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LARGE-SCALE EMBANKMENT OVERTOPPING PROTECTION TESTS

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by

Kathleen H. Frizell and James F. Ruff

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Kathleen H. Frizell[1] and James F. Ruff,[2] F. ASCE

Abstract

The U.S. Bureau of Reclamation (Reclamation), Colorado State University (CSU), and the Electric Power Research Institute (EPRI) have an ongoing cooperative research effort to determine low-cost, feasible methods for providing overtopping protection for embankment dams. Investigations have progressed to testing an overlapping tapered concrete block shape developed from Reclamation's laboratory flume tests and installing the blocks over gravel filter material in a near-prototype size facility. The overlapping portion of the block produces an offset, or step, where drains, located through the blocks, provide relief of uplift pressure in the underlying filter. The test program in the large facility closely matched that of the laboratory. The stability of the overlapping tapered block system has been confirmed by the large scale tests.

Purpose

The purpose of conducting large scale tests of overtopping protection methods is to confirm Froude scaling relationships or develop other relationships between laboratory data and the near prototype size facility. Should the block system developed from the laboratory data (Frizell, 1992) show stability, then the results may be comfortably extended to any size actual embankment dam.

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1 Hydraulic Engineer, U.S. Bureau of Reclamation, P.O. Box 25007, Denver, CO 80225

2 Prof. of Civil Engineering, Colorado State University, Engineering Research Center, Fort Collins, CO 80523.

Large-scale Facility and Initial Tests

The outdoor overtopping facility is near-prototype size, with a height of 15.24 m (50 ft) and is located at CSU, in Fort Collins, Colorado. The facility, shown in Figure 1, consists of a concrete headbox, chute, tailbox, and sump with a pump. The concrete chute on a 2:1 (H:V) slope, has a maximum width of 3 m (10 ft) with a removable wall installed to reduce the chute width to 1.52 m (5 ft) for the current testing program. Water is supplied through a 0.91 m (3-ft) pipe from Horsetooth Reservoir. A portion of the flow can be recirculated by pumping back from the tailbox to increase the total discharge through the facility. Unit discharges up to about 2.94 $m^3/m/s$ (31.6 $ft^3/ft/s$) have been tested.

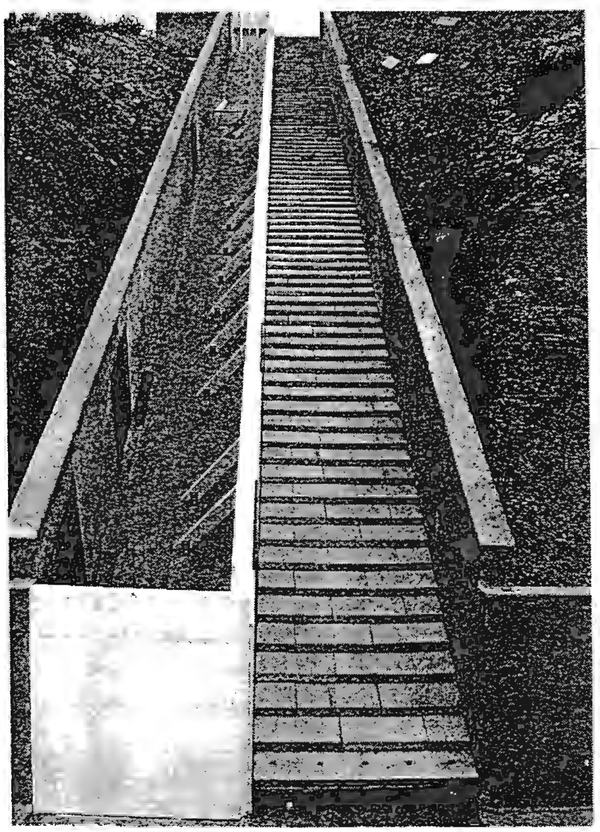

Figure 1. Fifty foot high flume facility used to test overlapping blocks for embankment dam protection.

Tests are currently being conducted on overlapping tapered concrete blocks design by Reclamation. The blocks are placed over 15.2 cm (6-in) of free-draining, angular, well graded, gravel filter material. The gravel is placed on the concrete floor with 10.1 cm (4-in) angle iron (with a gap above the floor to allow free discharge) placed every 1.81 m (6-ft) up the slope to prevent sliding. A wooden strip was installed along each wall to easily screen the gravel bedding and to prevent failure along the wall contact during operation.

