TURBULENT FLOW STURCTURE AT F > 1

N. T. Fazullin

Certain results of measurements of the structure of an open-channel flow at F > 1, where F is the Froude number, are presented.

The experiments were performed in a variable gradient glass channel of width B = 19.9 cm and length 7.0 m; the bottom of the channel was covered with gravel with mean diameter on the interval $7 < d < 10$ mm.

The averaged velocities were measured with a Pitot tube; the flow structure was investigated with a motion-picture camera.

The two-dimensional flow characterized by a mean velocity V = 130 cm/sec and by values of the dynamic velocity $V_* = 14.95$ cm/sec, Reynolds number R = 225,000, Froude number F = 3.47, and coefficient of hydraulic friction $\lambda = 0.106$. These values were determined from the expressions

$$V_* = \sqrt{ghJ}, \quad R = \frac{4hV}{\nu}, \quad F = \frac{\alpha V^2}{gh}, \quad \lambda = 8\left(\frac{V_*}{V}\right)^2$$

Here, h is the depth of the flow, g is the acceleration of gravity, J the hydraulic gradient, ν the kinematic viscosity, and α the kinetic energy coefficient.

The section in which the turbulent kinematic characteristics were investigated was 4.5 m from the channel inlet, which amounts to 80 uniform-flow depths. The flow uniformity was checked by comparing averaged-velocity distributions along the length of the flow.

The results of an investigation of the rms values of the velocity fluctuation along the vertical axis of the clear cross sections of the flow are presented in the table and in Figs. 1 and 2.

From a study of this material the following conclusions may be drawn.

1. The absolute values of the rms fluctuations, like their dimensionless values, referred to some mean characteristics of the clear cross section (maximum velocity u_+, mean velocity V, dynamic velocity V_*) increase with increase in the distance from the bottom, reaching a maximum of approximately 0.12h. Beyond this point the quantities

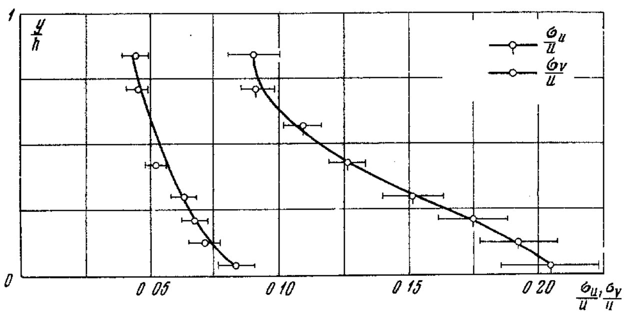

Fig. 1

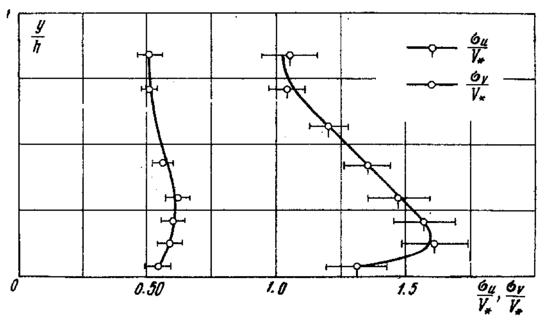

Fig. 2

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TABLE 1

y/h	u/V_*	σ_u/u	σ_v/u	σ_u/V_*	σ_v/V_*	σ_u/U_+	σ_v/U_+	σ_u/V	σ_v/V
0.038	6.4	0.204	0.083	1.31	0.53	0.113	0.046	0.150	0.061
0.125	8.4	0.192	0.071	1.61	0.59	0.139	0.051	0.186	0.068
0.211	9.0	0.174	0.067	1.57	0.60	0.135	0.052	0.180	0.069
0.297	9.75	0.151	0.063	1.47	0.62	0.127	0.053	0.169	0.071
0.425	10.7	0.126	0.052	1.35	0.56	0.116	0.048	0.155	0.064
0.570	11.0	0.109	—	1.20	—	0.103	—	0.139	—
0.711	11.4	0.091	0.045	1.04	0.506	0.090	0.044	0.119	0.058
0.840	11.6	0.090	0.044	1.05	0.506	0.090	0.044	0.120	0.058

$$\sigma_u,\ \sigma_v,\ \sigma_u/u_+,\ \sigma_v/u_+,\ \sigma_u/V,\ \sigma_v/V,\ \sigma_u/V_*,\ \sigma_v/V_*$$

begin to decrease and near the free surface assume almost constant values.

2. The rms values of the velocity fluctuations, referred to the local averaged velocity u (the intensities of turbulence σ_u/u and σ_v/u) increase steadily from the free surface in the direction of the bottom.

3. The longitudinal rms velocity fluctuations σ_u are much greater than the vertical σ_v. This is true over the entire vertical axis, including the region near the free surface.

Comparing the first and second conclusions, we may assume that it is more rational to characterize the turbulent velocity fluctuations by means of a characteristic such as the rms values referred to the local averaged velocity σ_u/u and σ_v/u, since this leads to a simple flow model that does not require separation into zones with different laws of variation of the relative values of the velocity fluctuations, as would be the case if the characteristics

$$\sigma_u/u_+,\ \sigma_v/u_+,\ \sigma_u/V,\ \sigma_v/V,\ \sigma_u/V_*,\ \sigma_v/V_*$$

were taken.

The third conclusion implies that at F > 1 there is turbulence anisotropy over the entire depth of the flow. The turbulence anisotropy near the walls is more important than that observed near the free surface where the ratio σ_u/σ_v is of the order of ~ 2.

The measurements were made during the period from 1966 to 1967 in the Moscow Laboratory of Flood Control and Water Resources of the State Hydrological Institute and in the Hydrophysical Laboratory of Moscow Lomonosov State University. In the course of the experiments the author consulted K. I. Rossinskii and B. A. Fidman.