ILLINOIS CENTER FOR TRANSPORTATION

CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 24-024
UILU-ENG-2024-2024
ISSN: 0197-9191

Report on Agency Survey and National Bridge Inventory Analysis for Damaged Steel Girders

Prepared By
Limo R. Schissler
Sanjana Ahershinge
Ahmed E. Ibrahim
Larry A. Fahnestock
James M. LaFave
Ahmed E. Elbanna
University of Illinois Urbana-Champaign

Research Report No. FHWA-ICT-24-021

A report of the findings of

ICT PROJECT R27-225
Strength and Serviceability of Damaged Steel Girders

https://doi.org/10.36501/0197-9191/24-024

Illinois Center for Transportation

November 2024

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-ICT-24-021	N/A	N/A

4. Title and Subtitle Report on Agency Survey and National Bridge Inventory Analysis for Damaged Steel Girders	**5. Report Date** November 2024 **6. Performing Organization Code** N/A
7. Authors Limo R. Schissler (https://orcid.org/0009-0004-9653-5348), Sanjana Ahershinge (https://orcid.org/0009-0004-7422-0804), Ahmed E. Ibrahim (https://orcid.org/0000-0002-2275-6293), Larry A. Fahnestock (https://orcid.org/0000-0003-3172-2260), James M. LaFave (https://orcid.org/0000-0001-6514-2163), Ahmed E. Elbanna (https://orcid.org/0000-0003-4079-2607)	**8. Performing Organization Report No.** ICT-24-024 UILU-2024-2024
9. Performing Organization Name and Address Illinois Center for Transportation Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaign 205 North Mathews Avenue, MC-250 Urbana, IL 61801	**10. Work Unit No.** N/A **11. Contract or Grant No.** R27-225
12. Sponsoring Agency Name and Address Illinois Department of Transportation (SPR) Bureau of Research 126 East Ash Street Springfield, IL 62704	**13. Type of Report and Period Covered** Interim Report 11/1/21–11/30/24 **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

https://doi.org/10.36501/0197-9191/24-024

16. Abstract

Bridge strikes—events where over-height vehicles impact bridge superstructures—are common across the United States and pose significant challenges for bridge owners. When a bridge strike occurs, bridge owners must assess the damage and determine what, if any, action is required. A survey of state highway agencies was conducted, and 23 responses were received. States reported general metrics about low-clearance bridges and bridge strikes, and data from the National Bridge Inventory were analyzed to provide additional insight. States also reported information about inspection, analysis, and repair practices for damaged girders. Overall, reported practices vary greatly between states and rely significantly on engineering judgement; there is potential to improve efficiency and efficacy. Results can be used to inform future research directions regarding steel girders damaged in bridge strikes, such as innovative methods for damage inspection, assessment, and repair.

17. Key Words	18. Distribution Statement
Steel Bridges, Girders, Girder Bridges, Impact Damage, Low-Clearance Bridges, Questionnaires, National Bridge Inventory	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	44 + appendices	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGMENT, DISCLAIMER, MANUFACTURERS' NAMES

This publication is based on the results of **ICT-R27-225: Strength and Serviceability of Damaged Steel Girders**. ICT-R27-225 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

Members of the Technical Review Panel (TRP) were the following:

- Spencer Koehler, TRP Chair, Illinois Department of Transportation
- Ruben Boehler, Illinois Department of Transportation
- Brandon Dudley, Illinois Department of Transportation
- Adrian Halloway, Illinois Department of Transportation
- Robert Perkins, Illinois Department of Transportation
- Frank Sharpe, Federal Highway Administration
- Dan Tobias, Illinois Department of Transportation
- Sarah Wilson, Illinois Department of Transportation

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

EXECUTIVE SUMMARY

Bridge strikes—events where over-height vehicles impact bridge superstructures—are common across the United States and pose significant challenges for bridge owners. When a bridge strike occurs, bridge owners must assess the damage and determine what, if any, action is required. A survey of state highway agencies was conducted to gather information about current practices, and 23 responses were received.

Most states reported having between 2,000 to 16,000 bridges in the inventory, and an average of 3.96% of the inventory was reported to be low-clearance bridges. The low-clearance threshold reported by each state ranged from 13.5 ft to 16.5 ft, and the most common threshold value was 14.5 ft. The breakdown of girder material types in the inventory differed significantly between states. The percentage of steel girders ranged from 10% to 76.5%, and the percentage of concrete girders ranged from 18.3% to 83%. The breakdown of inventory materials was compared to a breakdown of girder materials for bridge strike incidents. The comparison indicated that 14 of 21 states had a disproportionately high percentage of girder strikes on steel bridge girders, and eight states had a disproportionately high percentage of girder strikes on concrete bridge girders.

The survey results were supplemented by an analysis of data from the National Bridge Inventory. Three low-clearance thresholds were considered: 14 ft, 15 ft, and 16 ft. The analysis indicated that over half of states had a disproportionately high percentage of low-clearance bridges having steel as the main span material. Additionally, both nationally and in Illinois, less than 20% of all low-clearance bridges were built after 1980, even though 47% of bridges overall were built after 1980. This is important because older bridges may have different design parameters, such as lower-grade steel or non-composite design, that affect the damage caused during a bridge strike.

On the survey, most states reported between 2 to 30 annual bridge strikes. The average breakdown of bridge impact location was 88% on girders, 5% on piers/abutments, and 6% on other bridge components. There was no correlation between the reported annual cost and the reported number of strikes. The reasons for bridge strikes varied between states, and “vehicle/load too tall (no permit)” and “equipment loaded incorrectly” were the most common reasons for strikes.

After a damaging event, the bridge owner must inspect the bridge to determine what steps are needed. States reported using visual surveys, manual measurements, and manual photographs in nearly all damage cases. Nondestructive testing was used frequently in some states and rarely in others. Laser scans and drone photographs are innovative techniques that most states reported using rarely or never. Where damage concentrated in a small area is considered local, damage spread over some length is considered global, and combined damage consists of both local and global damage, states reported an average of 42%, 25%, and 33% of cases classified as local, global, and combined damage, respectively, but responses varied. States reported that damage extends to the bridge diaphragms/cross-frames, deck, bearings, and abutments/piers an average of 55%, 12%, 7%, and 2% of cases, respectively.

There was also variation in analysis methods that states reported using after a strike. Hand calculations and AASHTOWare were used most often. Shell element elastic and inelastic structural models and line element inelastic structural models were used least often. Some states used line element elastic structural models. There was no common procedure for determining the load rating of damaged girders or determining the course of action for temporary and permanent solutions.

Most states reported taking initial action within a few hours of a bridge strike and completing all work in less than a year. Heat straightening was the most common method for repairing damaged steel girders, and few states used mechanical straightening. Use of localized strengthening, partial-depth girder replacement, and full-depth girder replacement depends on the severity of the damage. Most states perform in-house repairs for less than half of damage cases.

Overall, reported practices vary greatly between states and rely significantly on engineering judgement; there is potential to improve efficiency and efficacy. Results can be used to inform future research directions regarding steel girders damaged in bridge strikes, such as innovative methods for damage inspection, assessment, and repair.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION AND BACKGROUND

Bridge strikes—events where over-height vehicles impact bridge superstructures—are common across the United States (e.g., Fu et al. 2004; Agarwal 2013) and pose significant challenges for bridge owners. An extreme example is a steel through-truss bridge on I-5 over the Skagit River in Washington that was struck by an over-height load and immediately collapsed in 2013 (NTSB 2014). A forensic investigation of this collapse was conducted by two of the present investigators and their colleagues (Stark et al. 2016). The study identified the probable damage sequence that led to collapse, along with critical transportation-related issues that contributed to the problematic scenario. Although steel girder bridges in general have more inherent redundancy than truss bridges, there are still many high-profile events where the striking vehicle becomes lodged or causes major damage and immediate action is required. For example, a bridge strike that occurred in Mahomet, Illinois on March 26, 2020, caused obvious structural damage, as shown in Figure 1. Significant plastic deformation was induced in the girder, where the bottom flange was displaced out of plane in conjunction with twisting of the cross-section. As a result of this damage, the traffic lane above the damaged girder was closed, and Illinois Department of Transportation (IDOT) replaced the entire damaged girder from abutment to abutment (Shaffer 2020). Although in this scenario the damage and need for repair are obvious, minor strikes often go unnoticed until routine inspections, but the damage still may not be negligible.

Figure 1. Photo. I-74 bridge over IL-47 on March 26, 2020.

Source: News-Gazette (2020)

In all cases, when a bridge strike is discovered, the responsible agency must assess the damage and decide what, if any, action is required. Focusing on steel girders, methods for their evaluation and repair exist but are relatively simplistic and were developed over three decades ago (Shanafelt and Horn 1984). The objective of this research project is to develop fundamental understanding of damage in steel bridge girders due to vehicle strikes and to translate that knowledge into a framework for structural inspection, assessment, and decision-making. Recommendations for evaluation of damaged steel bridge girders will inform revised load ratings and other necessary safety and operational responses. These advances will enhance the confidence in decision-making for actions required after a bridge strike. When damaged girders that are still functional can remain in service with only minor repairs instead of being replaced, sustainability and life-cycle costs are improved and any negative effect on motorists is reduced. This research integrates historical data and present-day field observations and measurements with a multi-stage suite of models and numerical simulations that can lead to practical tools for real-world assessment and decision-making.

As part of this investigation, a survey of transportation and highway agencies was conducted to identify their experiences with damaged steel girders. Survey questions were developed with input from IDOT, and the 32-question survey was distributed to state agencies via email. Overall, 23 states responded to the survey; participating states are colored in blue in the map in Figure 2. Not all states responded to every question. This report summarizes the results of the agency survey, and full responses are included in Appendix A.

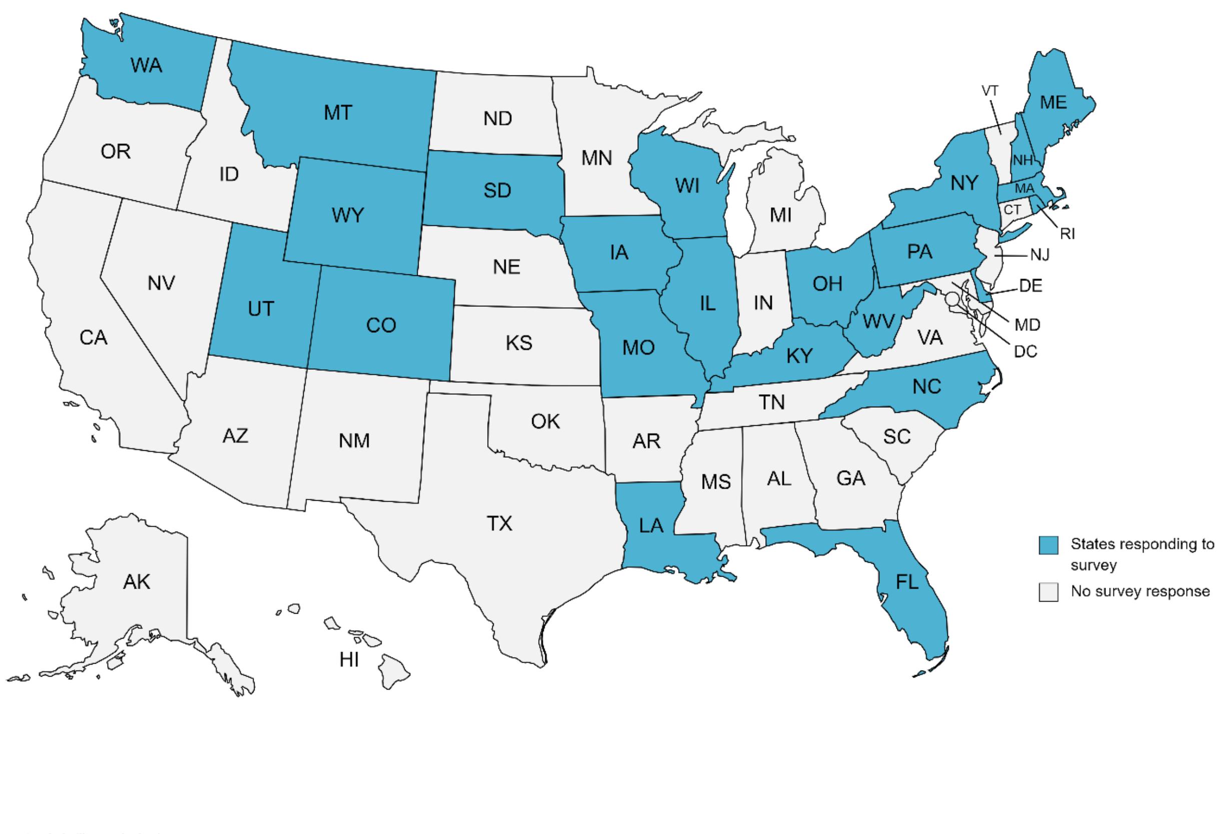

Figure 2. Map. States that responded to the agency survey.

CHAPTER 2: STATE INVENTORY AND LOW-CLEARANCE BRIDGE METRICS

States were asked to report information about their overall bridge inventory and inventory of low-clearance bridges. The number of bridges and number of low-clearance bridges are unique to each state and depend on many factors, such as land area, population, geography, and population density. No two states have identical bridge inventories, which may cause states to handle bridge strikes differently.

NUMBER OF BRIDGES IN THE INVENTORY

The distribution of number of bridges in the state inventory reported by survey respondents is included in Figure 3. The reported number of bridges ranges from 1,231 for Rhode Island to 32,110 for Pennsylvania. Most states reported between 2,000 to 16,000 bridges, with a larger number of states concentrated at the lower end of the distribution. The average number of bridges reported is 7,494.

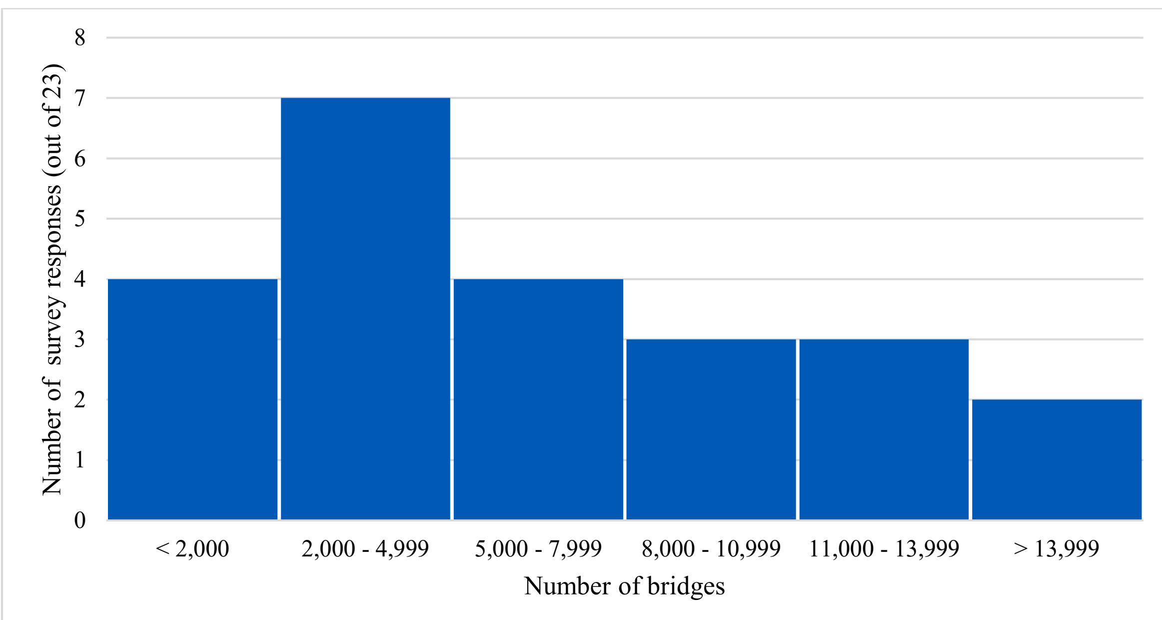

Figure 3. Histogram. Reported number of bridges in the state inventory.

The responses for the number of bridges were compared with data from the 2023 National Bridge Inventory (NBI). The agency survey was conducted in 2022, so a small discrepancy with the 2023 NBI data is expected due to bridges being constructed and/or decommissioned during the 2022–23 year. The NBI includes data about all bridges with spans of at least 20 ft carrying vehicular traffic. To better understand the numbers of bridges reported on the survey, the survey responses were compared to (1) the NBI total number of bridges in the state (including culverts), (2) the NBI total number of bridges in the state (excluding culverts), (3) the NBI number of bridges owned by the state highway agency (including culverts), and (4) NBI number of bridges owned by the state highway agency (excluding culverts).

Table 1 compares the results of the survey to each of these four categories from the NBI. The NBI category that best matches the survey result is highlighted in the table. The survey response entry is highlighted if the response does not match any NBI quantity. Seven states reported the total number of bridges (including culverts), one state reported the total number of bridges (excluding culverts), eight states reported the number of bridges owned by the state highway agency (including culverts), and one state reported the number of bridges owned by the state highway agency (excluding culverts). The remaining four states reported numbers larger than the total NBI number of bridges. It can be assumed that these states included bridges that are ineligible for the NBI (shorter than 20 ft, not carrying vehicular traffic) in their reporting on the survey.

The differences in inventory reporting for this question may indicate that respondents also interpreted later questions differently. For later questions related to bridge inventories, direct comparison between states' responses may not be appropriate.

Table 1. Comparison of Survey-Reported Number of Bridges in the State Inventory to Number of Bridges in the NBI. The matching quantity from the NBI is highlighted and shown in bold.

State	Survey response: number of bridges in the inventory	NBI total number of bridges (including culverts)	NBI total number of bridges (excluding culverts)	NBI number of state highway agency-owned bridges (including culverts)	NBI number of state highway agency-owned bridges (excluding culverts)
CO	3,469	8,954	6,961	**3,472**	2,643
DE	**1,780**	874	671	841	644
FL	12,745	**12,881**	10,323	5,751	4,702
IA	4,195	23,720	18,893	**4,138**	3,318
IL	7,824	26,873	21,951	**7,861**	6,213
KY	8,962	14,493	11,446	**9,094**	6,598
LA	13,000	**12,717**	10,165	7,728	6,187
MA	5,260	**5,281**	4,947	3,495	3,365
ME	**2,800**	2,521	2,114	2,029	1,699
MO	10,387	24,617	19,251	**10,384**	7,220
MT	**2,955**	5,218	4,877	2,418	2,223
NC	13,565	18,817	**13,580**	17,356	12,664
NH	2,450	**2,537**	2,252	1,302	1,174
NY	7,918	17,573	15,501	**7,538**	6,726
OH	10,547	26,960	25,006	**10,436**	9,752
PA	**32,110**	23,257	20,243	15,277	13,451
RI	**1,231**	782	738	588	559
SD	1,251	5,889	4,296	1,823	**1,249**
UT	3,056	**3,109**	2,429	1,884	1,488
WA	3,500	8,421	7,859	**3,340**	3,197
WI	14,430	**14,412**	12,259	5,326	4,667
WV	7,296	**7,323**	6,771	7,012	6,479
WY	1,635	3,131	2,626	1,962	**1,637**

DISTRIBUTION OF BRIDGE GIRDER MATERIAL TYPES IN THE INVENTORY

States reported the distribution of bridge girder material types in their inventory. The bridge girder material type varied greatly by state, as shown in Figure 4. The percentage of steel girders ranged from 10% to 76.5%, and the percentage of concrete girders ranged from 18.3% to 87%. Illinois has an approximately equal percentage of steel and concrete girders in the bridge inventory.

One significant outlier is that Delaware reported 50% of bridges constructed from "other" materials. A closer analysis of NBI data did not yield any insight into this response. Of all 874 bridges in Delaware in the NBI, including culverts, 53% have concrete main span material, 42% have steel main span material, and 5% are constructed with other materials. However, the number of bridges Delaware reported on the survey was over double the total NBI number of bridges (including culverts), so perhaps Delaware has many bridges constructed from other materials that are beyond the scope of the NBI.

As shown in Table 1, each state reported a number of bridges corresponding to a different NBI inventory category, so it can be assumed that the inventory breakdown also corresponds to different NBI bridge categories across the responding states. Therefore, direct comparisons between states using Figure 4 may not be appropriate. However, it is assumed that a given state responded consistently throughout their entire survey responses, so the distributions in Figure 4 can provide helpful context to a given state's other survey responses.

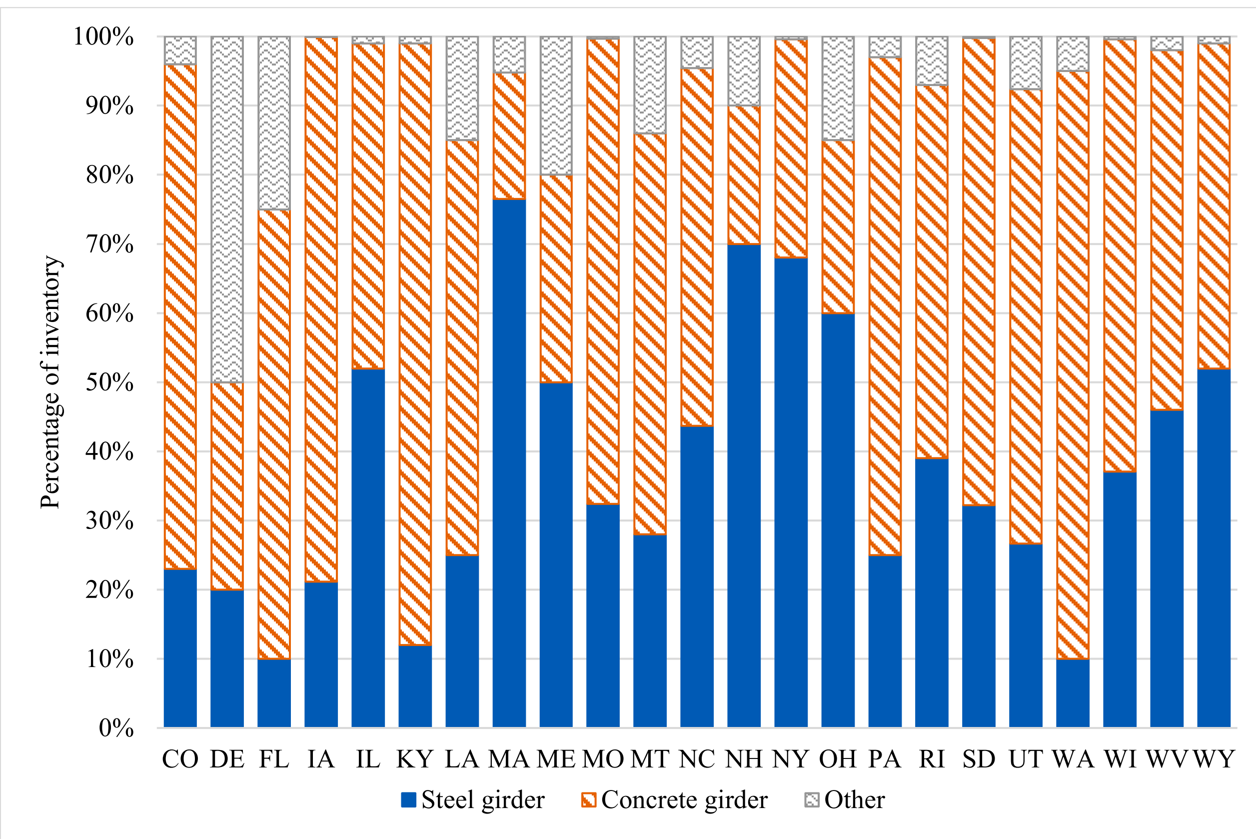

Figure 4. Bar chart. Distribution of girder materials in the inventory for each state.

LOW-CLEARANCE THRESHOLD AND PERCENTAGE OF INVENTORY

State highway agencies determine their own threshold for what height is considered low clearance. The low-clearance threshold values reported in the survey range from 13.5 ft to 16.5 ft, with the largest number of states reporting a threshold of 14.5 ft. Respondents were permitted to enter any number; most respondents reported a number rounded to the nearest 0.5 ft. Results are summarized in Figure 5, where one response of 13.99 ft was included with responses of 14 ft, one response of 14.75 ft was included with responses of 14.5 ft, and one response of 15.25 ft was included with responses of 15 ft. Illinois responded that 13.5 ft is the low-clearance threshold.

The percentages of low-clearance bridges reported in the survey range from 0.1% (Wisconsin) to 10% (Pennsylvania). The average percentage reported is 3.96%, and most responses were between 1% and 7%. Illinois reported that 2% of the state inventory is low clearance. The distribution of reported percentage of low-clearance bridges is included in Figure 6.

