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PRINCIPLES OF ENERGY DISSIPATION IN EROSION-CONTROL STRUCTURES

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The dissipation of kinetic energy in flowing water so that it will not cause undesirable erosion is a problem which has perpetually confronted engineers and agronomists. Certain new approaches to this problem have been developed in the Hydraulics Laboratory at Colorado A and M College and this paper is intended to present these ideas in summary form. The principles to be discussed are chiefly the distinction between the relative merits of horizontal dissipation of energy compared with vertical dissipation of energy, and the use of gravel as a riprap material for protection against scour.

Broadly speaking, kinetic energy in water may be dissipated in the horizontal direction, in the vertical direction, or in a combination of both directions.

Energy Dissipation in the Horizontal Direction

As may be seen in Fig. 1a, the dissipation of energy in the horizontal direction may be simply the result of roughness or drag on the boundary which will resist the water and cause the velocity to be reduced and the depth to be increased. Unfortunately, many hydraulic structures depend upon this principle for the dissipation of kinetic energy. The result is that banks and beds are badly eroded because the material composing the banks and bed are not sufficiently stabled to withstand the heavy, shear and drag forces of the high-velocity water. Once the velocity has been decreased to magnitude which the bed and bank material can withstand, the channel will remain stable. The use of boundary resistance alone, however, requires such a great length of channel that protecting it usually becomes an uneconomical venture.

The distance required to decrease the velocity and dissipate the kinetic energy in the horizontal direction can be reduced tremendously if the hydraulic jump is employed as illustrated in Fig. 1b. The hydraulic jump may be explained by the momentum principle of basic mechanics which is derived from Newton's fundamental equation $F = Ma$.

The hydraulic jump is a sensitive phenomenon which may move easily upstream or downstream and thereby become ineffective. Therefore, blocks or sills are usually placed on the floor of the channel to help stabilize the location of the hydraulic jump and to help reduce the length required for it to take place. A very effective and efficient design of a structure utilizing the hydraulic jump as an energy dissipator on the horizontal apron, together with chute blocks, floor blocks and dentated end sills, is the St. Anthony Falls Stilling Basin developed by Blaisdell. This development has proved to be extremely useful to hydraulic engineers throughout the world. The hydraulic jump is also used on a much larger scale in connection with storage dams. Notable among these are Norris Dam and Shasta Dam.

Despite the efficiency of the structures designed for the dissipation of kinetic energy in the horizontal direction, it is almost impossible to eliminate completely the waves and some high-velocity flow downstream from such structures. Therefore, it is necessary frequently to protect the banks and bed downstream against erosion from waves and localized high-velocity flow. Such riprap protection has been found to be most effective when applied in a graded form with sizes of material ranging from that of the bed and banks to the maximum size which is required to withstand the waves and high-velocity action of the water.

Energy Dissipation in the Vertical Direction

The dissipation of kinetic energy in the vertical direction involves the diffusion of a submerged jet into the surrounding flow or tail water. Such a jet may be travelling vertically upward, Fig. 1d, or vertically downward, Fig. 1c, but the effective dissipation of its kinetic energy is always dependent upon the jet being submerged.

The basic principles of diffusion of submerged jets are illustrated in Fig. 2. From this figure it may be seen that any jet issuing into a quiet body of its own fluid entrains fluid from the outside so that the discharge is increased as the energy is decreased. As a consequence, the momentum flux remains a constant, provided the pressure distribution is uniform throughout. This is particularly noticeable in Fig. 3 where the discharge Q is seen to increase with distance x downstream, the momentum flux M is seen to remain the same with distance downstream, and the energy E is seen to decrease with distance downstream. From these data, it is possible to determine the dissipation of energy which results from the diffusion of the submerged jet.

Examples of the dissipation of kinetic energy vertically downward is the simple drop in an irrigation canal, a roadside ditch, or a gully. This drop may be equipped with an apron which will force the horizontal dissipation of energy, or it may be equipped with a stilling pool in which the kinetic energy is dissipated vertically downward as shown in Fig. 1c.

A cantilevered pipe outlet, such as a culvert under a roadway, is another example of a situation where the dissipation of kinetic energy may be vertically downward and is also illustrated by Fig. 1c.

The dissipation of energy vertically upward may be accomplished by a manifold type structure such as that shown in Fig. 1d and Fig. 4. In this case the water is turned in the structure from horizontal to vertically upward and each of the jets is dissipated as it flows upward through the overhead water. When the jets have reached the surface, the kinetic energy has been largely dissipated. The energy which remains is spread out radially so that it too is rapidly dissipated as it moves downstream.

