REMR Technical Note CS-MR-9.1

SPECIALIZED REPAIR TECHNIQUE: Repair of Structures Damaged by Abrasion-Erosion

PURPOSE: To provide information on the causes of abrasion-erosion damage to concrete and guidance on corrective actions and selection of repair materials.

PROBLEM: Abrasion-erosion damage is a major problem requiring repair in concrete hydraulic structures. Abrasion-erosion damage results from the abrasive effects of waterborne gravel, rocks, and other debris being circulated over a concrete surface during construction or operation of a hydraulic structure. Abrasion-erosion is readily recognized by the smooth, worn-appearing concrete surface, which is distinguished from the small holes and pits in the concrete surface formed by cavitation-erosion (see REMR Technical Note CS-MR-9.2). Apparently, the rate of erosion is dependent on the size, shape, quantity, and hardness of particles being transported, the velocity of the water, and the quality of the concrete. While high-quality concrete is capable of resisting high water velocities for many years with little or no damage, the concrete cannot withstand the abrasive action of debris grinding on its surface. In such cases, abrasion-erosion ranging in depth from a few inches to several feet can result depending on the flow conditions. Figure 1 shows the relationship between bottom velocity and the size of particles that velocity can transport. Flows of 10 fps are capable of transporting particles up to 15 in. in diameter.

CONCRETE DAMAGE: Spillway aprons, stilling basins, sluiceways, and tunnel linings are particularly susceptible to abrasion erosion.

A typical stilling basin design includes a downstream end sill from 3 to 20 ft high intended to create a permanent pool to aid in energy dissipation of high-velocity flows. Unfortunately, these pools also serve, in many cases, to trap rocks, reinforcing steel, and similar debris. The stilling basins at Libby and Dworshak Dams, high-head hydroelectric structures, were eroded to maximum depths of approximately 6 and 10 ft, respectively. In the latter case, nearly 2000 cy yd of concrete and bedrock were removed from the stilling basin by erosion. Impact forces associated with turbulent flows carrying large particles such as rocks and boulders may contribute to the surface damage of concrete in such structures.

There are many cases where the concrete in outlet works stilling basins of low-head structures has also exhibited abrasion-erosion damage. Chute blocks and baffles within the basin are particularly susceptible to abrasion-erosion. Also, there have been several cases where baffle blocks connected to the basin training walls have created eddy currents behind the baffles, resulting in significant localized damage to the stilling basin walls and floor slab.