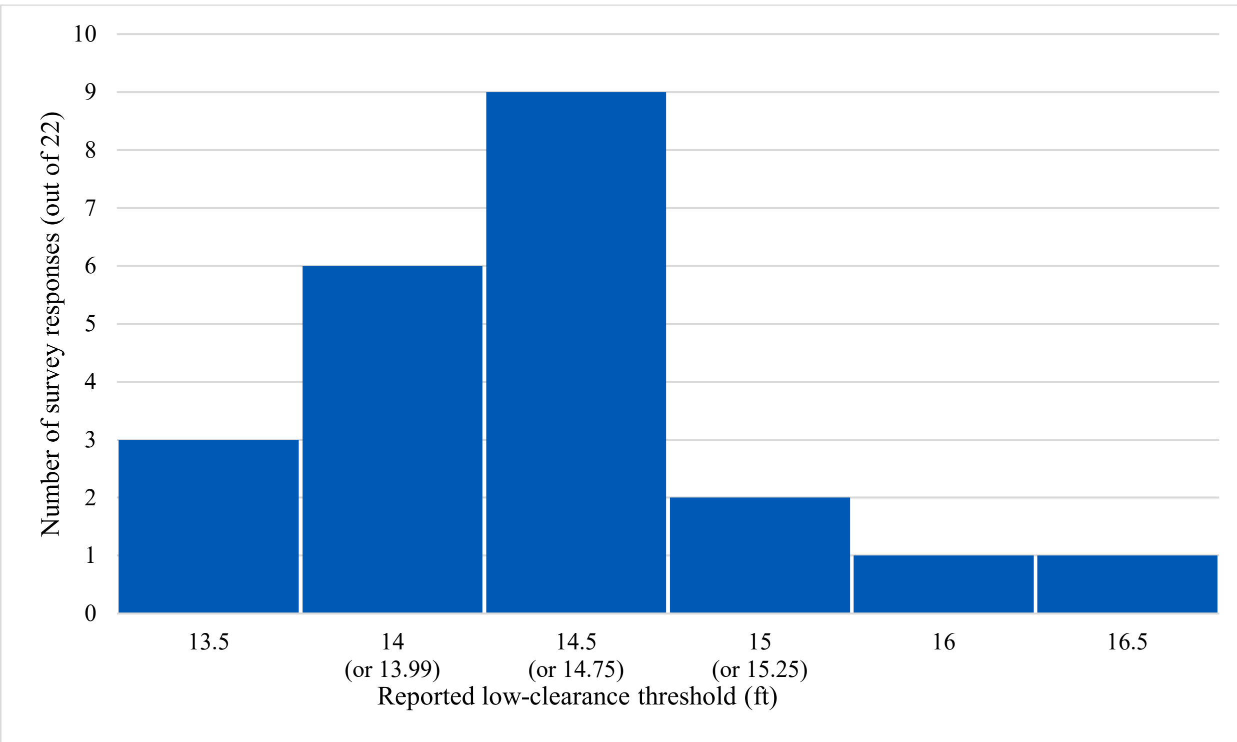

Figure 5. Histogram. Reported low-clearance threshold.

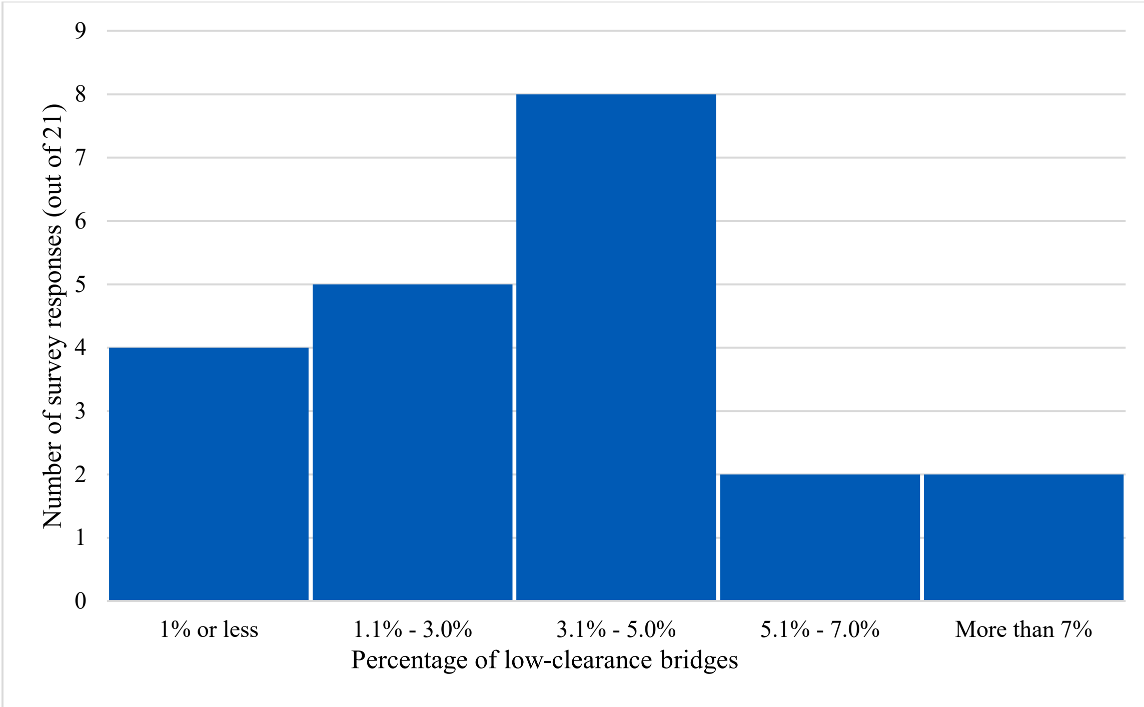

Figure 6. Histogram. Reported percentage of low-clearance bridges.

To gain additional insight into threshold values for low-clearance bridges, the Federal Highway Administration (FHWA) requirements for the design of bridges on the interstate system were reviewed (FHWA 2017). The FHWA requirements state:

> On Interstate sections in rural areas, the clear height of structures shall be not less than 4.9 meters (16 feet) over the entire roadway width, including the usable width of shoulder. On Interstate sections in urban areas, the 4.9-meter (16-foot) clearance shall apply to a single routing. On other Interstate urban routes, the clear height of structures shall be not less than 4.3 meters (14 feet). Design exceptions must be approved whenever these criteria are not met.

IDOT has additional clearance requirements for new and existing bridges, ranging from 14′-0″ to 16′-9″ minimum clearance depending on the functional classification of the bridge (IDOT 2010). The IDOT *Bureau of Design and Environment Manual*, Section 31-7.04(c), states:

> IDOT requires vertical clearances on new construction/reconstruction Interstate sections in rural areas and single routing through or around urban areas to be no less than 16 ft 09 in (5.1 m). The clear height of structures over other urban interstate routes shall not be less than 15 ft 00 in (4.5 meters). This clearance is required over the full roadway width (travel lanes and usable shoulders), including ramps and collector-distributor roadways within Interstate-to-Interstate interchanges. The FHWA allows a minimum 16 ft 00 in (4.9 m) in rural areas and along the single routing in urban areas. The minimum vertical clearance in other urban areas shall be no less than 14 ft 00 in (4.3 m).

The sections below, “NBI Bridge Clearance and Year of Construction” and “NBI State-Level Bridge Materials,” describe analysis of NBI data for low-clearance bridges. Because the low-clearance threshold varies depending on the agency requirement and bridge classification, it is not appropriate to consider one clearance as the low-clearance threshold for all bridges in the NBI. For simplicity, three clearance thresholds will be considered separately.

NBI BRIDGE CLEARANCE AND YEAR OF CONSTRUCTION

During informal discussions, the research team hypothesized that low-clearance bridges tend to be older than average. An analysis of data from the 2023 NBI confirmed that this hypothesis is correct. First, NBI data was filtered so that only relevant bridges are included in the analysis, as summarized in Table 2. Only bridges in the 50 US states and Washington, DC are included, and all culverts are excluded. Additionally, only bridges with owners listed as “City or Municipal Highway Agency,” “County Highway Agency,” “State Highway Agency,” “State Toll Authority,” or “Town or Township Highway Agency” are considered. After applying these filters, 457,375 of the total 621,581 bridges in the NBI remain.

Figure 7 is a histogram of bridge year of construction for the 442,824 of these bridges that have a main span material listed as steel or concrete. Bridges having other main span materials comprise a small portion of the inventory and are therefore not included in the histogram for ease of interpretation. Figure 8 is a similar histogram for steel and concrete bridges located in Illinois, where all other criteria in Table 2 were used to consider relevant bridges. Compared to the entire country, Illinois has a larger proportion of steel bridges built before 1980. Data from Figures 7 and 8 are presented in tabular format in Appendix B.

Note that the NBI entry for “year reconstructed” was not used for this analysis. The NBI definition of reconstruction is that the “type of work performed, whether or not it meets current minimum standards, must have been eligible for funding under any of the Federal-aid funding categories.” For this report, the age of the girders is of specific interest, but not all projects classified as reconstruction involve girder replacement. For example, IDOT bridge SN 016-0388 is listed as reconstructed in 1987, but a close review of the bridge construction documents reveals that although the bridge was widened from 12 to 16 girders in 1987, the original 12 girders remain in the structure. Therefore, the “year constructed” is used to classify the age of the NBI bridges for this report, even though there are select cases where the entire bridge has indeed been reconstructed more recently.

Table 2. Filters Applied to NBI Data for Analysis of Bridge Age and Main Span Material

NBI Category	Parameters Included
State	50 states and Washington, DC
Owner Agency	• City or Municipal Highway Agency • County Highway Agency • State Highway Agency • State Toll Authority • Town or Township Highway Agency
Main Span Design	All except “culvert”

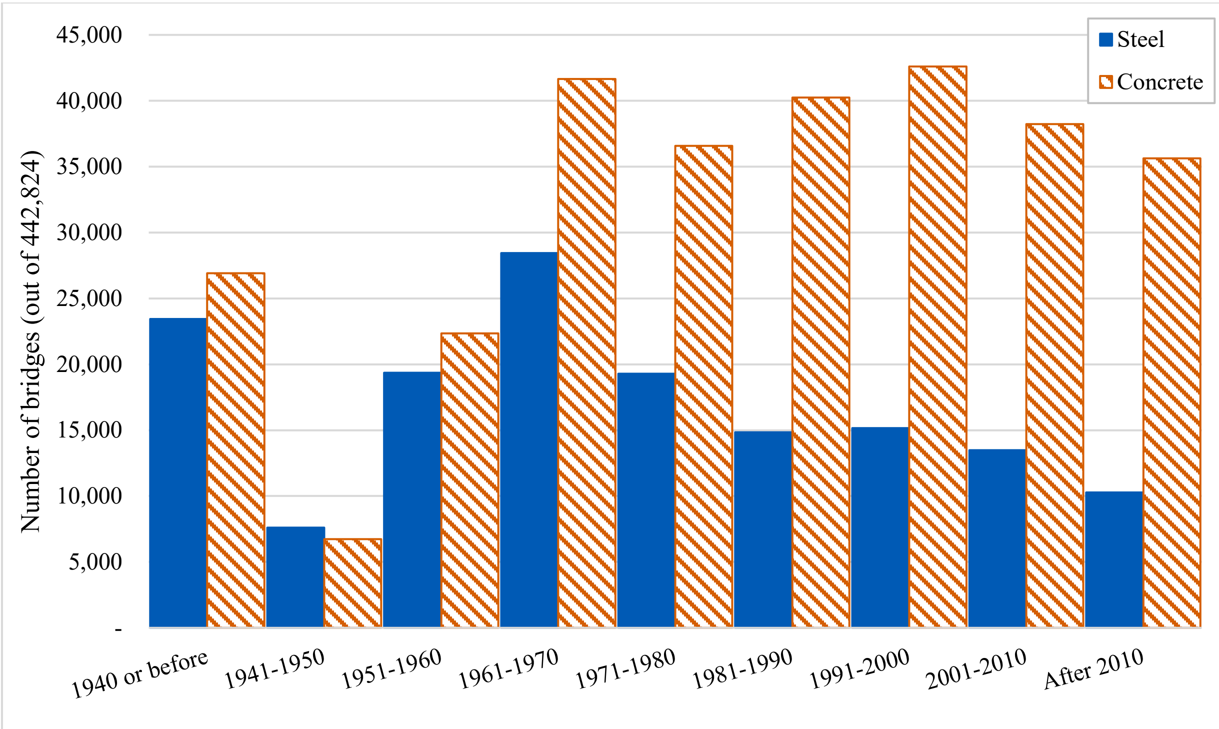

Figure 7. Histogram. Year of construction of steel and concrete bridges in the NBI, selected according to criteria in Table 2.

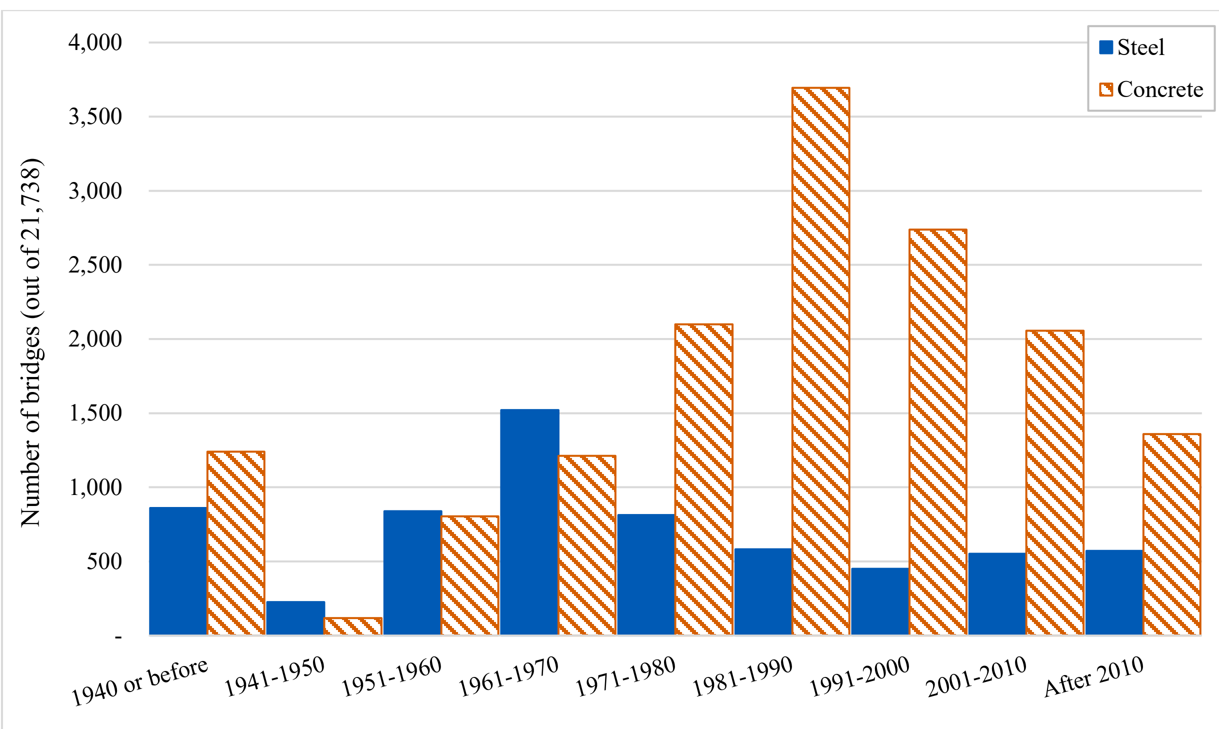

Figure 8. Histogram. Year of construction of steel and concrete bridges in the NBI located in Illinois, selected according to criteria in Table 2.

As described in the section “Low-Clearance Threshold and Percentage of Inventory,” the criteria for low-clearance bridges varies. For studying low-clearance bridges in the NBI, three low-clearance threshold values were used, where any bridge designated as passing over a highway (not a railroad, waterway, or other feature) and having a “vertical underclearance” greater than 0 ft but less than the specified threshold value is considered low clearance:

- 14 ft (4.27 m), the low-clearance threshold designated by FHWA for urban non-single interstate routings (classifies 2,267 bridges as low clearance).
- 15 ft (4.57 m), the low-clearance threshold designated by IDOT for urban non-single interstate routings (classifies 15,782 bridges as low clearance).
- 16 ft (4.88 m), the low-clearance threshold designated by FHWA for rural areas and urban single routings (classifies 30,686 bridges as low clearance).

The low-clearance thresholds are applied in addition to the filters in Table 2. Histograms corresponding to each low-clearance threshold are included in Figure 9 through Figure 11 for the entire country and Figure 12 through Figure 14 for Illinois. The same data are presented in tabular format in Appendix B. For both the entire country and Illinois, all three histograms show similar overall trends, regardless of low-clearance threshold. For the entire country, most low-clearance bridges were built in the 1950s, 1960s, and 1970s. As summarized in Table 3, for thresholds of 14 ft, 15 ft, and 16 ft, the percentages of low-clearance bridges in the entire country built after 1980 are 13%, 12%, and 17%, respectively, even though 47% of bridges overall were built after 1980. As summarized in Table 4, in Illinois, the trend is even more pronounced, with 55% of all Illinois bridges built after 1980 but only 10%, 13%, and 18% of low-clearance bridges built after 1980 for respective thresholds of 14 ft, 15 ft, and 16 ft. Therefore, bridge strikes are expected to involve mostly older bridges because most low-clearance bridges are older. In steel bridge construction, older bridges may have non-composite design and use lower-grade steel, which must be considered when evaluating the behavior of the bridge after a strike.

For all selected NBI bridges in Figure 7, there were more concrete bridges constructed compared to steel bridges for every decade except the 1940s. However, for low-clearance bridges in Figure 9 through Figure 11, there are several decades where there are more steel bridges constructed compared to concrete bridges. The trend for Illinois is similar, where recent bridge construction is dominated by concrete bridges, but more steel bridges were constructed than concrete bridges in the 1940s, 1950s, and 1960s. Low-clearance bridges in Illinois were almost exclusively constructed in the 1960s and 1970s, with over 75% of low-clearance bridges having steel main-span material, for all three low-clearance thresholds. As summarized in Tables 3 and 4, a larger percentage of low-clearance bridges are constructed from steel compared to the percentage of all bridges constructed from steel in the entire US and in Illinois.

From this analysis, it is clear that a significant portion of low-clearance bridges were built before 1980 and are constructed from steel, both in the US overall and in Illinois. Therefore, inspection and assessment of steel bridge girders damaged by impact is a relevant research topic.

Table 3. Comparison of All NBI Bridges Considered (per Table 2) to Low-Clearance Bridges Based on a 14 ft, 15 ft, and 16 ft Threshold

Description	All bridges considered	Clearance less than 14 ft	Clearance less than 15 ft	Clearance less than 16 ft
Number	457,375	2,267	15,782	30,686
Percent built after 1980	47%	13%	12%	17%
Percent steel	33%	42%	59%	52%
Percent concrete	64%	57%	41%	47%

Table 4. Comparison of All NBI Bridges in Illinois Considered (per Table 2) to Low-Clearance Bridges Based on a 14 ft, 15 ft, and 16 ft Threshold

Description	All bridges considered	Clearance less than 14 ft	Clearance less than 15 ft	Clearance less than 16 ft
Number	21,800	29	401	730
Percent built after 1980	55%	10%	13%	18%
Percent steel	29%	79%	78%	75%
Percent concrete	70%	21%	22%	25%

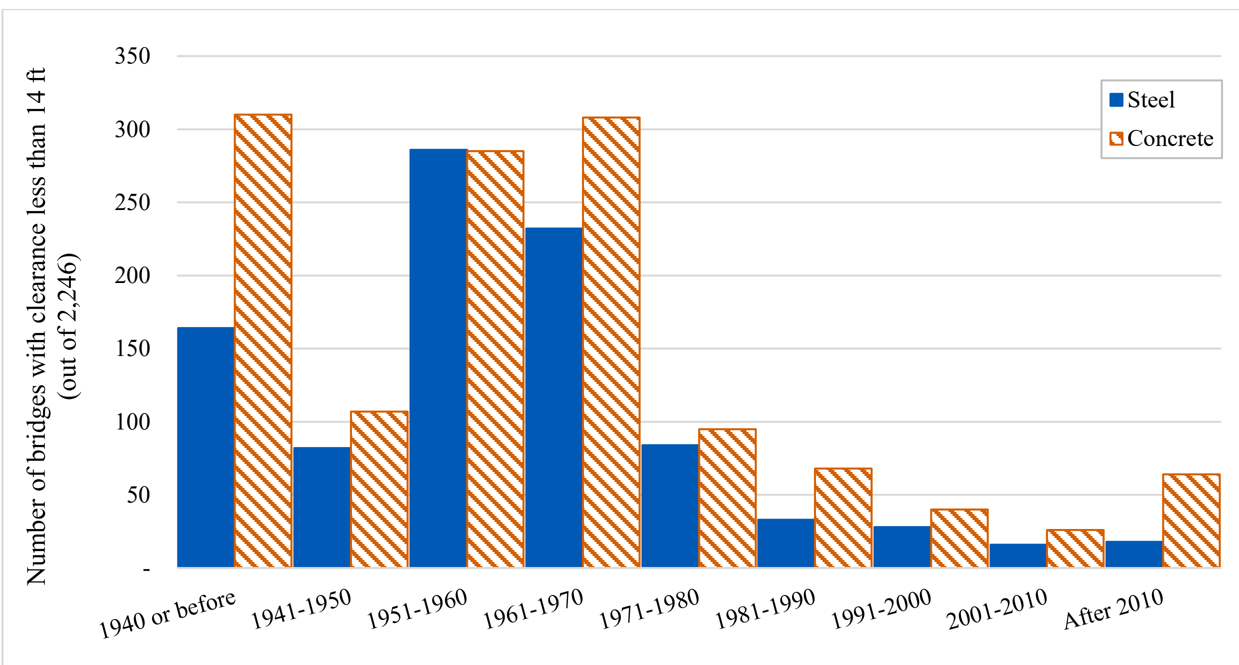

Figure 9. Histogram. Year of construction of steel and concrete bridges over roads having clearance less than 14 ft according to the NBI.

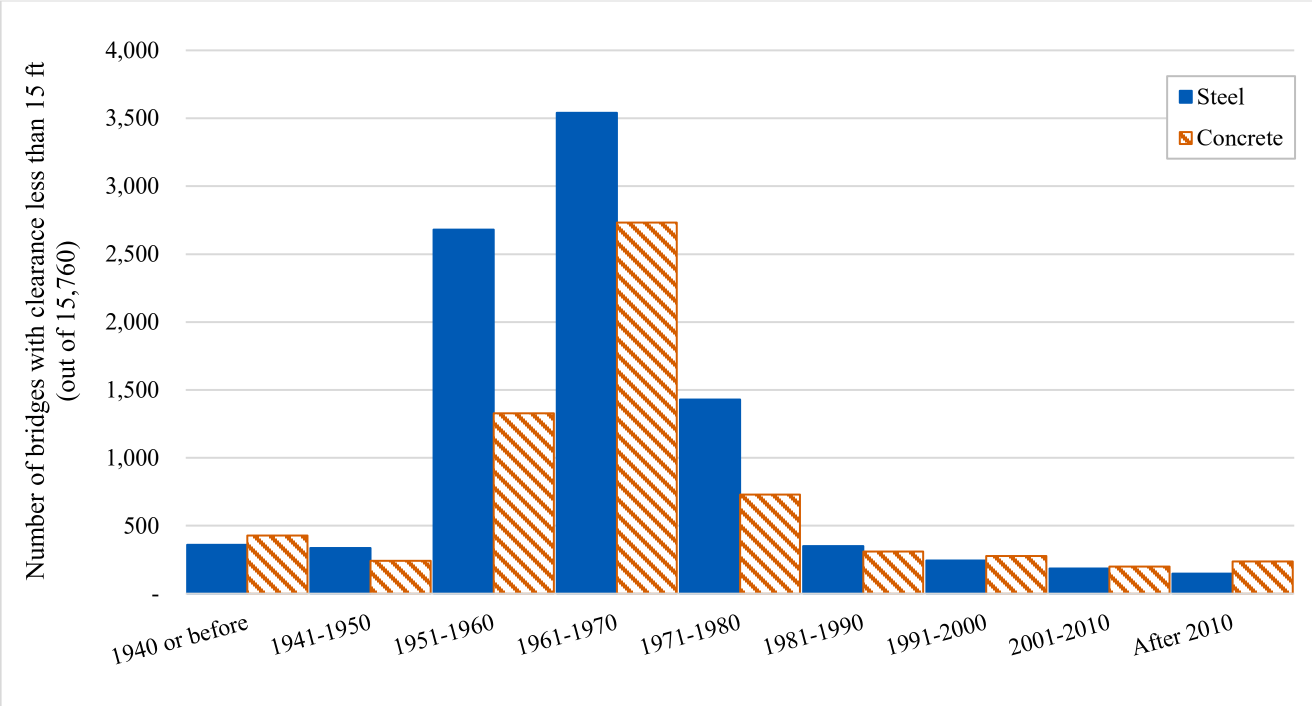

Figure 10. Histogram. Year of construction of steel and concrete bridges over roads having clearance less than 15 ft according to the NBI.

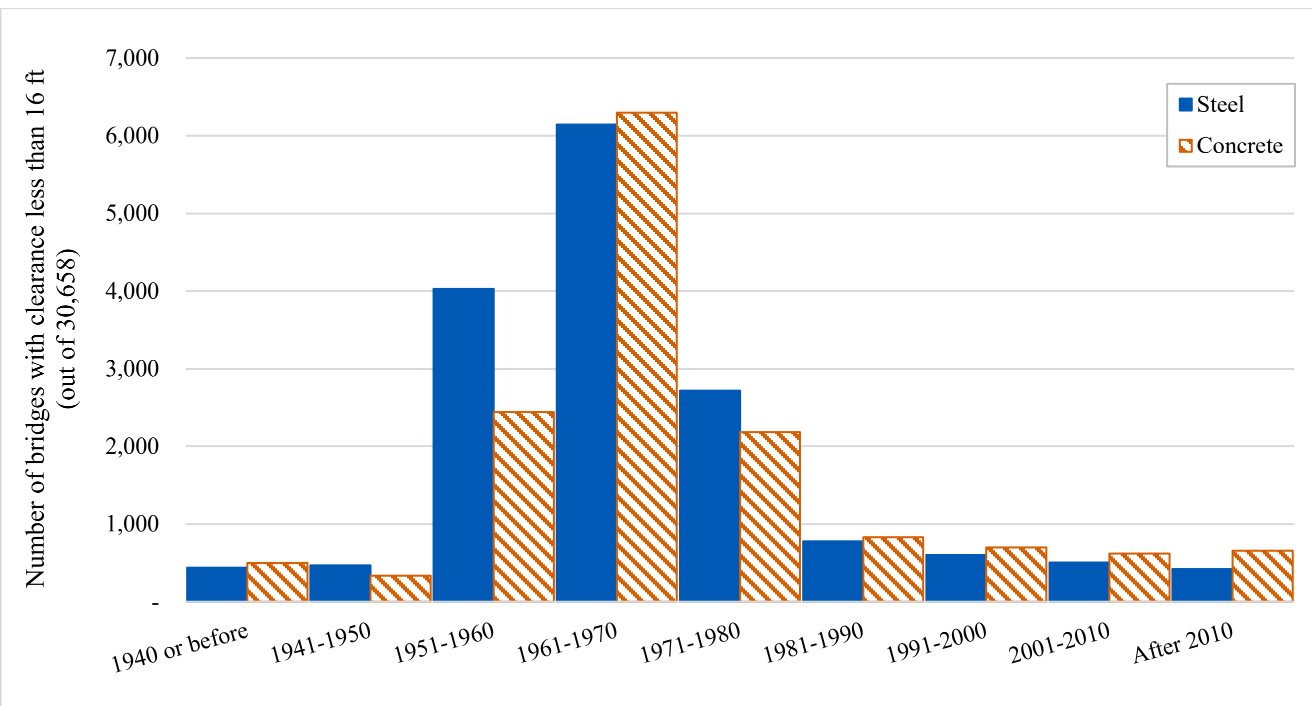

Figure 11. Histogram. Year of construction of steel and concrete bridges over roads having clearance less than 16 ft according to the NBI.

