



Project Summary

Texas Department of Transportation

0-4695: Guidance for Design in Areas of Extreme Bed-Load Mobility

Background

TxDOT is responsible for many miles of off-system highways that serve remote areas of rural Texas. These highways cross many of Texas' ephemeral streams. On many of these roads, traffic loads are insufficient to justify bridges over the stream crossings. As a result, a large number of low-water crossings are used.

Conventional engineering solutions for low-water crossings are to design and construct a culvert to convey relatively frequent hydrologic events (probably on the order of the two- to five-year return interval event), then armor the abutments such that scour is mitigated whenever the low-water crossing is overtopped. However, for the ephemeral streams in the Hill Country of the Edwards Plateau, this approach was not always successful. Over a four-year period from 1998–2002, a review of TxDOT's Maintenance Management Information System (MMIS) records revealed that at least \$672K was spent by TxDOT in Edwards, Kimble, and Real Counties for removal of sediment deposits and low-water crossing repair or replacement.

An *ad hoc* approach developed as TxDOT engineers sought a solution to the problem. However, without a technical understanding of the interaction between stream dynamics and engineered low-water crossings, only partial solutions were derived. The objectives of this project are to develop science and technology to understand the source of the problem and develop design guidelines for implementing results of the research.

What the Researchers Did

The project was broken into two phases. During the first phase of the project, initial fieldwork at three sites was conducted to measure streambed particle size distributions and collect other data. A literature review, a review of the MMIS records, a qualitative numerical model, and a qualitative physical model were developed. In the interim report at the end of the first project phase, the researchers reported that the costs associated with bed-mobility at low-water crossings were substantial. The literature review did not discover existing solutions to the problem. A qualitative numerical model implementing Parker's method for estimating bedload transport was used. The model application was 2 of 2 intended to demonstrate that the interaction of bedload transport and channel modifications associated with construction of low-water crossings was sufficient to account for field observations during and after hydrologic events. The qualitative physical model was intended to demonstrate that field observations could be replicated in the laboratory, at least roughly, to justify further use of physical modeling in development of additional project work.

The second phase of the project was to take what was learned during the first phase of the project and apply it to develop potential solutions to the problem. A set of tasks were undertaken to address the research problem:

- A detailed hydrologic and hydraulic model was undertaken of Johnson Fork Creek as a demonstration of application of current technology (GIS for sediment supply, HEC-HMS for hydrologic modeling, HEC-RAS for hydraulic modeling, then application of the Einstein, Meyer-Peters-Müller, and Parker bedload transport models).

Research Performed by:

Center for Multidisciplinary Research in Transportation (TechMRT),
Texas Tech University

Research Supervisor:

David B. Thompson, TechMRT

Researchers:

Theodore G. Cleveland, TechMRT
Xing Fang, TechMRT

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- A detailed geomorphologic study was conducted of the Llano River watershed, which resulted in publication of Heitmuller and others (2005).
- Additional physical modeling was executed using bed materials obtained from the initial fieldwork and existing and proposed design approaches to low-water crossings.
- The qualitative numerical model was developed as a screening tool.

What They Found

- The TxDOT MMIS database is not sufficient for determining actual costs associated with streambed mobility at low-water crossings.
- The materials comprising the bedrock of the affected area, combined with watershed and channel slopes, are such that materials will mobilize during episodic hydrologic events.
- The event return interval required to mobilize streambed materials may be as frequent as the five-year event.
- Based on the geomorphologic analysis, bed materials mobilize when the channel Froude number is about 0.5.
- Detailed numerical modeling using GIS, HEC-HMS, and HEC-RAS is feasible, but costly. Application of the Einstein, Parker, and Meyer-Peters-Müller bedload transport methods can be used to predict changes in base level at points of interest along a stream channel.
- Application of physical models confirmed that bed materials mobilize for a Froude number of about 0.5.
- A variety of conventional design approaches were examined using physical models. Multiple-barrel culverts have the potential to “self-clear” if the barrels are aligned with the major flow direction of the stream. The barrels should be “large” in comparison to mean particle size. A porous-foundation roadbed, if one can be engineered, might change the mechanics for bed-sediment mobilization such that culvert clogging is alleviated.

What This Means

- Detailed numerical models can be used to assess changes in streambed base level at problem sites. Although costly to implement and requiring substantial technical expertise to construct and interpret, such numerical models can be used to test potential design solutions. However, before implementation of detailed numerical modeling is widespread, additional testing or application of the models should be done to build confidence in the tools.
- Mr. George “Rudy” Herrmann suggested a potential design solution late in the project term. The approach is to use three culverts, one large and two small, in an offset invert configuration. One of these was constructed and passed a large amount of bed sediments that had accumulated upstream from the crossing. This solution should be tested in the laboratory to determine what combination of barrel diameters solves the problem.
- Although not specifically tested, the stream-channel section changes associated with placement of the low-water crossing above base level and the sloping of the approaches to reduce the roadway slope both impact the stream power of the channel. Because sediment-transport capacity is related to stream power, low-water crossing designers should consider impacts on stream power associated with relatively-frequent hydrologic events such that significant decreases in stream power are mitigated.
- Raising the roadway above the streambed and armoring the approaches does not seem to be an appropriate solution. Concrete armoring is susceptible to failure because of hydrostatic pressure on the downstream side of the crossing. Increasing the roadbed elevation above the streambed exacerbates the reduction in stream power.

For More Information:

Research Engineer - German Claros, TxDOT, 512-465-7403
 Project Director - Lewis Nowlin, TxDOT, 325-446-9603
 Research Supervisor - David B. Thompson, TechMRT, 806-742-3485

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