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Geo-Infrastructure Damage Assessment, Repair and Mitigation Strategies

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Problem Statement

The 2011 Missouri river flooding caused damage to many geo-infrastructure systems including levees, bridge abutments/foundations, paved and unpaved roadways, culverts, and embankment slopes in western Iowa. The total reported direct cost to repair flood-damaged transportation infrastructure on primary and secondary roadways in western Iowa was about $63.5 million. The extent of damage was in some cases directly observable, i.e., where segments of the roadway were washed away, but in many cases was undetermined, i.e., where the damage was below the pavement surface or around bridges.

Project Goals

The main goals of this research project were to assist county and city engineers by deploying and using advanced technologies to rapidly assess the damage to geo-infrastructure and develop guidance for repair and mitigation strategies and solutions for use during future flood events in Iowa.

Summary of Flood Damages Observed

Based on field reconnaissance of the flood-damaged areas (Figure 1), review of the damage inspection reports, and interviews with county engineers, the damages observed are summarized in Table 1.

Table 1. Summary of flood damages

<table>
<thead>
<tr>
<th>Paved Roadways</th>
<th>Bridges</th>
<th>Culverts</th>
<th>Unpaved Roadways</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Voids at shallow depths (&lt; 150 mm (6 in.)) due to erosion of base material</td>
<td>• Erosion of bridge approach backfill material</td>
<td>• Erosion of culvert backfill</td>
<td>• Erosion of gravel surface</td>
</tr>
<tr>
<td>• Voids at deeper depths (&gt; 150 mm (6 in.)) due to erosion of subsurface material</td>
<td>• Erosion of embankment foreslopes</td>
<td>• Separation of culverts</td>
<td>• Rutting under traffic loading (on gravel roads and other detoured roadways due to excessive loading, although not flooded)</td>
</tr>
<tr>
<td>• Complete erosion of pavements and underlying base/subgrade material</td>
<td>• Water outflow blockage</td>
<td>• Water outflow blockage</td>
<td>• Full breach of roadway embankments</td>
</tr>
<tr>
<td>• Erosion of granular shoulders</td>
<td></td>
<td>• Erosion of culvert backfill</td>
<td></td>
</tr>
</tbody>
</table>

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Figure 1. Post-flood damages

- Pavement damage due to erosion
- Full breach of roadway embankment
- Erosion of granular shoulder
- Erosion of abutment backfill
- Stripping of chip seal surface
- Cement grouting to fill eroded base

Figure 2. Ground penetrating radar scanning at a bridge site to identify subsurface voids/erosion in approach backfill

Figure 3. Laser scanning at a bridge site showing raw point cloud data and merged point cloud with photo
Key Findings and Outcomes

- FWD tests obtained shortly (< 30 days) after flooding indicated that the average modulus values in flooded zones were about 1.3 to 3.6 times lower than the values in non-flooded zones (see Figure 5 for example). In some areas, the foundation layers within the flooded zone gained strength over time, likely as the degree of saturation in the subgrade decreased. However, many sections did not show much improvement.

- FWD surface modulus measurements were influenced more so by the subgrade layer (which was relatively weaker) than the surface gravel layer.

- A simple chart was developed to predict modulus values from subgrade and gravel California bearing ratio (CBR) values along with typical values for different subgrade treatments, which can be helpful in determining target values.

- Erosion of backfill materials around culverts was observed at several locations, which in some cases resulted in potholes and complete breach of the roadways.

- Erosion of bridge approach backfill materials was observed at the two bridge sites assessed in this study, resulting in voids down to about 2 m (6.6 ft) below surface.

- Ground penetrating radar scanning identified changes in gravel layer thicknesses, culvert locations, weep holes under roadways, voids beneath pavements, and voids in bridge approach backfill materials.

- Three-dimensional (3D) laser scanning was performed at a breach site to demonstrate rapid and accurate volumetric calculations.

- A flow chart relating the damages, assessment techniques, and 20 different potential repair/mitigation solutions was developed (Figure 6).

Implementation Benefits and Readiness

Figure 6. Flow chart to select assessment techniques and repair/mitigation solutions.

1. Determine Critical Locations
   - Based on aerial imagery, LiDAR, contours map, visual inspection, floodwater depth, and historical information

2. Flood Water Receded?
   - YES
     - STAGE 1 Assessment
       - Identify areas with traffic safety concern (large subsurface voids)
       - Aerial Survey Visual Survey GPR Penetration Tests
   - NO
     - STAGE 2 Assessment
     - Paved Roadways
     - Unpaved Roadways
     - Bridge Abutments
     - Culverts
     - Backfill Erosion/Weep Holes
     - Culvert Separation
     - Outflow Blockage

- Damage to be evaluated: Underwater
- Using robotic pipelines/inspection methods
- At selected locations based on GPR scans
- Determine FWD modulus or CBR of subgrade to select appropriate treatment/stabilization options (refer to Chart)
- If water is still present in the culverts
- For dewatering in situ, only:
- For slurrying concrete (only if voids are small enough for the equipment to safely drive over the concrete)
- Control lift thickness as appropriate to compaction equipment
- On low-volume bridges
- Using rip-rap with geosynthetic over natural material
- Potential Mitigation Solutions

Assessment Options:
- Culverts
- Bridge Abutment/Culvert Backfill
- Paved/Unpaved Roadways
- Aerial Survey Pipe Crawler Underwater Sonar
- Aerial Survey Underwater Sonar
- Aerial Survey LiDAR

Initiate repair measures (Go to 4B)

- Voids at shallow depths (< 0.5 ft) due to erosion
- Voids at deeper depths (> 0.5 ft) due to erosion
- Complete Erosion of Base/Pavement
- Erosion of Granular Shoulders
- Full Breach of Embankment
- Erosion of Gravel Surface
- Rutting under Traffic Loading
- Abutment Backfill Erosion (Voids)
- Embankment Foreforeside Erosion
- Visual inspection, Pipe Crawler Underwater Sonar

Repair and Mitigation Solutions:
- A. Bio-Stabilization
- B. Bulk-Infil (Cement) Grouting
- C. Chemical Grouting
- D. Chemical Stabilization of Subgrade/Base
- E. Combined Soil Stabilization with Vertical Columns
- F. Electro-Osmosis
- G. Excavation and Replacement, H. Excavation and Replacement (using non-erodible fill), I. Fiber Reinforcement of Subgrade/Base
- J. Geosynthetic Reinforced Soil for Approach Backfill
- K. Geosynthetic Reinforcement/Seepage Drainage
- L. Geocell Confinement of Granular Materials
- M. High Energy Impact Roller Compaction
- N. Injected Light Weight Foam Fill
- O. Mechanical Stabilization (Blending)
- P. On-Site Recycling of Pavement Materials
- Q. Partial Encapsulation
- R. Rapid Impact Compaction, S. Sheet Pile Abutments, T. Rip-Rap for Erosion Protection

Notes:
- *Need field trials to evaluate effectiveness
- *Grouting voids when saturated can affect grout setting. Dewatering is recommended before grouting. Additional research is warranted in evaluating alternative materials for grouting.
- *Refer to chart for typical GBR or modulus values
- *May not be a viable option if subgrade is saturated/wet
- *Injecting foam under saturated conditions need additional evaluation