pencil on a given point in the magnified field, amounted to 10^{-2} cm. Even with concentrated attention these vibrations cannot be eliminated (*5*).

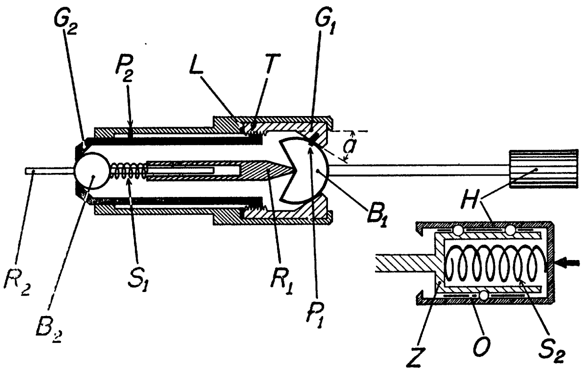

FIG. 1. A schematic cross section of the pencil-type micromanipulator. The tip, on the left, can be moved in three dimensions by moving the handle, on the right. The ratio between the magnitudes of the movements at the handle and at the tip can be set arbitrarily. Insert: Longitudinal shock absorber in the handle of the micromanipulator.

Micromanipulators have been made since the middle of the last century; a summary of such instruments in use today can be found in the handbook of McClung (*4*). The type constructed by Buchthal and Persson (*2*), and Buchthal (*1*) was selected as best suited for modification for the present purposes.

Fig. 1 shows the manipulator described in this paper. It involves a ball, B_1, rotating in a seat. In one side of the ball there is a cone-shaped cavity. The axis of this cone passes through the center of the ball and also through the handle, *H*, that actuates the ball. The depth of the cone is such that its apex does not quite reach the center of the ball. One end of a rod, R_1, rests in the apex of the cone. The other end of this rod is hollow, and fitted into it is a second rod, R_2, that goes through, and is solidly attached to, a smaller ball, B_2. The free end of R_2 is the tip of the manipulator, to which instruments can be attached. Moving the handle, *H*, produces movements of the point of the manipulator that are greatly reduced in amplitude. The amount of reduction in the movement from the handle to the tip of the manipulator is determined primarily by the depth of the cone; the closer the apex of the cone to the center of the ball, the smaller the movement of the tip.

In Buchthal's manipulator a special slide was provided to allow movement in the longitudinal direction of the manipulator. In our model the seat assembly G_1 of ball B_1 can be rotated by rotating the handle. This rotation moves the seat assembly G_2 of ball B_2 in the longitudinal direction by means of the threads, *T*. Ball B_1 has a groove in the plane of the drawing (not shown). A pin, P_1, fits in this groove so that rotation of the ball is transmitted to seat G_1. Thus the seat assembly G_1 can be rotated even when the axis of the handle does not coincide with the axis of the manipulator. A second pin, P_2, moving in a longitudinal groove in seat G_2 prevents a similar rotation of seat G_2. A leather ring, *L*, eliminates the backlash of seat assembly G_1 in the outside case.

The spring, S_1, has two functions: (1) it eliminates backlash in the threads, *T*, and (2) it holds balls B_1 and B_2 against their seats. This spring must be strong enough to hold ball B_1 so firmly against its seat that the handle will not fall down of its own weight, but not so strong that it will produce too much friction in the threads. Actually, it was found possible to obtain the required friction in the seat without increasing the friction in the threads by making the angle of the seat of the ball (angle *a* in Fig. 1) equal to 15 degrees.

For reduction ratios of 10 to 1 or less, the apex of the cone is so far from the center of the ball that the thrust from the spring is strong enough to rotate the ball when the handle is tilted slightly. The action of this spring and ball at these ratios is similar to the action of the ordinary toggle switch, and the handle is stable only at dead center. This condition can be controlled by inserting an auxiliary ring (not shown in the drawing) around ball B_1 inside seat assembly G_1. One side of the ring (toward the right of the drawing) is ground spherically

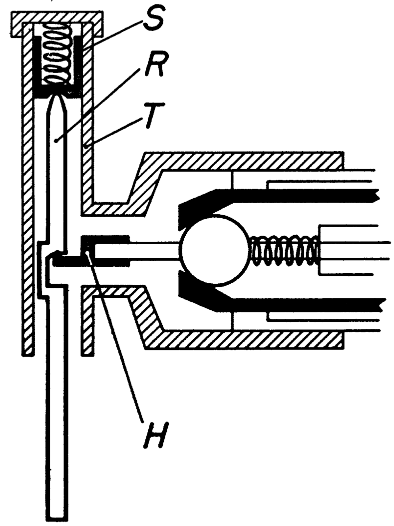

FIG. 2. T-Shaped attachment to change the horizontal type micromanipulator shown in Fig. 1 to a vertical type for operations in deep holes.

to fit the surface of the ball. On the other side of the ring (left) there is a spring that pushes against the beginning of the threads *T*, holding ball B_1 against its seat. The friction of the ball in its seat will then be great enough to keep the handle *H* in position. The force of spring S_1 can therefore be reduced and any toggle-switch action eliminated.

