Ohio Department of Transportation Research Project Fact Sheet

Verification of ODOT Rock Channel Design Procedures

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The Problem

A rock channel protection (RCP) is a riprap blanket provided downstream of culverts and storm drains outlets to mitigate streambed erosion by dissipating the flow energy. During high floods and storms, water discharged from culverts carries substantial amounts of kinetic energy, posing a threat to the structural safety and stability of culverts. To prevent the structural failure of culverts, the Ohio Department of Transportation (ODOT) uses a design procedure for the optimum length of RCP protection based on Figure 1002-4 in Volume 2 of the ODOT *Location & Design Manual*. However, the origin of the ODOT RCP design procedure and the basis for the figure are unknown.

Research Approach

The concept of scaled modeling was applied using laboratory flumes at Ohio University (OHIO) and University of Michigan (Michigan) to experimentally investigate the relationship between the length and depth of the RCP layer, culvert size, and outlet velocity. For this investigation, 15 experiments were conducted in a hydraulic flume at OHIO and Michigan labs to verify the RCP lengths against outlet velocities of 5 fps (1.5 m/s), 12 fps (3.7 m/s) and 20 fps (6.1 m/s) by changing culvert size, RCP thickness and its type. To reduce the amount of RCP material (Type A, B, and C as recommended by ODOT) and discharge, three different scaling factors (λ = 12, 24, 30) were applied. In each experiment, three different threshold values of the outlet velocity were determined: 1) the velocity V_1 causing the formation of bedforms due to erosion, 2) the velocity V_2 at which scour hole depth equals RCP thickness, and 3) the velocity V_3 when RCP rocks are displaced.

Findings

The experimental findings of OHIO flume based on V_2 results indicated that the current ODOT design procedure for determining RCP lengths was conservative (Figure 1). However, the findings of Michigan flume showed that at lower velocities the ODOT design procedure was more conservative (Figure 2). It was also found that most of V_2 velocities of OHIO flume belonged to supercritical flow regime while those of Michigan flume were close to subcritical flow regime. Regarding the findings and their implication for field applications, the V_1 and V_3 results from both flumes demonstrated distinct characteristics. The V_1 graph did not display a clear trend, primarily due to the absence of an objective criterion for V_1 measurement. Conversely, the V_3 graph partly resembled the V_2 graph, as RCP failure occurred immediately after the removal of sand support due to the formation of a scour hole.

Recommendations

When considering outlet velocities within the subcritical flow regime, the design graph from the Michigan flume can be used, whereas for supercritical flow conditions, the graph from the OHIO flume is recommended. Sites with saturated soil may benefit from utilizing the OHIO graph, whereas those with unsaturated soil could find the Michigan graph more applicable. The experimental results of OHIO and Michigan flumes can provide upper and lower bounds for RCP length respectively. Moreover, the results of OHIO flume should be considered to design the culvert based on inlet control while the outcomes of

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Michigan flume can be used to design the culvert based on outlet control. Finally, to further specify the design criteria of RCP length, the design procedure should incorporate flowrate as a critical parameter.

