

# ABSTRACTS OF GRADUATE THESES

## CAVITATION

**Cavitation and Pressure Distribution at Sluice-Gate Slots.** ARISTOKLI SPENGO. M. S. Thesis, June 1949; Professor McNowen, adviser. This thesis presents the results of an experimental investigation of pressure distribution along a boundary in the vicinity of a sluice-gate slot and of the critical cavitation number. Studies were conducted in a variable-pressure water tunnel and in an air tunnel at different scales. The slot shapes were rectangular, with width-depth ratios varying from 0 to 2, while the difference in elevation between the upstream and downstream edges of the slot was varied from negative to positive for each width-depth ratio. It was found that the pressure distribution along the upstream boundary in the case of negative super-elevation is a function only of super-elevation, while for positive super-elevation it is a function of the width of the slot also. The pressure distribution along the downstream boundary in the case of negative super-elevations is a function of the width of the slot and the super-elevation, whereas in the case of positive super-elevation it is a function of the cavitation number also.

**An Investigation into the Point of Incipient Cavitation of Submerged Jets.** JOHN P. WHITEHOUSE. M. S. Thesis, February 1952; Professor Rouse, adviser. The effect of temperature and nozzle geometry on the magnitude of the incipient cavitation parameter for a submerged liquid jet was investigated experimentally. Measurements were conducted in a 5x10-foot vacuum tank on jets from 1½-inch nozzles, and a hydrophone and recorder were used to detect cavitation. High-speed photographs showing that cavitation occurs in the zone of maximum turbulence of a submerged jet were obtained. Contrary to previous tests, the absence of temperature effects was clearly demonstrated, whereas the effect of the nozzle shape, although present, was not quantitatively evaluated. A design value of 0.6 for the incipient cavitation parameter of initially parallel jets was recommended.

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## HYDROLOGY

**Influence of Location of Storm Runoff on the Shape of the Unit Hydrograph.** YU-CHEH SOONG. M. S. Thesis, February 1950; Professor Howe, adviser. The purpose of this thesis was to study and analyze the relationships between the shape of the unit hydrograph and the rainfall in the Iowa River basin, which is characterized by a very large length-width ratio. The parameters used were the mean time and standard deviation characteristics of the unit hydrograph and the weighted mean distance and weighted concentration coefficient, which define the rainfall excess distribution over this basin. Relationships between mean time and weighted mean distance and between the standard deviation and a combination of basin characteristics were obtained.

**Minimum Expected Yield from Small Watersheds Using Synthetic Meteorological Years.** CHARLES E. LEWALD. M. S. Thesis, June 1950; Professor Howe, adviser. A method was developed for deriving a short synthetic meteorological period from Weather Bureau records for use in estimating the minimum yield of small watersheds. For use in conjunction with this synthetic meteorological period, a concept is proposed which eliminates the necessity for construction of a mass curve of monthly net yields. Advantages claimed are the following: (1) critical dry periods can be anticipated; (2) minimum yield expected can be predicted with regard to frequency of occurrence; (3) determination of net yield may be restricted to three synthetic meteorological years; and (4) for small watersheds the necessity of estimating monthly net yield and of constructing a mass curve has been eliminated.

**A Study of the Relationship between Watershed Characteristics and Distribution Graph Properties.** RICHARD G. WARNOCK. M. S. Thesis, February 1952; Professor Howe, adviser. In this investigation the properties of the distribution graph, including the time to peak, the time base, and the peak percentage of discharge were correlated with the watershed characteristics, size of the area, the land slope, and the shape of the basin. The data were taken from 33 Illinois drainage basins, ranging in size from 10.1 square miles to 1,364 square miles. The land slope was found to be an important factor in the correlations for areas smaller than 200 square miles. Inclusion of the shape, expressed as a compactness coefficient or a form factor, improved most of the correlations. Curves for the

derivations of the distribution-graph properties from the watershed characteristics are given.