The Bureau of Reclamation has developed special well-type of structures which dissipate jets issuing vertically upward or vertically downward into the wells. These structures are extremely useful for special installations associated with the control and delivery of irrigation water.

The flip-bucket or ski-jump type of spillway is an example of dissipation of energy in the vertical direction or a combination of dissipation in the vertical direction and the horizontal direction. This type of structure has been used for special installations but no generalized design criteria have been developed for it. It holds considerable promise, however, for use in connection with erosion-control structures. Actually, it has been developed to a much greater extent in Europe, in connection with large dams, than it has been in the United States even for small structures.

Protection Against Erosion

Protection against erosion by the high-velocity flow and the waves which are associated with energy dissipation structures may be either by rigid boundaries, such as concrete, or by alluvial boundaries, such as riprap armor-plating. Usually, rigid boundaries are extremely expensive and an attempt to economize on the thickness or design of rigid protection results in it breaking up or becoming undermined because of a lack of graded material underneath for protection.

The use of riprap as an armor-plating material has become increasingly popular as the need for more economical means of protection has increased. Unfortunately, however, considerable difficulty has been encountered in connection with the use of riprap material because confidence has been placed in the false theory that the larger the material the greater the protection. This has resulted in large rocks and broken pieces of concrete being dumped in to act as bank and bed protection downstream from structures. When such large objects are placed in the flow, high velocity jets are created around them and waves can lap in between them so that the fine material behind is gradually pulled out, the banks cave, the bed is eroded, and the riprap in some cases actually falls out of sight. In order to take full advantage of the large-size riprap, it is necessary to have a graded material underneath with sizes ranging from that of the bed and bank material up to that of the largest size of riprap. By this means such particle of riprap is protected by smaller particles underneath so that it will not become undermined.

Fortunately, one of the best forms of bank and bed protection is pit-run gravel because it has materials in it ranging from a small size to a large size -- thereby supplying its own protective gradation. This type of bank protection has been used very successfully and economically in many canals -- particularly in bends and downstream from structures where the high-velocity flow attacks the banks and the bed.

The same principles can be used in the protection of a scour hole underneath a jet which is falling vertically downward into a stilling pool, see Fig. 1c. Usually, it is not economical to dig the pool so deep that the jet will have all of its kinetic energy dissipated by the time it reaches the bottom of the pool. Therefore, it is helpful to line the stilling pool with a graded riprap material to protect it against scour and eventual undermining of the structure. Fig. 5 illustrates graphically the protection which occurs when riprap is used to reduce the scour in a scour hole under a jet falling vertically downward. With bed material having a maximum size of 1/4 inch, it may be seen that if the riprap is composed of only the large size, from 1-inch to 2-inch, it supplies much less protection than even the 1/4-inch to 1/2-inch size riprap. The graded riprap, however, which includes all sizes from 1/4 inch to 2-inches, supplies the maximum protection. Furthermore, this is the type of material which would most likely be found in a natural gravel pit.

<u>Summary</u>

1. The dissipation of kinetic energy in erosion-control structures may be accomplished in the horizontal direction, the vertical direction, or a combination of both directions, see Fig. 1.

2. Dissipation of energy in the horizontal direction has been given extensive study and the St. Anthony Falls Stilling Basin has been an outstanding result of laboratory and field investigations using this principle of energy dissipation.

3. Dissipation of energy in the vertical direction (either upward or downward), Fig. 1c and 1d, has received much less attention. Nevertheless, this method holds considerable promise for the development of structures which, in some cases, may dissipate energy at much less initial cost and over a smaller area than structures using the principle of energy dissipation in the horizontal direction.

4. A graded, pit-run, riprap has proven to be extremely effective as protection against erosion from high-velocity flow and waves. It is important, however, that the riprap be graded so that the larger-size material is protected from undermining by the smaller size material underneath.