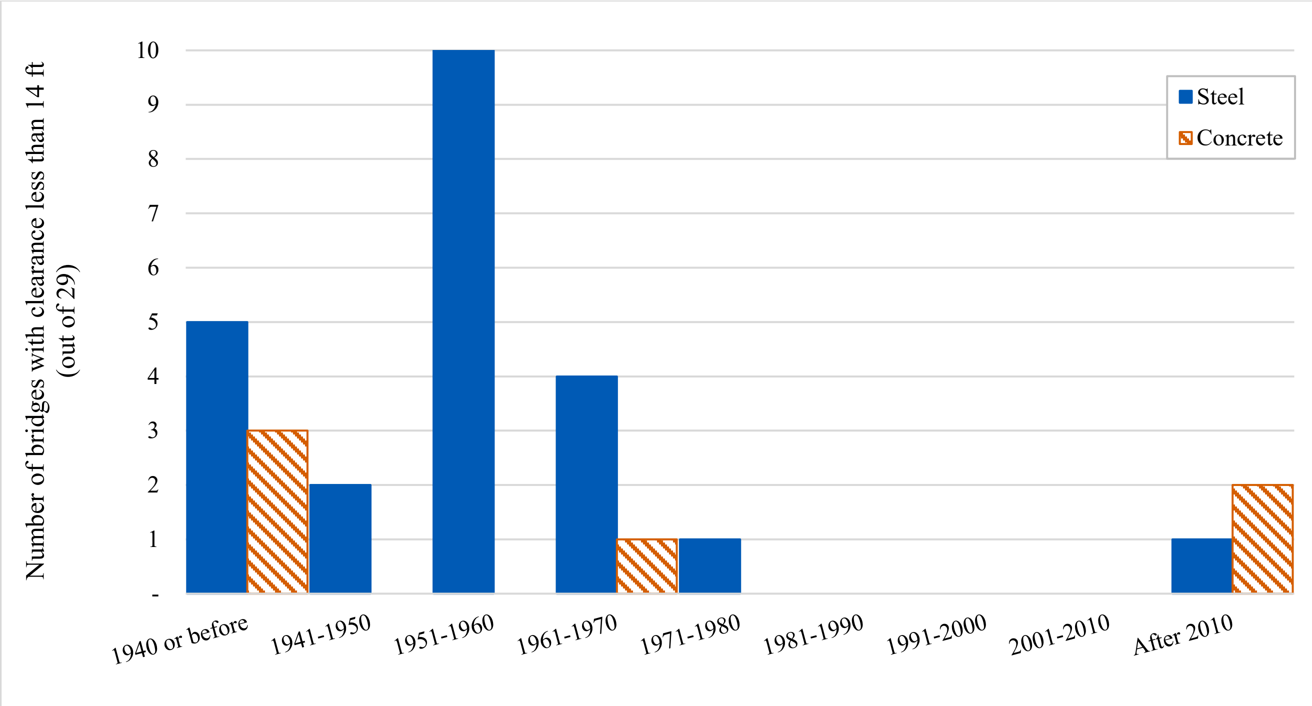

Figure 12. Histogram. Year of construction of steel and concrete bridges over roads located in Illinois having clearance less than 14 ft, according to the NBI.

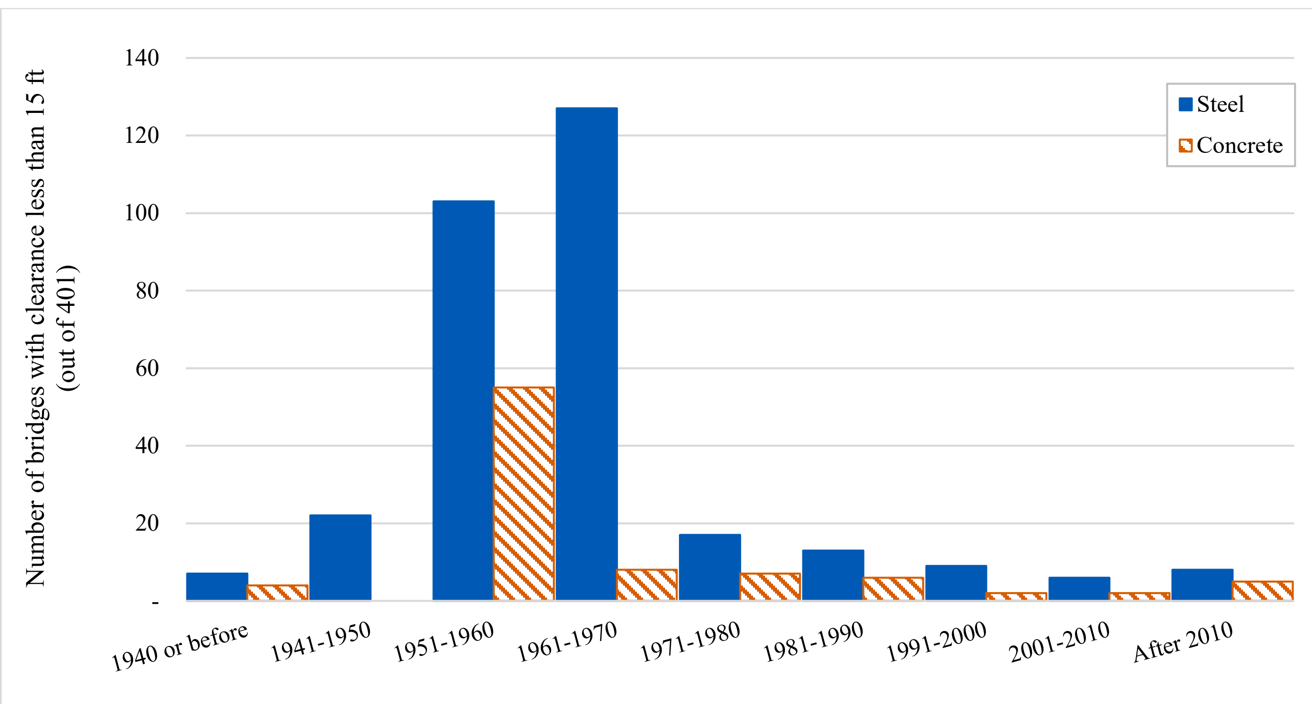

Figure 13. Histogram. Year of construction of steel and concrete bridges over roads located in Illinois having clearance less than 15 ft, according to the NBI.

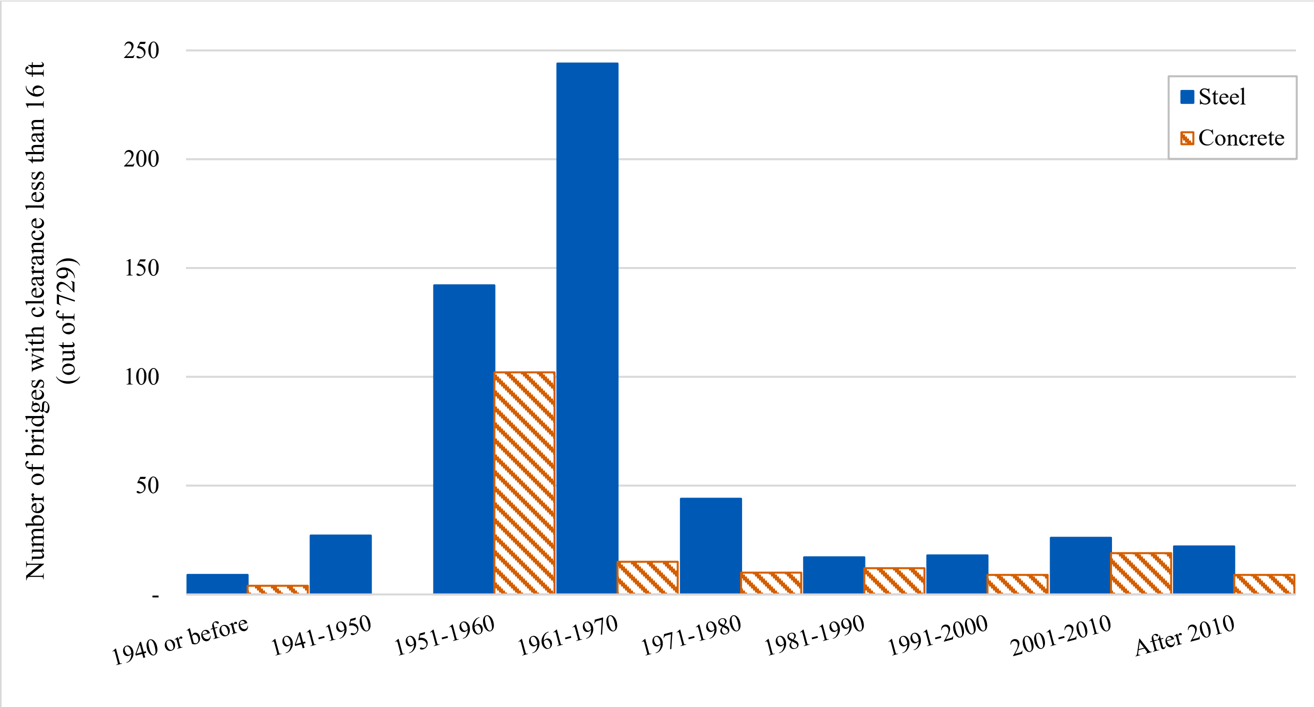

Figure 14. Histogram. Year of construction of steel and concrete bridges over roads located in Illinois having clearance less than 16 ft, according to the NBI.

NBI STATE-LEVEL BRIDGE MATERIALS

Data from the NBI was also analyzed to consider whether individual states tend to have a disproportionately higher percentage of low-clearance bridges having steel as the main span material. The girder material was identified based on the "Main Span Material" entry containing the terms "steel" or "concrete," respectively.

The same three low-clearance thresholds discussed previously were used for comparing low-clearance bridges at the state level. The term "all bridges" refers to all bridges in the NBI selected according to the criteria in Table 2. In Figure 15 through Figure 17, the steel and concrete bridge inventories for each state are represented by a blue circle and an orange triangle, respectively. The horizontal axis shows the percentage of all bridges in the state inventory having a given material, and the vertical axis shows the percentage of low-clearance bridges in the state inventory having the same material. For example, the blue circle at about (25%, 67%) in Figure 17 represents a state where steel-girder bridges make up 25% of the overall bridge inventory and 67% of the low-clearance bridge inventory.

The solid black line is the "equal line," which represents the location of points where a given girder material is attributed to equal percentages of both the overall and low-clearance state bridge inventories. Points that lie above the equal line indicate a state where the given girder material corresponds to a disproportionately high percentage of low-clearance bridges compared to the overall percentage of the state inventory. The number of states having disproportionately high percentages of low-clearance bridges constructed from steel and concrete is summarized in Table 5.

For every low-clearance threshold, the number of states having a disproportionately high percentage of steel low-clearance bridges is greater than the number of states having a disproportionately high percentage of concrete low-clearance bridges.

Bridges having main span materials other than steel or concrete are not included in these plots because other girder materials typically comprise a relatively small portion of the inventory in each state. However, because bridges of other materials are not included, it is possible for the same state to have both a disproportionately high percentage of steel and concrete low-clearance bridges. Or, it is possible for a state to have both a disproportionately low number of steel and concrete low-clearance bridges. Therefore, the sum of entries in any row of Table 5 is not necessarily 51 (for 50 states plus Washington, DC) and may instead be less than or greater than 51.

In states where other bridge materials comprise a small portion of the overall inventory and low-clearance inventory, the steel and concrete points for a given state show a nearly rotational symmetric relationship in Figures 15 through 17. For example, in Illinois, the overall inventory is 29% steel bridges and 70% concrete bridges, and the low-clearance (less than 16 ft) inventory is 75% steel bridges and 25% concrete bridges. In Figure 17, the blue dot at (29%, 75%) corresponds to the orange triangle at (70%, 25%), which is nearly rotationally symmetric about the point (50%, 50%). A nearly rotational symmetric pattern can be observed for some clusters of points. Overall, the low-clearance inventory in most states is comprised of a significant percentage of bridges having steel main span material, confirming that low-clearance steel bridges are relevant to individual states in addition to the entire country.

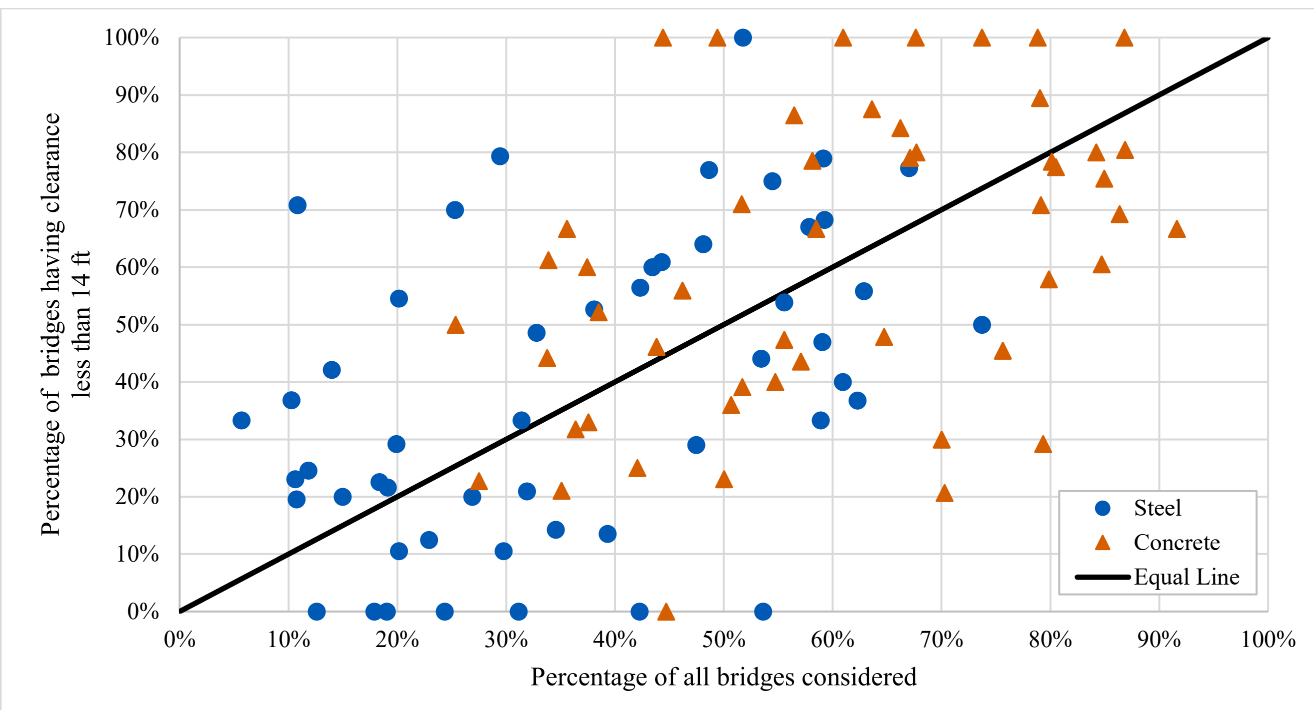

Figure 15. Scatterplot. NBI percentage of low-clearance bridges vs. percentage of all bridges for each state, considering a 14 ft low-clearance threshold.

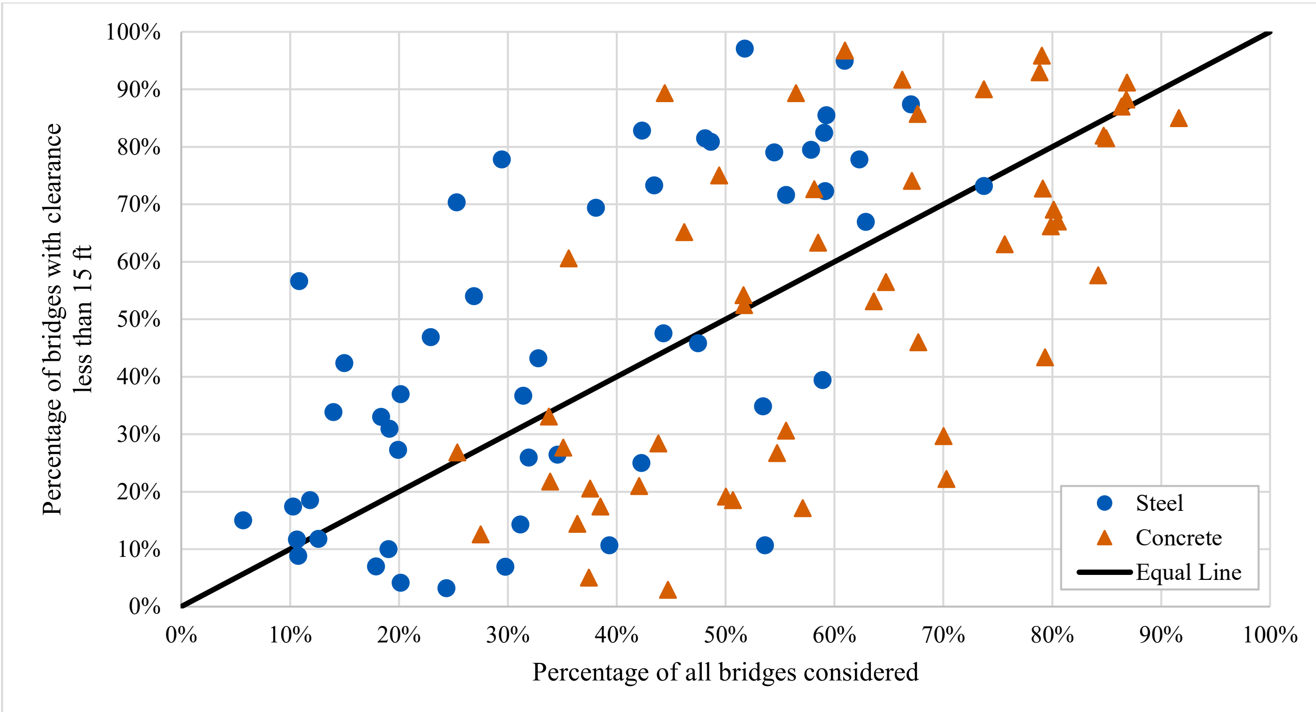

Figure 16. Scatterplot. NBI percentage of low-clearance bridges vs. percentage of all bridges for each state, considering a 15 ft low-clearance threshold.

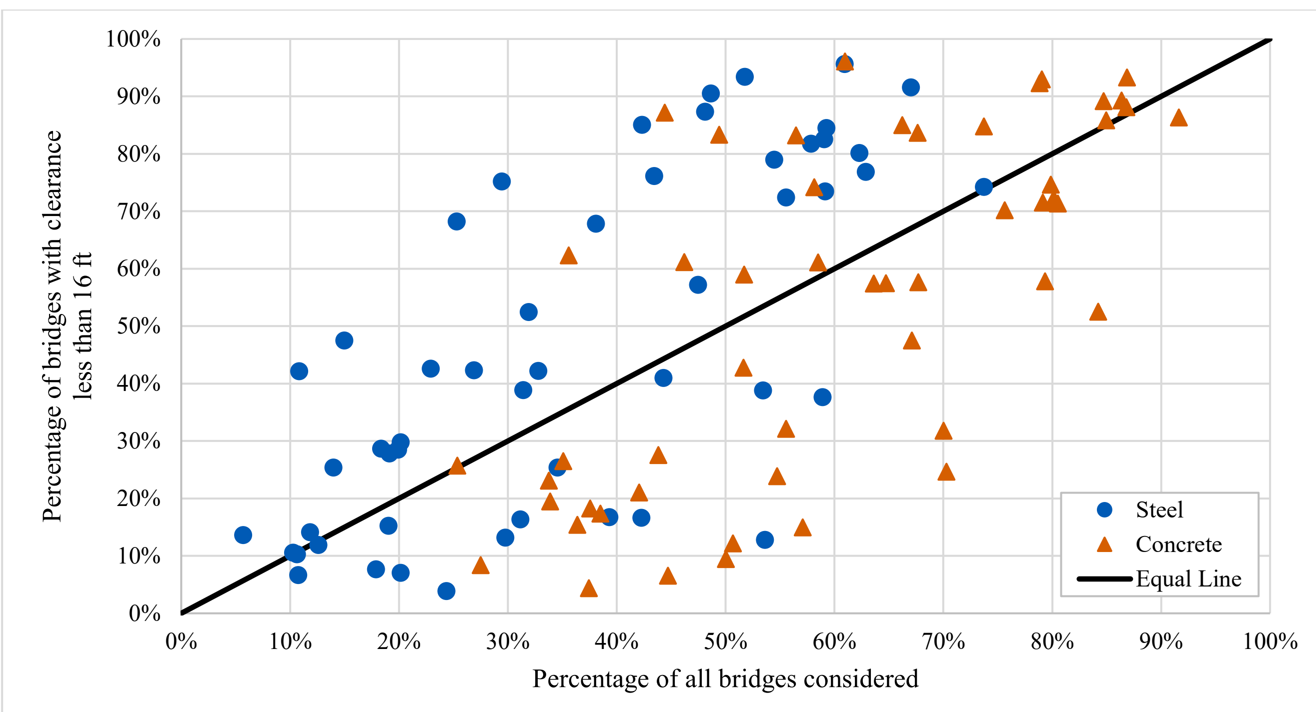

Figure 17. Scatterplot. NBI percentage of low-clearance bridges vs. percentage of all bridges for each state, considering a 16 ft low-clearance threshold.

Table 5. Number of States with Disproportionately High Percentages of Steel and Concrete Low-Clearance Bridges

Low-clearance threshold	Number of states with disproportionately high percentage of steel low-clearance bridges	Number of states with disproportionately high percentage of concrete low-clearance bridges
Clearance less than 14 ft	28	24
Clearance less than 15 ft	34	20
Clearance less than 16 ft	35	20

LOW-CLEARANCE SIGNAGE

On the agency survey, 18 states reported that they consider typical clearance signage for their agency-maintained bridges to be sufficient. Delaware, Iowa, Maine, Rhode Island, and South Dakota reported that signage is not sufficient. Delaware suggested that deterrence or even barriers were needed for low-clearance bridges, and Maine suggested raising the bridges in main corridors to increase clearance. Iowa responded “unknown” when asked for suggested improvements. Rhode Island stated that their Traffic Division is working on an “impact mitigation plan for low clearance structures that will include additional measures” such as an automatic over-height vehicle detection system. They also suggested adding more visible advanced signage ahead of low-clearance points. South Dakota stated that only one signed bridge is regularly struck, and the issue seems to involve truck routing using navigation systems meant for passenger vehicles. Pennsylvania indicated that they considered signage sufficient, but they suggested expanding intelligent transportation systems involving over-height vehicle detection. Louisiana mentioned consideration of installing clearance signs on bridges that have greater than the 16.5-ft low-clearance threshold. Massachusetts and Ohio stated that existing signage is adequate but ignored by drivers.

CHAPTER 3: BRIDGE STRIKES

Next, states were asked to report information about bridge strikes. Questions addressed both bridge strikes in general and bridge girder strikes specifically. The overall number of bridge strikes and total annual cost to repair damaged girders are not correlated. The most commonly reported location of bridge strikes was at girders, and a disproportionately high percentage of strikes affected steel girders compared to concrete girders.

ANNUAL NUMBER OF BRIDGE STRIKES

The annual number of bridge strikes reported by states ranged from 2 (Maine) to 250 (New York). Responses are summarized in Figure 18. The only states reporting more than 30 annual bridge strikes were North Carolina, Wisconsin, and New York, reporting 37, 45, and 250 annual strikes, respectively. Including these three states, the average number of annual bridge strikes was 25, but excluding these three states, the average number reduces to 11.1. Eleven states reported less than ten bridge strikes per year, and six of those states reported less than five bridge strikes per year.

