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U.S. Department of Transportation
Federal Highway Administration

U.S. DOT Gulf Coast Study, Phase 2

Engineering Case Study 1: Culvert Exposure to Precipitation Changes

This is one of 11 engineering case studies conducted under the Gulf Coast 2, Phase 2 Project. This case study focused on the vulnerability of a culvert to increased precipitation.

Description of the Site and Facility

Airport Boulevard is a major six-lane east-west arterial, flanked by a pair of two-lane bi-directional frontage roads that also utilize the culvert. According to Alabama Department of Transportation standards, the culvert should have at least 2 feet (0.6 meters) of freeboard above the 25-year flood level. This case study focused on whether this minimum amount of freeboard would be maintained under future potential climate scenarios. Flooding impacts on surrounding areas were also evaluated, based on performance of the culvert under potential future 100-year flood events.

Montlimar Creek is a man-made drainage canal. As can be seen in Figure 1, the Airport Boulevard culvert over Montlimar Creek is a four cell concrete box culvert with each cell having a 12 foot (3.7 meter) span (width) by eight foot (2.4 meter) rise (height). The culvert lies within a FEMA 100-year flood plain.

Climate Stressors and Scenarios Evaluated and Impacts on the Facility

Precipitation (and the resulting flow) is the primary environmental factor affecting the design of the culvert.

Climate data used in the analysis includes 24-hour precipitation depths for the 25-, and 100-year storm under each of the following scenarios:

- Observed precipitation values (1980-2009).
- The NOAA Atlas 14 90% Upper Confidence Limit.
- The "Wetter" narrative precipitation ranges developed under this project using downscaled climate data (end-of-century, 2070-2099 time period).[1]

These precipitation values were used to calculate the peak flow passing through the culvert using the U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) WinTR-20 program. The culvert performance was then evaluated using FHWA's HY-8 Version 7.2 program.

The analysis found that, under projected future precipitation scenarios, the culvert might not be adequate for the 25-year event. Not only were the freeboard requirements not maintained, but the roadway could actually be overtopped.

The potential extent of flooding during a future 100-year event was also evaluated, and the analysis showed that flooding could occur in the area east of the culvert.

1 For more information on the climate information referenced here, please refer to Climate Variability in Change in Mobile, AL (USDOT, 2012) and Screening for Vulnerability (USDOT, 2014).

Figure 1: Airport Boulevard Culvert over Montlimar Creek in Mobile, Alabama.
Photo credit: Jake Keller (Parsons Brinckerhoff).

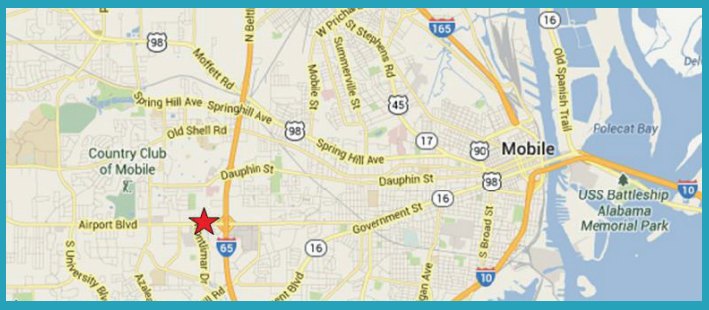

Figure 2: Location of Culvert in Mobile, Alabama.

Identification and Evaluation of Adaptation Options

The analysis identified four potential adaptation options, as shown in Table 1.

The effectiveness of increasing the number of culvert cells and increasing the size of the culvert was evaluated using the following steps:

1. The ability of the culvert (with the adaptation options implemented) to handle the range of projected 24-hour rainfall values and NOAA temporal rainfall distributions was assessed. Peak flows to the culvert were modeled using the Win TR-20 Program.
2. The hydraulic performance of the culvert (with the adaptation options implemented) under current and future flows was assessed using the HY-8 Version 7.2 program. Future culvert performance was assessed by determining whether at least 2 feet of freeboard would be achieved during a 25-year event, which is the standard used by the city of Mobile for this type of culvert.
3. Then, a Monte Carlo analysis was used to determine the adaptation option that is most likely to be cost-effective given the uncertainty associated with climate change. This analysis considered the two adaptation options involving culvert modification, and compared them against a business-as-usual scenario.

Measures	Description	Analysis	Conclusions
Regional drainage area management	Consider the entire drainage area and determine how best to manage drainage; for example, by putting restrictions on development or building more detention/ retention facilities.	Effectiveness not quantitatively analyzed because the analysis was meant to be site-specific, rather than incorporating the larger watershed.	An integrated plan could help reduce flooding risks over an area larger than just this culvert. However, a large-scale plan could have a lengthy implementation timeline and be costly.
Replace culvert with a bridge	Replace the culvert with a bridge to create a larger hydraulic opening.	Effectiveness not analyzed because the addition of a bridge would require major reconstruction of the roadway in order to achieve sufficient structure depth.	In this situation, the adaptation measure was deemed too costly to be a reasonable adaptation measure.
Culvert Modification – Add culvert cells (Option 1)	Add one 12 foot (3.7 meter) span by eight foot (2.4 meter) rise box culvert cell on each side of existing crossing.	Adaptation measures evaluated for current and projected 25- and 100-year events to understand whether the 2-foot minimum freeboard requirement would still be met.	Estimated to cost roughly $1.7 Million, and would be sufficient to meet the freeboard requirements under a lesser climate scenario.
Culvert Modification – Replace crossing with larger crossing (Option 2)	Replace current crossing with the largest crossing that would fit within the available space.		Estimated to cost roughly $2.5 Million, and would be sufficient to meet the freeboard requirements under a more extreme climate scenario.

Table 1: Potential Adaptation Measures

Potential Course of Action

The culvert design is sufficient for current conditions, but the roadway could be overtopped under projected future conditions. Increasing the size of the culvert would meet Mobile's design standards under all 25-year storm event scenarios, while increasing the number of culvert cells would not meet the design standards during a 25-year storm event under the more extreme climate scenario considered. However, while both adaptation options were determined to be economically feasible, increasing the number of culvert cells (Option 1) is more cost effective. The increased flood protection offered by increasing the culvert size is sufficient to outweigh its cost; meanwhile, the additional protection offered by Option 2 does not outweigh its marginal cost. The economic assessment also showed that there are likely to be substantial costs incurred if no adaptation actions are taken to address expected flooding at the culvert.

Lessons Learned

Culverts must be studied as part of a system. Managing the flow through one culvert may negatively impact downstream assets.

Monte Carlo analyses can be used in economic assessments to address the uncertainty of climate events. However, benefit-cost analyses are greatly influenced by what is included within the bounds of the analysis; this case study suggests a need to consider benefits beyond the road right-of-way.

For More Information

Resources:

Gulf Coast Study:
Engineering Assessments of Climate Change Impacts and Adaptation Measures

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