EPiC Series in Built Environment
Volume 5, 2024, Pages 813–821
Proceedings of 60th Annual Associated Schools of Construction International Conference

Design and Construction Practices for Efficient Bridge Deck Drainage

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The National Bridge Inventory (NBI) of the United States includes more than 600,000 bridges. A significant number of current bridges is structurally deficient and/or functionally obsolete. The Federal Highway Administration (FHWA) as well as State Departments of Transportation (DOTs) are investigating possible alternatives to improve the NBI bridges rating. Flooding and excessive rain are among the causes of bridges deterioration. Bridge deck runoff has been a prime source of pollution. In addition, reduced deck drainage efficiency due to poor design, mal construction practices, and lack of maintenance results in runoff accumulation on bridge decks. Increased accumulation of runoff results in traffic congestions, potential bridge deterioration due to increased corrosion, and a substantial impact on bridge aesthetics. Excessive runoff accumulation may result in hydroplaning and higher accidents rates. This paper presents the significance of properly designed, constructed, and maintained deck drainage systems. A nation-wide survey outcomes of State DOTs regarding best design, construction, and maintenance practices of deck drains is presented, and the relevant outcomes of their impact on bridge condition is highlighted. The implementation of bridge deck drainage best practices in bridge design projects will result in improved bridge functionality, increased bridges load rating, reduced maintenance, and improved aesthetics.

Key Words: deck drainage, inlets, scuppers, runoff, bridge maintenance, hydroplaning

Introduction

The National Bridge Inventory (NBI) of the United States includes more than 600,000 bridges. A significant number of the NBI bridges is structurally deficient and/or functionally obsolete. The American Society of Civil Engineers (ASCE) Report Card for America's Infrastructure shows that America's infrastructure scores a C-, and bridges in specific has a C score (ASCE, 2021). Despite the extensive effort conducted by the Federal Highway Administration (FHWA), and State Departments of Transportation (DOTs) to improve the bridge conditions, bridges with a "fair" overall rating are

T. Leathem, W. Collins and A. Perrenoud (eds.), ASC 2024 (EPiC Series in Built Environment, vol. 5), pp. 813–821

slightly increasing in number, while bridges with a "good" overall rating are decreasing. The Federal Highway Administration (FHWA), and other state DOTs are investigating possible alternatives to improve the condition of their bridge network including 1) the use of high strength materials for construction (Akhnoukh and Buckhalter, 2021, Akhnoukh, 2020a, Akhnoukh and Elia, 2019, Akhnoukh and Xie, 2010, and Akhnoukh, 2010, 2008), 2) expedite the construction and repair activities to reduce time and cost (Akhnoukh, 2020b, and Morcous and Akhnoukh, 2006), and 3) revise DOT standards and specifications used in bridge construction, inspection, and maintenance.

Bridges with substandard performance are classified as structurally deficient or functionally obsolete. Several factors contribute to bridge deterioration including the bridge age, overloading due to increased traffic, environmental attacks due to excessive snow, rainfall, and the use of de-icing chemicals. In addition to their contribution to bridge condition deterioration, snow, rainfall, and de-icing chemicals result in significant environmental implications if not properly discharged and treated. Pollutants in stormwater runoff include dirt, debris, organic residues, heavy metals from tire and break wear, and salt from roads and decks surface maintenance during winter. In order to avoid the direct discharge of storm water runoff from bridge decks to water streams, storm water control measures (SCMs) are being designed and constructed to collect storm runoff for final water treatment before discharging into streams (Dupuis, 2002; and Malina et al., 2005). The aforementioned SCM is denoted as bridge deck closed drainage system (see figure 1).

Figure 1. Example of closed bridge deck drainage system (Winston et al., 2015)

Closed drainage systems are increasingly used in replacement of open deck drains due to stringent environmental requirements and to avoid potential scour problems resulting from water discharged using open drains. Closed drainage system includes bridge deck (gutter), drain inlet or scuppers, closed piping system, and anti-clogging design features. Proper design and construction of deck drainage system is crucial to successfully discharge runoff, avoid potential corrosion problems associated with water/snow accumulation on bridge decks, maintain bridge aesthetics, and avoid potential traffic jams or accidents resulting from hydroplaning.

This research presents different parameters controlling the selection, design, and construction of bridge deck drainage systems, and highlights the advantages and disadvantages associated with different systems. Data collected from the literature and a nation-wide survey regarding the FHWA, and DOTs practices are compiled to provide recommendations for best design and construction practices for bridge deck drainage systems.

