Design Considerations for Embankment Protection During Overtopping Events

What Was the Need?
Roadways in the Red River watershed are prone to flooding and overtopping, where wide flows of water wash across the surface of the roadway. Downstream scour and erosion of roadway embankments can result in breach or washout of the entire roadway. Repairing the damage caused by flooding and overtopping can be costly and time-consuming, requiring lengthy road closures. Frequent flood events in recent years reinforce the need to protect roadways where flooding is likely to occur.

Raising the roadway to prevent overtopping is not a feasible solution, as flood plain law does not allow moving the problem elsewhere by backing up the water. The most cost-effective option is to allow floodwaters to overtop roadways and to try to protect their embankments from scour. Protecting roads from destructive scour and erosion by developing cost-effective scour prevention measures could greatly reduce the cost of repairs, as well as the time required to reopen the roadway after a flood event.

What Was Our Goal?
The goal of this project was to investigate the effectiveness of slope protection techniques to shield overtopped roadways and their downstream embankments from scour and erosion. A further goal was to use cost-effective methods that could be installed by local agencies instead of contractors. The researchers evaluated several “soft” design methods using an integrated approach of full-scale models and field monitoring.

What Did We Do?
Using the findings from a literature review, the research team developed a field-based program to collect data on the hydraulics associated with full-scale overtopping events. Researchers recorded flood stage at several locations near the Red River during overtopping events and evaluated the failure modes under natural conditions. Annual field monitoring occurred from 2013 through 2016 during overtopping events.

Next, the research team conducted a series of experiments at a full-scale laboratory facility to study the hydraulic and erosional processes associated with overtopping. The facility simulated a transverse section of a roadway and included an upstream water supply, road crest, shoulder and downstream embankment slope.

Two slopes were examined in the lab: 4:1 (horizontal:vertical) and 6:1. With bare soil used as a control, three erosion protection techniques were investigated: armored sod hydraulic soil stabilization, turf reinforcement mat (Enkamat) and flexible concrete geogrid mat (Flexamat). All three are alternatives to riprap and other hardscapes, and encourage vegetation to grow through a mat, helping to stabilize the soil and protect the embankment from scour and erosion.

What Did We Learn?
The researchers were able to draw some definitive conclusions from the laboratory experiments:

Roadway overtopping, where floodwaters flow unimpeded across roads, can be dangerous and costly. Researchers studied erosion, flow and shear stress to find new ways to protect roadways from this major safety concern.
Bare soil with no vegetative cover (the control) is highly susceptible to erosion and is the worst-case scenario. New installations should have established vegetation before the first overtopping event is expected.

All three mitigation techniques reduced erosion, but the flexible concrete geogrid mat provided the best protection. Researchers noted that these results describe overtopping that occurred immediately after the protection treatments were installed. Established vegetation and root growth would likely improve the performance of all techniques.

Initiation of erosion appears to be linked to small-scale inconsistencies in the soil, erosion control material and placement of the protection technique. Small failures can quickly develop into mass failure of the embankment.

Failure occurred in areas where the protection technique physically separated from the surface of the soil and exposed a direct pathway for the water to flow. Inflexible protection techniques were the poorest performers.

Common locations for failure were the toe of the slope and the upstream transition from the shoulder to the soil slope, with steeper slopes failing most often.

**What’s Next?**

No mature vegetation existed on the embankment slope in the laboratory flume, which mimics the post-construction period in the field. Full vegetation is more typical for much of an embankment’s life cycle. Since one of the most important functions of vegetation on a slope is the ability of its roots to anchor soil, further study of these techniques with mature vegetation could provide a better understanding of their effects.

Future studies should include other stabilization techniques as well as the effects of overtopping on frozen and thawing soils, through-embankment seepage or piping, and various soil types on performance of the stabilization technique. Future projects could also evaluate the use of multiple techniques along with the study of anchoring improvements and longevity of the erosion control products.

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“This project was a combination of basic and applied science, and is a great example of the university and MnDOT working together successfully to solve problems unique to our geography and climate.”

—Jeff Marr,
Associate Director,
Engineering and Facilities,
University of Minnesota
St. Anthony Falls Laboratory

“This project developed a fairly complete matrix of useful erosion protection measures that our own staff can implement—techniques that are less elaborate and more cost-effective than hiring contractors.”

—J.T. Anderson,
Assistant District Engineer, MnDOT District 2

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Sod is overlaid with geogrid to help stabilize the sod’s root system and soil beneath.