When a micromanipulator is used to operate in a small deep hole, difficulties arise with the lever-type manipulator that are not encountered with the slide type. In a slide-type manipulator all the movements are translational and it is possible, therefore, to change the length or angle of the tip without affecting the magnitudes and directions of the displacements in the other axes. Since in the lever-type manipulator the movements are produced by rotations, the linear displacement depends upon the position of the rotating axis.

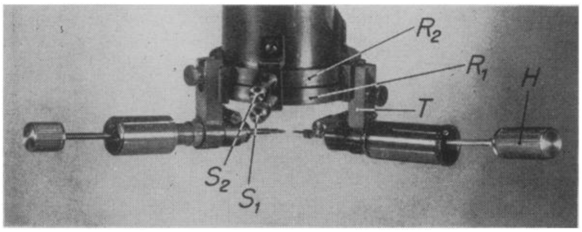

FIG. 3. Mounting for the manipulator on the objective tube of the microscope, eliminating the need for independent coarse adjustments of the manipulator.

The model shown in Fig. 1 was constructed for operations on the surface of the body. This model can be used for operations in narrow holes by adding a T-shaped attachment such as that shown in Fig. 2. To the tip of the manipulator we attach a hook, *H*, with a small point that fits into a niche in the center of the vertical rod, *R*. The upper end of the vertical rod rests on the bottom of the piston, *S*. A spring presses this piston firmly against the tip of the rod. If the hook moves upward, the whole rod is moved upward. A displacement of the hook forward or sideways produces a similar displacement (but one twice as great) of the lower tip of the vertical rod. In this manner movements of the handle *H* are transmitted undistorted to the lower tip of the vertical rod, where the surgical instruments are attached. The vertical tube, *T*, of this attachment for operations in a hole has an over-all diam of 4 mm. Consequently it can be placed fairly close to the objective of a microscope without obstructing the field of view.

The lever type of construction is capable of attenuating only the up-and-down and side-to-side vibrations of the hand, as should be obvious from a study of the diagram in Fig. 1. The lengthwise vibrations of the hand are transmitted to the point of the manipulator without attenuation. In addition to these vibrations, the shock produced when the hand touches the manipulator can destroy the preparation. In order to avoid this, it seemed advisable to provide the handle with a shock absorber, as shown in the insert of Fig. 1. A cylinder, *Z*, is fixed on the end of the handle rod. Two V-shaped grooves are cut on opposite sides of the surface of this cylinder. In the upper groove there are two ball bearings; in the lower, one. They are held in place by the tube, *O*. A similar pair of grooves is cut in the inner surface of the handle knob, *H*. A spring, S_2, lightly loads the shock absorber. This shock absorber allows displacement of the handle *H* along the longitudinal axis, but does not change the transmission of rotation from handle to rod.

The construction of a micromanipulator is complicated by the necessity for coarse, in addition to fine, adjustments. However, since the tip of a manipulator must always be in the field of the microscope during an operation, no provision need be made for these coarse adjustments of the manipulator itself if it can be attached to the microscope tube, as was done by Doty (*3*) and by Tschachotine (*6*). As shown in Fig. 3, a large vertical tube is fixed around the objective of a binocular preparation microscope. On the lower side of this tube are two rings, *R*, that can be turned easily. Two screws, S_1 and S_2, permit the adjustment of the friction of the rings, R_1 and R_2, relative to the microscope tube. An adjustable carrier for a manipulator is attached to each ring. The manipulators can be turned about their longitudinal axes in the tube, *T*, of the ring carrier. A pin serves to determine the position of the manipulator. If the angle of the handle, *H*, relative to the axis of the micromanipulator is kept constant, it is possible to take the manipulator out of the field of the microscope and return it again to exactly the same place. This makes the manipulators easily interchangeable, so that during an operation knives, needles, pipettes, etc., can be used just like ordinary surgical instruments.

For operations such as that on the cochlear partition of the inner ear, a manipulator reduction ratio of 50 to 1 seems to be suitable. Experience with similar operations seems to indicate that fenestration (in otosclerosis of the ear) would be improved by the use of a micromanipulator just as much as it was improved by the introduction of the binocular microscope. Experiments show that in many cases a manipulator with a reduction of 5 to 1 would be very useful.

The micromanipulator described here was constructed in the workshop of the Psycho-Acoustic Laboratory by Ralph Gerbrands.

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