#### MISCELLANEOUS

**Evaluation of Unconfined Flow to Multiple Wells by the Membrane Analogy.** VAUGHN E. HANSEN. Ph. D. Dissertation, June 1949; Professor Rouse, adviser. Tests were conducted on single and multiple wells, using unconfined sand models, to obtain information on the shape of the free surface of the water table near the well. After the free surface was corrected for the effects of capillary rise by use of flow-net principles, it was found that the surface could be approximated by a linear logarithmic function similar to that for confined flow. From these data dimensionless plots of boundary conditions in the vicinity of the well were made. With the boundary conditions at the well thus defined and the free surface near the well following a straight-line logarithmic function, a study was made of a thin rubber membrane to ascertain its feasibility as a model to solve complicated problems of multiple-well flow. When allowance was made for the limitations imposed by gravity and tension, it was found that the membrane gave the piezometric surface for confined flow and the free surface for unconfined flow from the zone of departure from the Dupuit curve to the well. Ease of construction, the variety of problems which may be solved, and the visual demonstration of the piezometric surface—all make this method of considerable practical value.

**Characteristics of Irrotational Flow from Axially Symmetric Orifices.** ABDEL HADI ABUL-FETOUH. Ph. D. Dissertation, August 1949; Professor Rouse, adviser. Although an exact analytical solution of the orifice problem has not yet proved feasible, use of the method of relaxation has permitted a numerical determination of the flow characteristics to be made with sufficient precision for the problem to be considered solved. The coefficient of contraction is found to be practically identical with that evaluated by von Mises for two-dimensional flow from slots over the entire range of area ratio, and reasonable agreement is shown to exist between measurement and computation. Co-ordinates of the jet profiles are presented in tabular and graphic form, and are found to differ appreciably from those previously adapted from the two-dimensional case. A composite dimensionless chart is also provided showing the distribution of pressure along the boundary and center line and

across the efflux section for the various area ratios. (See Reprint No. 83.)

**Approximate Analyses Interrelating Pressure Distribution and Axisymmetric Body Form.** EN-YUN HSU. Ph. D. Dissertation, February 1950; Professor McNown, adviser. Methods were presented for mathematically defining body forms with preassigned pressure or velocity distribution. Approximate solutions were obtained by means of (a) numerical methods and (b) a simplified analytical approach. In either case, the solutions are applicable to real flows only if the Reynolds number is large and the body well streamlined, so that the flow is essentially irrotational. The relaxation procedure, a numerical or finite-difference method for the solving of the appropriate differential equations of motion, was applied in finding the cavitation pocket form around a hemispherical head with parallel afterbody. As an expedient, a solution to the Laplacian equation in elliptical coordinates was obtained in a mathematical analysis based on the assumption that the body profile is slender. Two series of profiles, one symmetrical fore and aft and the other unsymmetrical, were evaluated for various specified pressure and velocity variations and for various ratios of maximum diameter to length. It can be concluded that the problem of defining, with good approximation, a body form with an assumed pressure distribution can be solved by the latter method. The solution is significant, in that form drag can be reduced and cavitation-free body forms can be obtained for known conditions of flow. (See Reprint No. 95.)

**Effect of a Cylindrical Boundary on the Drag of Spheres.** JOHN TERHUNE NEWLIN. M. S. Thesis, August 1950; Professor McNown, adviser. In an experimental investigation conducted with air flowing past spheres fixed on the axes of cylindrical tubes, the coefficient of drag for the spheres was determined from measurements of the distribution of pressure around the spheres. Sphere-to-cylinder diameter ratios from zero to 0.9 were investigated for Reynolds numbers between  $10^4$  and  $10^5$ . An approximate theoretical expression gave results which coincided with those observed for values of the diameter ratio greater than 0.75. These results extend those obtained in previous experiments using falling spheres (Reprint No. 81). (See "Drag of Spheres within Cylindrical Boundaries" by McNown and Newlin, *Proceedings of the First National Congress for Applied Mechanics*, Chicago, 1951, in press.)

