Joint Transportation Research Program

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A Laboratory Study of Apron-Riprap Design for Small-Culvert Outlets

The present study investigated primarily the appropriate stone sizing of on-grade riprap aprons, and more specifically whether the current INDOT design policy may be overly conservative, especially within the context of smaller culverts. In the study, laboratory experiments were performed with two pipe diameters, D = 4.25 in (0.35 ft) and 5.75 in (0.48 ft), and four stone sizes—median diameters estimated to be d_{50} = 0.61 in, 1.22 in, 1.73 in, and 2.24 in—for a range of discharges and tailwater depths. Video records were made of the laboratory apron to detect stone-mobilization events, and stable and unstable cases were distinguished. Logistic regression was then applied to develop equations delineating the boundary between stable and unstable regions for different riprap size classes in terms of d_{50}/D. These regression equations were then modified to ensure that they formed an ordered system in that each equation was more conservative than the next, to include a safety factor, and to set a minimum size for each size class consistent with the applicability of each equation. Procedures for applying the proposed equations are described.

Compared to the current INDOT design policy, the proposed approach typically predicts a smaller standard riprap class required for apron stability. In an application to a sample of actual culverts, the proposed approach, including the recommended safety factors, yielded a smaller required standard INDOT riprap class in 75% of cases, but, in a small number of cases with very low relative tailwater depths, the proposed approach did recommend a more conservative design. Of the other two main approaches to stone sizing for riprap aprons, the HEC-14 model was rather restricted in its range of application, but where applicable it was found to be

High-tailwater case

Low-tailwater case

somewhat more conservative in its stone-size recommendation, though in practice the recommended riprap class largely agreed with the proposed approach. The results of the other main approach, that due to Bohan (1970), were more erratic, with the maximum-tailwater equation being too lax and the minimum-tailwater equation being generally too stringent. Both the HEC-14 and the Bohan models tended to be less conservative than the proposed approach for larger values of d_{50}/D.

A secondary aim of the study was an examination of the velocity field downstream of the outlet, and the possible implications for scour downstream of the apron. Point velocity measurements were obtained for four cases, all with the same 4.25-in diameter pipe, three of which involved the largest (d_{50} = 2.2 in) stone, and one over a smooth bed. In the three cases with a stone apron, the apron extended a distance of ≈9*D* downstream of the outlet. In all four cases, substantial velocities (maximum velocities greater than 70% of the average outlet velocity) were observed beyond 4*D* (which is the minimum specified by INDOT design guidelines) and even beyond 8*D* (which is the largest apron length specified in HEC-14). A comparison between rough-bed and smooth-bed results indicated a measurable effect on maximum velocity due to the rough apron, but the reduction in maximum velocity is still likely insufficient to prevent scour downstream of the apron in most practical cases, even if the apron extends to 9*D*.

Reference

Bohan, J. P. (1970). *Erosion and riprap requirements at culvert and storm-drain outlets* (Research Report H-70-2). Vicksburg, MS: U.S. Army Engineer Waterways Station.

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