Literature Review

The primary objective of bridge drainage system is to remove runoff from the bridge deck before it accumulates on the deck and/or extends to the driving lanes and results in potential bridge deterioration and/or functional disruption. The main advantages of a well-designed/constructed bridge deck drain include 1) efficient discharge of runoff to avoid slowing traffic and/or accidents occurrence, 2) improve the bridge service life and minimize the life cycle cost of the bridge by slowing potential corrosion, 3) minimize or eliminate erosion at bridge foundation, and 4) preserve the structural integrity of the bridge and improve bridge aesthetics

Several research studies investigated the parameters affecting the efficiency of bridge deck drainage components including slotted drains, grate inlets, and scuppers (Johnson and Chang, 1984). Accordingly, the FHWA released three primary manuals dealing with hydraulic design, as follows:

- Hydraulic Engineering Circular – 12 (HEC-12; Johnson and Chang, 1984)
- Hydraulic Engineering Circular – 21 (HEC-21; Young et al., 1993)
- Hydraulic Engineering Circular – 22 (HEC-22; Brown et al., 2009)

Bridge drainage systems are classified into two types (FHWA, 2015): a) open deck drainage system; and b) closed deck drainage system. Open deck drainage system is constructed as a horizontal or a vertical penetration through the bridge barrier or curb. Closed deck drainage system is typically composed of scuppers on inlets at the bridge deck surface with closed piping system that extends from the base of the scupper/inlet down the superstructure of the bridge (abutments and piers). The closed deck drainage system discharges the runoff to a ground-based inlet. Closed deck drainage systems are more costly and require frequent maintenance as compared to open deck drains. However, they are used according to environmental mandates, and to avoid potential scour at bridge foundation level.

The FHWA and different State DOTs have conducted multiple research programs to evaluate and compare the efficiency of open and closed deck drainage systems. Open drains displayed higher efficiency and lower initial construction cost (SCDOT, 2006). However, open drainage system inlets displayed a higher tendency to clog as compared to closed drainage systems due to their smaller sizes. Thus, closed drainage systems with grate inlets are preferred when bridge runoff is significant and when debris are present within the runoff flow (FDOT, 2018). State DOTs report that bridges with a potentially contaminated runoff should include a closed deck drainage system in compliance with the National Environmental Policy Act (NEPA), while grade separating bridges may be designed to include open or closed deck drainage systems.

Research Objectives and Methodology

The main objective of this research project is to investigate the current design and construction practices for constructing bridge deck drains and provide a list of recommendations to increase the efficiency of deck drains in new bridge construction projects. In order to attain this objective, the research team conducted a comprehensive literature review available from federal and state entities and conducted a comprehensive survey to cover the 50 State DOTs to gather relevant information for their standards and specifications. Finally, the research team provided recommendations for best practices given the national consensus attained by the survey responses.

DOTs Bridge Drainage Design and Construction Practices

Feedback was received from twenty State DOTs in response to the national survey conducted by the project research team. The key parameters addressed in the survey include the following:

- Standard guidelines and specifications used by the DOT for bridge deck drainage design
- Sources of bridge deck drainage problems
- Problems associated with drainage system inlets
- Problems associated with drainage systems piping

- Parameters controlling the selection of closed deck drainage system
- Frequency of deck drainage inspection and type of inspection data collected

The outcomes of the aforementioned survey questions are listed in detail in the following section.

Standard Guidelines and Specifications used by State DOTs for Drainage Design and Construction

The research team collected information regarding the different standards and guidelines used by different state DOTs in design and construction of bridge drains. Information is collected by providing state DOT personnel in bridge and hydraulic divisions with a written questionnaire. Following the questionnaire, a telephone interview and/or web meeting is conducted with DOT personnel to discuss the questionnaire feedback provided and discuss potential recommendations. Feedback from 25 different states showed that the Hydraulic Engineering Circular (HEC-21) is widely adopted by surveyed states (12 states out of 25). HEC-12, HEC-22, and state developed manuals are used at a limited scale within state DOTs (see figure 2).