**A Direct Optical Method for Measuring Fluid Velocities in Laminar Flow.** ELLIS BERTRAM PICKET. M. S. Thesis, August 1950; Professor Posey, adviser. A method and apparatus for direct optical determination of the fluid velocity in any filament of steady, uniform, laminar flow in a pipe or channel are described in this thesis. The limitations of the method and apparatus are recognized and recommendations are made for their improvement. Observations were made on the ground-glass of a camera of the movement of minute aluminum particles, carried in suspension and illuminated in a vertical plane, in comparison with an electrically driven, variable-speed thread in front of the ground-glass. Velocities ranging from less than 0.001 foot per second to 0.100 foot per second were accurately observed, less than two minutes being required for each determination. Displacement of the plane of illumination permitted measurements to be made over an entire trapezoidal cross section.

**Entrainment of Air by Liquid Jets.** ROBERT W. SHIRLEY. M. S. Thesis, August 1950; Professor Rouse, adviser. The object of this experimental investigation was to determine the characteristics of air entrainment by a water jet plunging through the free surface of water in a tank. Data were collected for jets entering at angles varying from  $45^\circ$  to  $67^\circ$  and extrapolated to represent conditions of vertical entry. The rate of entrainment was evaluated as a function of the Froude number; further experiments with other liquids will be necessary to determine the extent of capillary and viscous influences.

**Drag Coefficients of Multiple Plates as a Function of Solidity Ratio.** TIEN-TO SIAO. M. S. Thesis, August 1950; Professor Rouse, adviser. Tests of composite plates of three series—squares, rings, and screens—were conducted in the low-speed air tunnel of the Institute. Drag forces were measured directly by means of an external beam balance. While each of the composite plates was symmetrical, for each series they were varied by changing the solidity ratio  $S$  and the number  $n$  of the constituent parts. A third geometric parameter  $b/s$  (the ratio of the width to the center-to-center spacing of the constituent parts), which is dependent on  $S$  and  $n$ , was also used. The test results of each series were plotted in curves giving at once the relation of the drag coefficient and the three geometric parameters. It was found, moreover, that some surfaces

of constant solid area produced a greater drag when subdivided than when intact. (See discussion by Siao in Reprint No. 94.)

#### MODEL STUDIES

**A Study of Flow from a Submerged Sluice Gate.** HAROLD ROBERT HENRY. M. S. Thesis, February 1950; Professor Rouse, adviser. An investigation was undertaken at model scale to obtain the mean-flow and turbulence characteristics of a sharp-edged sluice gate operating at various degrees of submergence. A generalized diagram for the discharge coefficient as a function of opening and submergence ratios was prepared from the results of the experiments and was compared with impulse-momentum requirements. Measurements of the intensity of turbulence by means of the Appel tube were used to evaluate the energy changes from section to section. (See discussion by Henry in Reprint No. 88.)

**Pressure Distribution on the Downstream Face of a Submerged Weir.** MICHAEL BAR SHANY. M. S. Thesis, June 1950; Professor Alin, adviser. A determination was made of the pressure variation along the downstream face of a model of a low spillway operating under various degrees of submergence, in order to evaluate the magnitude of its contribution to the stability of the spillway structure. As a secondary aspect, discharge coefficients for various degrees of submergence were determined.

**Modification of Pressure Distribution Around Buildings Due to Parapets.** PHILIP S. NACY. M. S. Thesis, June 1951; Professor Howe, adviser. Flat-roofed building models with parapets of different heights were tested in a wind tunnel, pressures being measured at various points on their surfaces in a continuation of a previous thesis by Chien, Feng, and Wang ("Pressure Distribution on Models of Three-Dimensional Buildings Exposed to Moving Air," *Studies in Engineering*, Bulletin 33, 1949, p. 52). The results were compared with those of the previous thesis by means of pressure-distribution contour maps. A large decrease in the intensity of negative pressure on the roof occurred as the result of the addition of a parapet, while only a slight effect was noted on the walls.

**The Effect of Lip Angle on Flow under a Tainter Gate.** ARTHUR TOCH. M. S. Thesis, February 1952; Professor Metzler, adviser. Observations of various parameters of flow were made on a model Tainter gate of 1-foot radius  $r$  at various magnitudes of the gate

opening  $b$ , trunion height  $a$ , headwater elevation  $h$ , and tailwater elevation  $t$ . The experiments were conducted in a glass-walled flume, 1 foot wide, 2 feet deep, and 10 feet long. All measurements were reduced to three dimensionless diagrams showing the discharge coefficient  $C$  as a function of  $h/r$ ,  $t/r$ ,  $b/r$ , and  $a/r$  for both free and submerged efflux.