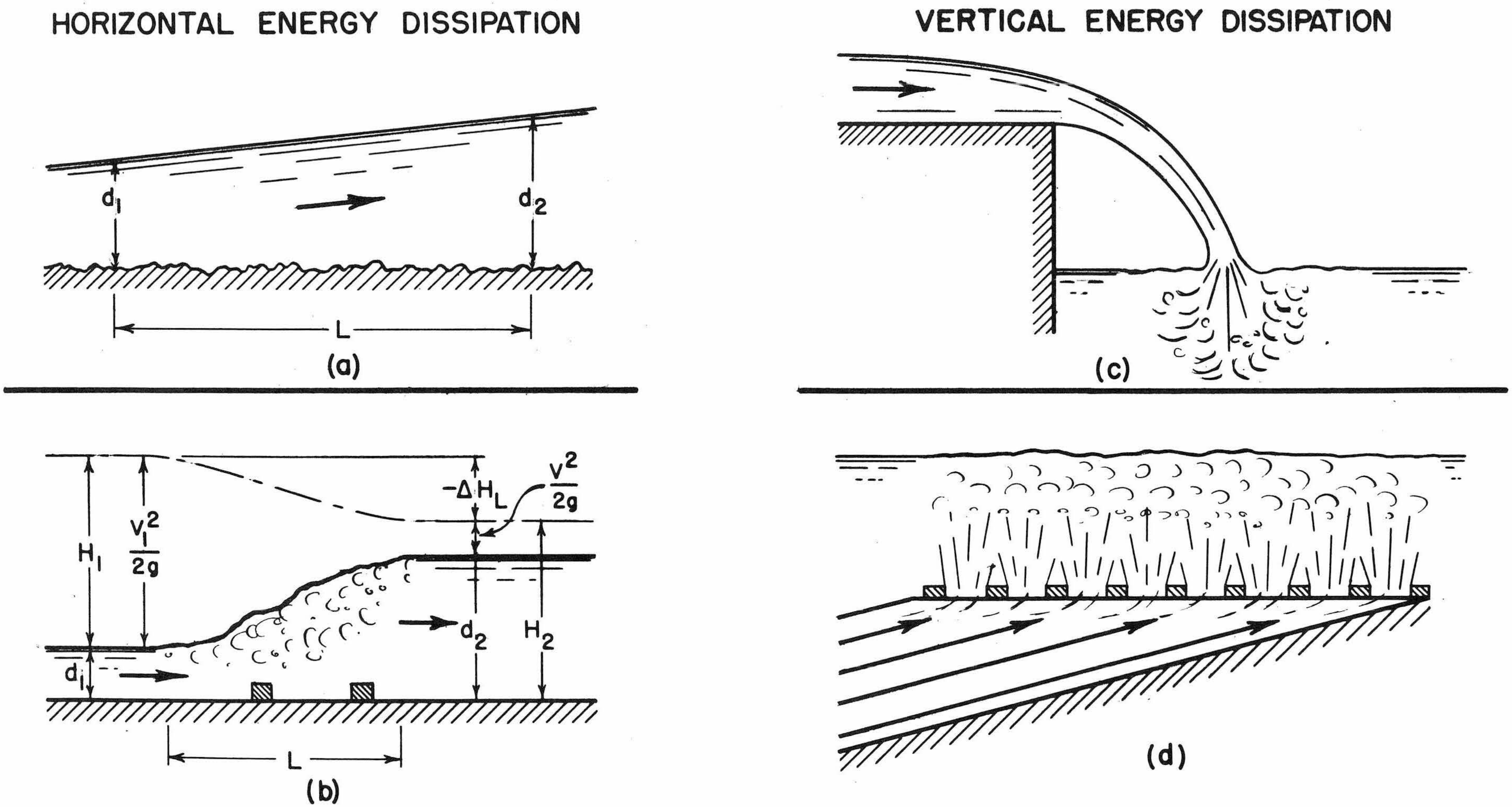

Fig. 1 Methods of dissipation of kinetic energy.
(a) channel resistance, (b) hydraulic jump,
(c) downward, (d) upward

