

0-6549: Hydraulic Performance of Staggered-Barrel Culverts for Stream Crossing

Background

The interaction of sediment transport and drainage structures at highway stream crossings is a relatively ignored component of engineering design. Use of hydraulic structures to accommodate aquatic species is progressing, and this knowledge, at least conceptually, is relevant to the transport of stream-carried solids through hydraulic structures.

However, when bed material transport rates are relatively high and comprised of solids too large to travel in suspension, then current drainage structures might not function as intended. Under such conditions, solids may become trapped in and around the structure and lead to untimely service failures. This project attempted to understand how to accommodate such episodic loads of solids material using different culvert geometries—in particular the staggered-barrel configuration (Figure 1).

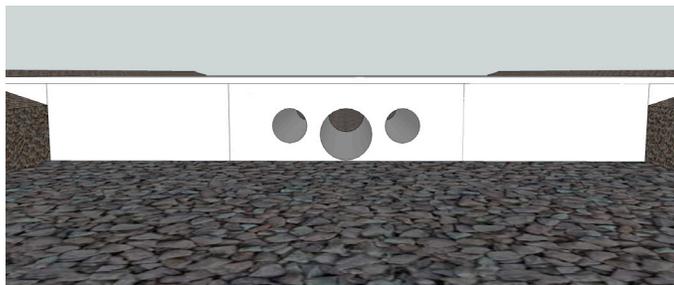


Figure 1. Staggered-Barrel Culvert System Sketch (Looking Upstream).

What the Researchers Did

Researchers conducted a literature review of relevant information from past studies on transport of solids in pipeline systems; specific studies examining sediment transport in single-barrel, multi-barrel, and bottomless culverts; and a summary of available bed load data. An extensive database of thousands of experiments and field studies was assembled into a screening tool to estimate solids transport from a minimal physical description of a stream system.

The screening tool uses a database-search or “similarity” algorithm (Figure 2) in a fashion similar to the Peterson design charts, which relate certain hydraulic properties

that are deemed assessable to practicing engineers, either by direct measurement or reasonable desktop approximation, to make estimates of mobile solids flux in a stream from predictor variables such as channel slope, clear-water discharge, and solids dimension.

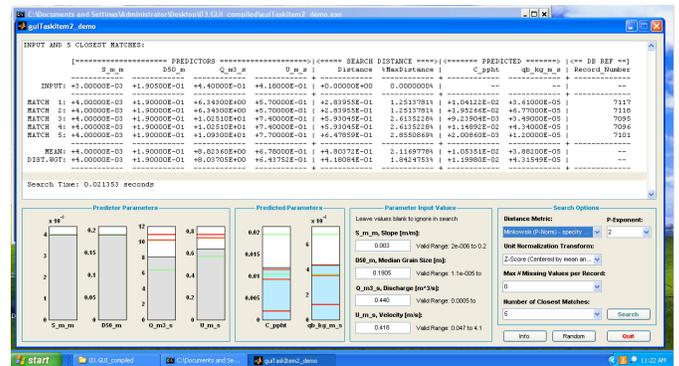


Figure 2. Screening Tool GUI.

Quantitative physical modeling using small models (Figure 3) was conducted to examine relative capability to convey solids through different types of culvert arrays to quantify, as far as practical, the volume of solids conveyed while accommodating hydraulic requirements. Several different models were examined: circular, rectangular, and staggered-elevation circular were the principal systems.

Both in-line (axis of culvert is aligned with the stream axis) and skew experiments were conducted. The model and literature results were analyzed to establish some guidance for solids management in mobile bed systems.

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Figure 3. Physical Modeling Laboratory.

What They Found

Based on the physical model experiments, with interpretation of the literature and limited field information, researchers found:

- As the slope of the systems increases, more solids are mobilized and moved through the system.
- As the area of culverts is increased, more solids are mobilized and moved through the system (Figure 4).
- The staggered-barrel systems performed consistently with their culvert open area. Hence, the experiments showed no particular advantage to the staggered-barrel systems, except in skew settings, where the staggered-barrel systems transported more solids than anticipated based on culvert open area.

Stage-conveyance plots showed that the largest open area systems have a curve closest to the approach section stage conveyance until submergence.

The screening tool was applied in several examples to show how it might be used to assess the impact of a culvert system in a solids transport situation. Solids size bracketing was used in the examples, and using the bracketing—assuming the other variables are more precisely known—the tool returned values consistent with experimental results.

What This Means

The physical model experiments were inconclusive; however, some general suggestions based on the literature

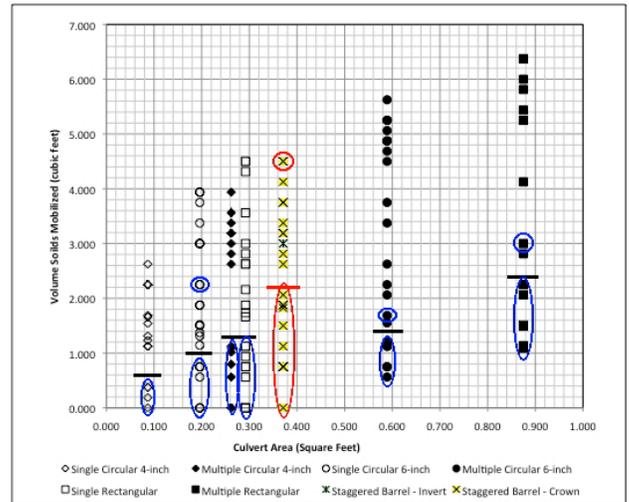


Figure 4. Solids Mobilized versus Culvert Area with Skew Experiments Identified.

examined, the actual experiments, and results from the screening tool suggest the following:

- Culvert open area is an important engineering decision with the following considerations:
 - The culvert system should be near the centerline of the stream to create the necessary acceleration to carry solids through the system. Spreading the culverts across the channel allows the approach flow to decelerate too much, wastes momentum, and allows deposition to occur.
 - The culvert system should match the stage conveyance of the approach section at the desired clear-water discharge. Circular arrays are likely to be more useful in incised streams. Different diameters like that of the staggered-barrel system make sense in such a matching exercise.
 - A main barrel should be at grade or slightly below the stream grade so that the solids do not have to move vertically to get through the system.
- Using the screening tool to predict culvert system capacity is illustrated in several examples.
- There is a lack of field results; post-event elevation surveys with the aim to produce accurate bed elevation models should be collected where practical and used to further refine the findings of this research.

For More Information

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