#### OPEN-CHANNEL FLOW

**Experimental Investigation of the Discharge Coefficient for a Rectangular Side Weir.** RUSSELL JORDAN KENNEDY. M. S. Thesis, August 1949; Professor McNOWN, adviser. Variation of the discharge coefficient of a side weir was investigated for various channel and weir geometries and for Froude numbers between 0.1 and 0.7. A flume of rectangular cross section and a level side weir set into one wall were used throughout the laboratory investigation. The geometries selected for testing corresponded more closely to those found in water-supply and sewage systems than to those sometimes used for spillway sections in large dams. The tests were restricted to sharp-edged weirs. A significant variation in discharge coefficient was observed for the range of Froude numbers between 0.3 and 0.7, and for still higher values an unstable and partial hydraulic jump was observed in the immediate vicinity of the weir. Data were reduced to dimensionless parameters, the coefficient of discharge being presented in both tabular and graphical form as a function of the Froude number and ratios of length dimensions.

**A Study of Meanders.** CEZAR P. NUGUID. M. S. Thesis, August 1950; Professor Posey, adviser. Field measurements were made of meandering streams in the vicinity of Iowa City, Iowa. A length-measuring device was developed which served very well for the measurement of the talweg of the streams, readings being taken during the winter when the streams were ice covered and easily accessible. From qualitative observations an attempt was made to evaluate the variables numerically. Among others, the following conclusions were drawn: (1) that a stream tends to maintain an equilibrium slope within its system, resulting in meandering; (2) that true meandering streams may be considered as graded streams for practical engineering purposes; (3) that irregularities in meander patterns are due to local changes in alignment caused by non-uniform bank conditions; and (4) that it is possible to obtain a

quantitative relation between discharge, bed load of sediment, and slope.

**Experimental Investigation of the Discharge Coefficient for a Rectangular Side Weir.** CARLOS ACOSTA-SIERRA. M. S. Thesis, February 1951; Professor McNown, adviser. The variation of the discharge coefficient for a rectangular side weir was determined for two limiting conditions not covered in previous investigations: (a) zero sill height above the floor of the channel, and (b) channels effectively very wide. The discharge coefficient was evaluated as a function of the Froude number and of the geometrical characteristics of the channel and of the weir.

**Effect of Submergence of Stilling Basin Sidewalls on the Hydraulic Jump.** STAVROS NICOLAOU. M. S. Thesis, August 1951; Professors Howe and Alin, advisers. An experimental investigation of the effects of submergence of the sidewalls of a stilling basin on the downstream elevation of the hydraulic jump was made in a rectangular flume 2.5 feet wide. Three different channel widths and several wall heights were tested. It was found that flow returning over the sidewalls along their upstream length appreciably decreased the downstream depth of the hydraulic jump, and quantitative values were determined for the range of variables studied.

#### PIPE FLOW

**Studies of Multiple Laterals in Manifold Flow.** ADOLFO YANES. M. S. Thesis, February 1951; Professor McNown, adviser. Earlier studies of flow through multiple laterals were extended to determine: (1) the effect of port spacing of multiple-port manifolds on the variations in pressure and head losses. ("Studies of Manifold Flow." JULIO ESCOBAR. M. S. Thesis, August 1948. *Studies in Engineering*, Bulletin 33, 1949, p. 57); (2) the influence of symmetrically placed ports on the pressure increase downstream from the ports; and (3) practical methods of applying the data on diverging flow in multiple manifolds obtained by Barton ("A Study of Diverging Flow in Pipe Lines." JAMES R. BARTON. M. S. Thesis, August 1946. *Studies in Engineering*, Bulletin 33, 1949, p. 56). Measurements were made for flow in 1- and 2-inch pipes, and the observed results were found to depend somewhat on the Reynolds number of the pipe flow.

