Nebraska Department of Transportation
SPR FY21(009)
September 2023

Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Energy Dissipation Optimization for Circular Culverts

Research Objectives

The overarching objective of this research is: to develop and improve energy-dissipation designs for circular culverts in order to mitigate downstream erosion, lessen sedimentation and blockage by debris, minimize the footprint of the energy dissipation structure, and reduce installation cost.

To accomplish the above objective, the following goals have been identified: 1) Review information that is relevant to culvert energy dissipation, including energy dissipation downstream of box and round culverts, dam spillway stilling basins, state-of-the-art dissipation practices, and existing structures already constructed by NDOT. 2) Select types of dissipation structures for laboratory testing. The focus will be on two structures currently used by NDOT – the weir and the staggered weir wall types – that would benefit from formalized design documentation. Alternative types that are economical, have the greatest potential for dissipating energy, limit downstream impact, and are expected to effectively pass sediment and debris will also be considered. 3) Build models of selected types for hydraulic testing in the laboratory. 4) For a range of design flows, test different geometries of energy dissipation models (e.g., various heights and locations of weir walls) and simultaneously investigate economy, dissipation effectiveness, and self-cleaning capabilities. 5) Use the information collected in the lab to develop and optimize the methodology for designing dissipation structures, incorporating it into the existing NDOT design procedure.

Research Benefits

1. Documented design detail for all currently used dissipation structure types.
2. Possible extension of the design to include non-traditional applications such as sites with incomplete hydraulic jumps at the outlet.
3. Reduced cost of installation resulting from improved understanding of geometric limitations of the structures.
4. Decreased maintenance for new designs due to reduced sedimentation and clogging.
5. Smaller footprints for completed structures, leading to lessened right-of-way requirements, reduced environmental impacts, and expedited project delivery.
6. Improved effectiveness of the energy dissipation structures will lead to reduced downstream erosion impacts. Reduced erosion will lead to reduced sedimentation in downstream water bodies and wetlands.
7. Quantification of energy losses will include the transition from a circular pipe to a rectangular box structure, potentially resulting in size reductions of energy dissipation structure designs.

Background

Energy dissipation at culvert outlets is important for reducing harmful impacts of culvert outflows on the receiving channel and for minimizing soil loss through scour and erosion. Current energy dissipation methods for circular culverts include the use of riprap basins or rigid concrete structures. Both options require significant cost in materials, maintenance, and right-of-way.

The proposed research will review existing energy dissipation methods downstream of culverts, investigate weir energy dissipators and staggered weir walls for use with circular culverts, and study energy dissipator effectiveness for low-energy flows that lead to incomplete hydraulic jumps.

In 2004, NDOT research examined the use of weir energy dissipators for rectangular culverts. The method has proven valuable and effective for minimizing velocities and decreasing cost and has been included in FHWA's Hydraulic Engineering Circular No. 14: Hydraulic Design of Energy Dissipators for Culverts and Channels. NDOT has already installed similar dissipators (including weir and staggered weir wall dissipators) downstream of circular culverts, but there is no formal design procedure for this application. Although NDOT Roadway Hydraulics has developed methods of analysis for the new application, they do not have any guidance on the validity of the analysis method because no specific research has been conducted. The current method of analysis does not account for energy losses associated with the transition from a round pipe to a concrete box cross section. These additional losses may reduce the necessary size of the dissipation structure. As part of the proposed research, we would like to develop and validate a formal design procedure and simultaneously optimize design details of the resulting dissipator geometry.

In addition, it is of interest to extend the range of application of these dissipation structures to include low-energy flows that do not have the energy needed to form a complete hydraulic jump at the outlet. The result will be the ability to construct effective and cost-efficient energy dissipation structures for a more complete range of possible flow conditions.

Optimization of the design of these dissipators has the potential to simultaneously reduce construction and maintenance costs, reduce right-of-way requirements, and limit downstream wetland and channel impacts. Reducing wetland and channel impacts in the proximity of and downstream of the culverts has the potential to better satisfy environmental permitting requirements and expedite project delivery.

Conclusion

Two types of energy dissipation devices at circular culvert outlets were investigated: full-length weirs and staggered weirs. Related literature was reviewed; a model broken-back circular culvert and dissipation basin was built; instrumentation was installed to measure discharge, piezometric head, and velocities; and four sizes of full-length and staggered weirs were tested over a range of discharges and tailwaters. Weir heights ranged from D/8 to 4D/8, in which D was the culvert diameter. The two weir types were subjected to two styles of tests: (1) tests unaffected by tailwater and (2) tailwater-influenced tests. For tall full-length weirs (3D/8 and 4D/8), basin outlet depths could be reasonably predicted with a simple weir equation, general assumptions about the upstream flow, and the energy equation with no head losses. For shorter weirs (D/8 and 2D/8), the flow skimmed the weir, and the weir equation was invalid, especially for high discharges. In these cases, the weirs were not effective energy dissipators. For the tallest weirs, the ratio of outlet energy and the critical depth was roughly constant. The outlet specific energy was about 3.2 and 2.9 times the critical depth for weir heights of 4D/8 and 3D/8, respectively. Similar results were found for the staggered weir, but specific energy was found to be 2.7 and 2.9 times the critical depth for weir heights of 4D/8 and 3D/8, respectively. Results can be used to determine dissipation basin outlet velocities for incoming runout Froude numbers in the range of 3.8 to 4.6 for full length and staggered weirs with heights ranging from D/8 to 4D/8.

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Interested in finding out more?
Final report is available at:
NDOT Research Website

NDOT Recommendations Based Off Research Project

Upon completion of the present research, several potential improvements to the experimental setup and future energy dissipation structure tests were identified. Phase II of this project Optimization of Energy Dissipation Using Staggered Weirs will start July 2024, which will follow up with the following objectives:

a. Optimize the geometry of the staggered weir to improve its effectiveness.
b. Extend its range of applicability by modifying the testing system so that we can investigate a much wider set of inlet Froude numbers and inflow conditions.

The result will be a method that NDOT can apply to dissipate energy at circular culvert outlets. The method will reduce outlet erosion, while requiring less space and costing less than traditional energy dissipation methods.

- *As provided by Julie Ramirez, Lead TAC Member*

Research Readiness Level (RRL) Assessment

Level: Applied Research/Proof of Concept/Laboratory Level

RRL 2

Technology Transfer

Webinars/Presentations

- Hydraulic Measurements and Experimental Methods Conference, ASCE, Fort Collins Colorado, June 25-28, 2023

This brief summarizes Project SPR-FY21(009)
“Energy Dissipation Optimization for Circular Culverts”
Nebraska Department of Transportation Research Program