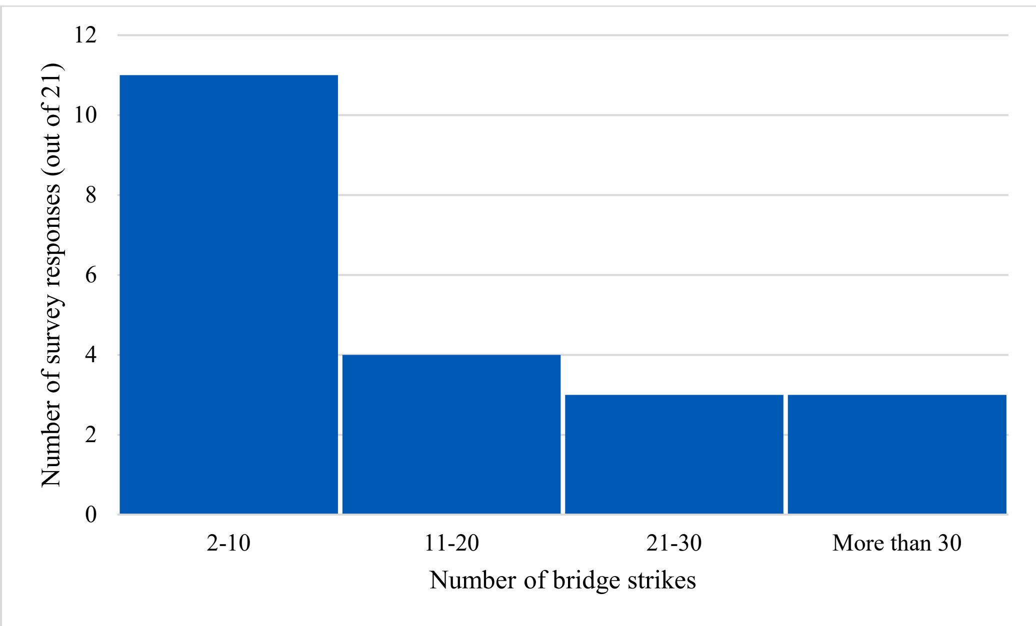

Figure 18. Histogram. Annual number of bridge strikes.

BREAKDOWN OF BRIDGE IMPACT LOCATION

Survey respondents reported the approximate breakdown of bridge impact location. As shown in Figure 19, girders are most often impacted during a bridge strike event. The average breakdown of impact locations was 88% on girders, 5% on piers/abutments, and 6% on other bridge components. New Hampshire reported an unusually large number of bridge impacts on other bridge components (50%). Elsewhere in the survey, they stated that there are a “large number of timber covered bridges which are struck frequently,” which is a potential explanation for the “other” bridge components that were reported to be impacted.

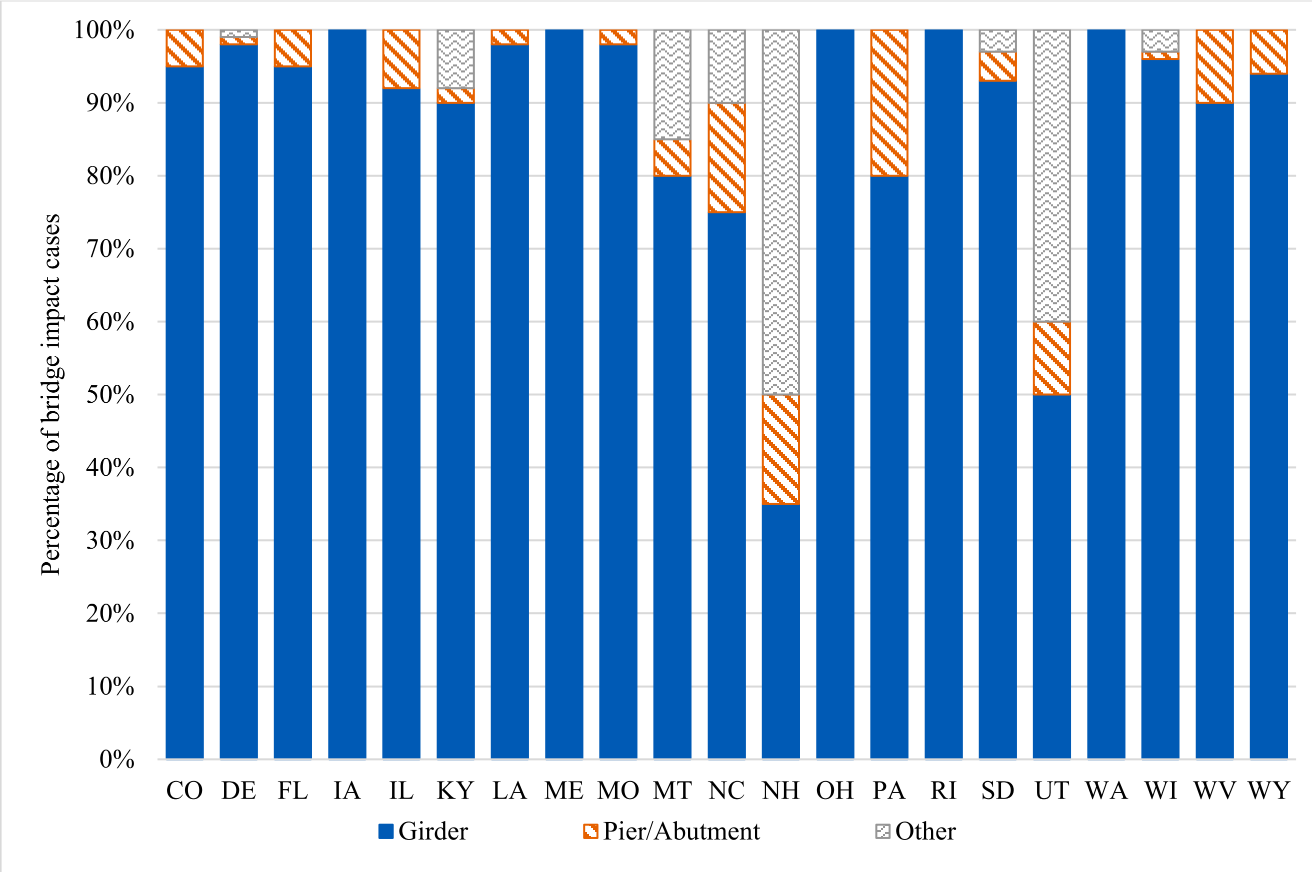

Figure 19. Bar chart. Breakdown of bridge impact location.

ANNUAL COST INCURRED FOR DETECTION AND REPAIR OF DAMAGED GIRDERS DUE TO BRIDGE STRIKES

The annual cost of detection, repair, and replacement of damaged girders due to bridge strikes is summarized in Figure 20. Seven of the 17 respondents reported annual costs of less than $1 million, and only five respondents reported costs of $2 million or more. The annual cost of detection and repair is not significantly correlated with the annual number of bridge strikes observed, as shown in Figure 21. However, the number of bridge strikes reported includes all bridge strikes, not only strikes on girders, so these quantities are not directly comparable, which may partially explain why there is no observable correlation. Furthermore, the extent of the damage and choice of repair techniques are usually handled on a case-by-case basis and would also affect the annual cost of repairs.

Of the 17 states reporting cost data, the four states with the largest number of bridge strikes have a relatively low cost per strike, which could indicate that the strikes do not cause severe damage, or the states have developed cost-effective measures to assess and repair typical damage. New York, which reported 250 annual bridge strikes, did not respond to the question about annual cost and is therefore not included in this assessment.

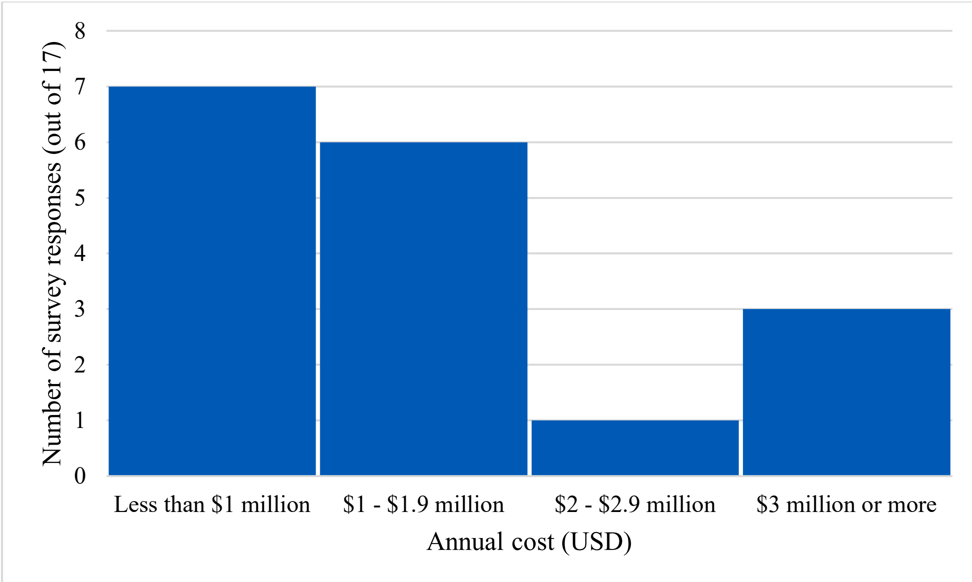

Figure 20. Histogram. Annual cost of detection and repair of bridge strikes (USD).

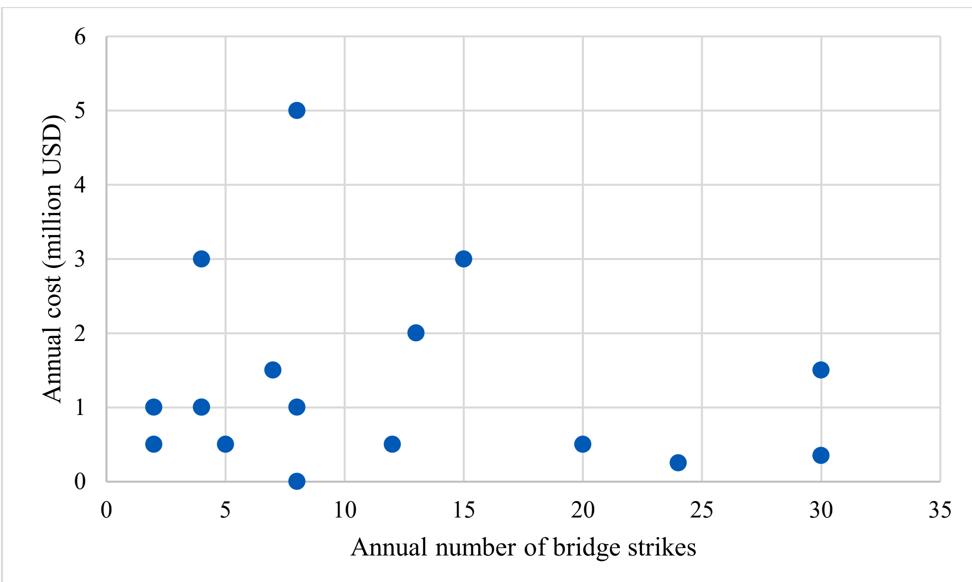

Figure 21. Scatterplot. Reported annual cost vs. annual number of bridge strikes.

DISTRIBUTION OF MATERIAL TYPES FOR GIRDER STRIKES

Survey respondents were asked to report the distribution of bridge girder materials between steel, concrete, and other materials for all bridges in their inventory. Then, respondents were asked to report the same distribution for girder strikes. In Figure 22, the percentage of girder strikes versus the percentage of bridge inventory was plotted for steel, concrete, and other materials. An “equal” line is also plotted to visualize the scenario where a given percentage of girder strikes corresponds to the same percentage of the bridge girder material in the inventory. Table 6 includes the full responses for each state.

Of the 21 states that fully responded to both questions, 14 states had a disproportionately high percentage of girder strikes on steel bridge girders. This can be visualized in Figure 22 by counting the number of blue points above the equal line. Six states had a disproportionately low percentage of girder strikes on steel bridge girders, and one state had the same percentage of strikes on steel bridge girders as the percentage of bridges with steel bridge girders in the inventory. Eight states had a disproportionately large percentage of girder strikes on concrete girders, and 13 states had a disproportionately small percentage of girder strikes on concrete girders. A few concrete data points are very similar and therefore overlap in Figure 22, so the complete data are summarized in Table 6. Most states reported a small percentage of bridges made from other materials, so this dataset is not the focus of this report.

An important factor to consider is that bridge strikes on steel girders may be easier to observe compared to bridge strikes on concrete girders. In the case of a minor hit-and-run strike on an older concrete girder, it may be difficult to distinguish between bridge strike damage and spalling from other damage causes.

Seven of the eight states having a disproportionately large percentage of strikes on concrete girders had over 55% of concrete bridge girders in their inventory. States with a larger percentage of concrete bridge girders were more likely to have a disproportionately large number of bridge strikes on concrete girders. A disproportionately large percentage of bridge strikes on steel girders did not necessarily correspond with a larger percentage of steel girders in the bridge inventory.

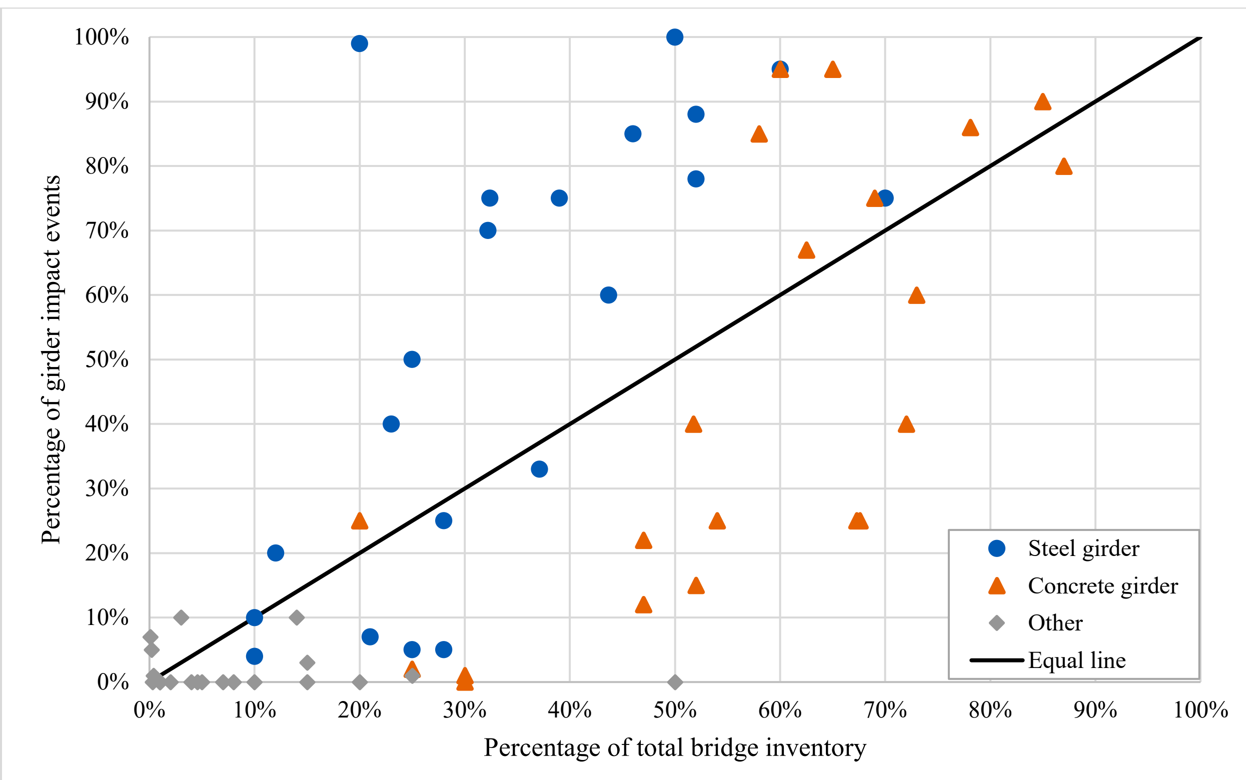

Figure 22. Scatterplot. Percentage of girder strikes vs. percentage of bridge inventory for each girder material.

Table 6. Inventory and Girder Strike Breakdown between Steel Girders, Concrete Girders, and Other Girder Materials

State	Inventory: steel girder	Inventory: concrete girder	Inventory: other girder material	Bridge strikes: steel girder	Bridge strikes: concrete girder	Bridge strikes: other girder material
CO	23%	73%	4%	40%	60%	0%
DE	20%	30%	50%	99%	1%	0%
FL	10%	65%	25%	4%	95%	1%
IA	21%	78%	0%	7%	86%	7%
IL	52%	47%	1%	88%	12%	0%
KY	12%	87%	1%	20%	80%	0%
LA	25%	60%	15%	5%	95%	0%
MA	77%	18%	5%	–	–	–
ME	50%	30%	20%	100%	0%	0%
MO	32%	67%	0%	75%	25%	0%
MT	28%	58%	14%	5%	85%	10%
NC	44%	52%	5%	60%	40%	0%
NH	70%	20%	10%	75%	25%	0%
NY	68%	32%	0%	–	–	–
OH	60%	25%	15%	95%	2%	3%
PA	25%	72%	3%	50%	40%	10%
RI	39%	54%	7%	75%	25%	0%
SD	32%	68%	0%	70%	25%	5%
UT	28%	69%	8%	25%	75%	0%
WA	10%	85%	5%	10%	90%	0%
WI	37%	63%	0%	33%	67%	1%
WV	46%	52%	2%	85%	15%	0%
WY	52%	47%	1%	78%	22%	0%

PERCENTAGE OF BRIDGE STRIKES REPORTED IMMEDIATELY

States are only able to begin the assessment and repair process after a bridge strike is reported; therefore, the speed of reporting bridge strikes is important. For the purposes of the survey question, states were instructed to consider a bridge strike reported within 1–2 days after occurrence as an "immediate" report. Of 20 states responding to the question, 14 indicated that bridge strikes are reported immediately after occurrence at least 80% of the time. Only three states indicated that 50% or less of bridge strikes are reported immediately. One challenge in reporting is that some bridge strikes are "hit and run" incidents that may not be discovered until regular inspections.

REASONS FOR BRIDGE STRIKES

For the approximate breakdown of reasons for bridge strikes, respondents were given the categories of "vehicle/load too tall (no permit)," "vehicle/load too tall (permit obtained, wrong route)," "equipment loaded incorrectly," and "other" with an option to explain any other reasons for strikes. Illinois listed 60% in the "other" category and explained that many bridge strikes are hit-and-run, so there is no way of knowing the reason. North Carolina listed 50% in the "other" category and cited dump trucks with beds up from paving roads as a cause of damage. Other reasons mentioned included equipment malfunction, driver health condition, and accidents. The breakdown of reasons for strikes varies greatly by state. Wyoming and Louisiana commented that they did not have data on the reasons for bridge impacts, and three additional states did not respond to the question. In a different question, Massachusetts noted that there are a significant number of strikes annually. They noted that there is a lack of enforcement, and "many times the strikes are not reported." The summary of the breakdown of reasons reported by each state is included in Figure 23.

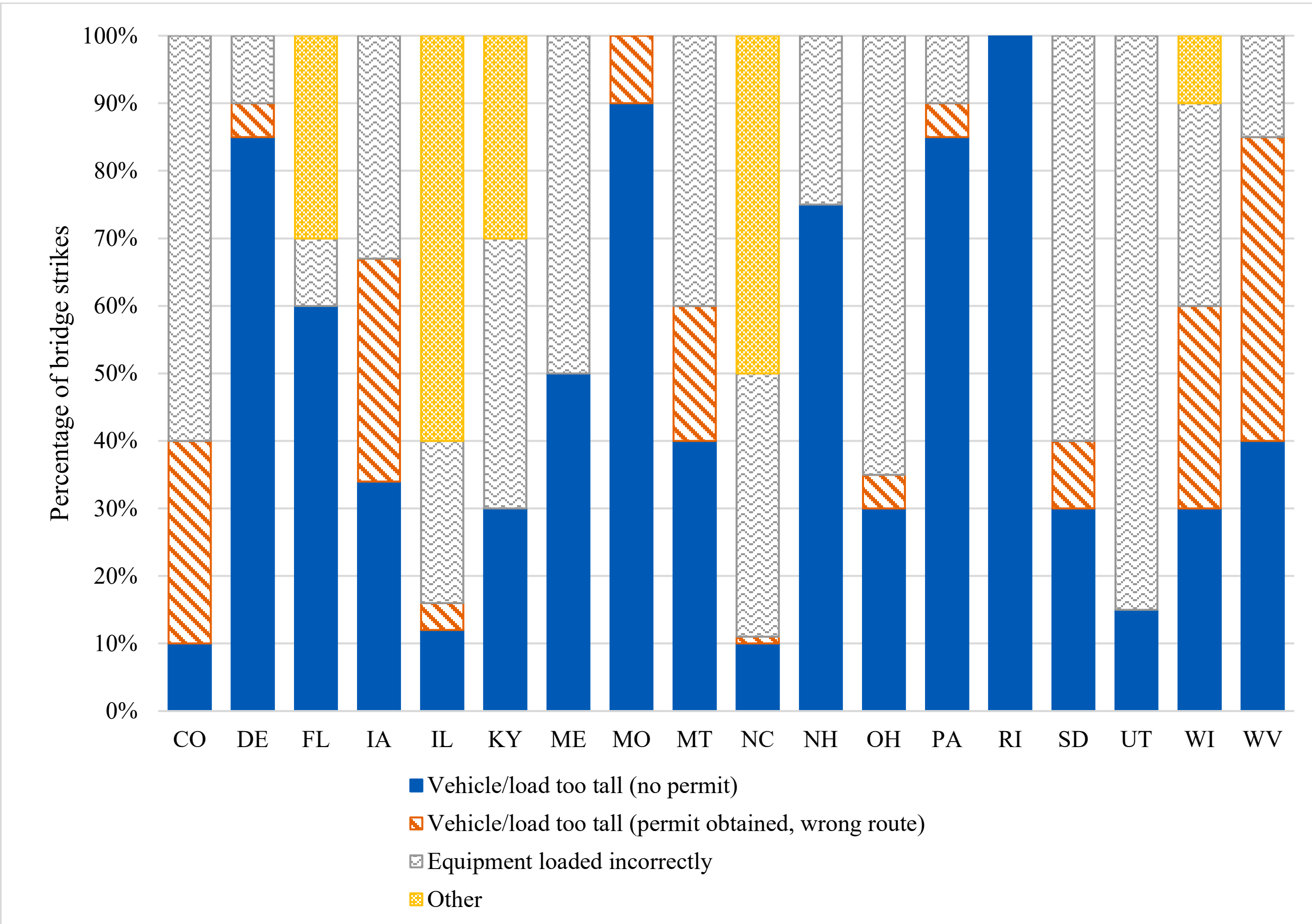

Figure 23. Bar chart. Breakdown of reasons for bridge strikes.

RAILROAD-OWNED BRIDGES OVER STATE HIGHWAYS

States were asked to report how strikes on railroad-owned bridges over state highways are handled. In general, states reported that railroad owners are responsible for repairs and costs associated with strikes on railroad-owned bridges over state highways. The state department of transportation may provide support or assist with traffic control.

In the majority of the 20 states responding to this question, the state department of transportation notifies the railroad owner, who is responsible for repairs. In Illinois, Montana, North Carolina, New York, and West Virginia, the state handles traffic control while the railroad coordinates inspections and repairs. In Montana, the state may also respond or do a special inspection to ensure there is no danger to the traveling public. In Pennsylvania, the state responds to the incident and provides life safety support while the railroad owner is responsible for permanent repairs and costs. In Wisconsin, the railroad responds initially, and the state may get involved upon request. In Colorado, the state department of transportation is notified of impacts over state roads. The state works with the railroad to ensure that it is safe to open the road after an inspection.

Only two states reported exceptions where the state is responsible for some or all repairs. In Utah, the state makes repairs to damaged railroad bridges due to an agreement with the railroad that the state will maintain everything below the bottom of ballast. Florida stated that each bridge has a maintenance agreement. If the state is responsible for maintenance, the state pays for the repairs after the repair schedule is finalized in agreement with the railroad owner.

CHAPTER 4: DAMAGE ASSESSMENT

After a bridge strike occurs, the bridge owner must inspect the bridge to assess damage. There was some variation in inspection techniques between states, but traditional inspection techniques, such as visual surveys and manual measurements, were reported to be used more commonly than newer techniques, such as laser scans and drone photographs. Both local and global damage may occur separately or together, and damage frequently extends to diaphragms/cross-frames.

BRIDGE INSPECTION METHODS

States reported the percentage of cases in which various inspection methods were used after a damaging event. Figure 24 shows the percentage of the time that states used a visual survey, manual photographs, manual measurements, nondestructive testing, laser scans, and drone photographs. States had the opportunity to report other methods used, but no additional methods were mentioned.

