Flow Around Bends in Stream Channels

GLADYS E. BRADEN, Duluth, Minnesota

For almost every statement made about flow around bends, a contrary one has appeared in the literature. Our earliest records were never controversial. They were the result of simple observations of natural streams and of attempts to harness various watercourses. Lost in myth is the record of one hydraulic engineer who kept his head because he did not displease his Chinese ruler. He was apparently able to control a meandering stream. It was only in comparatively recent times that the Chinese kept written records of their attempts to control the flow of water. In England the Romans built embankments, discernable even today, to protect their farms from destruction by the winding Thames and Ouse. In India the vagaries of flowing water are such that they have always taxed the ingenuity of hydraulic engineers. The men battled with streams which swept away bridges as if they were so many straws, and with others that as soon as they felt the obstruction of the bridge built over them, abandoned their old channels for good, and left the structure spanning dry ground. Out of this struggle in India grew a rich literature on streams and a number of formulas for their control. Canals were built which were prevented by guide banks from meandering widely, and whose flow was so regulated that neither scour nor deposition took place. In India engineers had 60 years in which to make mistakes and learn how to avoid them. In the United States hydraulic engineers made mistakes comparable to those made on canals in India

In Europe investigation of flow around bends dates from 1868 when L. Fargue applied empirical laws to the regulation of the Garonne River. He later developed a theory supporting these laws. James Thomson (1876) wrote an article in which he discussed helical flow. Few articles by either geologists or engineers on this particular phase of fluid flow appeared in the literature until about 1930 when it received an impetus.

In helicoidal flow as the main filaments of water make their way downstream they scour successively the concave banks first on one side of the channel and then on the other. They move down the concave banks and erode most vigorously near the downstream end of the scour hole, and then they cross the channel where they approach the surface. They make their deposits in the slackest water along the convexities. The flow is counterclockwise along one concave bank and clockwise in the next one. An adjustment is made in the reaches or tangents between the bends. Ideally the water surface is level there. In large streams the difference in elevation of the water at opposite sides of the bend is ordinarily not more than two or three inches, but when the velocity is increased in time of flood it may be much more. At the beginning of a curve the water along the convex bank is depressed, making most of the adjustment there, with the result that the water along the concave bank, without rising, is left higher than that along the convex. At the end of the bend the water along the concave bank is suddenly depressed so that this drop alone is practically responsible for all the adjustment of water levels between bends. However, if the bend is very sharp, water along the concave bank may actually rise and there will be upstream flow for a short distance (Blue, Herbert and Lancefield, 1934). The upstream flow becomes part of an eddy. This phenomenon is rarely seen.

Tests on the Iowa River support the theory of helicoidal flow (Blue, Herbert and Lancefield, 1934). Mockmore (1943) concluded that this type of flow does exist, although the helical pattern is an exceedingly complex one. If the water encounters channel irregularities, localized turbulence may arise which will distort the pattern to such an extent that its existence may be doubted. Experiments by Vogel and Thompson (1933) showed that although bed materials moved across the channel, bottom currents did not cross with them. They doubted that helicoidal flow exists.

The theory of helicoidal flow is discredited by certain phenomena found along the Mississippi River at certain points. Where the bend is very sharp, it frequently happens that bars are formed along the concave banks and that steep banks develop along the convexity. Yarnell (1930) observed that the greatest velocity was along the convexities in his experiments with 180° pipe bends. Davis (1902) noted this unusual type of flow on some streams in Pennsylvania as did Tower (1906). The Conoduguinet near Harrisburg is one of these streams. Scobey (1939) found that water welled up along concave banks and that the swiftest current was along the convex banks. Surface flow was from the outer bank of the channel to the convex one.

The present author constructed a model stream in unconsolidated sediments on a mountain slope near Lander, Wyoming. It received its water from the overfow of an irrigation ditch. The streamlet had very sharp bends, that is, hairpin or 180° bends. If small amounts of soil were placed on the outside of the bends where minute deposits were being made, the thread of the current began to shift. Cutting became more active along the convex bank and the long tangents of the bends became shorter. When still more material was added to that along the concave bank, the streamlet suddenly switched from cutting on the convexity to cutting on the cancave bank. The long, straight tangents quickly assumed the more typical form of meander.

