SECTION B, GEOLOGY

Pictures and Patterns of Open Channel Flow

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The flow picture of a young stream in a glaciated region is complex and ever changing. Stream velocity, pressure, and temperature never remain constant at any point. A special case of unsteady flow, the pulsating, sometimes occurs. During flood stages the flow may become cavitating; superelevation develops at bends; and parts of the channel suffer such translocation of bed material that the cross sectional area will be widened or narrowed.

When the flow is being aerated, bubbles of various sizes from large to microscopic form and travel in both main current and secondary flows. The bubbles may mark the outline of wakes and move downstream with a line of dissipating vortices. Very small bubbles, one sign of cavitation (Braden, 1949) may occur as a result of vorticity. Occasionally bubbles pile up into steep-sided structures a foot across and several inches high.

Hydraulic jumps (Braden, 1958) form where there is an abrupt change in gradient from the steep to the gentle and also where the stream bed is humped up. During low stages of flow even the larger cobbles in the channel provide the requisite change in gradient for the formation of miniature jumps.

Between adjacent boulders and boulder and channel wall the flow is constricted. Water is backed up by the boulders, depressed between them, and expanded immediately downstream where the channel is widened. In the constricted areas velocity is increased, but both upstream and downstream there is a loss of head. If the channel is enlarged suddenly deceleration takes place rapidly and is accompanied by eddying turbulence for some distance downstream. The eddies die out because of viscosity, and heat is lost to the flow.

Most of the boulders in the streams are bluff or blunt bodies with their axes askew to the direction of flow. Commonly velocities on opposite sides of the boulders differ in magnitude. At very low Reynolds numbers, even for such blunt objects, the streamlines which spread apart and round the boulders will close behind them so that no wake will form. Commonly this occurs only when the boulders are completely streamlined and their axes parallel to the direction of flow.

The first stage in the development of a wake appears when the streamlines broaden out behind the boulder. Nemenyi (1940) discussed five distinct types of wakes. Water particles which round a boulder come to rest on opposite sides of it. They accumulate there, receive a rotary motion from the surrounding flow, and develop into eddies. Their momentum becomes so great that they break away and travel downstream in parallel paths and finally lose their identity. Other eddies form and leave the boulder, and the process continues. Because of the shedding of vortices, high rotational velocities may occur in the flow and correspondingly low pressures in the vortex cores. This leads to cavitation (Kermeen, McGraw and Parkin, 1956). The point of separation of the eddies may be where the boulder has its greatest width or a little farther upstream or downstream. The boundary layer (Braden, 1950) which adheres to the boulder determines the position of separation. Vorticity which is generated in the boundary layer diffuses from the vortex layers and is added to the vortex pairs. The vortex pair is stationary at low Reynolds numbers, and asymmetrical at higher ones. When the vortex pair is asymmetrical, vortices separate alternately from the boulder. As they disintegrate downstream they give rise to a turbulent wake. Not only the Reynolds number, but the degree of turbulence of the main flow, and the boulder's shape and nearness to another boulder or the channel wall are the deciding factors in the behavior of the vortex pair.

When separation takes place upstream from the points of greatest width of a boulder, there is a relatively wide turbulant wake. When it is downstream, the wake is decreased in width. The turbulent boundary layer has greater kinetic energy than the laminar and so permits the flow to continue further around the boulder before it is brought to rest. A separation point may be fixed if the boulder has a shape resembling a thin circular disk placed normal to the flow. Laboratory experiments with disks and other shaped objects may be applied to the flow in a stream with an open channel. There is practically no variation in the flow pattern with a change in the Reynolds number. The point of separation cannot shift regardless of the condition of the boundary layer. The width of the wake remains constant.

Pulsating flow is especially noticeable at bridge piers. There is a ryhthmic pulsation of water level. The water level may be as much as 6 inches higher at one pier than at the adjoining one, where there is the opposite phase. Such flow has been seen on streams in the Duluth, Minnesota area when they undergo rapid velocity and pressure changes. There were wakes behind bridge piers and also behind boulders. Another case of pulsating flow was seen on a stream near Lander, Wyoming. The wake which formed swung sharply from side to side. The surface of discontinuity which was between the wake and the main flow jerked convulsively as the wake started to swing from one side of the channel to the other. This erratic movement continued only an instant or two. Wakes with great turbulent movements were observed on several occasions when there was pulsating flow. Grundsky (1930) reported a case of pulsating flow on a canal. The pulsations were noticed for a distance of two to three miles upstream from the place where they were best developed.

A number of flow patterns are developed on vigorous young streams. Some are commonplace, but a few are rarely seen. The magnitudes of flood flows and the condition of bed and banks are factors in deciding the patterns produced. Some patterns are produced in streams having moveable beds. Other patterns are the result of flow over rigid beds, that is, those cut into hard rock or over boulders that are wedged so tightly together that not even exceptional floods can move them from their fixed positions. Streams with converging and diverging channels have distinctive flow patterns. There are numerous eddies, some with vertical vortices others with horizontal ones some of which erode dangerously. There are eddies that move bed material downstream; reverse eddies shift it upstream.

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