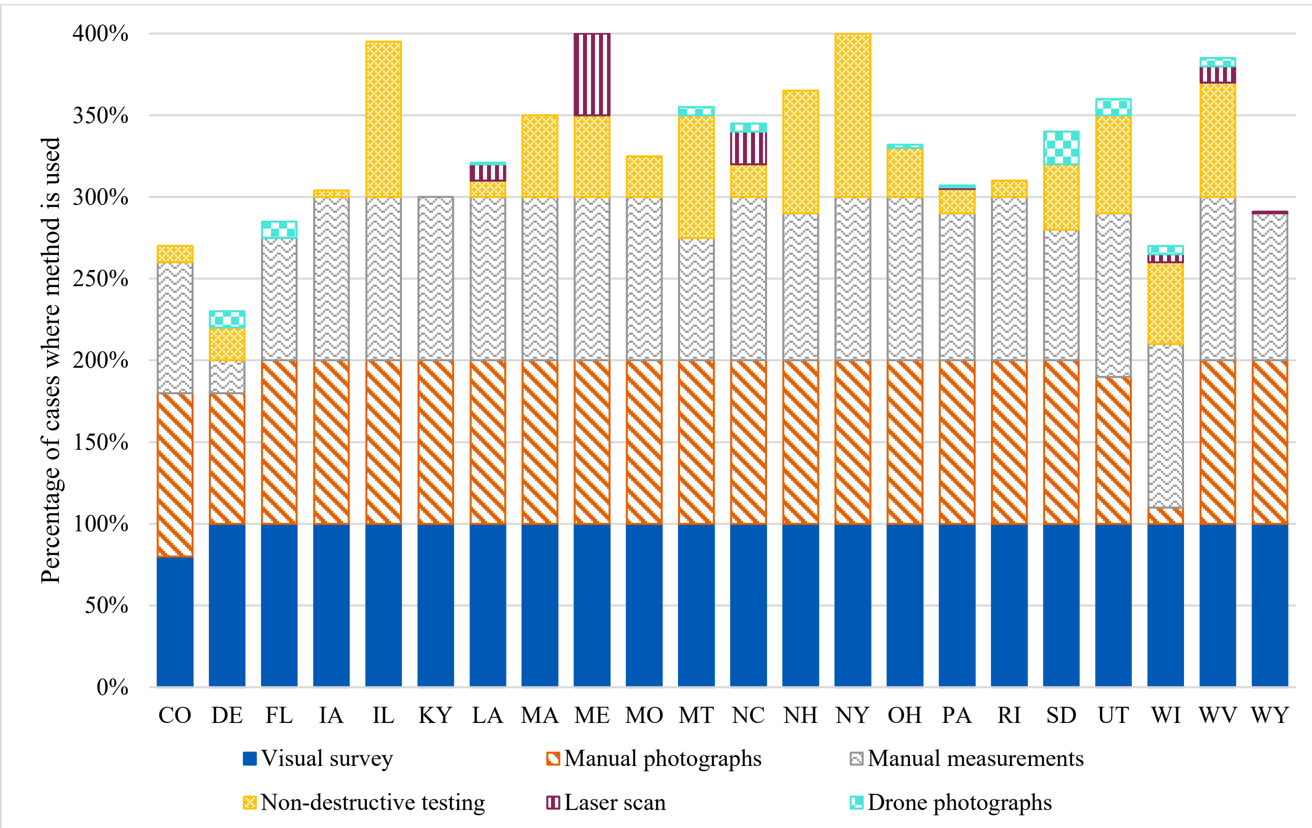

Figure 24. Bar chart. Methods used for bridge inspection after a damaging event.

Figure 25 summarizes general trends for use for each inspection method. Overall, visual surveys, manual photographs, and manual measurements are established methods that were used on average over 90% of the time in all states. Nondestructive testing is an emerging method that is used frequently in some states but not in others. This method was used 37% of the time on average, but there is a 32% standard deviation, indicating that usage varies significantly between states. Laser scans and drone photographs are innovative inspection methods that are used less frequently. Laser scans were used a maximum of 50% of the time, and drone photographs were used a maximum of 20% of the time, although the overall average usage was less than 5% of cases for both methods. Therefore, there is potential to modernize inspection methods by incorporating emerging technologies.

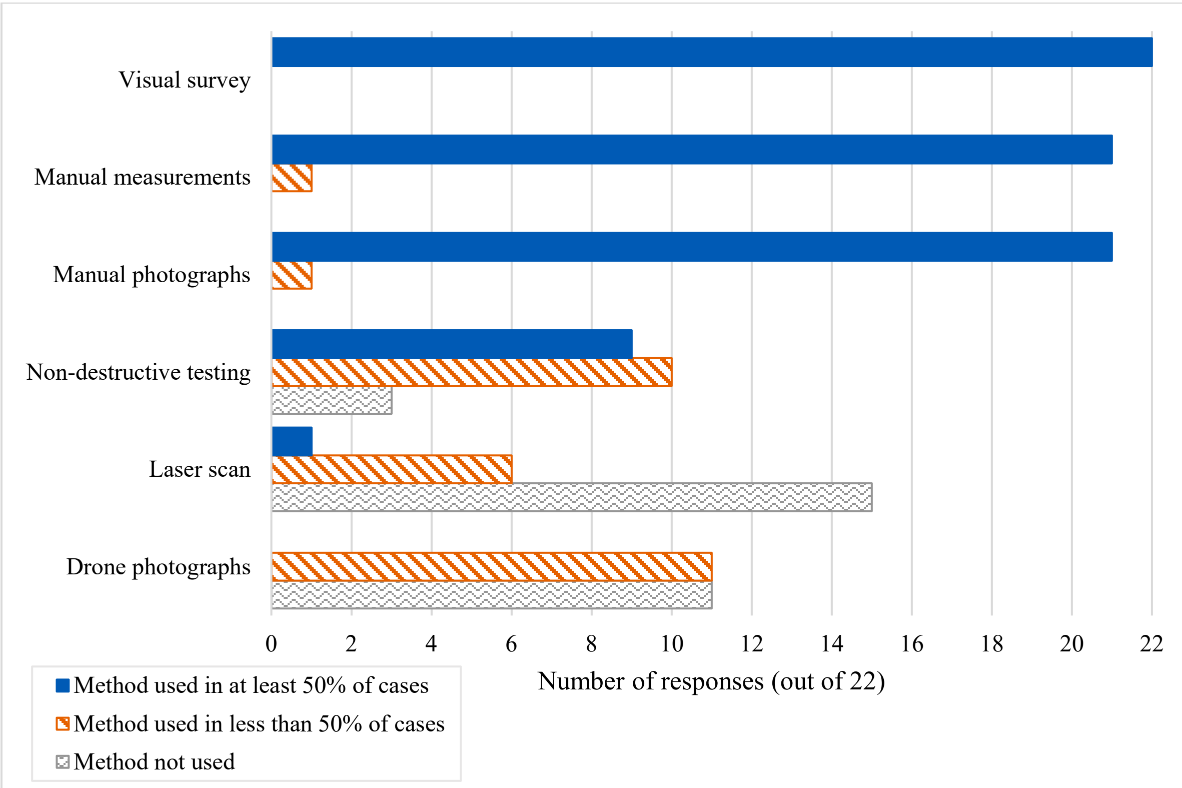

Figure 25. Graph. Frequency of inspection types used after a damaging event.

BREAKDOWN OF LOCAL, GLOBAL, AND COMBINED DAMAGE

The breakdown of damage considered local, global, and combined gives an indication of the level of severity of damage in bridge strikes in different states. Damage concentrated in a small area (e.g., nicks, gouges, and tears) is considered local, and damage spread over some length in the girder is considered global. Combined damage cases have both local and global damage resulting from the same bridge strike incident. Cases where damage is characterized as global or combined likely require more expensive, time-consuming, and/or urgent assessment and repairs because bridge capacity may be significantly impacted.

The breakdown of damage characterization varies greatly between states, as shown in Figure 26 and summarized in Table 7. Eleven states reported over 50% of damage cases could be categorized as global or combined. As seen in Figure 27, there is a weak positive correlation between the percentage of damage considered global or combined and the annual cost of repair/replacement of damaged girders due to bridge strikes, for the 17 states that responded to both questions. This suggests that global and combined damage are more expensive to repair. States must be prepared to address both local and global damage instances because both occur.

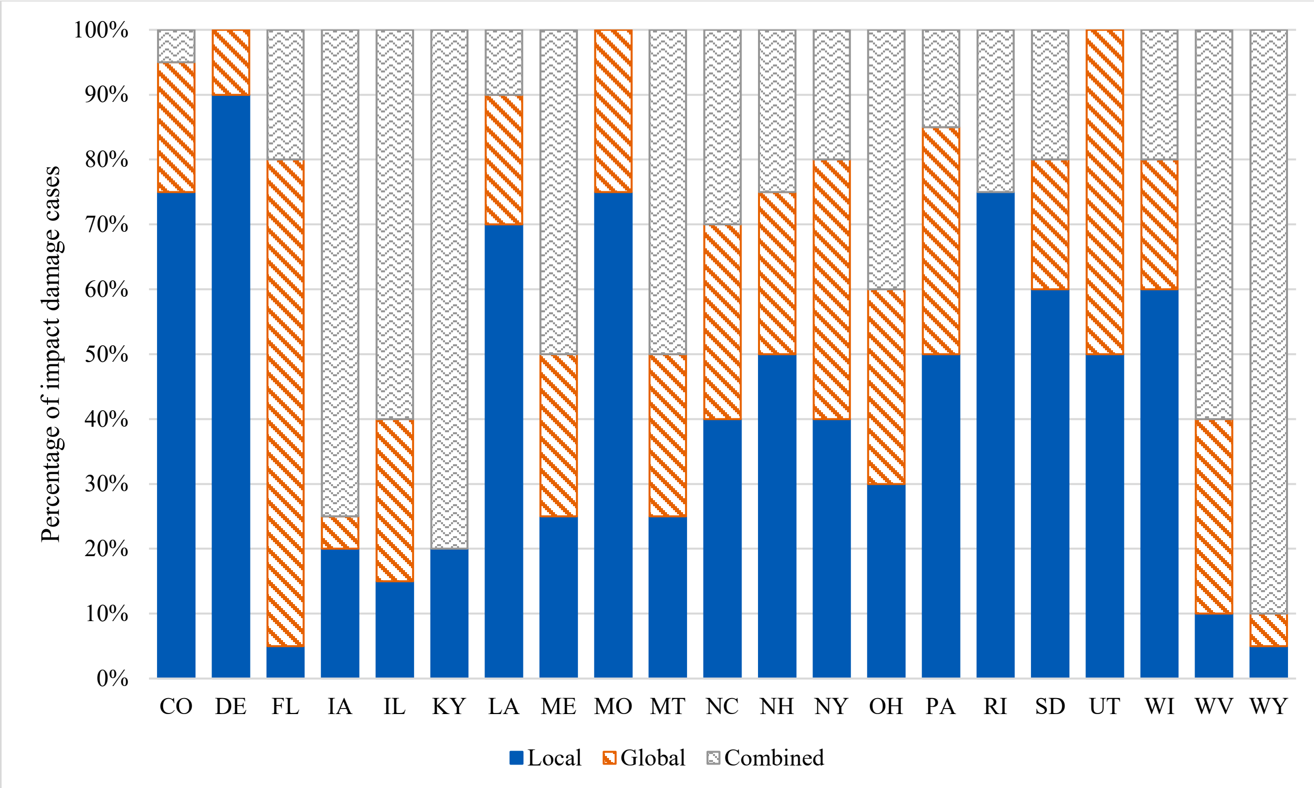

Figure 26. Bar chart. Breakdown of local, global, and combined damage from bridge strikes.

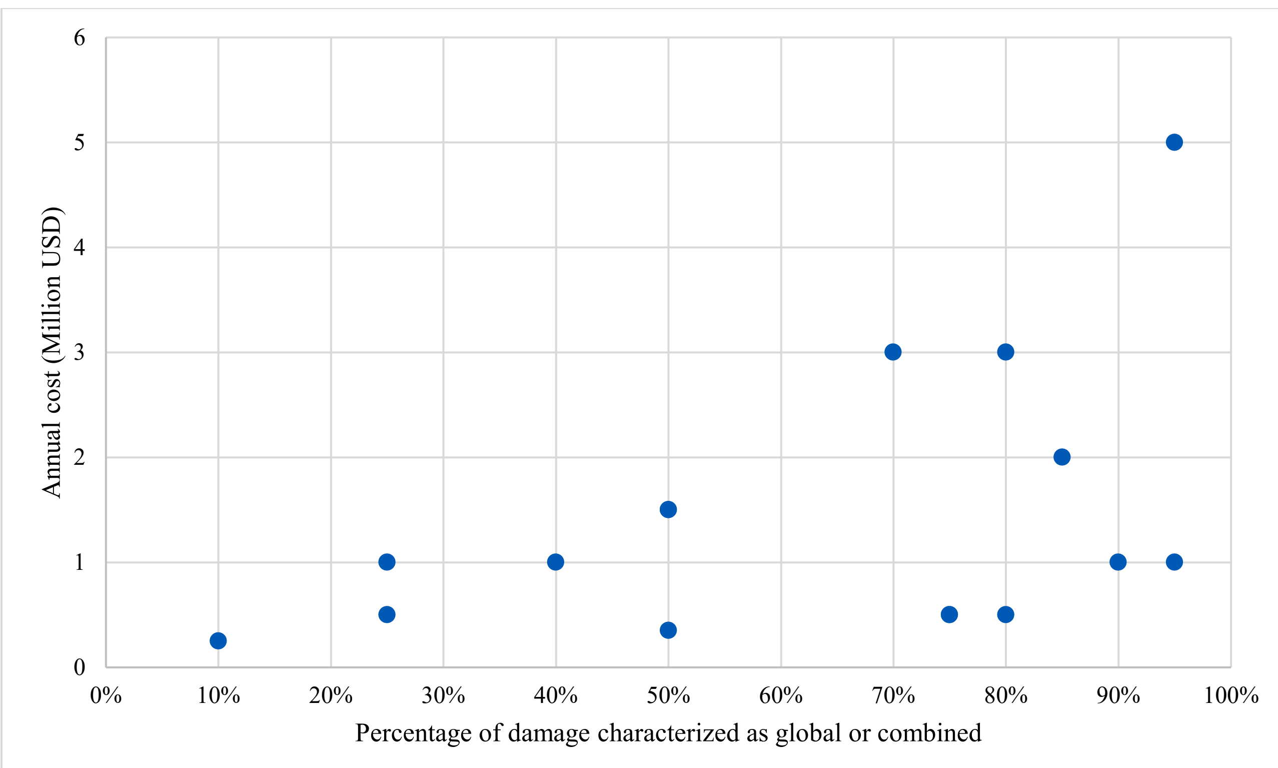

Figure 27. Scatterplot. Annual cost vs. percentage of global and combined damage for bridge strikes.

Table 7. Summary of Responses for Percent of Damage Categorized as Local, Global, and Combined

Damage characterization	Average	Standard deviation	Minimum	Maximum
Local	42%	26%	5%	90%
Global	25%	17%	0%	75%
Combined	33%	27%	0%	90%

DAMAGE EXTENDING TO OTHER BRIDGE ELEMENTS

Girder strike events can cause damage to other bridge elements as well. The extent of damage can affect the type of analysis required to assess safety, the type of repair, and the cost of repair. A wide range of values were reported for the percentage of cases where damage extends to other bridge elements, as shown in Figure 28 and summarized in Table 8. Table 9 includes the full numeric state responses. Five states (Delaware, Florida, Missouri, Montana, and Utah) reported that damage extends to other bridge elements less than 50% of the time. Other states reported that other bridge elements are frequently damaged; for example, Louisiana, Ohio, Rhode Island, and Kentucky reported that diaphragms/cross-frames were damaged in 80% or more of cases. Overall, diaphragms/cross-frames were most likely to be damaged by girder strike events, with an average of 55% of cases causing damage. Decks, bearings, and abutments/piers were damaged in less than 15% of cases, on average. Kentucky reported that bridge decks are damaged in 60% of girder strike cases, which is an outlier.

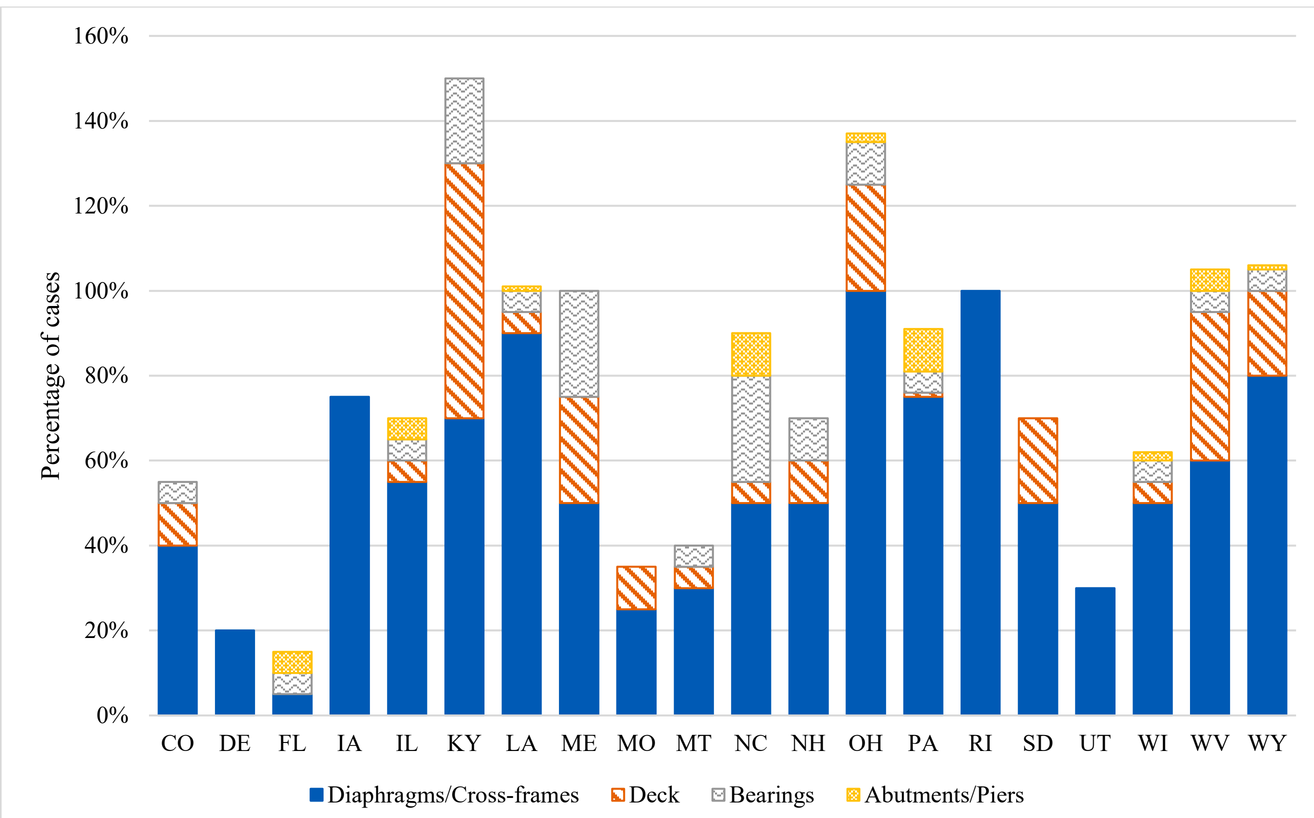

Figure 28. Bar chart. Percentage of cases where damage extends to other bridge elements.

Table 8. Summary of Responses for Percentage of Cases Where Damage Extends to Other Bridge Elements

Bridge element	Average	Standard deviation	Minimum	Maximum
Diaphragms/Cross-frames	55%	26%	5%	100%
Deck	12%	15%	0%	60%
Bearings	7%	8%	0%	25%
Abutments/Piers	2%	3%	0%	10%

Table 9. Percentage of Cases Where Damage Extends to Other Bridge Elements

State	Diaphragms/ Cross-frames	Deck	Bearings	Abutments/Piers
CO	40%	10%	5%	0%
DE	20%	0%	0%	0%
FL	5%	0%	5%	5%
IA	75%	0%	0%	0%
IL	55%	5%	5%	5%
KY	70%	60%	20%	–
LA	90%	5%	5%	1%
ME	50%	25%	25%	–
MO	25%	10%	0%	0%
MT	30%	5%	5%	0%
NC	50%	5%	25%	10%
NH	50%	10%	10%	0%
OH	100%	25%	10%	2%
PA	75%	1%	5%	10%
RI	100%	0%	0%	0%
SD	50%	20%	0%	0%
UT	30%	0%	0%	0%
WI	50%	5%	5%	2%
WV	60%	35%	5%	5%
WY	80%	20%	5%	1%

PARAMETERS CAUSING GREATER DAMAGE

States were asked to select whether small skew, large skew, impact near splice, short spans, large spans, composite beams, and/or non-composite beams seemed to commonly cause greater damage. There was no limit to the number of parameters selected. Results are summarized in Table 10. The parameters selected by the greatest number of states were impact near a splice and non-composite beams, each with six states selecting each parameter. No states selected small or large skew, one state each selected short spans and composite beams, and three states selected long spans as a parameter causing greater damage. From these responses, there are no parameters that can be identified as causing greater damage because the states did not agree on what, if any, factors contribute to greater damage.

Table 10. Parameters Reported to Cause Greater Damage

Parameter	Number of states
Small skew	0
Large skew	0
Impact near splice	6
Short spans	1
Long spans	3
Composite beam	1
Non-composite beam	6

UNUSUAL BRIDGE STRIKES WARRANTING FURTHER INVESTIGATION

States were asked whether there have been any unusual bridge strikes that warrant further investigation/research. Most states responded that there have not been any notable strikes. Louisiana responded “yes” but did not provide further information.

Colorado reported having an average of about one bridge strike per year that requires additional analysis and major repairs. Illinois described a recent case resulting in a fire and beam warping where material coupons were tested to ensure that the steel was not compromised. “A couple” other strikes in Illinois “have resulted in cracks that are typically arrested with a hole and inspected frequently for propagation.”

New Hampshire reported a “large number of timber covered bridges which are struck frequently.” They reported “determining proper steps to decrease the prevalence of these events including additional warning signs/devices, portal frames, and outreach.”

CHAPTER 5: STRUCTURAL ANALYSIS AND DECISION-MAKING

After a bridge strike occurs, the responsible agency must determine the appropriate course of action for temporary and permanent repairs. In general, states reported that an initial inspection and analysis is often used as the basis for deciding the immediate course of action, and a more detailed investigation may be performed if needed to determine the long-term solution. States reported a variety of analysis methods and generally agreed that bridge strikes are handled on a case-by-case basis. Additionally, most states reported taking initial action within a few hours of being informed of the strike and completing full repairs within one year or less.

ANALYSIS METHODS FOR ASSESSMENT OF DAMAGED GIRDER CAPACITY

States reported the percentage of cases in which various analysis methods were used for assessment of damaged girder capacity. The options listed were hand calculations, AASHTOWare, line element elastic structural model, line element inelastic structural model, shell element elastic structural model, shell element inelastic structural model, and other, with the option to explain other methods of assessment. Percentages need not sum to 100% because multiple analysis methods could be used on the same damaged case. However, many states' responses summed to less than 100%, which may indicate that there are some cases where no analysis methods are used.

As shown in Figure 29, responses varied greatly, and there does not appear to be a standard analysis method used by most states. Even for the most frequent methods of analysis, hand calculations and AASHTOWare, responses ranged from 0% of the time to 100% or 95% of the time, respectively. The responses are summarized in Figure 30 and Table 11. Eight states reported using hand calculations at least 50% of the time, and seven states reported using AASHTOWare at least 50% of the time. Twelve states each reported using hand calculations and AASHTOWare for 10% of cases or less.

Line element elastic structural models were used frequently in a few states and rarely in other states. Four states used line element elastic structural models over 50% of the time, but 15 states used these models 10% of the time or less. The least frequent methods of analysis were line element inelastic structural models, shell element elastic structural models, and shell element inelastic structural models; each were used less than 3% of the time, on average. Over 20 states reported using each of these methods 10% of the time or less.

A variety of other methods were also reported. Kentucky reported using a different load rating software to assess girder capacity. In Massachusetts, a consultant typically performs checks if the capacity is in question. Illinois mentioned that 20% of cases use qualitative engineering judgement to determine if action is needed. Missouri reported that load rating software may be used to assess minor damage, but severe damage is assessed using engineering judgment from senior engineers. Pennsylvania also mentioned using a different analysis software to perform re-rating of beams.

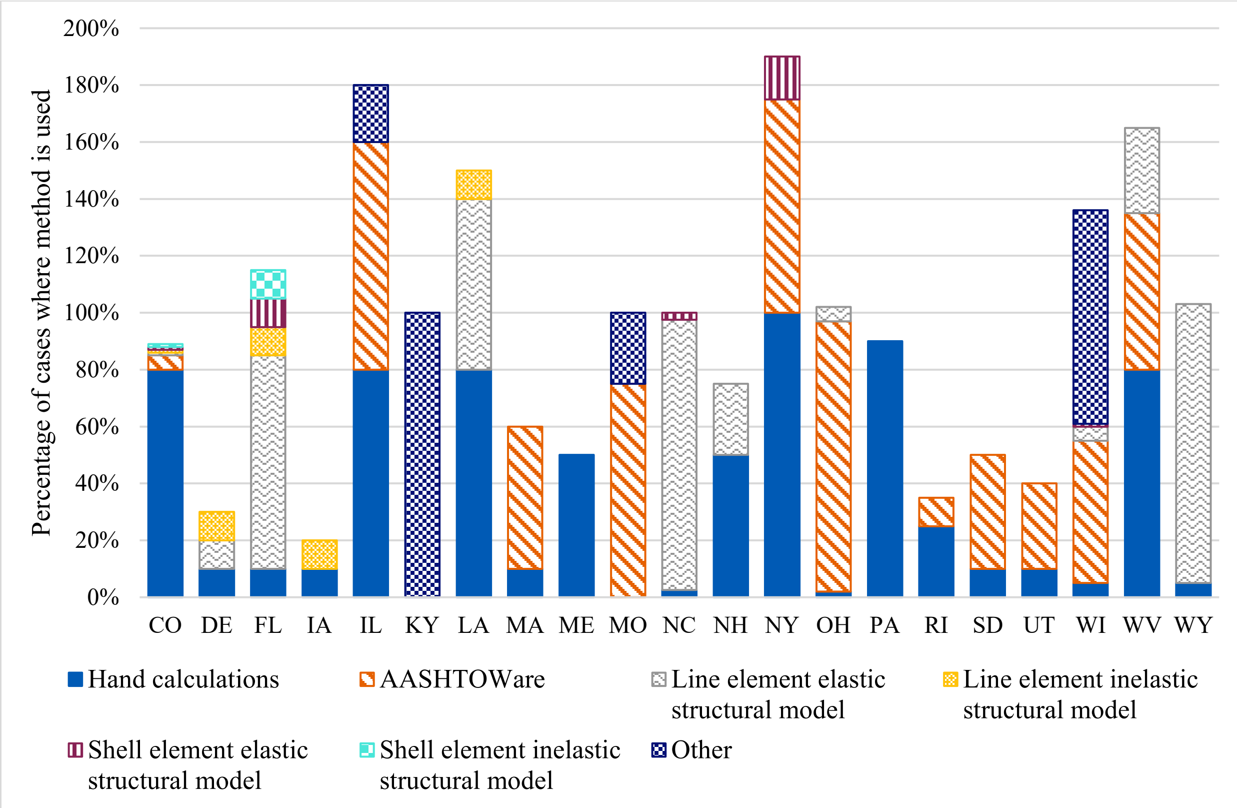

Figure 29. Bar chart. Methods used for analysis after a girder strike.

