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ENERGY DISSIPATION IN THIRTY-FOOT BROKEN-BACK CULVERTS USING LABORATORY MODELS

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PROJECT TITLE
ENERGY DISSIPATION IN THIRTY-FOOT BROKEN-BACK CULVERTS USING LABORATORY MODELS

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OVERVIEW There are 121 scour-critical culverts on the Interstate System (ISTAT), the National Highway System (NHS), and the State Transportation Program (STP) in Oklahoma. The average replacement cost of these culverts is about $121M. The purpose of this project is to develop a means for energy dissipation in broken-back culverts so that deterioration (and expense) due to water scour can be minimized downstream.

RESULTS The purpose of a culvert is to safely pass water underneath the roadways constructed in hilly topography or on the side of a relatively steep hill. A broken-back culvert is used in areas of high relief and steep topography, as it has one or more breaks in profile slope (Figure 1).

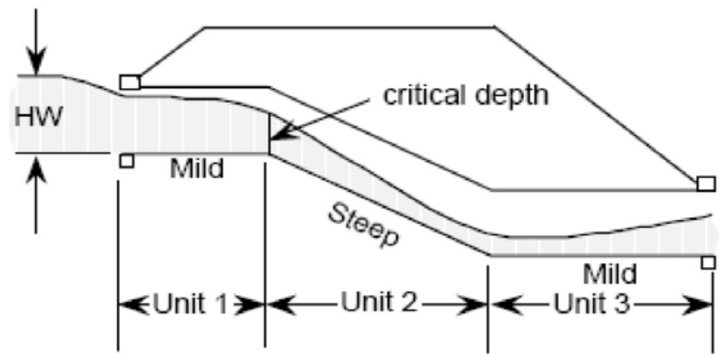

Figure 1 Illustration of Broken-Back Culvert Units

This research investigated the reduction in scour, which is a destructive form of erosion, downstream of a broken-back culvert by forming a hydraulic jump inside the culvert. The hydraulic jump is a natural phenomenon of a sudden rise in water level due to a change from supercritical flow to subcritical flow, i.e., when there is a sudden decrease in the velocity of the flow. This sudden change in velocity causes considerable turbulence and loss of energy. Consequently, the hydraulic jump has been recognized as an effective method for energy dissipation and scour mitigation.

Broken-back culvert experiments were conducted in the laboratory with scale models (Figure 2). The prototypes for these experiments included a two barrel 10-foot by 10-foot and a two barrel 10-foot by 20-foot reinforced concrete culvert with affixed friction blocks and/or sills to create the hydraulic jump and resultant energy loss. The drop between inlet and outlet was set at 30 feet (previous phases of this study investigated other drop heights). Three flow conditions were simulated, consisting of 0.8, 1.0 and 1.2 times the culvert depth.

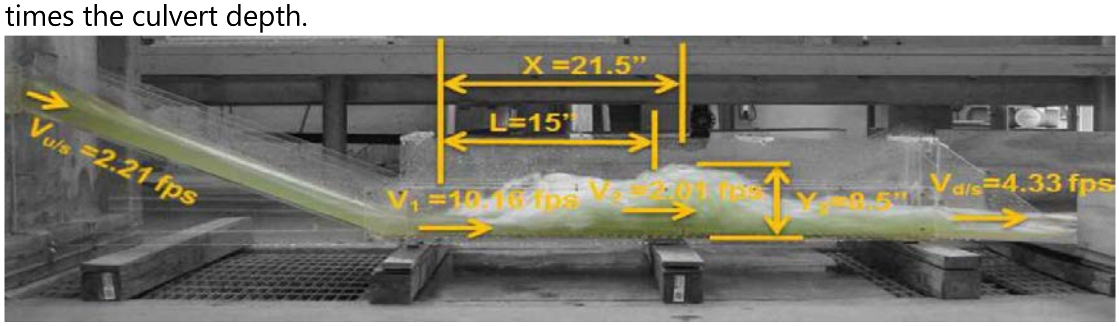

Figure 2 Hydraulic Jump Characteristics for an Experiment in this Study

The Froude number (Fr1) classifies the jump as an oscillating to steady jump. In this study, the Fr1 of the hydraulic jump created in the flat part of the culvert ranged between 2.53 and 5.66. The jump began nearly at the toe by placing sills and friction blocks of different sizes in the flat part.