The blocks, shown in Figure 2, are 0.37 m (1.23 ft) long and 63.5 mm (0.21 ft) high with a maximum thickness of 0.11 m (0.375 ft). The blocks are fabricated 0.61 m (2 ft) and/or 0.31 m (1 ft) wide with drains located through the block from the rise of the step to the underside. Two 0.61 m wide blocks and one 0.31 m wide block comprise each row in the facility. The blocks are installed shingle-fashion from the toe and are alternated so that there are no continuous seams in the flow direction except along the walls.

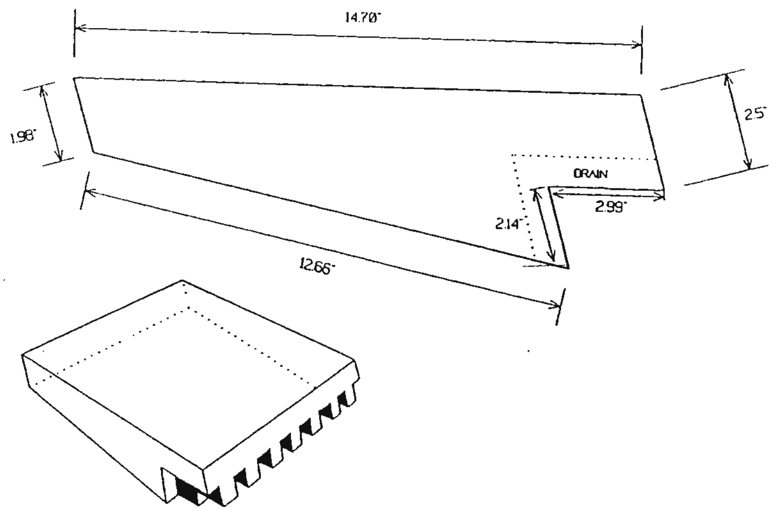

Figure 2. Wedge block dimensions.

At the crest of the structure, a small concrete cap was placed to transition from the flat approach to the first row of blocks. At the toe of the concrete slope is a fixed concrete end block to support the blocks up the slope. A row of blocks are tied down to the angle iron on the floor at about third points up the slope. Where the blocks will be under the tailwater at the toe of the slope, the blocks are pinned together longitudinally through the overlapping area parallel to the slope.

Test procedure

The laboratory tests performed by Reclamation in 1990 and 1991 are being repeated in the large scale facility. The initial tests, under flows similar to scaled laboratory flows, were conducted to obtain pressure data for block stability analyzes. The instrumented blocks (Fig. 2), and accompanying piezometer blocks buried in the gravel bedding, were installed in five locations down the slope of the facility. Pressures measured on the block faces and in the gravel bedding are used to determine the stability of the hydraulically designed block shape.

Flow description

During initial startup of the flume, under a very low discharge, the fines and dirt were flushed from the bedding material. Flushing lasted a very short time and was observed by the brief coloring of the water. After shutting off the water, slight settling of the blocks was apparent; however, there was no sliding or noticeable trend to the settling. Throughout the testing no further noticeable settling of the blocks occurred. The maximum settlement was about 2 to 3 cm (0.79 to 6.11 in).

The many discharges tested in the flume produced varied flow conditions over the blocks. The very small flows were almost entirely broken up by the block shape leaving no noticeable thickness of solid water. As the discharge increased, the boundary layer took longer to develop, eventually developing for the largest flow one third to one half the distance down the slope.

Stability

The question of stability of the protective system is the most critical for an embankment dam. Any failure or instability in the system could cause a catastrophic failure of the entire dam during an overtopping event. Laboratory data shows that the ability of the blocks to relieve the uplift pressure, combined with the impact of the water on the block surface, make the blocks inherently stable. The near-prototype tests, completed thus far to a unit discharge of 2.94 $m^3/m/s$ (31.6 $ft^3/ft/s$), indicate that the blocks are stable and will perform satisfactorily.

The stability of the block system has been analyzed as a function of the total forces acting on individual blocks down the slope. The block weight and impact pressure act on the block and slope in a downward (positive) direction to keep the blocks on the slope (Fig. 3). The uplift pressure in the bedding material underneath the block and the low pressure zone created by the block offset act in an upward (negative) direction tending to lift the blocks from the embankment surface. In the analysis, a net positive force indicates a stable block.

Pressure data were gathered to compute the magnitude of the forces acting on the block surfaces. In general, the pressures in the impact zone on the block increased with discharge and remained the same or decreased slightly with distance down the slope. Decreasing pressure magnitudes with distance down the slope are, most likely, a function of flow aeration. Of course, the weight of the block is constant. In general, the pressure in the offset area of the block decreases with discharge and distance down the slope. Between step 44 and step 74 down the embankment the pressures in the offset area became negative.