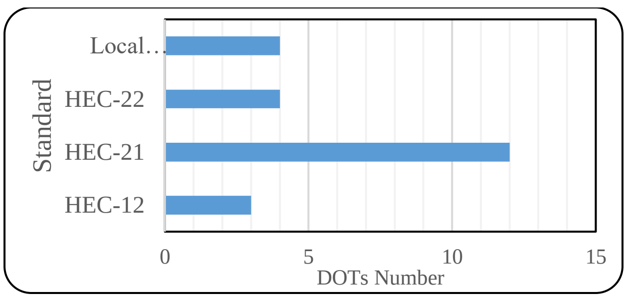

Figure 2. Standards and guidelines adopted by different State DOT

Sources of Bridge Deck Drainage Problems

According to the literature collected, deck drainage problems are attributed to three prime sources due to poor design, poor construction practices, and/or lack of maintenance. Failure in deck drainage systems can lead to serious damage to the bridge structure and/or functionality. Bridge deck drainage problems source includes:

- Inlets problems as inefficient inlets, clogged inlets, and problems associated with fewer inlets, inlets dimension, inlets spacing, etc. (see figure 3)

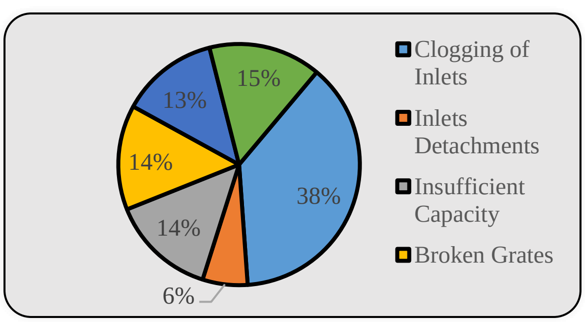

Figure 3. Bridge deck drainage inlet problems

- Pipe problems including insufficient sizing (pile diameter), slopes, connections, poor pipe materials resulting in corrosion, or poor installation resulting in leaks, etc. (see figure 4).

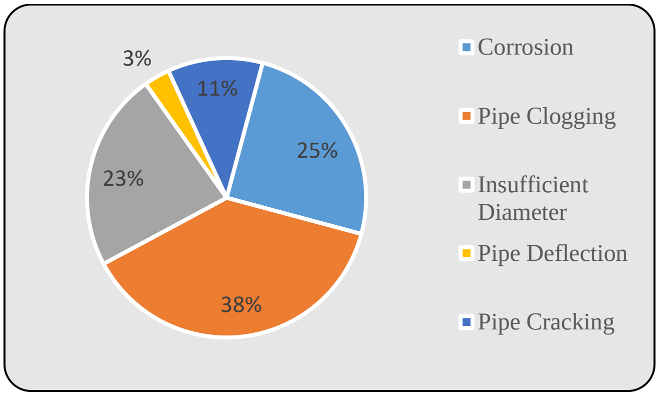

Figure 4. Bridge deck drainage piping problems

Parameters Controlling the Selection of Closed Deck Drainage Systems

Bridge deck drainage system is selected based on multiple factors. The survey responses indicated that open deck drainage systems are more economic and are easier to construct as compared to closed deck drains. However, the construction of closed deck drains is sometimes mandated due to specific project parameters including the geometrical conditions, bridge span, existence of facilities below the bridge, the bridge location, and environmental restrictions that may require a closed drainage system for the discharge of the storm runoff (see figure 5).

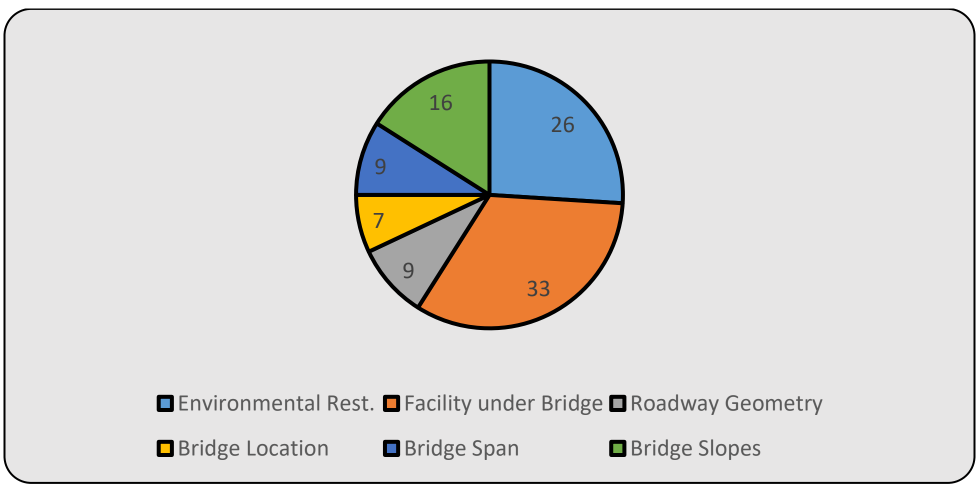

Figure 5. Parameters considered for closed deck drainage system selection

Closed bridge drainage could be constructed using external system attached to the bridge superstructure or using embedded piping systems. Bridge and hydraulic engineers determine the closed drainage type to be used according to multiple parameters including inlet and outlet design restrictions, cleanout locations, ease of constructability, and whether or not freeze-thaw cycles are existent. Typically, increased freeze-thaw cycles result in the construction of external closed drains to avoid internal pipe destruction and its negative consequences on bridge elements (see figure 6).