## SEDIMENT

**Effect of Shape of Particles on Their Settling Velocities—Triaxial Particles.** HIMANSU RANJAN PRAMANIK. M. S. Thesis, February 1950; Professor McNOWN, adviser. In an extension of Malaika's study of the effects of particle shape on fall velocity ("Effect of Shape of Particles on Their Settling Velocity." JAMIL MALAIKA. Ph. D. Dissertation, February 1949. State University of Iowa *Studies in Engineering*, Bulletin 33, 1949, p. 59, and Reprint No. 85), an investigation was made of particles having the form of rectangular prisms and double pyramids with all three axes unequal. Observations were made for Reynolds numbers (based on the diameter of the sphere having the same volume) between  $10^{-4}$  and  $10^3$ , and values were determined for a shape coefficient to be applied to Stokes' equation. It was found that within the Stokes range the value of the shape coefficient for a particle of known axis ratio and orientation can be estimated within 5 per cent from the theoretical curves for the settling velocity of an ellipsoidal particle. For higher Reynolds numbers, curves were presented which can be used to estimate settling velocities for particles of any shape with an accuracy of 15 per cent. (See "Particle Shape and Settling Velocity" by McNOWN, Malaika and Pramanik, *Proceedings Third International Congress for Hydraulic Research*, Bombay, India, 1951, in press.)

**Accelerated Motion of a Sphere.** MARION ROBERT CARSTENS. Ph. D. Dissertation, June 1950; Professor McNOWN, adviser. The forces on an oscillating sphere in a fluid medium were studied by experimental means. To facilitate measurements, the mass of the oscillating system was adjusted so as to produce resonance; in this way the inertial effective force and the dissipative (shear) force could be evaluated separately. The sphere motion was assumed to be at least approximately simply harmonic, and the data were compared with the results of the theory given by Stokes for laminar oscillatory motion. Variations of a virtual-mass coefficient and an equivalent laminar-resistance coefficient were determined for various Reynolds numbers and various relative amplitudes. The experimental results were applied to an allied problem of a stationary sphere in an oscillating fluid. The experimental results, as applied to this problem, were found to correspond closely with the data of an experiment performed earlier in Germany. The analysis

was extended to include an approximate indication of the diffusion characteristics of suspended sediment in water.

**Mutual Influence of Two Freely Falling Spherical Particles and the Effects of a Plane Vertical Boundary on a Single Spherical Particle.** JAGDISII RAJ BAMMI. M. S. Thesis, August 1950; Professor McNown, adviser. A study was made of the effects of a neighboring sphere and of a nearby vertical plane boundary on the settling velocity of a single sphere. It was found that the settling velocity was affected appreciably for horizontal spacings of ten diameters or less. The magnitude and zone of influence of these effects were found to decrease with increasing Reynolds number, becoming negligible for the highest number tested (700) except for very small spacings. For comparatively large spacings the effects of the container were found to be large; for spacings greater than 4 sphere diameters the velocity of the two spheres was less than that of a single sphere in an infinite medium. (See Reprint No. 100.)

**An Investigation of the Effect of Bridge-Pier Shape on the Relative Depth of Scour.** DOUGLAS E. SCHNEIBLE. M. S. Thesis, June 1951; Professor Rouse, adviser. Results of tests made on various shapes of piers and on various scour arresters used as adjuncts to the pier were discussed as a part of an experimental investigation on the bridge-scour problem conducted for the Iowa State Highway Commission and the U. S. Bureau of Public Roads. Reductions obtained in relative depth of scour, referred to a basic pier, were as great as 25 per cent for a pier with an elongated right section and 50 per cent for a scour arrester properly located on the basic pier. (See "Scour Around Bridge Piers and Abutments—Second Progress Report" by E. M. Laursen and A. Toch, Proceedings of the Thirty-first Annual Meeting, Highway Research Board, Washington, D. C., January 1952, in press.)