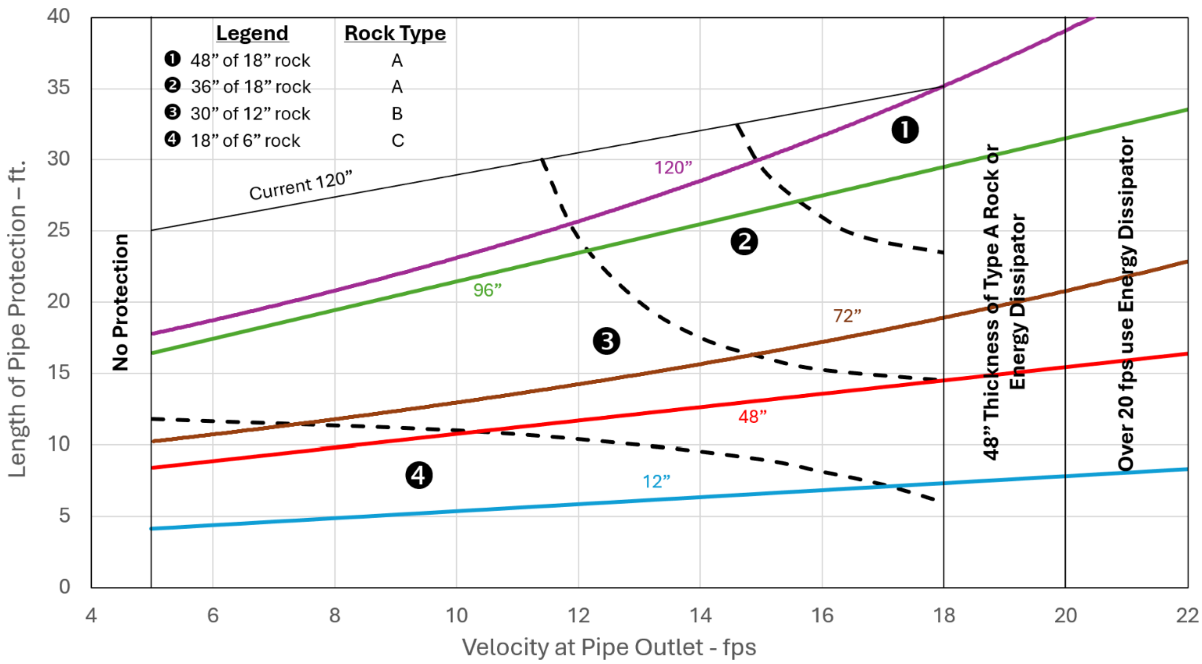

Figure 1. RCP design graph based on the regression of V2 data of OHIO flume. (12" = 1' = 1 ft = 0.305 m; 1 fps = 1 ft/s = 0.305 m/s) Note: Supercritical flow over saturated soil

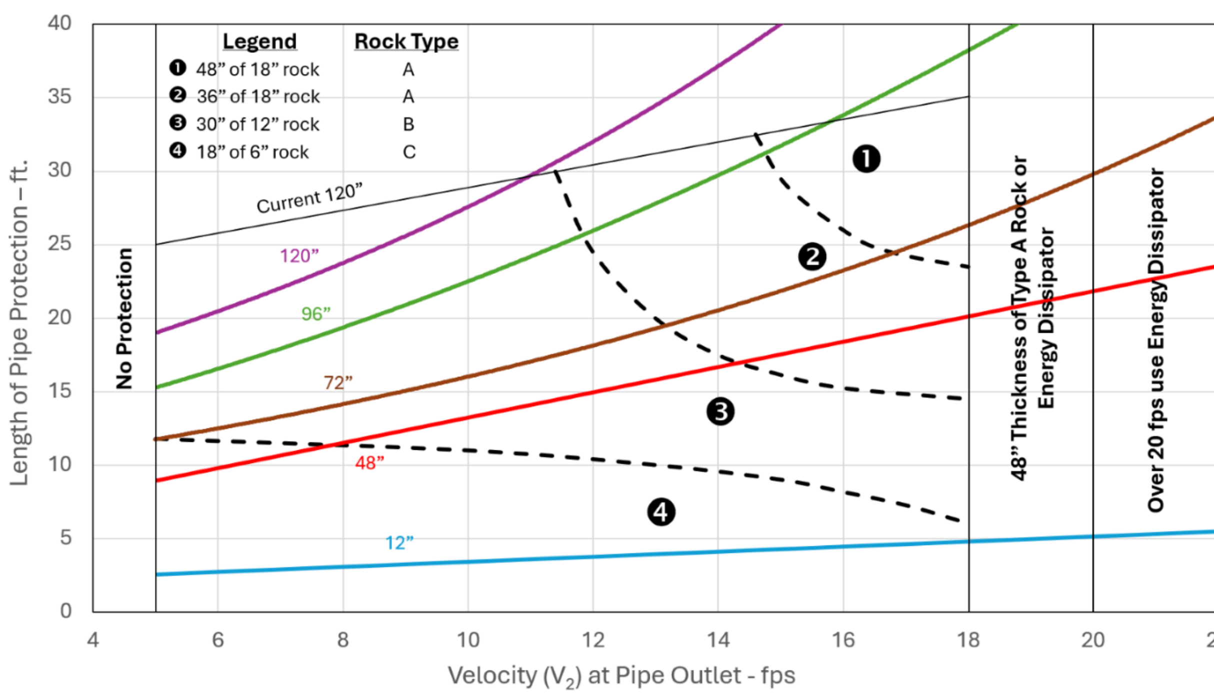

Figure 2. RCP design graph based on the regression of V2 data of Michigan flume. (12" = 1' = 1 ft = 0.305 m; 1 fps = 1 ft/s = 0.305 m/s) Note: Subcritical flow over unsaturated soil

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