Bridge Deck Drainage

Introduction

The presence of bridge barriers, curbs, and raised medians impedes the ability of rainfall runoff to drain off of bridge decks into ditch systems, as it does on a typical barrier free rural roadway. Instead, rainfall collects and is channeled along these barriers until it reaches a drainage point of sufficient capacity (such as a deck drain or the end of the barrier). An insufficient drainage point can result in ponding of this runoff, resulting in encroachment onto the roadway surface and may result in hydroplaning if sufficient depth of water accumulates.

Encroachment of drainage water onto driving lanes can result in a road safety hazard due to hydroplaning and driver expectations of a clear roadway. Drivers generally expect a consistent experience on a certain classification of road. The presence of bridges can introduce unexpected differences, including changes in drainage. These changes can result in unpredictable driver behavior such as swerving or braking.

Hydroplaning is a phenomenon in which a thin layer of water film prevents direct contact between the vehicle tires and the roadway, resulting in a loss of driver control. Prediction of hydroplaning occurrence has been linked to tire pressure, tire thread, pavement material, pavement rutting, vehicle speed, and depth of water film.

Local pooling of drainage water for extended durations on the bridge deck can also result in an increased rate of bridge deck deterioration (crack propagation, accelerated rate of rebar corrosion).

Background

The Department’s practice for bridge deck drainage has been to use sufficient deck drains combined with optimized bridge geometry to minimize lane encroachment and local pooling. Prior to 2010, the Department did not have a formal practice for deck drainage and typically defaulted to location specific guidelines for design storm criteria and assessed each major bridge on a per site basis.

Safety considerations include driver behavior when presented with unexpected ponding, splashing from adjacent vehicles, and vehicle hydroplaning. Use of below deck piped drainage systems is generally avoided due to capital and maintenance costs, expected low reliability (durability, clogging, segments becoming separated and/or unattached), and safety concerns. Drainage issues should receive early attention at the planning stage when there is opportunity to optimize bridge geometry, as noted in the Bridge Conceptual Design Guidelines.

Deck drains are an accepted practice for bridge deck drainage over rivers, as recognized in the former Alberta Operational Statement titled “Bridge Maintenance” published by
Fisheries and Oceans Canada. In some cases, deck drains may be inappropriate, such as at sites draining over travel lanes and on rivers where the bridge is located just upstream of a water intake system. In other cases, it may be desirable to avoid deck drains for aesthetics (e.g. for grade separation and interchange bridges), or for erosion control considerations (e.g. over headslopes). In these cases, it is important that bridge deck drainage be evaluated and appropriate mitigation measures taken.

Discussion

A minimum desirable longitudinal gradient for bridges of 1% is specified in Section 4 of the AT Bridge Structures Design Criteria (BSDC) document (version 7.0, May 2012). The use of deck drains as normal practice for river crossings is stated in Section 22 of the BSDC.

The department's recent practice for evaluation of bridge deck drainage is to combine the Rational Method equation for runoff flow rate estimation with the Manning equation for calculation of resulting flow depth adjacent to the barrier (bridge rail or raised median). These equations are based on the document titled “Design of Bridge Deck Drainage, Hydraulic Engineering Circular No.21” (FHWA, 1993). Combining these two equations and accounting for cumulative deck drain discharge at key locations along the bridge deck facilitates calculation of the encroachment of drainage runoff onto travel lanes.

Alberta Transportation recommends the following values to be used in these equations: a runoff coefficient ‘C’ = 0.9, a design rainfall intensity ‘i’ = 75mm/hr (see Appendix B for more information), and a roughness coefficient of ‘n’ = 0.016. The estimation of discharge through deck drains can be assessed using procedures published for various deck drain types in the FHWA document. For safety reasons, encroachment should be minimized with a desirable maximum encroachment of 0m into the driving lane for divided highways and 1.0m for undivided highways (see Appendix B).