**Protection of Earth Embankments by Riprap of Uniform Size.** JOSE O. DE ABREU-LIMA and WILLIAM B. MORGAN. M. S. Thesis, August 1951; Professors Posey and Metzler, advisers. The effects of shape, size, and thickness of riprap of a uniform size on the protection of a horizontal sand bed against horizontal flow was investigated, with a view toward extending it to the protection of embankments. Two shapes of riprap, two sizes for each shape, and four thicknesses for each size were studied. Results indicate that the

shape has no noticeable effect, the size determining the protective quality for a given thickness. The results also indicate that riprap of uniform size would not be practicable, since only a small increase in the velocity requires a large increase in thickness of riprap to prevent failure.

**The Effect of Sand-Trap Proportions on the Efficiency of Operation.** ALY BALIGH. M. S. Thesis, August 1951; Professor Rouse, adviser. An experimental investigation of a two-dimensional model of a sand trap showed that the efficiency of two-dimensional traps is dependent upon the ratio of the length of the trap to the depth of the oncoming flow and the ratio of the fall velocity of the sediment particles to the velocity of the oncoming flow. Results were plotted as dimensionless curves, relating the trap efficiency to the length and velocity ratios, the length ratios investigated being  $\frac{1}{4}$ , 1, and 4, and the velocity ratios ranging from 0.12 to 20.

**A Study of the Transportation of Sand in Pipes.** JOHN PINNA CRAVEN. Ph. D. Dissertation, August 1951; Professor Rouse, adviser. An experimental investigation was conducted to determine the parameters and functional relationships which describe the movement of sediment in pipes flowing full. A mathematical expression for the piezometric gradient was derived from an examination of existing bed-load equations. Introduction of the Darcy-Weisbach equation furnished a functional relationship for the ratio of the volume of sediment in the pipe to the volume of the pipe. Analysis of the mechanics of movement provided additional relationships for the limiting values of the piezometric gradient and the obstructed-volume ratio. The experimental program was planned so that these relationships could be determined. The experimental results indicated that the transport phenomenon can be divided into three regimes: that for which the piezometric gradient is governed by the transport-discharge ratio; a transition region; and that for which the piezometric gradient is independent of the transport-discharge ratio and dependent on the properties of flow, the roughness of the boundary, and the critical shear of the sand bed.

**Effect of Spacing and Size Distribution on the Fall Velocity of Sediment.** PIN-NAM LIN. Ph. D. Dissertation, August 1951; Professor McNowan, adviser. The effects of spacing and size distribution of sediment in suspension on the fall velocity of the particles were investigated, both theoretically and experimentally, for homo-

geneous suspensions of uniform particles. The problem was essentially one of evaluating the hydrodynamic interference due to the superposition of velocity fields generated by the falling particles. Expressions for the velocity components induced at an arbitrary point in a suspension were derived on the basis of Oseen's theory of viscous flow around a sphere. A theoretical relationship between the actual and reference fall velocities was then developed from these expressions. Results of this theory were compared with those observed in the laboratory for suspensions of samples of sand and of glass beads, the samples having been carefully prepared so that the fall velocities of all particles in a given sample were the same. Observations were made for concentrations (by immersed weight) between 0.1% and 6%, for which surprisingly large reductions in velocity—10% to 30%—were recorded. The findings have been shown theoretically to be applicable to stratified suspensions of non-uniform particles as well. This indicates the possibility of applying the results obtained to the practical problems of sediment-size analysis. (See "Sediment Concentration and Fall Velocity" by McNown and Lin, Second Midwestern Conference on Fluid Mechanics, Columbus, Ohio, 1952, in press.)

**The Transportation of Uniform Sand in a Smooth Pipe.** HARRY H. AMBROSE. Ph. D. Dissertation, June 1952; Professor Rouse, adviser. The purpose of this study was to identify the parameters which govern the transport of sand in pipes and to determine their functional relationship. As an extension of the dissertation by Craven, tests were performed in a single plastic pipe of variable slope with three sizes of sediment ranging from fine to very coarse sand. The rates of sand and water discharge, slope, and geometry of the bed and flow were measured by specially designed equipment. Investigation was made of conditions for full-pipe flow and for free-surface discharge, both with and without an inert sand bed. The results were reduced to three generalized functions of practical use in designing drainage systems.