This study provided guidance for optimal broken-back culvert design. For new culvert construction, the best option to maximize energy dissipation under open channel flow conditions is to use one 5.83-foot sill located 33.33 feet from the outlet. The maximum length of the culvert can be reduced by 25 feet to 30 feet using a middle sill. For existing and new culverts, the best option is to use one end sill with a height of 6.67 feet. In pressure flow conditions, the optimal location for a 4.17-foot sill was determined to be at a distance of 31.67 feet from the outlet. The length of the culvert can be reduced by 25 feet to 30 feet. Also, for new and existing culverts, the optimal end sill to use is one 4.17-foot sill under pressure flow conditions. Such a scenario is important where right-of-way problems exist for culvert construction.

A slotted sill was also investigated, which has a cut in the middle for cleanup purposes (Figure 3). The regular and slotted sills contain two small orifices at the bottom to allow the culvert to completely drain. The slotted sill was designed to perform similarly to the regular sill, but allow some additional water, sediments, and debris to pass through so there is less build up behind the sill. This study validated that provide nearly identical energy dissipation results. In open channel flow conditions, the best option to maximize energy dissipation is to use one 5.83-foot slotted sill located 33.33 feet from the outlet, and for end slotted sill, use 7.5-foot height. In the pressure flow conditions, the optimal slotted sill was 5-foot placed at a distance of 41.67 feet from the outlet, and for end slotted sill is to use 4.17-foot height.

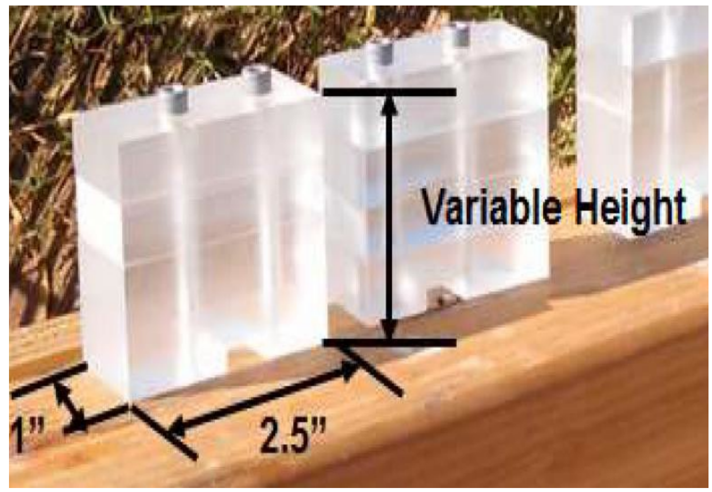

Figure 3 Slotted Sill

Several types of friction flat-faced friction blocks were tested. The impact of friction blocks on energy dissipation was found to be minimal. Friction blocks could not give sufficient energy dissipation by themselves, unless several larger friction blocks, such as 5 × 5 feet (3 × 3 inches in laboratory scale), was used. These large friction blocks worked like a sill if more than two friction blocks were placed. No friction blocks were used to further dissipate the energy.

The study found that slotted sill experiments yielded results most applicable to the new and existing construction of culverts for open and pressure flow conditions. Adding friction blocks to a slotted sill did not significantly increase the energy dissipation with these experiments. It was found that the friction blocks represented only a 2% increase in the energy dissipation; therefore they are not economical or practical to the culvert design. Also, the culvert barrel could be shortened by reducing a section at the end of the channel where the water surface profile is more uniform.

The following are the recommendations based on the results of the experiments:

- The slotted sill is recommended for use because of ease of cleaning drains faster and higher energy dissipation.
- Numerical modeling explores the possibility of flow of energy dissipation for any size of drop. Once the numerical modeling methodology is perfected, it can be used for any drop of broken-back culvert and will not have to be for fixed 6, 12, 18, 24, and 30 feet.

POTENTIAL BENEFITS The results of this study and a previous related study can enhance broken-back culvert design and help to mitigate costly water scour damage. The research targeted maximizing energy loss within the broken-back culvert, thus minimizing the scour around the culvert and decreasing the degradation in the downstream channel. This will reduce the construction and rehabilitation costs of culverts in Oklahoma.