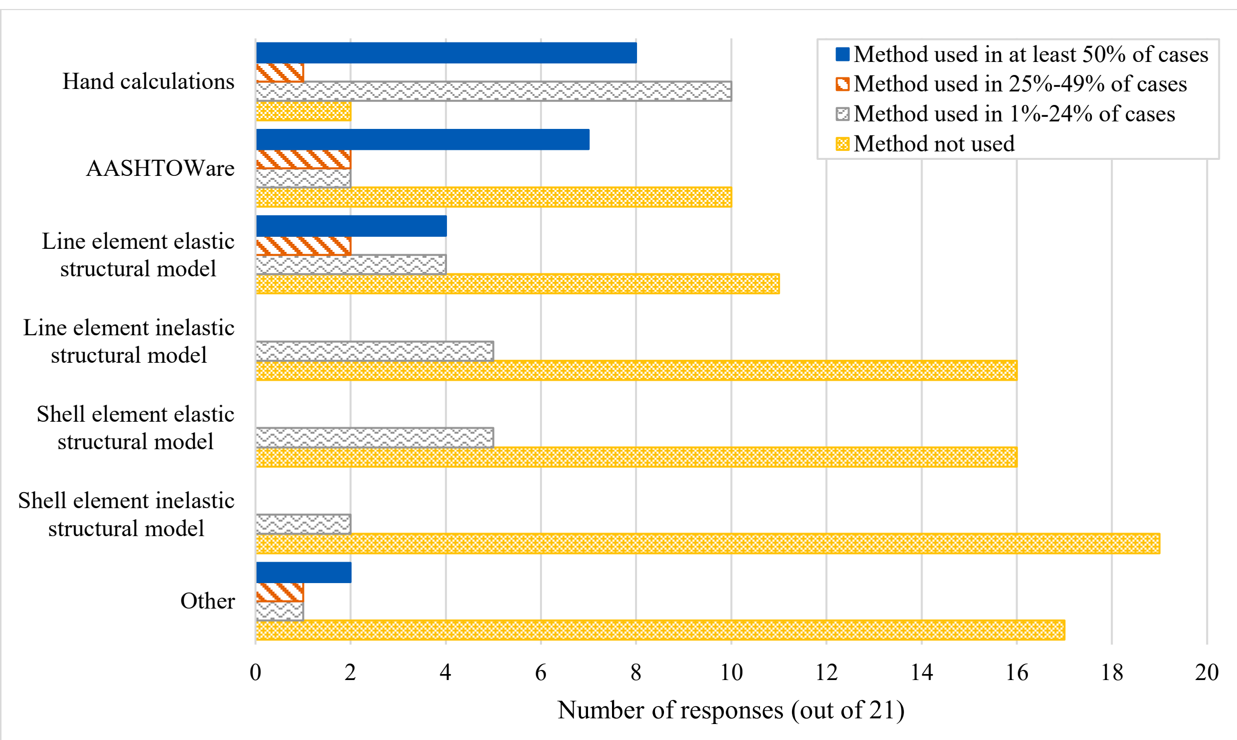

Figure 30. Graph. Frequency of analysis methods performed after a girder strike.

Table 11. Summary of Responses for Analysis Methods Performed after Girder Strike

	Average	Standard deviation	Minimum	Maximum	Number of states responding at least 50% of cases	Number of states responding 10% of cases or less
Hand calculations	34%	36%	0%	100%	8	12
AASHTOWare	27%	33%	0%	95%	7	12
Line element elastic structural model	19%	33%	0%	98%	4	15
Line element inelastic structural model	2%	4%	0%	10%	0	21
Shell element elastic structural model	1%	4%	0%	15%	0	20
Shell element inelastic structural model	1%	2%	0%	10%	0	21
Other	11%	27%	0%	100%	2	16

ASSESSMENT METRICS FOR EVALUATING STRUCTURAL ANALYSIS RESULTS

Reported assessment metrics for evaluating structural analysis results of damaged girders varied. Some states (Florida, Illinois, Kentucky, New Hampshire, Rhode Island, Utah) referred to evaluating capacities, revising load ratings, or quantifying damage in similar ways. Other states (North Carolina, South Dakota, West Virginia) referred to geometric or inspection data such as section loss, length of cracking, distortion, and other modes of damage. Delaware noted that a visual inspection is performed to determine whether further analysis is needed. Colorado stated that engineering judgement is used for minor impacts, whereas structural analysis is used for major impacts. This directly differs from the response from Missouri, which stated that structural analysis is only used for minor damage because structural analysis of severe damage is “not realistic and is a waste of time.” In Missouri, severe damage is discussed by senior engineers, who create a plan for addressing the damage.

Iowa reported that there are no specific metrics documented for evaluating structural analysis results. Pennsylvania reported that a professional engineer is required to perform structural analysis and sign and seal the analysis. Approved analysis software is used to perform re-rating of beams. Wyoming submitted a detailed response about structural analysis assumptions for impact damage in both steel- and concrete-girder bridges. The response is included in Appendix A.

As observed in the responses, the severity of damage and resulting load rating are the most common metrics for evaluating structural analysis results, but the type of analysis and level of detail reported varied significantly by state. There is not a unified procedure between multiple states, and most states' responses were not indicative of a consistent protocol used internally. Additionally, some variability in assessment is expected due to the unique nature of each bridge strike incident.

PROCEDURE FOR DETERMINING LOAD RATING OF DAMAGED AND REPAIRED BRIDGES

Similar to the assessment metrics for evaluating structural analysis results, the procedure for determining load rating of damaged and repaired bridges varied across states. Some states appeared to have a consistent internal procedure for load rating, whereas others handle load rating on a case-by-case basis using engineering judgement.

Several states (Illinois, Kentucky, Massachusetts, Missouri, North Carolina) mentioned considering section loss in load rating of damaged beams. Other states (Colorado, Maine, New Hampshire, West Virginia) also mentioned engineering judgement, handling each damage scenario on a case-by-case basis, and considering multiple factors such as amount of damage, load paths, composite behavior, and cross-frame damage. Additionally, several states (Illinois, Missouri, New York, South Dakota, Utah) mentioned using AASHTOWare to assess damage in some or all cases. Illinois gave a detailed description of the load rating process:

> Sketch of damaged beam and cross-sections using provided photos and measurements; calculation of new section properties (moment of inertia) for one or more damaged cross-section; artificial web and flange section loss inputs into AASHTOWare that result in a similar section modulus as the damaged section over the length range of damage; use of resulting load ratings to determine level of restriction.

Iowa stated that the "load rating engineer review(s) damaged and repaired conditions and evaluates the bridge using an appropriate analysis method." Delaware stated that a visual inspection is performed to determine if more analysis is needed. Ohio also stated that a visual inspection is performed to assess the stability of the structure, assessing factors such as the number of beams damaged out of the total number of beams on the bridge, which beams are damaged, and how many lanes of traffic are carried on the bridge. Wyoming stated that lane restrictions are imposed to reduce the live load to a damaged girder, and it is assumed that all girders below a lane restriction will not control and do not need to be load rated. Massachusetts stated that damaged beams cannot be opened to live load unless an inspection has been performed.

Montana did not mention a specific load rating technique but described that any damaged steel beams are repaired to at least their original capacity. Superficial dings may not be repaired, but dings may be monitored with nondestructive testing on subsequent NBI inspections. Similarly, Utah reported that it is assumed that repaired steel girders do not have any reduction in capacity.

CRITERIA USED TO DETERMINE THE COURSE OF ACTION FOR TEMPORARY AND PERMANENT SOLUTIONS

States were asked to report any criteria used to determine the course of action for both temporary and permanent solutions after a bridge strike incident. Some states provided separate responses for both the temporary and permanent solutions, whereas others only provided one response. In general, states handle criteria for the course of action on a case-by-case basis. The bridge may be partially or fully closed if deemed necessary by initial visual inspection or further analysis. Criteria to determine an appropriate permanent repair typically includes damage severity assessment, cost evaluation, and consideration of the number of past repairs on the same girder.

Some states either only answered the question about temporary solutions or provided very similar responses for both temporary and permanent solutions. Colorado noted that Region Bridge Design units are notified and responsible for designing and implementing any needed repairs. Delaware stated that a visual inspection is performed to determine if more action is needed. Florida stated that "remaining capacity, bridge location, and upcoming projects" were important factors in determining solutions. Kentucky, Massachusetts, New Hampshire, and Ohio stated that the extent or severity of damage is used to determine the course of action, and Maine stated that a cost vs. risk analysis is performed.

States submitted a range of responses for criteria specific to temporary solutions. Iowa considers average daily traffic (ADT), route type, and detour length, and North Carolina considers routes, level of damage, and location of damage. Illinois specified that partial or full lane/bridge closures may be implemented before any analysis is performed if damage looks severe, and Montana also mentioned that immediate actions are usually based on a visual inspection that may include nondestructive testing and measurements. Both Illinois and Montana stated that additional analysis and consideration of the load rating determines whether lanes will reopen or remain closed until a repair is performed. A temporary repair may be performed until a permanent repair is feasible. Missouri and Utah mentioned that engineers discuss the damage and decide what course of action is needed.

For criteria specific to permanent solutions, states typically perform a more detailed capacity assessment and consider the history of the damaged girder. Heat straightening was mentioned by several states (Missouri, Montana, Rhode Island, South Dakota, West Virginia, Wyoming) as a course of action that is typically considered, but states noted that cracks, tears, prior heat straightening in the same location, and other factors may disqualify a girder from heat straightening. Wyoming summarized cost considerations that were also expressed by other states:

> When the cost for repair of localized and global damage approaches full girder replacement, full replacement is suggested. If it felt that the repair of localized and global damage will not restore 100 percent capacity, full replacement is suggested.

Illinois stated that "in order to determine the extent of the work to be completed, measurements near the point of impact are taken and strain calculations are made using the guidelines of NCHRP Report 271." Louisiana stated that their goal is "to return the structure to the condition it had just prior to the collision damage." Pennsylvania mentioned consideration of road user delay costs, and

North Carolina cited the age of the structure and number of impacts as other factors that are considered.

MULTIPLE GIRDER REPAIRS AT THE SAME LOCATION

Respondents reported that when a girder is damaged multiple times at the same location, it is typically straightened or repaired between one and three times before it is replaced. Utah was an exception, reporting that a girder is typically repaired nine times before replacement. Ohio reported that the number of repairs before replacement "depends on how many beam lines are on the bridge," and that the number of repairs before replacement is decided on a case-by-case basis.

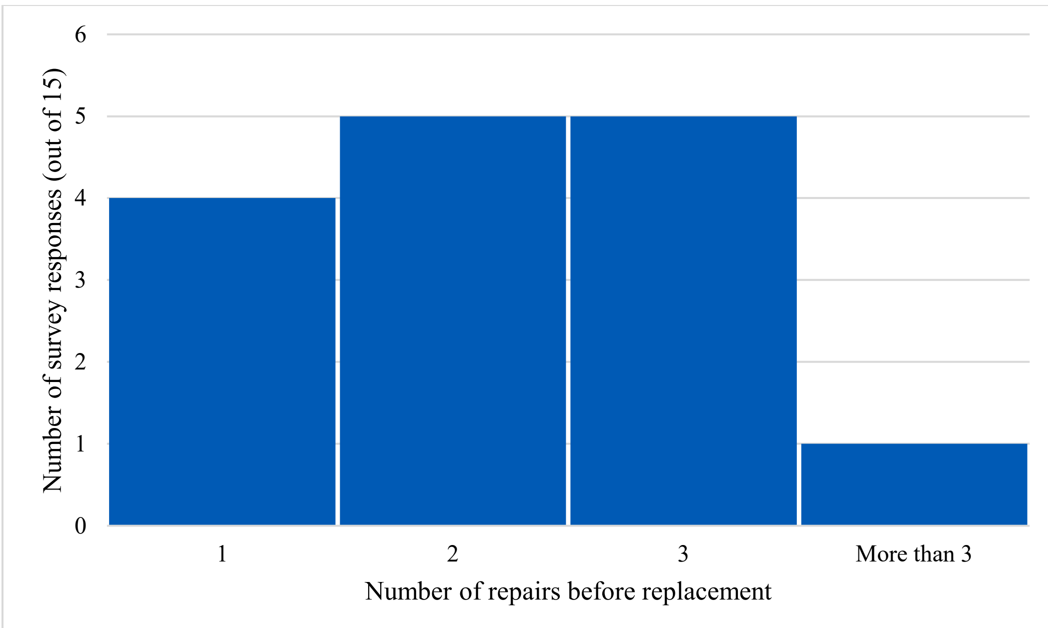

Figure 31. Histogram. Number of girder repairs before replacement.

TIME TYPICALLY REQUIRED TO TAKE ACTION

Of the 21 states that reported a time typically required to take initial action after a steel girder is damaged, 17 states reported that action is taken within a few hours from the time of damage, and three reported that action is taken in one week or less. The responses are illustrated in Figure 32. Kentucky reported that more than one year is typically required before initial action is taken. This is a clear outlier, especially because Kentucky reported that 100% of bridge strikes are reported immediately after occurrence, so it is assumed that this response was a mistake.

The amount of time typically required to complete all work varied from one month or less to more than one year. The most common response was 6–12 months, with 8 responses. Eleven of 21 states reported taking at least 6 months to complete all work. Illinois was an outlier, reporting that over a year is typically required to complete all work. Responses are summarized in Figure 33.

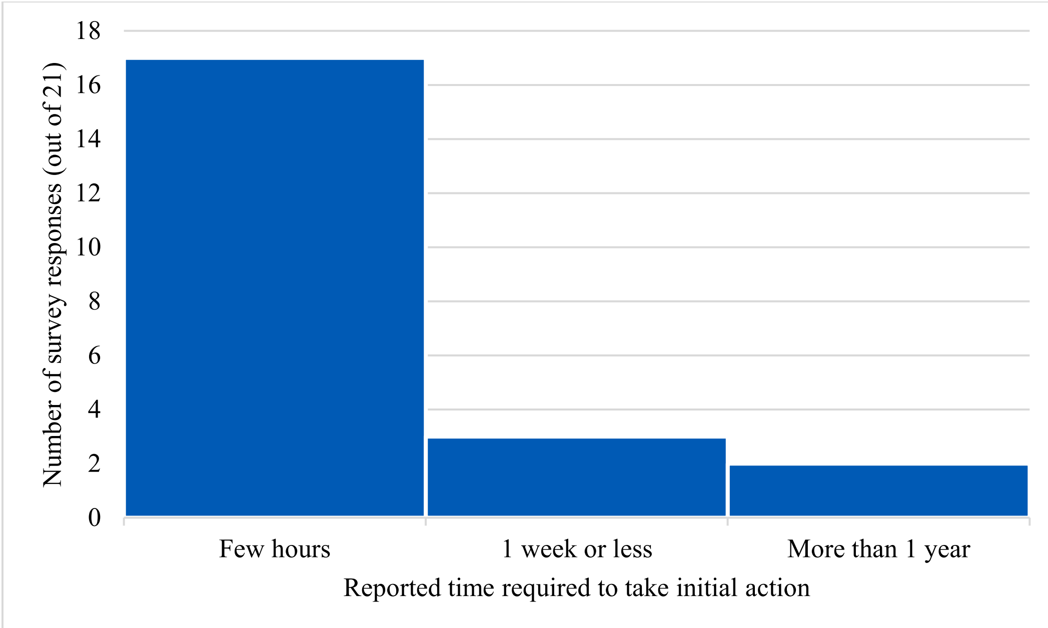

Figure 32. Histogram. Time required to take initial action after a steel girder is damaged.

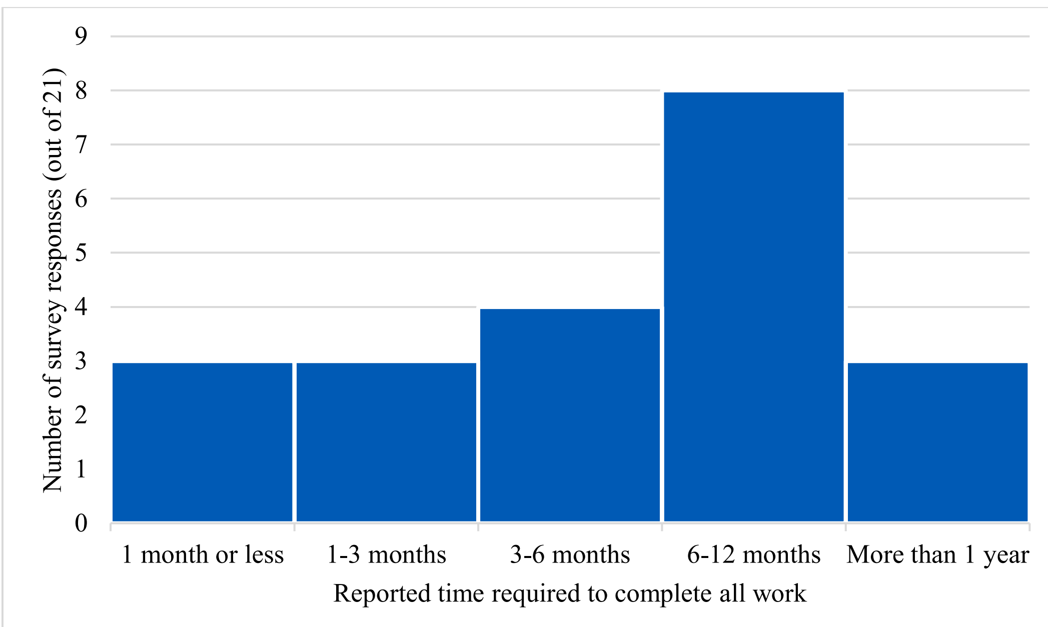

Figure 33. Histogram. Time required to complete all work after a steel girder is damaged.

CHAPTER 6: REPAIRS

Similar to the assessment criteria, states generally reported handling repairs on a case-by-case basis. Many states reported using heat straightening often unless there were cracks or tears that require a partial or full girder replacement. States reported detecting and removing nicks, cracks, and gouges from girders where appropriate. Most state agencies perform in-house repairs less than half of the time, with a few agencies never performing in-house repairs.

REPAIR METHODS

States were asked to report the percentage of the time that mechanical straightening, heat straightening, localized strengthening, partial-depth girder replacement, full-depth girder replacement, and other repair techniques were used. Responses need not sum to 100% in case multiple repair techniques are used for the same damage instance. States also reported the percentage of the time that “nothing” is done, but the responses for this category did not make sense in combination with the results from the other categories, so it was assumed that this portion of the question was not interpreted as intended, and the category “nothing” was not included in the analysis or plots below. Full responses are plotted in Figure 34.

As illustrated in Figure 35, the most common repair method was heat straightening. On average, states used heat straightening for 38% of damage cases. Of the 22 responses to the question about repair, 10 states reported using heat straightening at least 50% of the time. Only four states reported using heat straightening less than 10% of the time. Illinois was the only state that performed mechanical straightening for a significant portion of cases. Illinois performs mechanical straightening for 55% of cases, but only two other states reported using mechanical straightening at all: Pennsylvania (10%) and North Carolina (5%).

In general, the percentage of cases in which localized strengthening, partial-depth girder replacement, and full-depth girder replacement are used is highly state-dependent, with some states using these techniques frequently and others not using them at all. Table 12 includes a summary of the responses. On average, the percentage of cases in which these techniques are used is 25%, 12%, and 22%, respectively. Some states perform full-depth girder replacement more often than partial-depth girder replacement, but others perform partial-depth girder replacement more often. Kentucky and Louisiana reported performing full-depth girder replacement in 80% and 90% of cases, which was significantly higher than other states. In a different question (17), Massachusetts reported an increasing number of strikes requiring full-girder replacement “due to the stiffness of the load and the lack of awareness by drivers.”

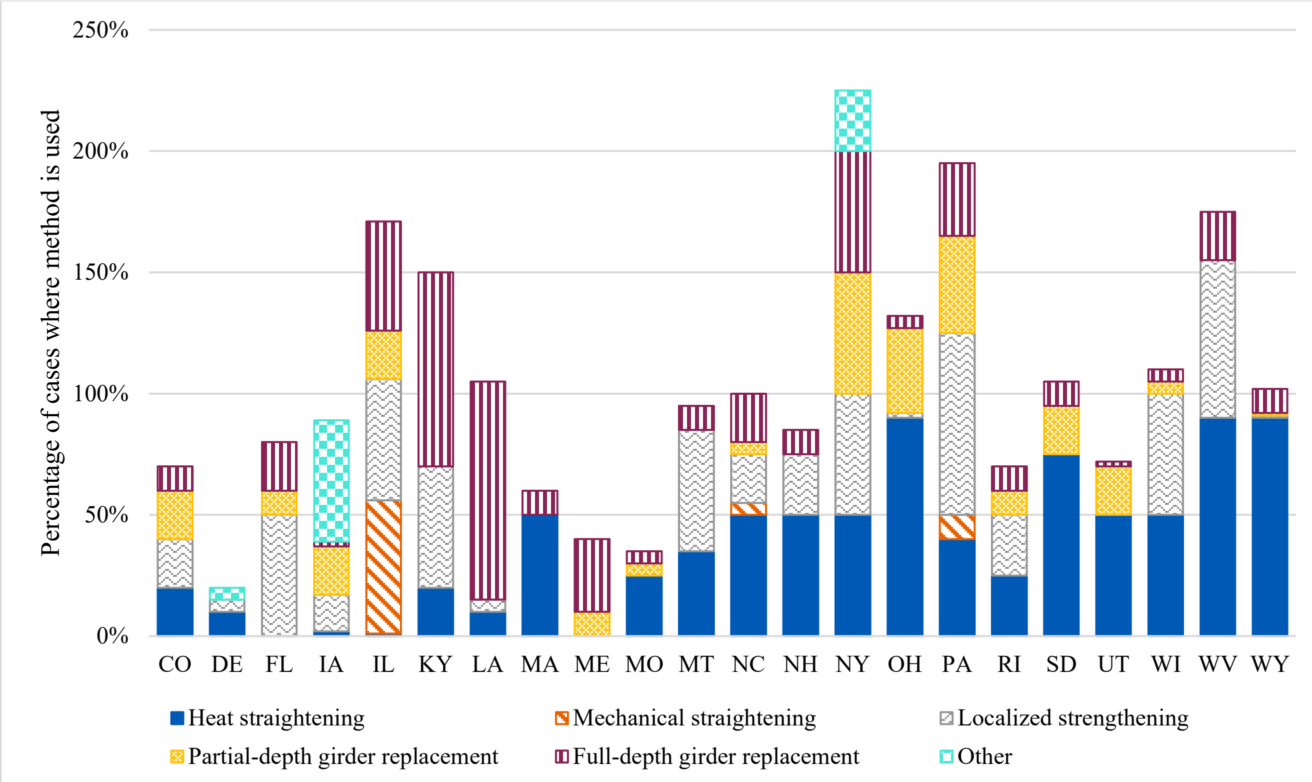

Figure 34. Bar chart. Repair methods used for damaged steel girders.

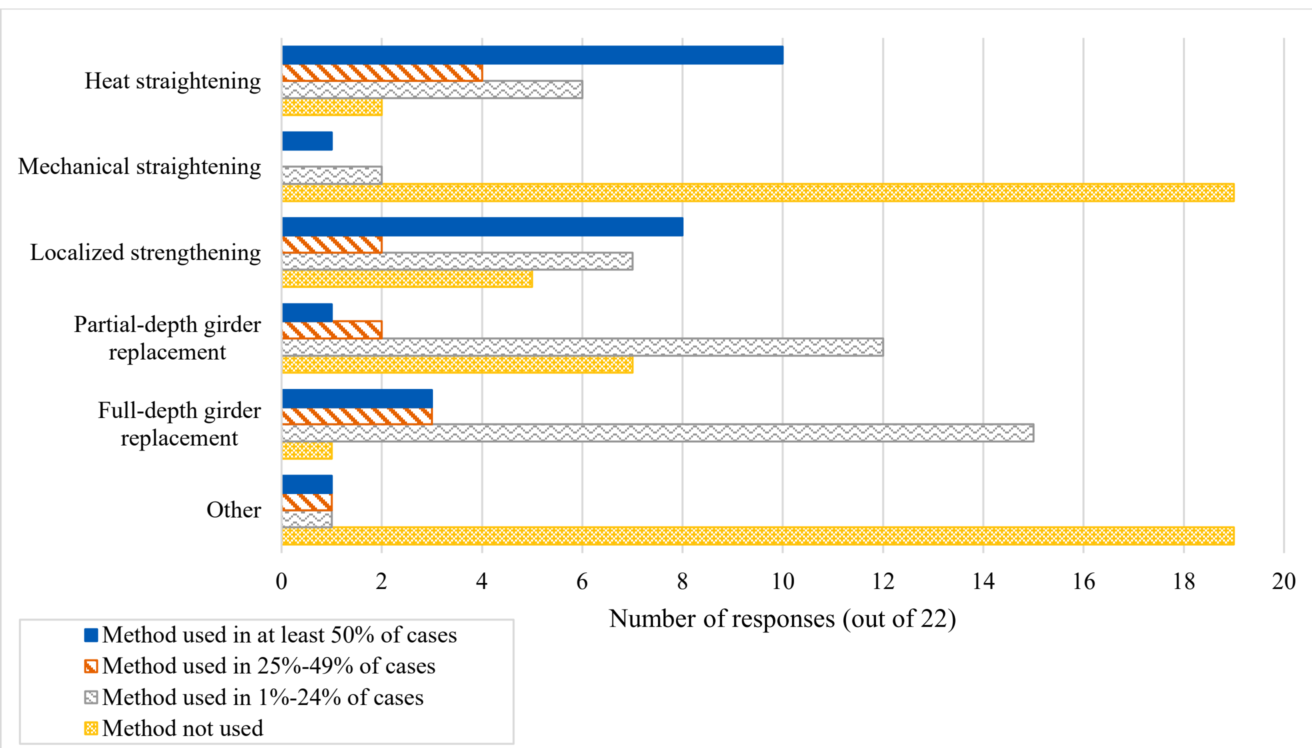

Figure 35. Graph. Frequency of repair methods performed for damaged steel girders.