In most cases, the presence of debris and subsequent abrasion-erosion damage

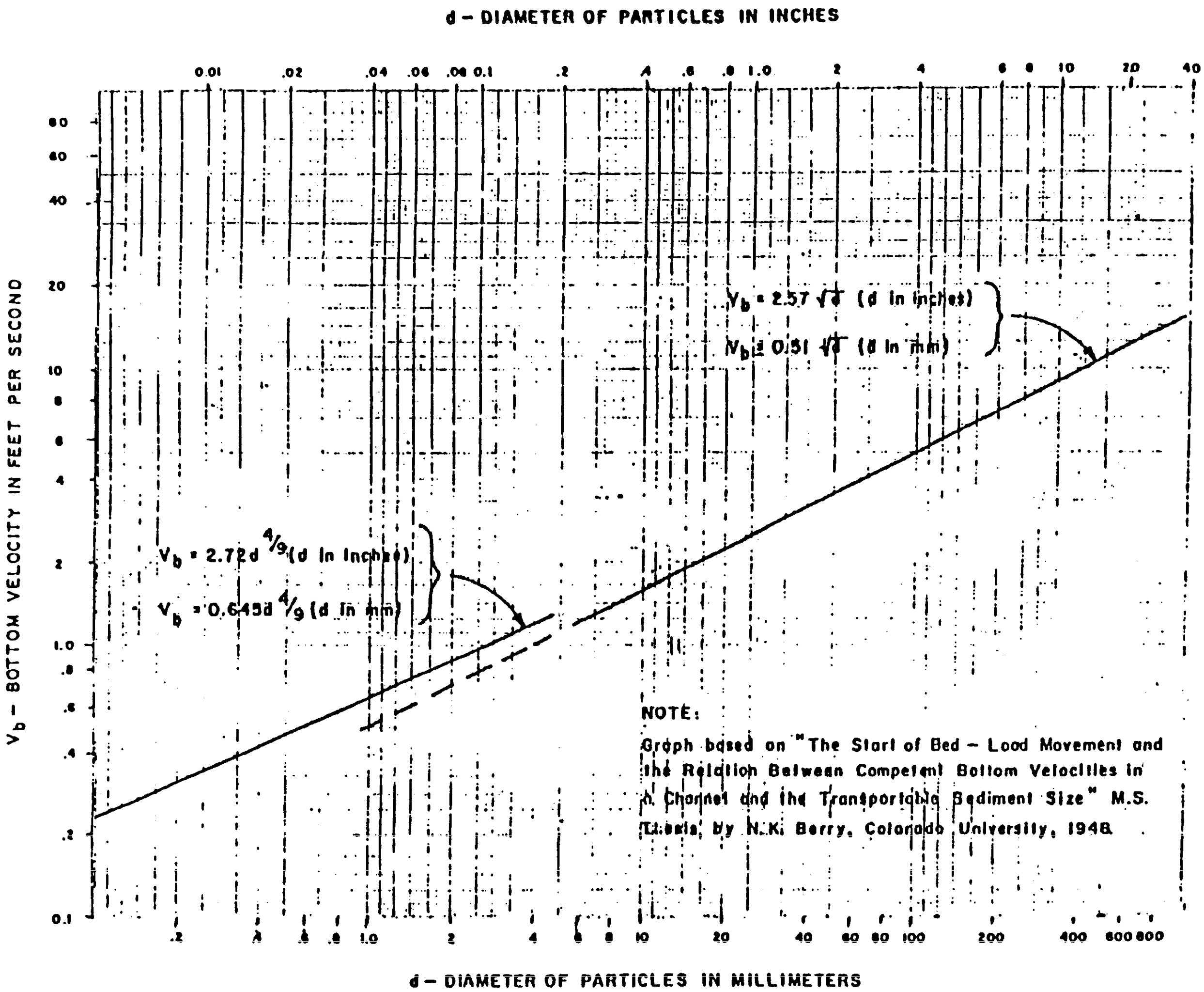

Figure 1. Relation between competent bottom velocity and transportable sediment size

is the result of one or more of the following: (a) construction diversion flow through constricted portions of the stilling basin; (b) eddy currents created by diversion flows or powerhouse discharges adjacent to the basin; (c) construction activities in the vicinity of the basin, particularly those involving cofferdams; (d) nonsymmetrical discharges into the basin; (e) separation of flow and eddy action within the basin sufficient to transport riprap from the exit channel into the basin; and (f) topography of the outflow channel (Ref a).

HYDRAULIC CONSIDERATIONS: Given appropriate flow conditions in the presence of debris, all of the construction materials currently being used in the repair of stilling basins are susceptible to some degree of erosion. While improvement of materials should reduce the rate of concrete damage due to erosion, this alone will not solve the problem. Until the adverse hydraulic conditions which can cause abrasion-erosion damage are minimized or eliminated, it will be extremely difficult for any of the construction materials currently being used to perform in the desired manner. Prior to repair of major structures, hydraulic model studies of the stilling basin should be conducted to identify potential causes of erosion damage and evaluate the effectiveness of various modifications in eliminating those undesirable hydraulic conditions. If the model test results indicate it is impractical to eliminate the undesirable hydraulic conditions, provision should be made in design to minimize future damage. For example, the following measures should be considered in repair of stilling basins:

a. Include provision (debris traps, low division walls, etc.) for minimizing circulation of debris.

b. Remove baffles which are connected to stilling basin walls.

c. Based on hydraulic model studies, revise the exit configuration (shape and height of end sill, training wall flare, shape of exit channel, etc.) to maximize flushing of the stilling basin and to minimize chances of debris from the exit channel entering the basin.

REPAIR MATERIALS: It is imperative that materials are tested and evaluated prior to use in hydraulic structures subjected to abrasion-erosion damage. A variety of test methods including rubbing types of apparatus, dressing wheel, shot blast (ASTM C 418), rolling steel balls under pressure (ASTM C 779), and modified Los Angeles rattles (ASTM C 131 and 535) have been used to determine abrasion-erosion resistance of concrete surfaces. These tests, designed to simulate heavy foot or wheeled traffic on concrete surfaces, are not intended to model abrasion by waterborne particles. The Corps of Engineers' test CRD-C 63-80, "Test Method for Abrasion-Erosion Resistance of Concrete (Underwater Method)" (Ref b), is a better model of the abrasive action of waterborne particles on a hydraulic structure. This test procedure involves subjecting the concrete specimens to abrasion-erosion caused by the wear of steel grinding balls on the concrete surface. The steel grinding balls are propelled by water in the test chamber. The water is in turn propelled by a submerged mixer paddle. Water velocity on the surface of the specimen is approximately 6 fps. Test specimens are periodically removed from the apparatus to determine the amount of abrasion-erosion damage. The damage is quantified and reported as a percentage of original mass lost. The development of the test procedure and data from tests of various concrete mixtures are described in Ref c. The following factors should be considered in selecting abrasion-erosion materials:

a. Abrasion-resistant concrete should include the maximum amount of hardest available coarse aggregate and the lowest practical water-cement ratio. The abrasion-erosion resistance of concrete containing chert aggregate has been shown to be approximately twice that of concrete containing limestone (Figure 2). Given a good, hard aggregate, any practice that produces a stronger paste structure will increase abrasion-erosion resistance. In some cases where hard aggregate was not available, high-range water-reducing admixtures and silica fume have been used to develop very high compressive strengths (approximately 15,000 psi at 28 days) and overcome problems with unsatisfactory aggregate (Ref d). Apparently, at these high compressive strengths, the hardened cement paste