Optimization should include considerations to the longitudinal grade, shoulder width (to a maximum of 3.5m, as specified in the Roadside Design Guide), number of deck drains, amount of driving lane encroachment and length of encroachment (partial vs entire structure), roadway classification (design speed, lane width, number of lanes, driver behavior), safety concerns, and costs. Detailed design of deck drains is further discussed in the Bridge Structures Design Criteria document.

Recommendation

The current practice for bridge deck drainage assessment is formally accepted as the department's best practice. Technical details of the assessment process are included in the Appendix. Deck drainage impacts are to be considered at the bridge conceptual design stage to minimize the potential for deck drainage issues while there is still room for alignment, gradeline and bridge opening modifications. Site specific optimization, including the risks associated with deck drainage concerns, should occur for all projects with final bridge drainage design being completed during the detailed structural design phase. If maximum desirable lane encroachments cannot be met, a design exception may be
considered by AT, with appropriate documentation and justification. In some cases, a
safety audit may also be required.

The recommended design parameters are:

\[ i = 75 \text{ mm/hr} \]
\[ C = 0.9 \]
\[ n = 0.016 \]
Maximum lane encroachment = 0m for Divided Highways, 1.0m for Undivided Highways

Contact

Questions or further information on this guideline may be directed to the Bridge Planning
Specialist, Alberta Transportation.

Adopted:

\[ \text{Director, Bridge Engineering} \]
\[ \text{Executive Director, Technical Standards Branch} \]
Appendix A – Technical Details of Bridge Deck Drainage Assessment

**Rational Method Equation:**

The Rational method equates the rate of rain water falling on the bridge deck to the volume of runoff and the equation is as follows:

\[ Q = \frac{CiA_d}{3600} \]

where:

\( Q \) = runoff rate (L/s)  
\( C \) = runoff coefficient (0.9 to be used for bridge decks)  
\( i \) = rainfall intensity (mm/hr), 75mm/hr  
\( A_d \) = contributing deck area (m²) to point of analysis

**Manning Equation:**

The Manning equation relates the depth of flow to the runoff rate as follows:

\[ Q = \frac{1000A_f R^{\frac{2}{3}} S^\frac{1}{2}}{n} \quad ; \quad R = \frac{A_f}{P} \]

where:

\( Q \) = runoff rate (L/s)  
\( A_f \) = flow area (m²)  
\( P \) = wetted perimeter (m)  
\( R \) = hydraulic radius (m)  
\( S \) = longitudinal slope of deck (m/m) at point of analysis  
\( n \) = roughness coefficient (use \( n = 0.016 \) for bridge decks)
The typical runoff channel will have the following shape:

where:

\[ Y = \text{depth of flow (m)} \]
\[ e = \text{superelevation or crown rate} \]
\[ T = \text{top width of flow (m)} \]

Therefore:

\[ T = \frac{Y}{e} \quad ; \quad A_f = \frac{Y^2}{2e} \quad ; \quad P = Y\sqrt{\left(1\! + \! \frac{1}{e^2}\right)} \]

**Solution:**

- For specified \( T \) (typically \( T = \) shoulder width for no encroachment), calculate longitudinal flow capacity (\( Q \), Manning eqn.).
- Use \( Q \) with Rational Method equation to calculate length to first deck drain.
- Calculate deck drain spacing using deck drain flow (at specified \( T \)) with Rational Method eqn. (deck drain flows may be estimated for standard configurations from procedures in FHWA, 1993).
- Use spacing as approximate guide to optimally locate deck drains on structure.
- Iterative solution may be required for variable grade/width bridges decks.
Appendix B – Design Parameter Determination

Reasons for selection of 75 mm/hr as the design rainfall intensity:

- Based on a factor of safety of 1.25 provided on a 60mm/hr rainfall intensity
- Allows for an additional allowance for potential future climates changes. Increased magnitude of short duration, high intensity storms have been identified as a potential risk for infrastructure management by Environment Canada.
- Minimal incremental impact/cost to structure design (width, number of deck drains)
- Comparable to the City of Edmonton design intensity (76mm/hr)

