The Hydraulic Jump in Natural Streams

GLADYS E. BRADEN, Duluth, Minnesota

In natural streams hydraulic jumps form at the foot of sloping channels at some stages of flow, provided the velocity is above that of wave propagation. The jump may be identified by its visible foaming backward-moving top layer, and by its location either in the pool or on the sloped channel immediately above it, or even straddling the change in grade. The jump is an abrupt wave or rise in the water surface, and is the result of a sudden retardation of the flow as it moves into a region of slower-moving water in either a horizontal channel or pool. As the water passes through the jump there is much turbulence and boiling, and violent internal eddies are set up as it expands. Kinetic energy changes into potential energy, and the stream loses velocity. In reality, the jump consists of two flows, separated by a surface of discontinuity. (Stevens, 1940). The bottom flow is the rapidly moving one, and accounts for almost all the total energy loss. The upper flow is the backward-moving one of sluggish foamy water. When a hydraulic jump is produced in a glass flume in a laboratory, the upper flow is seen to be a roller with a horizontal axis, from which masses of foaming water are torn away by the live jet which comprises the lower component of the jump. The visible foamy tops of the jumps may be of either the direct or indirect type. A single rise of water gives the direct type. In natural streams the undular type is more often seen. (Bakhmeteff, 1937). The latter consists of a series of oscillations of decreasing amplitude.

High velocity flow moves down a sloped channel as a jet and at the change of grade enters a region having lesser velocity. The entrance of the jet with its attendant bubbles may be seen often in small pools of exceptionally clear streams. The bubbles acting as solids are diffused into the surrounding water. As the jet goes into the pool it expands laterally and loses some of its energy to the surrounding water. It may or may not pass through the jump stage. It may shoot along the bottom of the pool and create an eddy with a horizontal axis, or flow out of the pool as a wave. In other words, if the pool is very deep the jump may be drowned out. In a short pool the jet may strike an obstruction and spray out into the air. In an especially shallow pool, but not necessarily a short one, the water may spray up and out. If the pool is long enough and of the right depth for the amount of water that enters it, a jump will form. Sometimes an "incomplete" jump forms. Five types of possible action have been given by Maxwell (1934), who stated that the types are not clear-cut and that they may merge one into another (Stanley 1934).

A number of factors determine the location of the jump. For example, it has been found that either an obstruction, in this particular case, a weir, placed across the channel, or an abrupt rise in the channel bottom will prevent the jump from migrating downstream (Forster and Skrinde, 1950). In a natural stream the jump will move either upstream or downstream depending upon the geometry of the pool at a particular time, but it will move within a very limited distance. Below dams the jump forms either on the aprons or ogee spillways or in the stilling basin of outlet works. In a natural stream not obstructed by the works of man the jump would be prevented from travelling downstream by a rock ledge across the channel or by cobbles and boulders so deposited as to act as a weir, or by an abrupt rise in the channel bottom.

Engineers can bring about the formation of a jump and control scour in the stilling basin and hence immediately downstream. They may lengthen or shorten the stilling basin below a dam as needs be, and adjust the tailwater level. The apron may be extended and the end sill raised. A protective covering is laid down upon the channel bottom so that scour will not become dangerous and result in undermining the dam. It is only under ideal conditions that excessive scour does not take place. Some scour does take place and as a small pit and dune are formed a protective ground roller (Morris, 1943) comes into being. A natural water cushion may develop. In either case excessive scour is prevented and the toe of the dam is not eroded. In natural streams, not obstructed by hydraulic structures, scour may proceed apace. Engineers guard against the formation of eddies which would scour the sides of the stilling pools. The presence of large-scale eddies may be as harmful to a stream channel as is high mean velocity (Kalinske, 1940). In North Shore of Lake Superior streams, pools are to be found in which eddies have caused severe erosion to the banks.

The hydraulic jump is an effective mixing device. During spring floods small tributary channels of the streams enter Lake Superior along its north shore carrying varying amounts of red clay in suspension. Their waters flow into the master streams as ribbons of different degrees of intensity of color. When the waters pass through the hydraulic jump they are so thoroughly mixed that the surface flow has the same coloring. The jump is used as a mixing device and for aeration in waterworks.

The hydraulic jump is a potent dissipator of energy. It is used on both artificial and natural streams to cut down velocity and prevent undue scour. In addition to its use in waterworks, it is used in flumes and irrigation ditches. It is sometimes used on mountain sides below small check dams. It is widely used in connection with hydraulic structures, and its work in reducing stream velocity may be supplemented by both baffle piers and blocks below dams.

REFERENCES CITED

Bahmeteff, Boris A. 1932. The hydraulic jump and related phenomenon. Amer. Soc. Mech. Engrs., Trans. 54: APM-54-1-1 — APM-54-1-12.

Forster, John W. and Raymond A. Skrinde, 1950. Control of the hydraulic jump by sills. Amer. Soc. Civil Engrs., Trans. 115: 973-987.

Kalinske, A. A. 1940. Relation of the statistical theory or turbulence to hydraulics. Amer. Soc. Civil Engrs., Trans. 108: 1545-1566.

Morris, B. T. 1943. Hydraulic design of drop structures for gully control. Amer. Soc. Civil Engrs., Trans. 108: 887-918.

Stanley, C. Maxwell. 1934. Study of stilling basin design. Amer. Soc. Civil Engrs., 99: 490-512.

Stevens, J. C. 1940. Discussion of article by Kalinske. Ibid. Am. Soc. Civil Engrs., Trans. 105: 1571-1572.