The uplift pressures were measured by using piezometer blocks buried in the gravel bedding at about the same locations down the slope as the instrumented blocks where surface pressures were measured.

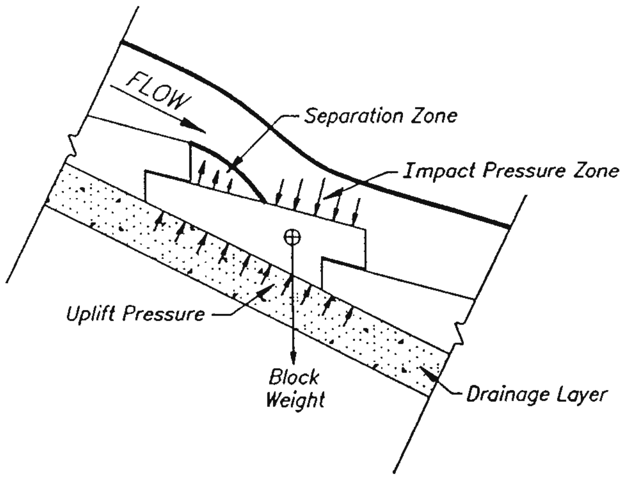

Figure 3. Forces acting on wedge block.

The underdrain pressures were assumed to be linear between the measurement locations. The underdrain pressures show a gradual increase over about the first 45 steps, as would be expected from the pressure data and low flow velocities. These data confirm the hypothesis that flow would be forced into the bedding near the top of the slope. At about 50 steps down the slope the pressures begin quickly decreasing to the fixed toe of the slope where the pressure increases slightly to about 0.15 m (0.5 ft) of positive pressure for all flow rates.

Conclusions

The overall stability of the block system down the slope is given in Figure 4. The resultant vertical force on the block at various locations down the slope is the sum of all the measured pressures integrated over the appropriate areas. These data show that the block system is stable at all locations down the slope and for all flow rates tested, with the exception of slight instability at the toe for the smallest unit discharge. In general, there is from 30 to 170 pounds of force per foot of width in the downward direction holding the blocks on the slope. In this initial analysis consideration was given to the additional benefit of block overlap. The overlap forces would further enhance the block system stability.

These initial calculations on the block stability confirm analytically the visual observation that the block system is inherently stable. This conclusion will be further investigated by more clearly defining the underdrain pressures with more measurement locations.

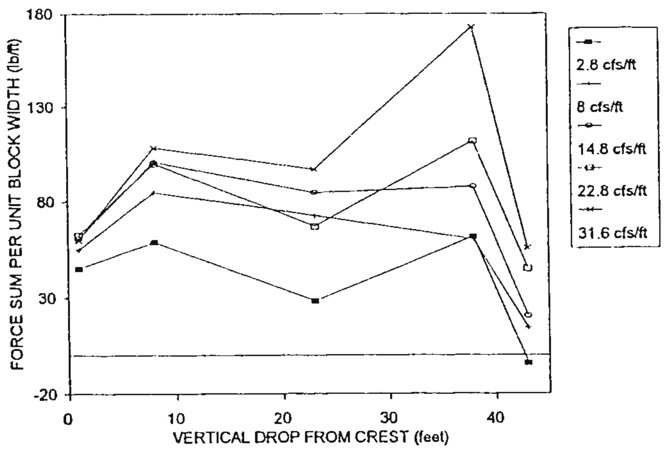

Figure 4. Block stability indicated by summation of pressure forces acting on wedge blocks at locations down the slope.

Future tests

Full model-prototype comparisons will be made at the completion of the tests in the spring of 1993. The remaining tests will primarily measure velocity, air concentration, additional pressures in the bedding material, and block stability under tailwater conditions. The final tests will address stability of the block system after satisfactorily initiating weaknesses in the block system.

Initial model/prototype comparisons show favorable scaling of the pressure field. Relationships and effect of air concentration on the velocity or pressure scaling have yet to be determined.

Upon completion of tests with the block system, the facility will be used to test large size riprap. This will allow confirmation of the numerous laboratory studies with riprap and determine the limits where riprap may be used to protect steep slopes during small overtopping events.

References

1. Frizell, K.H., 1992, "Hydraulics of stepped spillways for RCC dams and dam rehabilitations," Proceedings, 1992 ASCE Roller Compacted Concrete III Conference, pp. 423-439, San Diego, CA, February 2-5.