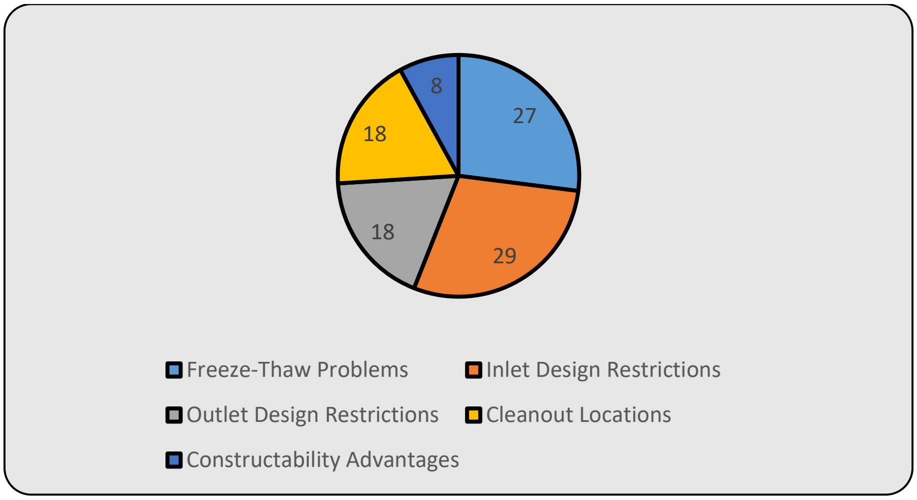

Figure 6. Design parameters controlling selection of external closed drain designs

Internal (embedded) closed drainage system is preferred by several state DOTs for different reasons. Mostly, its contribution to bridge aesthetics and due to its increased durability (see figure 7).

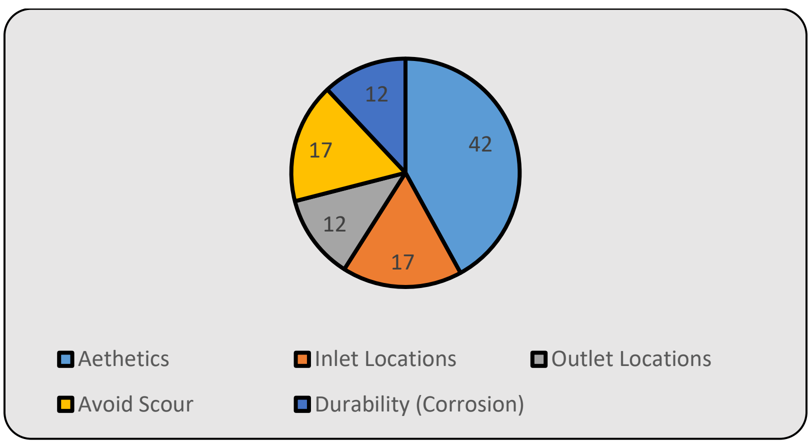

Figure 7. Design parameters controlling the selection of embedded closed drain designs

Frequency of Inspection and Type of Inspection/Maintenance Data Recorded

The frequency of bridge inspection is standardized by most state DOTs including bridge drainage system inspection. Routine inspection is the most common type for the inspection of bridge deck drains. State DOTs report that deck drains tend to clog, so a routine inspection is required. A fewer number of state DOTs conduct inspections based on different other parameters including:

- Complaints by commuters
- Observed performance

- Age of bridge drainage systems
- Guidelines followed by DOT including the use of bridge management systems (BMSs), deterioration models, etc

Detailed State DOTs feedback and responses is collected and compiled to develop consensus regarding the optimum timing for maintenance (see figure 8).