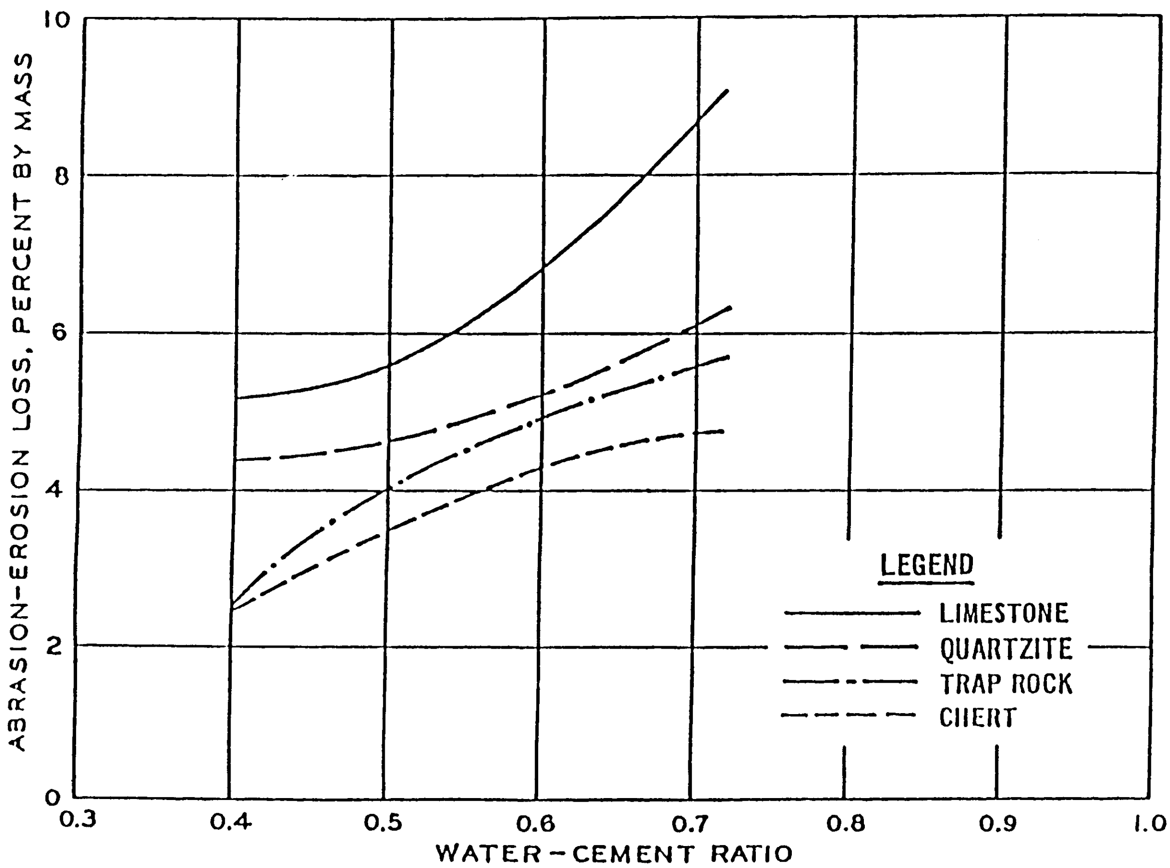

Figure 2. Relationship between water-cement ratio and abrasion-erosion loss

assumes a greater role in resisting abrasion-erosion damage and the aggregate quality becomes correspondingly less important.

b. While the addition of steel fibers would be expected to increase the impact resistance of concrete, fiber-reinforced concrete is consistently less resistant to abrasion-erosion than conventional concrete. This is attributed primarily to the fact that fiber-reinforced concrete generally has less coarse aggregate per unit volume of concrete than that of comparable conventional concrete.

c. The abrasion-erosion resistance of vacuum-treated concrete, polymer concrete, polymer-impregnated concrete, and polymer portland-cement concrete is significantly superior to that of comparable conventional concrete. The increased costs associated with materials, production, and placing of these and any other special concretes in comparison with conventional concrete should be considered during the evaluation process.

d. Several types of surface coatings have exhibited good abrasion-erosion resistance in laboratory tests. These include polyurethanes, epoxy resin mortar, furan resin mortar, acrylic mortar, and iron aggregate toppings. However, some difficulties have been reported (Ref e) in field applications of surface coatings, primarily due to improper surface preparation and thermal incompatibility between coatings and concrete. More recently, formulations have been developed which have properties more similar to the concrete substrate.

OPERATIONS: In existing structures, balanced flows into the basins, using all gates, should be maintained so as to avoid discharge conditions where eddy action is prevalent. Substantial discharges that can provide a good hydraulic jump without creating eddy action should be released periodically in an attempt to flush debris from the stilling basin. Guidance as to discharge and tailwater relations required for flushing should be developed through model-prototype tests. Periodic inspections should be required to determine the presence of debris in the stilling basin and the extent of erosion. If the debris cannot be removed by flushing operations, the basin should be cleaned by other means.

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