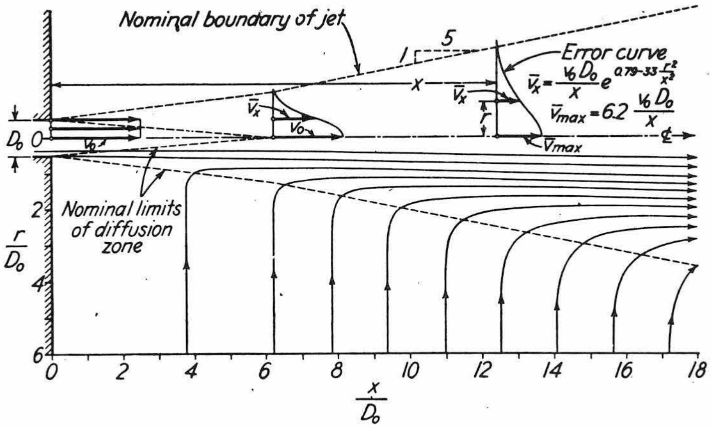

Fig. 2 Mean flow characteristics of a submerged jet

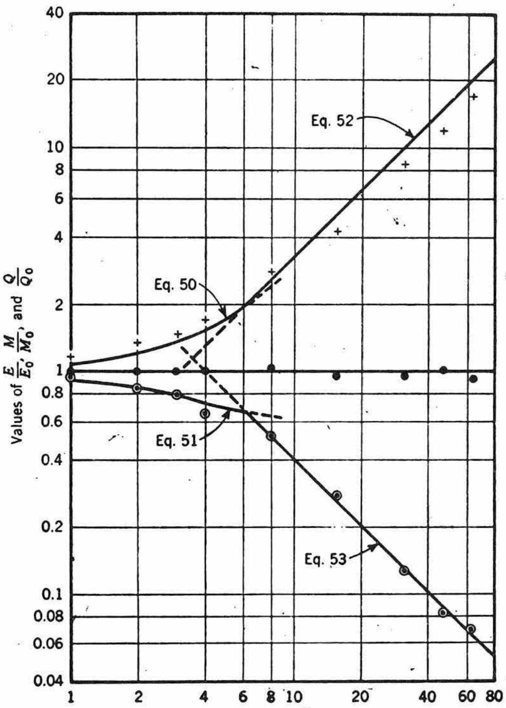

Fig. 3 Distribution of volume, momentum, and energy