Reason for use of 60 mm/hr as the rainfall intensity:

- Based on a physical threshold for driver visibility and probability of occurrence that is specific to Alberta
- 60mm/hr is the average annual, maximum 5 minute rainfall intensity across Alberta. This is based on Intensity Duration Frequency (IDF) data published by Environment Canada. Twenty nine IDF Curves from across the Province were analyzed, with an average period of record of 28 years of data and maximum period of record of 59 years. The earliest gauge data dates back to 1914.
- Based on recorded data, rainfall intensity exceeding this value would be expected about 40 times during a bridge structure’s 75 year design life. Probabilities of occurrence for other rainfall intensities are summarized in the table below.

<table>
<thead>
<tr>
<th>Rainfall Intensity (mm/hr)</th>
<th>Estimated Number of Occurrences during a Bridge Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>235</td>
</tr>
<tr>
<td>40</td>
<td>130</td>
</tr>
<tr>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>150</td>
<td>2</td>
</tr>
</tbody>
</table>

- 5 minutes is the shortest intensity rainfall measurement recorded by Environment Canada. Lesser duration storms are considered to have minimal impact on traffic behavior due to the very short duration. Longer duration storms are likely to exceed the time of concentration of rainfall on most bridge decks. As an example, the time of concentration of rainfall with a 60mm/hr intensity on a 100m long bridge, assuming a 1% grade, is about 0.85 minutes (HEC 22).
• A 60mm/hr rainfall intensity results in a significant reduction in visibility (25% based of clear day visibility). Little incremental visibility loss is expected to occur for higher intensities as shown in the table below (adapted from Texas Transportation Institute).

<table>
<thead>
<tr>
<th>Rainfall Intensity (mm/hr)</th>
<th>Visibility (m)</th>
<th>% of Clear Day Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>0mm</td>
<td>3048</td>
<td>--</td>
</tr>
<tr>
<td>25mm</td>
<td>1387</td>
<td>46</td>
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<tr>
<td>50mm</td>
<td>866</td>
<td>28</td>
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<td>60mm</td>
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<td>25</td>
</tr>
<tr>
<td>75mm</td>
<td>657</td>
<td>22</td>
</tr>
<tr>
<td>100mm</td>
<td>540</td>
<td>18</td>
</tr>
</tbody>
</table>

Reasons for selection of 0m lane encroachment for divided highways:
• These bridge structures typically carry higher volumes of traffic (to warrant twinning) and are often located times in urban/semi-urban areas.
• These roadways are typically designed to a higher standard (design speed of 130km/hr, wider shoulders) and will generate higher travel speeds, resulting in drivers expecting a greater level of service and not expecting to be required to slow down.
• There is a probability of a vehicle in the adjacent lane, travelling at different speeds, which may impede the ability to see or react to a hazard such as an encroachment.

Reasons for selection of 1.0m lane encroachment for undivided highways:
• These bridge structures typically carry lower volumes of traffic and are typically in rural areas.
• These roadways are typically designed to a lower standard (design speed of 110km/hr), resulting in lower travel speeds and a reduced expectation of level of service.
• There is a low combined probability that encroachment will occur on both sides of a bridge structure, at the same time as when two vehicles are passing by each other during the design storm event.
• A typical design vehicle width of 2.6m and lane width of 3.7m (AT’s Highway Geometric Design Guide, 1996) allows a driver to stay within their lane even after moving over to avoid the 1.0m encroachment on lower classification roadways.
References

Alberta Transportation, Bridge Conceptual Design Guidelines (2014)
Alberta Transportation, Bridge Structures Design Criteria (2012)
City of Edmonton Design Standards, Chapter 3: Drainage (2012)
Environment Canada, Intensity Duration Frequency Curves (2011)
Federal Highway Administration, Design of Bridge Deck Drainage: HEC 21 (1993)
Federal Highway Administration, Hydraulic Design of Safe Bridges (2012)
Texas Transportation Institute, Rainfall and Visibility – The View from Behind the Wheel (1975)