Table 12. Summary of Responses for Repair Methods Performed for Damaged Steel Girders

Repair method	Average	Standard deviation	Minimum	Maximum	States responding at least 50% of cases	States responding 10% of cases or less
Heat straightening	38%	30%	0%	90%	10	6
Mechanical straightening	3%	12%	0%	55%	1	21
Localized strengthening	25%	25%	0%	75%	8	9
Partial-depth girder replacement	12%	14%	0%	50%	1	14
Full-depth girder replacement	22%	24%	0%	90%	3	13
Other (explain)	4%	12%	0%	50%	1	20

DETECTION AND REMOVAL OF SMALL CRACKS, NICKS, AND GOUGES IN THE GIRDERS

States were asked to report whether any measures were taken to detect and remove small cracks, nicks, and gouges in the girders, such as grinding to reduce stress concentration. Kentucky reported that no measures are taken for detection and removal of small cracks, nicks, and gouges. The remaining 20 states reported a variety of measures taken, including griding out nicks and gouges, arresting cracks, and drilling. Iowa and New York reported using a 1:10 slope for any grinding performed. North Carolina reported that small cracks are welded in certain situations.

Five states mentioned using various nondestructive testing methods to inspect for cracks: Illinois, Massachusetts, Missouri, New York, and South Dakota. Specific methods mentioned include dye penetrant testing, magnetic particle testing, and ultrasonic testing. Missouri stated that these techniques may also be performed after a heat straightening "to see if any cracking… manifested after the heat straightening is done." New York stated that cracks, nicks, and gouging that are repaired by welding or griding may be "re-tested to verify crack removal," depending on the depth and location. Utah referenced their special provision (UDOT 2024) for details about measures taken.

HEAT STRAIGHTENING

Out of 21 responses, 19 states reported using heat straightening in some capacity. Florida stated that heat straightening was "not needed in a bridge yet," and Maine listed "lost departmental expertise" as the reason for not performing heat straightening. Illinois noted that heat straightening has only been used "a couple of times in the last 20 years" and explained that a "moratorium was put on the practice due to some serious brittle issues that occurred many years ago." In Illinois, heat straightening "has only been used in cases in which traffic disturbances would have been too severe to handle using conventional removal and replacement techniques." New York uses heat shrink straightening only, with limits on temperatures and restraining forces. In a different question, Massachusetts noted that they have nearly a dozen strikes annually that require heat straightening.

Respondents were asked to comment on how the heat straightening process is handled to avoid brittle behavior. Seven states mentioned hiring a specialty contractor. In some cases, the survey respondent was unsure how the contractor handled the process, whereas in other cases, engineers (from the state highway agency or elsewhere) were involved in developing the heating scheme while the contractor executed the scheme. Eight states mentioned having temperature limits or heating scheme requirements to prevent brittleness. Four states referred to provisions, documents, or industry knowledge as guiding the process. Three states specifically mentioned the involvement of an engineer.

North Carolina states that the contractor is required to follow the AASHTO *Guide for Heat-Strengthening of Damaged Steel Bridge Members* (Avent 2008). In March 2023, after the survey was completed, this document was superseded by the Federal Highway Administration's *Manual for Heat Straightening, Heat Curving and Cold Bending of Bridge Components* (Geoghegan et al. 2023).

INSTANCES OF UNANTICIPATED/EARLY FAILURE OF A PARTICULAR REPAIR TECHNIQUE

Only two states reported instances of unanticipated/early failure of a particular repair technique. Illinois reported that there have been instances in which cracks propagate beyond crack arrestor holes. This is addressed by going back and installing additional crack arrestor holes beyond the original hole. Wyoming reported one case where "an over height impact caused a brittle failure of a web-to-flange weld after multiple heat straightenings." Earlier in the survey, Wyoming reported that when a girder is damaged multiple times at the same location, it is typically straightened or repaired two times before it is replaced. It is not clear whether this unanticipated brittle failure influenced their policy on the number of times that girders are repaired before replacement.

REPAIRS DONE BY AGENCY PERSONNEL

Most states perform in-house repairs for less than half of cases. The only states performing over 50% of repairs in-house are Illinois (95%), Colorado (75%), and New Hampshire (75%). Seven states reported performing 0% of repairs in-house. Figure 36 shows the distribution of responses.

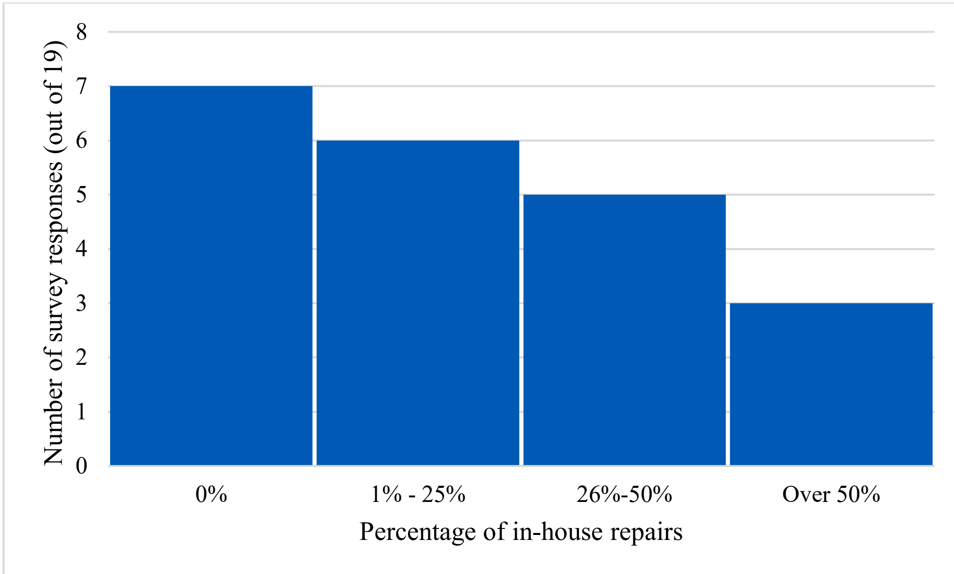

Figure 36. Histogram. Percentage of repairs performed "in-house" by agency personnel.

CHAPTER 7: SUMMARY

Bridge strikes, which cause unexpected, unique, and potentially severe damage, pose a significant challenge to bridge owners. A survey of state highway agencies was conducted to understand states' experiences with bridge strikes and repair of damaged girders. On the agency survey, states reported that an average of 88% of strikes are located at girders, and 14 of 21 states reported a disproportionately high number of bridge strikes on steel girders compared to concrete girders. Analysis of NBI data indicated that low-clearance bridges tend to be older and are more likely to have a main span material of steel instead of concrete.

Damage may extend to other elements and most commonly affects diaphragms/cross-frames. The reasons for bridge strikes vary and are not always known. There was no observable correlation between annual cost and annual number of bridge strikes, but responses to other questions indicate that states may have interpreted the question about cost differently. The cost of repair varies depending on the type of repair required. Most states take action within a few hours of receiving a report of a bridge strike, and all repairs are typically completed within less than a year in most states.

States reported that visual surveys, manual photographs, and manual measurements were used for an average of over 90% of bridge strike cases. Nondestructive testing is an emerging inspection method that is used in some states, and laser scans and drone photography are innovative methods that are rarely used, so there is potential to improve inspection efficacy by implementing these techniques. States also reported a wide variety of analysis methods and assessment metrics for damaged girders. In general, states handle analysis and assessment on a case-by-case basis, and there is a significant amount of engineering judgement.

Repair methods for damaged steel girders depend on the severity of damage. States reported that heat straightening and localized strengthening are used most often, whereas mechanical straightening is rarely used. Partial-depth and full-depth girder replacements may be performed in instances of severe damage.

Overall, the survey results indicate that many bridge strikes affect steel bridge girders. There is an opportunity to develop innovative inspection and assessment techniques to improve efficiency and reduce the amount of engineering judgement necessary when evaluating steel bridge girders that have been damaged by impact.

REFERENCES

Agarwal, A. K. 2013. "Strikes on Low Clearance Bridges by Over-Height Trucks in New York State." University Transportation Centers Program. https://doi.org/10.21949/1528896.

Avent, R. R. 2008. *Guide for Heat-Straightening of Damaged Steel Bridge Members: Final Draft of the AASHTO Guidelines.* No. FHWA-IF-08-999. Federal Highway Administration.

Federal Highway Administration. 2017. "Vertical Clearance on the Interstate System." Accessed May 21, 2024. https://www.fhwa.dot.gov/design/design_standards.cfm.

Fu, Chung C., J. R. Burhouse, and G. L. Chang. 2004. "Overheight Vehicle Collisions with Highway Bridges." *Transportation Research Record*, 1865 (1), 80–88. https://doi.org/10.3141/1865-12.

Geoghegan, F., R. Medlock, and B. Packard. 2023. *Manual for Heat Straightening, Heat Curving and Cold Bending of Bridge Components.* No. FHWA-HIF-23-003. Federal Highway Administration.

Illinois Department of Transportation. 2010. *Bureau of Design and Environment Manual.* Revised May 2024. Springfield, IL: IDOT.

National Bridge Inventory. 2023. "Download NBI ASCII files." Accessed May 17, 2024. https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm.

National Transportation Safety Board. 2014. "Collapse of the Interstate 5 Skagit River Bridge Following a Strike by an Oversize Combination Vehicle, Mount Vernon, Washington, May 23, 2014." National Transportation Safety Board. Accident Rep. NTSB/HAR-14/01. Washington, DC.

News-Gazette. 2020. "Accident Damages I-74 Bridge in Mahomet." *The News Gazette,* March 26, 2020. https://www.news-gazette.com/news/local/courts-police-fire/accident-damages-i-74-bridge-in-mahomet/article_e5289c4b-265f-5794-83b5-594fcdafc8f5.html

Shaffer, M. 2020. Personal communication, e-mail from April 27, 2020.

Shanafelt, G. O. and W. B. Horn. 1984. "Guidelines for Evaluation and Repair of Damaged Steel Bridge Members." Transportation Research Board. No. HS-037 759. http://onlinepubs.trb.org /Onlinepubs/nchrp/nchrp_rpt_271.pdf.

Stark, T. D., R. Benekohal, L. A. Fahnestock, J. M. LaFave, J. He, and C. Wittenkeller. 2016. "I-5 Skagit River Bridge Collapse Review." *ASCE Journal of Performance of Constructed Facilities*, 30 (6): 0401606. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000913.

Utah Department of Transportation. 2024. "Standard Specifications and Standard Drawings." Accessed May 21, 2024. https://www.udot.utah.gov/connect/business/standards/.

APPENDIX A: SURVEY QUESTIONS AND RESPONSES

2. How many bridges are in your inventory?

Table 13. Survey Responses to Question 2

State	Number of bridges in the inventory
CO	3,469
DE	1,780
FL	12,745
IA	4,195
IL	7,824
KY	8,962
LA	13,000
MA	5,260
ME	2,800
MO	10,387
MT	2,955
NC	13,565
NH	2,450
NY	7,918
OH	10,547
PA	32,110
RI	1,231
SD	1,251
UT	3,056
WA	3,500
WI	14,430
WV	7,296
WY	1,635

3. In your inventory, what is the breakdown of bridge girder material types? (Sum to 100%)

Table 14. Survey Responses to Question 3

State	Inventory percentage of steel girder bridges	Inventory percentage of concrete girder bridges	Inventory percentage of bridges with other girder materials
CO	23%	73%	4%
DE	20%	30%	50%
FL	10%	65%	25%
IA	21%	78%	0%
IL	52%	47%	1%
KY	12%	87%	1%
LA	25%	60%	15%
MA	77%	18%	5%
ME	50%	30%	20%
MO	32%	67%	0%
MT	28%	58%	14%
NC	44%	52%	5%
NH	70%	20%	10%
NY	68%	32%	0%
OH	60%	25%	15%
PA	25%	72%	3%
RI	39%	54%	7%
SD	32%	68%	0%
UT	28%	69%	8%
WA	10%	85%	5%
WI	37%	63%	0%
WV	46%	52%	2%
State	52%	47%	1%

4. What is considered a “low clearance” height threshold? (Enter Numerical Value in ft, e.g. 13.75)

5. What percentage of bridges in your inventory falls into the “low clearance” category?

6. What is the approximate total annual cost incurred for detection and repair/replacement of damaged girders due to bridge strikes? (Answer in Million USD)

7. Approximately how many bridge strikes are observed annually?

Table 15. Survey Responses to Questions 4, 5, 6, and 7

State	“Low clearance” height threshold (ft)	Percentage of inventory falling into the “low clearance” category	Annual cost incurred for detection and repair/replacement of damaged girders due to bridge strikes	Approximate annual number of bridge strikes
CO	13.50	0.78%	0	8
DE	14.50	5.00%	0.25	24
FL	13.99	10.00%	5	8
IA	14.75	2.00%	0.50	12
IL	13.50	2.00%	2	13
KY	14.50	2.00%	3	4
LA	16.50	5.00%		3
MA	14.50			
ME	14.50	5.00%	0.50	2
MO	14	0.60%	0.50	20
MT	15	6.60%	0.50	5
NC	14.50	1.88%		37
NH	13.50	5.00%	1.50	7
NY	14	0.60%		250
OH	14	5.00%	3.00	15
PA	14.50	10.00%	1.50	30
RI	14	4.70%	1	8
SD	15.25	5.00%	1	2
UT	16	6.00%	0.35	30
WA				
WI	14.5	0.10%		45
WV	14.50	2.00%	1	4
WY	14	4.00%	1	4

8. What is the approximate breakdown of bridge impact location? (Sum to 100%)

Table 16. Survey Responses to Question 8

State	Bridge impact location: Pier/Abutment	Bridge impact location: Girder	Bridge impact location: Other
CO	5%	95%	0%
DE	1%	98%	1%
FL	5%	95%	0%
IA	0%	100%	0%
IL	8%	92%	0%
KY	2%	90%	8%
LA	2%	98%	0%
MA			
ME		100%	
MO	2%	98%	0%
MT	5%	80%	15%
NC	15%	75%	10%
NH	15%	35%	50%
NY			
OH		100%	
PA	20%	80%	
RI	0%	100%	0%
SD	4%	93%	3%
UT	10%	50%	40%
WA		95%	
WI	1%	96%	3%
WV	10%	90%	0%
WY	6%	94%	0%

9. What percentage of bridge strikes is reported immediately (1–2 days) after occurrence?

Table 17. Survey Responses to Question 9

State	Percentage of strikes reported immediately
CO	90%
DE	99%
FL	90%
IA	90%
IL	84%
KY	100%
LA	100%
MA	
ME	100%
MO	25%
MT	75%
NC	50%
NH	90%
NY	
OH	75%
PA	90%
RI	50%
SD	60%
UT	80%
WA	
WI	95%
WV	85%
WY	90%

10. For girder impact events, what is the breakdown of bridge girder material types? (Sum to 100%)

Table 18. Survey Responses to Question 10

State	Steel girder	Concrete girder	Other
CO	40%	60%	0%
DE	99%	1%	
FL	4%	95%	1%
IA	7%	86%	7%
IL	88%	12%	0%
KY	20%	80%	0%
LA	5%	95%	0%
MA			
ME	100%		
MO	75%	25%	0%
MT	5%	85%	10%
NC	60%	40%	
NH	75%	25%	0%
NY			
OH	95%	2%	3%
PA	50%	40%	10%
RI	75%	25%	0%
SD	70%	25%	5%
UT	25%	75%	0%
WA	10%	90%	
WI	33%	67%	1%
WV	85%	15%	0%
WY	78%	22%	0%

11. What is the approximate breakdown of reasons for bridge impacts events? (Sum to 100%)

Table 19. Survey Responses to Question 11

State	Vehicle/load too tall (no permit)	Vehicle/load too tall (permit obtained, wrong route)	Equipment loaded incorrectly	Other	Explanation (if other)
CO	10%	30%	60%	0	
DE	85%	5%	10%		
FL	60%	0%	10%	30%	Equipment malfunction
IA	34%	33%	33%		
IL	12%	4%	24%	60%	60%; a majority of bridge impacts are hit-and-run, so we have no way of knowing the reason.
KY	30%	0%	40%	30%	Driver health condition, or accident
ME	50%		50%		
MO	90%	10%	0%		0
MT	40%	20%	40%		
NC	10%	1%	39%	50%	50 Dump trucks with beds up from paving roads
NH	75%	0%	25%		
OH	30%	5%	65%		
PA	85%	5%	10%		
RI	100%				
SD	30%	10%	60%		
UT	15%	0%	85%		0
WI	30%	30%	30%	10%	
WV	40%	45%	15%		0

12. How are impacts on railroad-owned bridges over state highways handled?

Table 20. Survey Responses to Question 12

State	Response
CO	CDOT is notified of all impacts over our roads. We work with the railroad to ensure that is safe to open the road after an inspection.
DE	DOT responds and notifies railroad en route
FL	It can vary, depending on the maintenance agreement on these bridges. If the state is responsible for maintenance, the state will pay for the repairs. An agreement over the schedule needs to be finalized with the railroad owner first.
IA	The RR is notified and responsible for repairs.
IL	The district contacts the RR in question to handle bridge action and then assists with traffic control on the roadway below.
KY	Railroad responsibility
LA	By the owning railroad and in coordination with LA DOTD.
MA	
ME	
MO	Railroad is notified.
MT	The State may respond or do a special inspection to ensure there is no danger to the traveling public (Assist emergency response with traffic control, girder stability, debris on road, loose rubble that may fall, etc...), but it is the owners (RR) responsibility to ensure the safety and serviceability of the impacted structure to carry train traffic.
NC	Railroad coordinates inspections and repairs for railroad-owned bridges. NCDOT maintains highway traffic detours and clearance checks.
NH	We have not had this occur.
NY	Railroad is generally responsible for response damage assessment for their structure, state handles M&PT
OH	Railroad handles
PA	PennDOT will respond to the incident & provide the necessary support for life safety. Railroad owner is contacted and will be responsible for permanent repairs and costs.
RI	We only have one low clearance RR bridges over a roadway (local road) that is impacted frequently. This structure is owned/maintained by the RR and all impact(s) are handled by the RR owner.
SD	Not really handled. The only location that gets hit is on a low speed route. It's been hit hundreds of times with no damage to the bridge. There was an over-height detection system installed with little benefit if any.
UT	The state makes these repairs because of the agreement with the railroad to maintain everything below the bottom of ballast.
WA	
WI	Generally, these are handled by the railroad initially and WisDOT will get involved upon request
WV	Repairs are handled by the respective railroad company. Any maintenance of traffic, traffic control, closures, etc. that are required to maintain the safety of the travelling public using the affected highway would most likely be handled by WVDOT.
WY	The railroad owner is contacted.

13. Would you consider typical clearance signage for your agency-maintained bridges to be sufficient, and if not, how could it be improved?

Table 21. Survey Responses to Question 13

State	Sufficient (Yes/No)	Suggested improvement
CO	Yes	
DE	No	Need deterrence or even barrier for low clearance bridges
FL	Yes	
IA	No	Unknown.
IL	Yes	None
KY	Yes	
LA	Yes	We could consider putting clearance signs on bridges that have greater than the 16.5-ft legal clearance. I believe Texas shows numbers greater than legal clearance on signs.
MA	Yes	We have adequate signage but many just like to ignore.
ME	No	Raise the bridges in main corridors
MO	Yes	
MT	Yes	
NC	Yes	
NH	Yes	
NY	Yes	
OH	Yes	Can't fix stupid
PA	Yes	Expand ITS involving over height vehicle detection.
RI	No	Our Traffic Division is working on impact mitigation plan for low clearance structures that will include additional measures such as automatic OH vehicle detection system. Also, adding more visible advanced signage ahead of low clearance points.
SD	No	Only 1 signed bridge gets hit and the issue seems to involve GPS units or phones meant for passenger vehicles used for truck routing.
UT	Yes	
WA	Yes	
WI	Yes	
WV	Yes	N.A.
WY	Yes	

14. If damage concentrated in a small area (e.g., nicks, gouges, tears) is characterized as local damage and damage spread over some length in the girder is characterized as global damage, what percentage of impact damage is viewed as local versus global? (Sum to 100%):

Table 22. Survey Responses to Question 14

State	Local	Global	Combined
CO	75%	20%	5%
DE	90%	10%	0.00%
FL	5%	75%	20%
IA	20%	5%	75%
IL	15%	25%	60%
KY	20%	0.00%	80%
LA	70%	20%	10%
ME	25%	25%	50%
MO	75%	25%	0%
MT	25%	25%	50%
NC	40%	30%	30%
NH	50%	25%	25%
NY	40%	40%	20%
OH	30%	30%	40%
PA	50%	35%	15%
RI	75%	0%	25%
SD	60%	20%	20%
UT	50%	50%	0%
WI	60%	20%	20%
WV	10%	30%	60%
WY	5%	5%	90%

15. For girder impacts, what percentage of cases have damage that extends to these other elements of the bridge? (Do not sum to 100%)

Table 23. Survey Responses to Question 15

State	Diaphragms/ Cross-frames	Deck	Bearings	Abutments/Piers
CO	40%	10%	5%	0%
DE	20%	0%	0%	0%
FL	5%	0%	5%	5%
IA	75%	0%	0%	0%
IL	55%	5%	5%	5%
KY	70%	60%	20%	
LA	90%	5%	5%	1%
ME	50%	25%	25%	
MO	25%	10%	0%	0%
MT	30%	5%	5%	0%
NC	50%	5%	25%	10%
NH	50%	10%	10%	0%
OH	100%	25%	10%	2%
PA	75%	1%	5%	10%
RI	100%	0%	0%	0%
SD	50%	20%	0%	0%
UT	30%	0%	0%	0%
WI	50%	5%	5%	2%
WV	60%	35%	5%	5%
WY	80%	20%	5%	1%

16. Are there parameters that seem to commonly cause greater damage? (Check all that apply)

Table 24. Survey Responses to Question 16

State	Small skew	Large skew	Impact near splice	Short spans	Long spans	Composite beam	Non-composite beam
CO				X			
DE			X				
FL							X
IA							
IL							
KY							
LA			X		X		
MA							
ME					X		X
MO							
MT							
NC			X		X		
NH							X
NY							
OH							
PA			X				X
RI							
SD			X			X	
UT							
WA							
WI							
WV			X				X
WY							X

17. Have there been unusual bridge strike events that warrant further investigation / research?

Table 25. Survey Responses to Question 17

State	Response
CO	Yes. We average about one Bridge strike a year that requires additional analysis and major repairs.
DE	
FL	No
IA	No
IL	One strike recently that resulted in a fire and beam warping; resulted in having material coupons tested to make sure the steel wasn't compromised. A couple strikes have resulted in cracks that are typically arrested with a hole and inspected frequently for propagation.
KY	
LA	Yes
MA	A lot of the data you are requesting is currently available by our tracking methods. We have a significant number of strikes annually with nearly a dozen requiring heat straightening. As of late there have been a number that require girder replacement of the fascia girder due to the stiffness of the load and the lack of awareness by the drivers. Much of ours is due to lack of enforcement and many times the strikes are not reported.
ME	
MO	No.
MT	
NC	
NH	NH has a large number of timber covered bridges which are struck frequently. We are determining proper steps to decrease the prevalence of these events including additional warning signs/devices, portal frames, and outreach.
NY	
OH	no
PA	N/A
RI	Not at this time.
SD	
UT	No
WA	
WI	
WV	None come to mind.
WY	No

18. In what percentage of cases are these methods used for bridge inspection after a damaging event? (Do not sum to 100%)

Table 26. Survey Responses to Question 18

State	Visual survey	Manual measurements	Nondestructive testing	Laser scan	Manual photographs	Drone photographs	Other
CO	80%	80%	10%	0%	100%	0%	0
DE	100%	20%	20%	0%	80%	10%	
FL	100%	75%	0%	0%	100%	10%	
IA	100%	100%	4%	0%	100%	0%	
IL	100%	100%	95%	0%	100%	0%	0
KY	100%	100%	0%	0	100%	0%	
LA	100%	100%	10%	10%	100%	1%	
MA	100%	100%	50%	0%	100%	0%	
ME	100%	100%	50%	50%	100%	0%	
MO	100%	100%	25%	0%	100%	0%	0
MT	100%	75%	75%	0%	100%	5%	We have relatively few steel impact events (guesstimate one every 2 to 4 years)
NC	100%	100%	20%	20%	100%	5%	
NH	100%	90%	75%	0%	100%	0%	
NY	100%	100%	100%	0%	100%	0%	
OH	100%	100%	30%	0%	100%	2%	
PA	100%	90%	15%	1%	100%	1%	
RI	100%	100%	10%	0%	100%	0%	
SD	100%	80%	40%	0%	100%	20%	
UT	100%	100%	60%	0%	90%	10%	
WI	100%	100%	50%	5%	10%	5%	
WV	100%	100%	70%	10%	100%	5%	
WY	100%	90%	0%	1%	100%	0%	

19. In what percentage of cases are these analysis methods used for assessment of damaged girder capacity? (Do not sum to 100%)

Table 27. Survey Responses to Question 19

State	Hand calculations	AASHTO-Ware	Line element elastic structural model	Line element inelastic structural model	Shell element elastic structural model	Shell element inelastic structural model	Other	Explain (other)
CO	80%	5%	1%	1%	1%	1%	0%	
DE	10%	0%	10%	10%	0%	0%	0%	
FL	10%	0%	75%	10%	10%	10%	0%	Remaining section, section loss.
IA	10%	0%	0%	10%	0%	0%	0%	
IL	80%	80%	0%	0%	0%	0%	20%	20%; use of qualitative engineering judgement to determine if action is needed.
KY	0%	0%	0%	0%	0%	0%	0%	Other load rating software
LA	80%	0%	60%	10%	0%	0%	0%	
MA	10%	50%	0%	0%	0%	0%		Consultant checks typically if capacity is in question
ME	50%	0%	0%	0%	0%	0%	0%	
MO	0%	75%	0%	0%	0%	0%	25%	25% Minor damage may be analyzed using load rating software. Severe damage is assessed using engineering judgment from senior engineers.
MT	0%	0%	0%	0%	0%	0%	0%	Damaged Steel girders are usually classified as either repairable or non-repairable, then, after fatigue and economic feasibility considerations, the beam is either repaired or replaced.
NC	2.50%	0%	95%	0%	2.50%	0%	0%	
NH	50%	0%	25%	0%	0%	0%	0%	I do not understand this question.