flux downstream from orifice

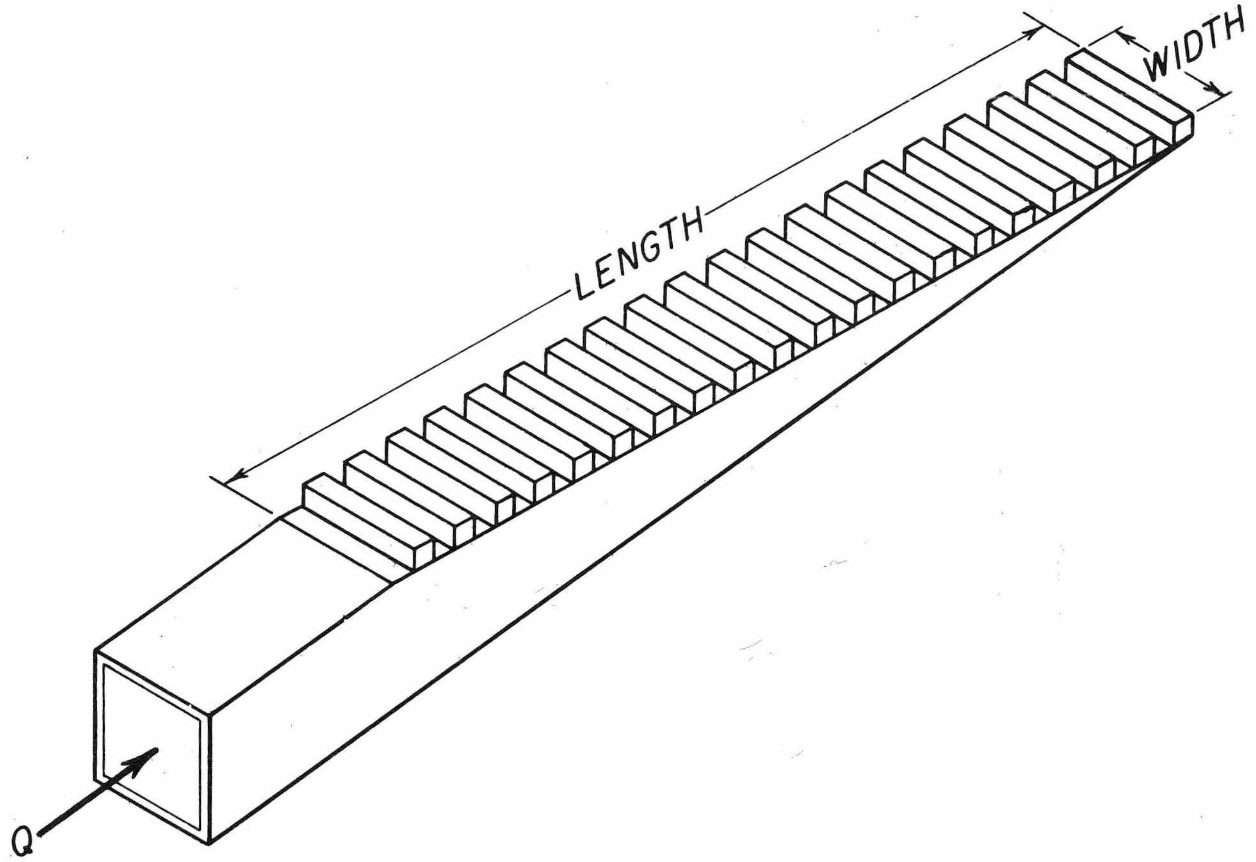

Fig. 4 Manifold stilling basin

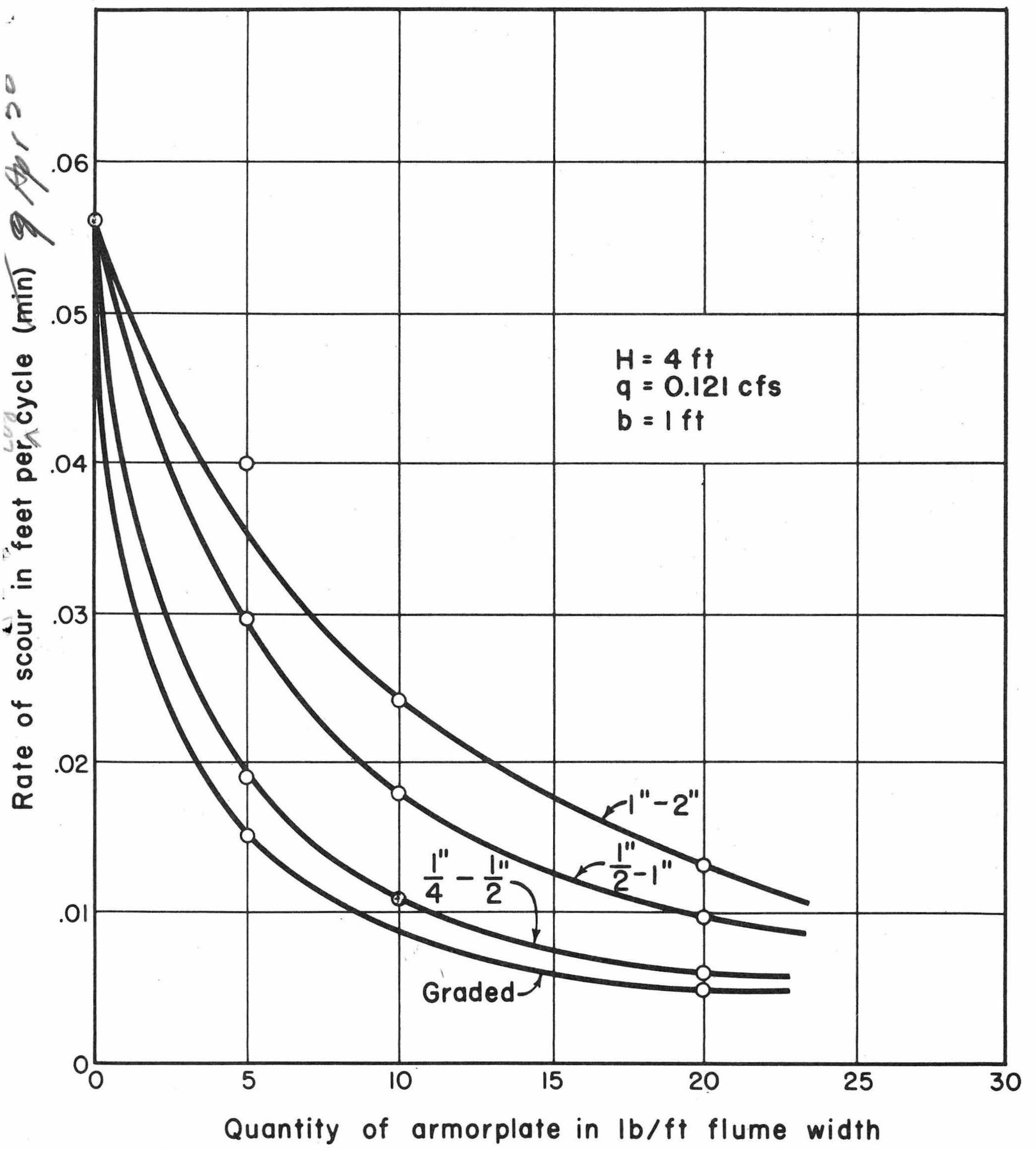

Fig. 5 Effect of armorplate on rate of scour