**Tests of Protection of Erosible Material by Graded Riprap.** HENRY DE SILVA MANAMPERI. M. S. Thesis, June 1952; Professor Posey, adviser. Investigations were made to determine (1) the velocities of overflow at which a sand bed would be disturbed when protected by various thicknesses of uniformly graded round gravel, the flow approaching the test section over both a smooth and a

rough channel bottom, and (2) the protective qualities of crushed-stone layers satisfying the Terzaghi-Vicksburg criteria for effective filter blankets. Results indicated that the velocities of failure were higher with the rough bottom than with the smooth bottom and that a properly graded blanket material gave satisfactory protection to a sand bed subjected to overflow or to a combination of overflow and upward flow through the blanket.

#### TURBULENCE

(The following thesis was inadvertently omitted from "Third Decade of Hydraulics at the State University of Iowa," *Studies in Engineering*, Bulletin 33, 1949.)

##### **Diffusion Characteristics of Turbulence in an Open Channel.**

JAMES M. ROBERTSON. M. S. Thesis, January 1940; Professor Kallinske, adviser. Measurements were made of the diffusive power of turbulence by direct experimental means, using motion-picture photography of particles suspended in the flow. The diffusion coefficient was found to vary from zero at the channel bottom, through a maximum at about half depth, returning to zero at the surface. The variation through the vertical of the root-mean-square values of two of the three fluctuating velocity components was determined, as was the variation in the length scale of the turbulence. Some studies also were made of the transverse horizontal diffusion near the surface of the water. (See Reprint No. 26.)

**The Development of a Turbulence Pitot for Use in Water.** DAVID W. APPEL. Ph. D. Dissertation, June 1949; Professor Rouse, adviser. An instrument having the form of a Prandtl pitot with an elastic diaphragm between the tip and the side piezometer openings was developed. The deflection of the diaphragm is proportional to the differential pressure and is detected electrically through the change in reluctance of a small coil behind the diaphragm. The characteristics of the instrument were determined from measurements in a submerged jet. Its directional and frequency limitations are discussed.

**Characteristics of Mean Flow and Turbulence at an Abrupt Two-Dimensional Expansion.** HSIEH-CHING HSU. Ph. D. Dissertation, February 1950; Professor Rouse, adviser. This study was undertaken for the purpose of tracing the energy changes at an abrupt two-dimensional flow expansion. The experiments were made just beyond the bell inlet of a rectangular air tunnel. Pres-

sure intensities were measured by means of wall piezometers, the longitudinal component of the mean velocity with a pitot tube, and the components of turbulence with a hot-wire anemometer. The energy equation for the mean and the secondary motion was integrated to indicate the change of the various terms in the longitudinal direction. It was found that the viscous dissipation of the mean motion and the energy transferred to turbulence are small, in comparison with the total loss, except near the boundaries and in the initial section of the expansion. The rate at which energy is supplied by the mean motion is high near the initial section, drops rather rapidly, rises a little near the section where the stable eddy ends, and approaches a constant value thereafter. The dissipation rate, following a different trend, is small at the beginning, reaches a maximum near the mid-length of the eddy, and gradually drops toward a constant limit.

**Gravitational Convection from Line Sources.** HAROLD W. HUMPHREYS. M. S. Thesis, February 1950; Professor Rouse, adviser. The distributions of mean velocity and temperature were measured in the zone of turbulent convection above single and parallel line sources of heat located on a horizontal boundary. All data were reduced to a dimensionless form satisfying the basic momentum equation and the hypothesis of similarity. The results obtained are directly applicable to the problem of fog dispersal over airfields and may also be of value in such widely varied fields as meteorology, chemical engineering, and oceanography.

**An Exploratory Investigation of Boundary-Layer Development on Smooth and Rough Surfaces.** WILLIAM DOUGLAS BAINES. Ph.D. Dissertation, August 1950; Professor Rouse, adviser. The object of this study was to conduct and evaluate the results of preliminary tests on turbulent flow along smooth and rough boundaries, for use in planning long-range investigations of this subject in connection with resistance of ship hulls. The measurements involved the determination of velocity and turbulence distribution in the boundary layer along a plane surface suspended in an air tunnel. The most important characteristic of the flow, the drag of the surface, was computed from the velocity measurements through use of the momentum equation. One size of granular roughness was used in the rough-surface experiments and the relative roughness was varied by changing the velocity of the flow and the effective length of the

surface. (See "A Literature Survey of Boundary-Layer Development on Smooth and Rough Surfaces at Zero Pressure Gradient," by W. D. Baines, report to the Office of Naval Research, 1952.)