Shukry (1949) concluded that spiral flow exists in straight as well as in curved channels, and that a complicated pattern comes into being in the bend area where the flow originating in the straight approach channel interferes with that produced by the bend. Natural streams are made up of a series of bends separated by tangents of varying lengths. Any disturbance of the pattern of flow in a bend affects the flow in the downstream tangent, and it in turn affects that in the next bend. The result may be a very complicated pattern.

Linder (1953) found that, when banks erode with difficulty, the material from the caving bank is carried downstream and deposited on the same side of the channel. Bed load from the convexity opposite the caving bank is carried across the thread of the stream to the convex bar, provided that the material entering the area under consideration is supplied at a rate faster than the banks are caving. If the material enters at the same rate as the banks are caving, the material will not be carried across the thread of the stream. When banks erode rapidly, bed load does not cross the stream, but is deposited on the same side of the stream from which it was derived.

In centrifugal spiral motion currents that are leaving the scour hole with an upward inclination are not deflected uniformly toward the opposite side of the stream. Shukry (1949) found that the filaments of water are grouped in separate zones which develop separate scour regions. The scoured material crosses the channel diagonally and is deposited along the convex bank. He found that if the depth-width ratio was decreased, the convexity increased in volume and the scoured area became deeper. Natural streams have a low depth-width ratio and consequently there are numerous examples of convexities or meander scrolls that have increased in volume conspicuously and of scoured areas that show not only fluting but an unusual depth for the size of the stream.

When flow is supercritical, strong waves may appear within the bend area and may persist for a considerable distance downstream. The waves hit first one side of the channel walls and then the other several times as they pass through the bend area. Modifying the channel bottom will change this flow pattern. Engineers recommend banking, i. e. the gradual raising of the stream bed on the outside of the curve or the lowering of it on the inside (Knapp, 1949). The walls should have a decreasing radius that just matches the increase in cross slope. However, banking a stream with supercritical flow and rectangular bed and adjusting its side walls, will give equilibrium conditions for only one velocity and one depth of flow (Knapp, 1949). For all other velocities and depths of flow shock waves will appear.

Of late years the experiments made on the flow of water have yielded far more accurate results than were obtainable heretofor. The newer apparatus gives a complete picture of the various flow patterns. Articles based on the newer findings of stream flow are now beginning to appear in engineering literature. Geologists have a considerable literature on meandering streams, and since no two streams are exactly alike, their articles give a variety of opinions on almost every phase of the subject.

LITERATURE CITED

Blue, F. L. jr., J. K. Herbert, and R. L. Lansfield. 1934. Flow around a river bend investigated. Civil Engineering 4: 258.

Davis, W. M. 1902. Systematic geography. Am. Philosophical Soc. Proc. 41: 251.

Knapp, Robert T. 1949. Design of channel curves for supercritical flow. Am. Soc. Civil Engrs. Proc. 75: 1325.

Linder, C. P. 1953. Diversions from alluvial streams. Am. Soc. Civil Engrs. Trans. 119: 261.

Mockmore, C. A. 1943. Flow around bends in stable channels. Am. Soc. Civil Engrs. Proc. 69: 344, 369.

Scobey, Fred C. 1939. The flow of water in irrigation and similar canals. U. S. Dept. Agr. Bull. 652: 53-54.

Shukry, Ahmed. 1949. Flow around bends. Am. Soc. Civil Engrs. Proc. 69: 734-739.

Thompson, James. 1876. On the origin of the windings of rivers in alluvial plains, with remarks on the flow of water in pipes. Royal Soc. London Proc. 25: 5-8.

Tower, Walter S. 1906. Regional and economic geography of Pennsylvania, Pt. 1 The Central Plateau. Geog. Soc. Phila. Bull. 4: 134.

Vogel, Herbert D. and Thompson, Paul W. 1933. Flow of water in river bends. Civil Engineering. 3: 268.

Yarnell, David L. 1930. The flow of water around bends. Engineering News-Record. 105: 940.