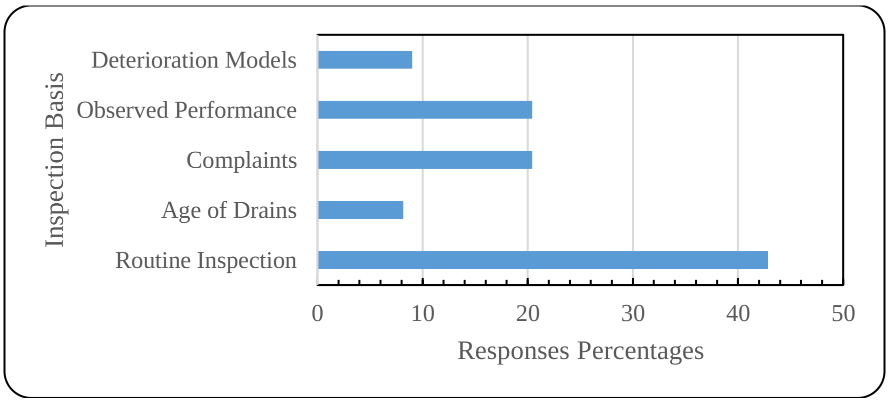

Figure 8. Frequency of DOT inspection for bridge drains

Different drainage design and construction parameters are included in the inspection (see figure 9). The checklist for drains inspection includes:

- Deck drains inlet number
- Deck drains inlet locations
- Current conditions of deck drains
- Performance of bridge deck drains
- Age of bridge deck drainage components (inlets, pipes, grates, scuppers, etc.)
- Previous inspection dates
- Pipes details (size and material)
- Size and type of inlets
- Others including photographs and recorded videos of bridge drains

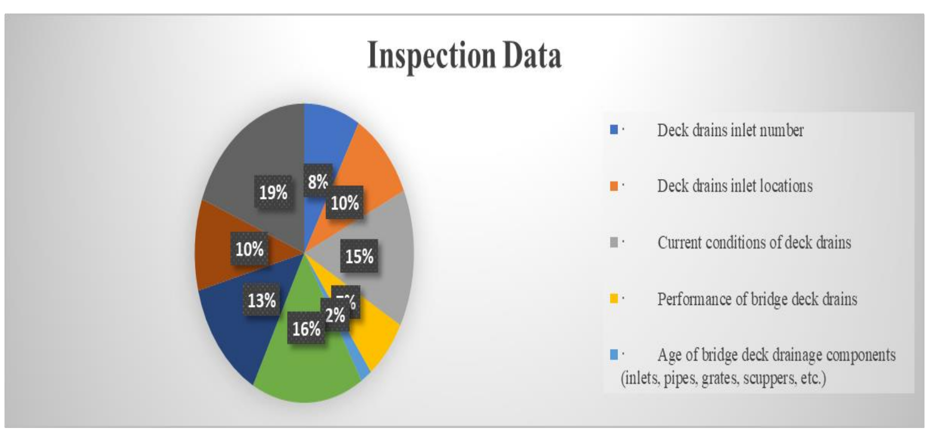

Figure 9. Inspection parameters reported by different State DOTs

Conclusions and Recommendations for State DOTs

Efficient bridge deck drainage systems are required to properly discharge storm runoff and avoid accumulation of water/snow on bridge decks. Proper drainage increases the bridge service life, improve bridge aesthetics, and reduces travel disruption and/or accidents due to hydroplaning. Based on State DOTs feedback, open bridge drainage is more economic and easier to construct. However, closed drains are more environmentally compliant. Problems associated with bridge drainage systems includes insufficient inlet sizing, improper location and spacing of drain inlets, drain inlets and/or piping clogging, and insufficient piping diameters. State DOTs maintenance are recommended to mitigate problems associated with substandard performance of bridge deck drains. Maintenance could be conducted periodically, or according to complaints received from bridge users. Sufficient maintenance can successfully restore drain functionality and preserve the bridge condition.

Suggestions for Future Research

Adopting the research findings would result in improved bridge conditions for state DOTs. However, future research should focus on attaining these advantages at a reduced cost. Thus, the incorporation of building information modeling (BIM) and artificial intelligence (AI) in bridge maintenance and repair procedures is recommended. Few research efforts have been made in this area considering the bridge drainage problems (Meadati et al., 2011 and 2012, and Xiao et al., 2018), thus, further research is recommended to attain maintenance benefits at reduced cost.

ACKNOWLEDGEMENTS

The authors would like to acknowledge NCDOT for funding this research project. The research team acknowledges engineer Trey Caroll, engineer Mustan Kadibhai, and Dr. Curtis Bradley for their continuous support to their research activities.

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