State	Hand calculations	AASHTO-Ware	Line element elastic structural model	Line element inelastic structural model	Shell element elastic structural model	Shell element inelastic structural model	Other	Explain (other)
NY	100%	75%	0%	0%	15%	0%	0%	
OH	2%	95%	5%	0%	0%	0%	0%	remaining beam capacity
PA	90%	0%	0%	0%	0%	0%	0%	PennDOT approved analysis software are normally used to perform re-rating of beams.
RI	25%	10%	0%	0%	0%	0%	0%	
SD	10%	40%	0%	0%	0%	0%	0%	
UT	10%	30%	0%	0%	0%	0%	0%	0
WA								
WI	5%	50%	5%	0%	1%	0%	75%	
WV	80%	55%	30%	0%	0%	0%	0%	
WY	5%	0%	98%	0%	0%	0%	0%	

20. What assessment metrics are used for evaluating structural analysis results of damaged girders?

Table 28. Survey Responses to Question 20

State	Response
CO	For minor impacts - Engineering Judgment. For major impacts - Structural Analysis
DE	visual inspection to determine if more analysis is needed
FL	revise existing load ratings and adjust for current conditions.
IA	No specific metrics documented.
IL	Comparison to undamaged ratings; controlling force effect (shear/moment); consideration of temporary measures that may prevent traffic from reaching the damaged beam; use of damaged load rating to determine if load restriction or closure is needed.
KY	If it can carry load
LA	
MA	
ME	
MO	Analysis of minor damage may be done, reducing the section. Analysis of severe damage is not realistic and is a waste of time. Most severe damage is discussed by our senior engineers and a game plan for dealing with the structure is is determined.
MT	
NC	Special inspection data
NH	Typically Strength I case if damage is minor and to be left un-repaired. Otherwise, the beam is repaired and again analyzed with Strength I methods.
NY	
OH	estimate of damage and determine capacity
PA	PennDOT requires a Professional Engineer to QA structural analysis and sign & seal the analysis.
RI	We typically just follow our traditional load rating guidelines
SD	quantify damage, section loss, etc.
UT	The load rating.
WA	
WI	
WV	Length of affected area, horizontal distortion, vertical distortion, quantify cracking, length of cracking, quantify gouging, ripping, tearing.
WY	Damaged girders Steel Bridges Distorted or buckled intermediate bracing are assumed to be ineffective and the unbraced length of the girder is increased accordingly. The top flange is considered unbraced where there is a gap or significant spalling between the top flange and the deck. Girder section properties are reduced for deep gouges, web cracks and flange cracks, as appropriate. The live load of the adjacent girder is increased to account for load shedding from severely distorted girders. Additional dead load is applied to the adjacent girder to account for load shedding when a gap exists between a girder top flange and soffit. Additional dead loads due to barriers are considered in the load rating. A single lane wheel fraction is used when the clear distance between restrictive features is less than 18 feet. Concrete Bridges The capacity of the member is not reduced if concrete loss around the primary reinforcing steel is below the neutral axis.

State	Response
	Shear stirrups are considered ineffective if closely spaced vertical cracks of a moderate to large width are present. The location of the laps and the bar development of the primary reinforcing steel are evaluated closely if concrete is missing around rebar. The area of steel is reduced accordingly to account for gouges, cracks, and section loss of mild reinforcing steel. Prestressing strands with nicks or gouges are neglected in the calculation of the member capacity. Additional dead loads due to barriers are considered in the load rating. A single lane wheel fraction is used when the clear distance between restrictive features is less than 18 feet. Repaired bridges Assume 100 percent capacity has been restored after the girder has been repaired.

21.What procedure is used for determining load rating of damaged and repaired bridges?

Table 29. Survey Responses to Question 21

State	Response
CO	Amount of damage, remaining load paths, live-load distribution, etc., (basically Engineering Judgment).
DE	visual inspection to determine if more analysis is needed
FL	Remaining capacity, safety under the bridge, needed temporary solutions.
IA	The load rating engineer reviews damaged and repaired conditions and evaluates the bridge using an appropriate analysis method.
IL	Sketch of damaged beam and cross-sections using provided photos and measurements; calculation of new section properties (moment of inertia) for one or more damaged cross-section; artificial web and flange section loss inputs into AASHTOWare that result in a similar section modulus as the damaged section over the length range of damage; use of resulting load ratings to determine level of restriction.
KY	Negate the loss of concrete, broken rebar, exposed presstressing strands, twisted steel
LA	
MA	The struck beam cannot be opened to live load until at a minimum it has been inspected. Typically we check it without the element in question - e.g. a loss of the flange area for the gouge or loss of flange for a crack. Then based on results we will decide how to move forward.
ME	engineering judgement
MO	AASHTO is followed. Reduction in section may be done for minor damage on girders. Load rating engineers will decide how to best model minor damage. Severe damage is reviewed by experienced engineers and is typically repaired within a certain timeline by heat straightening or member repair.
MT	Typically, we have repaired any damaged steel beam to at least original capacity with either designed splices, heat straightening, or remove and replace. I can't recall anything other than superficial dings that was not repaired. (If dings create a stress riser and are shallow, they may be mitigated with grinding, documented, and then followed up with special attention and possible NDT on all subsequent NBI inspections)
NC	Remove damaged area from element section and run analysis.
NH	Case-by-case considering redundancy, composite behavior, deck damage, X-frame damage, etc. Roadway width and partial closure are considered when the damage is isolated to a portion of the bridge.
NY	Hand Calculations and AASHTOWare
OH	stability of the structure - done visually. How many beam lines are damaged. How many beam lines are on the bridge total. How many lanes are on the bridge. Which beams are damaged.
PA	Bridge data collection (from damage) and then performance of the new bridge load rating.
RI	We follow our bridge inspection procedures for all impact damage and if severe enough would warrant a critical finding per the NBIS. The temporary solution is based on coordination between our bridge inspection unit and others within the Bridge Engineering Division. If the beam is severely impacted, we would immediately remove traffic from a portion of the bridge or the entire bridge depending on the particular case.
SD	model damaged areas in BrR
UT	We assume no damage to repaired steel bridge girders. AASHTOware BrR is used to access damage in rare cases.
WA	
WI	
WV	We have no official procedure for load rating damaged and repaired girders. Each situation is handled on a case-by-case basis. If distortion is considered significant, affected beams/girders/structural members are unloaded by closing bridge, lanes, or shoulders.
WY	Lane restrictions are implemented to reduce the live load to a damaged girder. It is assumed that all girders below a lane restriction will not control and do not need to be load rated.

22.What criteria are used to determine the course of action for a temporary solution (e.g., partial closure, full closure, temporary carrier beam, temporary shoring, etc.)?

Table 30. Survey Responses to Question 22

State	Response
CO	The Region Bridge Design Units are notified and if needed a repair is designed and implemented by the Regions.
DE	visual inspection to determine if more action is needed
FL	Remaining capacity, bridge location, upcoming projects.
IA	ADT, Route Type, and Detour length.
IL	Partial or full lane/bridge closures are the quickest measure and are implemented sometimes before analysis is performed if damage looks particularly severe. Following initial analysis, lanes may be re-opened or remain closed depending on how poor the load rating is. When analysis indicates a beam may not be able to support dead load, temporary shoring is required in addition to closures. Depending on the schedule of IDOT's in-house repair team, certain temporary strengthening measures may be taken as a placeholder repair until a more permanent partial or full beam replacement can occur.
KY	depends on the severity
LA	We have analyzed structures to see if they can carry full, partial, or zero traffic in their damaged condition.
MA	Extents of damages and secondary damages (e.g. bearing issues, diaphragms & connections).
ME	Cost vs risk analysis
MO	Significant hits are discussed by senior engineers and decisions made on closure and/or shoring. Lesser hits with minor damage are typically not repaired and will be discussed with our Program Manager on any course of action that is needed.
MT	Usually a decision is made in the field during a damage inspection as to what immediate actions are necessary based on a visual inspection that may also include NDT and measurements. Only if a follow up analysis is done (not always done for obvious reasons) that considers damage, deflection, and distortion measurements and shows that the beam(s) are safe to carry load, only then would the bridge/beams be opened back to carry traffic.
NC	Route, route over, level of damage, location of damage
NH	Extent of damage. Case-by-case.
NY	All of the above.
OH	type and extent of damage.
PA	If a redundant load path is not obtainable or if live load cannot be isolated from the damaged beams, then move to closure of the bridge.
RI	We do not have specific criteria for determining the long-term solution but evaluate on a cse-by-case basis, however, we typically heat straighten steel beams (majority structure type of our overpasses). If heat straightening cannot be performed for steel beam, we would replace a section of the beam or the entire beam depending on the severity/damage. For concrete bridges, we have only had one case of severe impact and that beam was replaced.
SD	will use partial closure if traffic can be moved far enough away to virtually eliminate live loads on damaged girder(s).
UT	The inspectors consult the the structural engineers and the structural engineer uses engineering judgement to determent the course of action.
WA	
WI	
WV	Handled on a case-by-case basis. Each
WY	Heat straightening of steel girder is always considered as a permanent solution. When the girder has been heat straightened in the same location more than once, full girder replacement is suggested. When the cost for repair of localized and global damage approaches full girder replacement, full replacement is suggested. If it felt that the repair of localized and global damage will not restore 100 percent capacity, full replacement is suggested.

23.What criteria are used to determine the course of action for a permanent solution (e.g., straightening, partial girder replacement, full girder replacement, etc.)?

Table 31. Survey Responses to Question 23

State	Response
CO	
DE	visual inspection to determine if more action is needed
FL	
IA	Potential cost, extent of damage, route type, ADT, and ADTT.
IL	In order to determine the extent of the work to be completed, measurements near the point of impact are taken and strain calculations are made using the guidelines of NCHRP Report 271.
KY	depends on the severity of the damage, and the type of bridge.
LA	Our goal is to return the structure to the condition it had just prior to the collision damage.
MA	
ME	
MO	Minor to moderate damage is discussed internally and the feasibility of repair is decided. Severe damage is repaired by some form of repair of elements of girders including girder replacement in some manner. Severe distortion is typically heat straightened. One a girder gets more than one heat straightening, then we start leaning towards some form of girder replacement.
MT	Rips, tears, or cracks, depending on severity, orientation, and location would generally disqualify a beam from repair or heat straightening. Previous hits, age of structure, material grade, and future fatigue life left/desired will factor into the economic decision on whether to repair or replace (assuming repair is an option structurally).
NC	Age of structure, level of damage, number of times of repair, number of impacts
NH	
NY	All of the above
OH	
PA	Past repair procedure success or not, information / solutions and costs for replacement vs repair costs. Road user delay costs are also considered for temporary or permanent repair strategies.
RI	-
SD	-severity of damage -Only allow 3 heat straightenings performed on the same steel -large cracks or tears tend to drive at least those areas towards at least partial replacement
UT	An engineering evaluation is made considering the extent of damage, load rating, location of damage, and redundancy of effected bridge element.
WA	
WI	
WV	If the member has never previously been heat straightened or heat straightened no more than one time, that method of repair would likely be chosen if damage lends itself to such. If heat straightening is not possible or feasible, full girder replacement would be considered. WVDOT seldom if ever uses partial girder repair concepts.
WY	

24. In what percentage of cases are these methods used for repair of damaged girders? (Do not sum to 100%)

Table 32. Survey Responses to Question 24

State	Mechanical straightening	Heat straightening	Localized strengthening	Partial-depth girder replacement	Full-depth girder replacement	Other	Nothing
CO		20%	20%	20%	10%	0%	80%
DE	0%	10%	5%	0%	0%	5%	0
FL		0%	50%	10%	20%		50%
IA	0%	2%	15%	20%	2%	50%	0%
IL	55%	1%	50%	20%	45%	0%	5%
KY		20%	50%	0	80%	0%	20%
LA	0%	10%	5%	0%	90%	0%	0%
MA		50%			10%		40%
ME				10%	30%		
MO		25%	0%	5%	5%		75%
MT	0%	35%	50%	0%	10%	0%	0%
NC	5%	50%	20%	5%	20%	0%	0
NH		50%	25%	0%	10%	0%	25%
NY	0%	50%	50%	50%	50%	25%	
OH		90%	2%	35%	5%		60%
PA	10%	40%	75%	40%	30%	0%	0
RI		25%	25%	10%	10%		25%
SD		75%	0%	20%	10%	0%	25%
UT	0%	50%	0%	20%	2%	0%	50%
WI		50%	50%	5%	5%		20%
WV	0%	90%	65%	0%	20%	0%	10%
WY		90%	1%	1%	10%		1%

25. Are there any measures taken by your agency for detection and removal of small cracks, nicks and gouges in the girders (e.g., grinding to reduce stress concentrations)?

Table 33. Survey Responses to Question 25

State	Response
CO	Grinding out nicks and gouges in the girder flange. Drilling a 1" hole to arrest cracks in the webs.
DE	drilling out cracks, grinding
FL	Grinding, punch holes.
IA	Yes. Grinding is performed. We use a 1:10 tapered flare.
IL	Every impact location receives a close inspection to determine the severity of the gouges. Gouges are grinded and inspection for cracks are conducted using Dye Penetrant or Magnetic Particle testing.
KY	no
LA	For cracks, sometimes an arresting hole is drilled.
MA	We use NDT at weld locations to determine if any cracks have developed as well as at impact locations.
ME	grinding to reduce stress concentrations
MO	Dye penetrants and mag flux may be used on minor to moderate damage to look for cracking. These techniques may also be done as part of the heat straightening to see if any cracking is manifested after the heat straightening is done.
MT	We have done some in-house mitigation of cracks (stop drilling, grinding, peening, etc...). We have also mitigated cracks, arch strikes, attachments, etc... in contract work at part of Federal Aid rehab projects.
NC	Grinding to reduce stress concentrations, welding of small cracks in certain situations.
NH	Small nicks/gouges are ground smooth and touched up with primer/paint.
NY	NDT methods including MT, PT, and UT are used for detection and locating ends of cracks. Depending on depth and location cracks, nicks, and gouges are repaired by welding or grinding and are re-tested to verify crack removal. If repair is performed by grinding alone the final profile is done to a 1:10 slope.
OH	grinding and drill out end of cracks
PA	Yes. Grinding of steel gouges and scrapes to lessen the chance of crack initiation.
RI	Small cracks are arrested. Nicks and gouges are typically not repaired if they are minor. We would grind if necessary.
SD	mag particle grinding when possible drilling crack tips when removal isn't possible
UT	yes, see our special provision.
WA	
WI	
WV	Any significant gouges are ground smooth. Cracks are arrested by drilling an arrest hole at the end of the crack and in most cases compression grommets are utilized.
WY	Shallow gouges are ground smooth. Suspected cracks in welds are evaluated via magnetic particle testing, removed & rewelded.

26. When a girder is damaged multiple times at the same location, how many times is it typically straightened or repaired before it is replaced?

Table 34. Survey Responses to Question 26

State	Response
CO	3
DE	2
FL	3
IA	1
IL	1
KY	2
LA	
MA	3
ME	1
MO	
MT	
NC	3
NH	1
NY	
OH	
PA	2
RI	
SD	3
UT	9
WA	
WI	
WV	2
WY	2

27. Does your agency use heat straightening? If no, why? If yes, how is the process handled to avoid brittle behavior?

Table 35. Survey Responses to Question 27

State	Yes/No	Reason (if no)	Process (if yes)
CO	Yes		Years ago maintenance would hire a girder straightening company, i.e., Flame On, etc, to straighten steel girders. During that time they were trained on the method of straightening girders. I am not familiar with the method.
DE	Yes		Follow industry standards and limit to no more than 2 straightenings
FL	No	Not needed in a bridge yet.	
IA	Yes		Expert contractor is hired. Heating to specific temperature limits is used to prevent brittle behavior.
IL	Yes	It has been used very seldom in Illinois (only a couple of times in the last 20 years). A moratorium was put on this practice due to some serious brittle issues that occurred many years ago. Right now it has only been used in cases in which traffic disturbances would have been too severe to handle using conventional removal and replacement techniques.	For the few instances in which heat straightening has been used, we have required structural engineers to develop heating schemes and specialized contractors to complete the work.
KY	yes		keep heat below required temps. Check heat throughout process to ensure steel never gets above that. After a bridge has gone through 2-3 heat straightening cycles in one spot, heat straightening is no longer considered a viable fix and other methods are used.
LA	Yes		Only used when evaluation indicates this to be an acceptable solution.
MA	Yes		Contractor on call hires a designer to do calculations and then they are reviewed and approved before completing the heat straightening.
ME	No	Lost Departmental expertise	
MO	Yes		Not sure. Companies that specialize in this type of work are brought in to do the work.
MT	Yes		We contract out any heat straightening to qualified specialty contractors.
NC	yes		Contractor required to follow AASHTO Guide for Heat-Straightening of Damaged Steel Bridge Members with inspectors monitoring steel temperatures throughout the process.

State	Yes/No	Reason (if no)	Process (if yes)
NH	Yes		Bureau of Bridge Maintenance has the methods. I am not familiar with the process.
NY	Heat shrink straightening only.		Iterative process with strict limits on temperatures and restraining forces.
OH	yes	Answer to question 26 depends on how many beam lines are on the bridge. We do not set an arbitrary No. of hits before we replace.	don't understand this question
PA	Yes		Past successes with heat straightening on certain beam damage. As per our Design Manuals and Construction specifications and standards
RI	Yes		Left to the designer to assess
SD	Yes		Plans require temperature requirements to minimize embrittlement.
UT	Yes		see our special provision
WA			
WI			
WV	Yes		Heat limited to 1200 degrees (1100 degrees for quenched and tempered steel). Straightening accomplished by use of "V" heats, rectangular heats, line heats, edge heating, or spot heats. Forced cooling is not permitted. Straightening is accomplished with as little mechanical force as possible.
WY	Yes		Limit temperature to 1200 °F to ensure repairs are below the transformation temperature. No mechanical force is applied between 300 & 700 °F (blue brittle range). No artificial colling above 250 °F. Vee-heats are shifted over the yield zone.

28. What percentage of repairs are done in-house by agency personnel?

Table 36. Survey Responses to Question 28

State	Response
CO	75%
DE	0%
FL	5%
IA	0%
IL	95%
KY	0%
LA	30%
MA	0%
ME	50%
MO	50%
MT	0%
NC	10%
NH	75%
OH	
PA	10%
RI	10%
SD	0%
UT	10%
WI	0%
WV	
WY	20%

29. Describe any instances of unanticipated / early failure of a particular repair technique.

Table 37. Survey Responses to Question 29

State	Response
CO	None are know of.
DE	N/A
FL	
IA	None.
IL	The only issue we have seen is instances in which we have tried to stop further development of cracks using crack arrestor holes. Sometimes we will have to go back and install additional holes because the crack propagated beyond the original hole. Due to procedures we use for repairs of steel structures tend being pretty conservative, we can't point a particular practice, beside the crack arrestor hole, that have resulted in an unanticipated or early failure.
KY	None, unless somebody hits it again
LA	
MA	
ME	
MO	None.
MT	none, but our recent (last 25 years) data set is relatively small with steel girder impact damages
NC	
NH	None.
NY	None that I know of. It should be noted that NYSDOT maintains our own Field Welder and Ultrasonic Technician certification programs.
OH	can't think of any
PA	N/A
RI	NA
SD	
UT	none
WA	
WI	
WV	None known.
WY	An over height impact caused a brittle failure of a web-to-flange weld after multiple heat straightenings.

30. What time period is typically required to take initial action (e.g., closure, temporary repair) after a steel girder is damaged, from the time of damage?

31. What time period is typically required to complete all work (e.g., permanent repair or replacement) after a steel girder is damaged, from the time of damage?

Table 38. Survey Responses to Questions 30 and 31

State	Time period typically required to take initial action	Time period typically required to complete all work
CO	Few hours	6-12 months
DE	Few hours	1-3 months
FL	Few hours	1 month or less
IA	Few hours	3-6 months
IL	Few hours	More than a year
KY	More than 1 year	More than a year
LA	1 week or less	6-12 months
MA	Few hours	More than a year
ME	Few hours	1-3 months
MO	Few hours	6-12 months
MT	Few hours	3-6 months
NC	Few hours	6-12 months
NH	1 week or less	1 month or less
NY	Few hours	1-3 months
OH	Few hours	1 month or less
PA	Few hours	6-12 months
RI	Few hours	3-6 months
SD	1 week or less	6-12 months
UT	Few hours	3-6 months
WA		
WI		
WV	Few hours	6-12 months
WY	Few hours	6-12 months

32. What external references (manuals, guides) and/or research results are used for any of the above items? Please enter URLs or name and details of the references.

Table 39. Survey Responses to Question 32

State	Response
CO	
DE	NSBA/AASHTO collaboration documents
FL	
IA	https://iowadot.gov/siims/IowaDOT_EmergencyResponseManualForBridges.pdf
IL	Provided at beginning of project by TRP chair.
KY	
LA	Our Bridge Design Manual and AASHTO LRFD Bridge Design Specifications.
MA	
ME	
MO	
MT	https://mdtinfo.mdt.mt.gov/other/webdata/internal/bridge/memos-templates/memos/low-clearance-signs.pdf
NC	FHWA Guide for Heat-Straightening of Damaged Steel Bridge Members
NH	
NY	None.
OH	
PA	https://www.dot.state.pa.us/public/PubsForms/Publications/PUB%2015M.pdf PennDOT Publication 15M - Design Manual Part 4- Structures
RI	
SD	
UT	none
WA	
WI	
WV	AASHTO/AWS D1.5 Bridge Welding Code
WY	

APPENDIX B: SELECTED NATIONAL BRIDGE INVENTORY DATA

Table 40. Year of Construction of Steel and Concrete Bridges in the NBI, Selected According to Criteria in Table 2

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	23,429	26,912
1941–1950	7,610	6,731
1951–1960	19,371	22,347
1961–1970	28,442	41,646
1971–1980	19,296	36,575
1981–1990	14,835	40,239
1991–2000	15,161	42,607
2001–2010	13,486	38,236
After 2010	10,278	35,623

Table 41. Year of Construction of Steel and Concrete Bridges in the NBI Located in Illinois, Selected According to Criteria in Table 2

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	861	1,241
1941–1950	226	117
1951–1960	839	804
1961–1970	1,520	1,212
1971–1980	813	2,099
1981–1990	583	3,695
1991–2000	450	2,739
2001–2010	552	2,057
After 2010	572	1,358

Table 42. Year of Construction of Steel and Concrete Bridges over Roads Having Clearance Less than 14 ft according to the NBI

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	164	310
1941–1950	82	107
1951–1960	286	285
1961–1970	232	308
1971–1980	84	95
1981–1990	33	68
1991–2000	28	40
2001–2010	16	26
After 2010	18	64

Table 43. Year of Construction of Steel and Concrete Bridges over Roads Having Clearance Less than 15 ft according to the NBI

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	360	428
1941–1950	337	241
1951–1960	2,681	1,329
1961–1970	3,539	2,731
1971–1980	1,430	730
1981–1990	350	311
1991–2000	245	278
2001–2010	186	199
After 2010	147	238

Table 44. Year of Construction of Steel and Concrete Bridges over Roads Having Clearance Less than 16 ft according to the NBI

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	439	501
1941–1950	469	334
1951–1960	4,029	2,440
1961–1970	6,143	6,296
1971–1980	2,718	2,181
1981–1990	775	829
1991–2000	602	697
2001–2010	506	618
After 2010	423	658

Table 45. Year of Construction of Steel and Concrete Bridges over Roads Located in Illinois Having Clearance Less than 14 ft, according to the NBI

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	5	3
1941–1950	2	0
1951–1960	10	0
1961–1970	4	1
1971–1980	1	0
1981–1990	0	0
1991–2000	0	0
2001–2010	0	0
After 2010	1	2

Table 46. Year of Construction of Steel and Concrete Bridges over Roads Located in Illinois Having Clearance Less than 15 ft, according to the NBI

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	7	4
1941–1950	22	0
1951–1960	103	55
1961–1970	127	8
1971–1980	17	7
1981–1990	13	6
1991–2000	9	2
2001–2010	6	2
After 2010	8	5

Table 47. Year of Construction of Steel and Concrete Bridges over Roads Located in Illinois Having Clearance Less than 16 ft, according to the NBI

Year of construction	Number of steel bridges	Number of concrete bridges
1940 or before	9	4
1941–1950	27	0
1951–1960	142	102
1961–1970	244	15
1971–1980	44	10
1981–1990	17	12
1991–2000	18	9
2001–2010	26	19
After 2010	22	9