**The Development of the Turbulent Boundary Layer on Steep Slopes.** WILLIAM JOHN BAUER. Ph. D. Dissertation, August 1951; Professor Rouse, adviser. Development of the boundary layer on steep slopes controls not only the loss of head but also the onset of air entrainment; the ability to predict its rate of growth is therefore essential to proper spillway design. This dissertation describes a laboratory investigation of the variation in velocity distribution on smooth and rough channel beds for a series of slopes and rates of discharge. The boundary-layer thickness, the coefficient of local resistance, and the parametric shape of the velocity profile are analyzed as functions of the Reynolds number and the relative roughness. These functions are shown to be in accordance with general boundary-layer theory, and essentially independent of both slope and discharge. A practical method is then proposed for computing the limit of boundary-layer development on concrete spillways. (See paper of same title in *Proc. A. S. C. E.*, 1952, in press.)

**An Experimental Investigation of the Boundary-Layer Development Along a Rough Surface.** WALTER L. MOORE. Ph. D. Dissertation, August 1951; Professor Rouse, adviser. As a continuation of the initial boundary-layer study by Baines, experiments were performed in the air tunnel on a flat surface roughened with transverse bars under conditions of zero pressure gradient. The same geometric form was produced at three different scales, covering a 12-fold variation in absolute size. Velocity profiles were taken and compared with those obtained by other investigators. The values of the surface-resistance coefficient determined from measurement were compared with those predicted analytically. The velocity distribution for the boundary layer along the three surfaces was found to differ significantly from that for a conduit, though expressible in terms of similar parameters. The surface-resistance coefficient was in poor agreement with that predicted by the von Kármán relation, but approximated the Schlichting equation; however, a significant deviation, depending on the absolute size of the roughness, was apparent. (See "A Literature Survey of Boundary-Layer Development on Smooth and Rough Surfaces at Zero Pressure Gradient," by W. D. Baines, report to the Office of Naval Research, 1952.)

## STAFF PUBLICATIONS NOT AVAILABLE AS REPRINTS

Discussion by Hunter Rouse and J. S. McNown of "Hydrodynamic Design of the 48-Inch Water Tunnel at Pennsylvania State College," by D. Ross, J. M. Robertson, and R. B. Power; *Trans. S.N.A.M.E.*, 1949.

"Fluid Mechanics," "Hydrodynamics," "Hydraulics," by Hunter Rouse, *Encyclopedia Americana*, 1950.

"Flexible Mats May Reduce Scour at Piers of Small Bridges," by D. W. Appel, *Eng. News-Rec.*, May 25, 1950.

"Investigation of Flexible Mats to Reduce Scour around Bridge Piers," by C. J. Posey, D. W. Appel, and E. Chamness, Jr., Thirtieth Annual Meeting of Highway Research Board, Washington, D. C., Research Report No. 13-B, April 1951.

Discussion by T. T. Siao of "An Investigation of Flow through Screens," by W. D. Baines and E. G. Peterson; *Trans. A.S.M.E.*, Vol. 73, p. 467, 1951.

Discussion by Hunter Rouse of "An Investigation of Flow through Screens," by W. D. Baines and E. G. Peterson; *Trans. A.S.M.E.*, Vol. 73, p. 467, 1951.

"Sur l'entretien des eaux portuaires sous l'action de la haute-mer," by J. S. McNown, *C.R.A.S.* (Paris), May 28, July 2, July 27, 1951.

Discussion by D. W. Appel of "Model Tests Using Low-Velocity Air," by James W. Ball; *Trans. A.S.C.E.*, Vol. 117, 1952.

"Wind Pressure on Elementary Buildings Forms Evaluated by Model Tests," by J. W. Howe, *Civil Eng.*, Vol. 22, No. 5, pp. 42-46, May 1952.

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