Barrier Rail for Historical Contexts: Identifying the Research Need

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Executive Summary

Summary

This literature review methodology involves selecting relevant studies, analyzing their quality, and synthesizing key themes and findings to summarize the current state of research and identify gaps for further exploration. The review of documents regarding barrier rails for historic bridges highlights some findings relevant to Caltrans:

1. Balancing Safety and Historical Preservation:
    - Historic bridges require specific attention due to their protected status and the need to meet contemporary safety standards. Existing original railings often fail to meet current crash-test and safety criteria mandated by the AASHTO Manual for Assessing Safety Hardware (MASH).
2. Current Solutions:
    - Caltrans has successfully developed and crash-tested the Type 86H bridge railing, meeting the MASH TL-4 safety standards. This design specifically addresses the dual need for crashworthiness and preservation of historical aesthetics, making it suitable for some of the California's historical bridges.
    - Indiana's research presented three strategies—inboard railing (installing a modern, crash-tested railing inside the original historic railing), curb railing (installing a modern railing directly onto the existing curb, particularly suitable for bridges that feature sidewalks), and simulated historic railings (e.g., Type 86H)—demonstrating feasible solutions applicable to a broad spectrum of historic railing types.
3. Design and Regulatory Compliance:
    - Projects within the historical zones require close coordination and early engagement with regulatory entities, as these bridges involve complex regulatory compliance mandating extensive documentation of preservation alternatives and measures to minimize harm.
    - Guidelines focus on safety, aesthetic preservation, and maintenance for bridges, with an emphasis on historic integrity and context-sensitive treatments.

Identified Specific Needs for Caltrans

Expanded Design Catalog

Caltrans needs a comprehensive catalog of tested, historically compatible railing designs that align with diverse bridge typologies and regional aesthetics.

Enhanced Guidance for Unique Conditions

Additional guidelines are required for bridges with rare or unique railing types that cannot readily adopt existing standardized railing designs like Type 86H.

Clearer Lifecycle and Maintenance Protocols

Guidance and best practices for maintaining long-term integrity, aesthetics, and safety performance of historic bridge railings need to be clearly documented and standardized.

Economic and Environmental Analysis Framework

Improved methodologies are necessary to evaluate the economic feasibility, lifecycle costs, and environmental impacts of railing replacement or rehabilitation projects.

Gaps in Current Findings

Design Approaches

Limited comprehensive catalog or database of historically appropriate barrier designs suitable for different bridge types and regional contexts. The documents provide examples of compatible designs, but there is no comprehensive catalog of historically appropriate barriers for various bridge types and regions.

Environmental Adaptability

Insufficient data on railing performance under varying environmental stressors common to California (e.g., coastal salt exposure).

Economic and Environmental Analysis

Limited comprehensive analysis addressing economic feasibility, lifecycle costs, and long-term maintenance.

Recommendations

Develop an Expanded Bridge Railing Catalogue

Initiate a project to compile an extensive reference catalogue of crash-tested, historically sensitive railings adaptable to California's diverse bridge types.

Enhanced Regulatory Coordination

Establish routine early-phase coordination with the related regulatory bodies to streamline project approval processes.

Lifecycle and Maintenance Guidelines

Create detailed long-term maintenance guidelines addressing environmental factors, ensuring historical and safety criteria are consistently met.

Focused Research Initiatives

Conduct further research addressing structural and aesthetic challenges posed by rare historic railing types and develop innovative solutions.

Economic and Sustainability Assessment Tools

Implement methodologies for evaluating economic impacts, lifecycle sustainability, and maintenance requirements in railing rehabilitation projects.

Detailed Findings

The Manual for Assessing Safety Hardware (MASH) compliance is the current standard for roadside safety hardware, including bridge rails and barriers. However, historical bridge contexts present unique challenges where full MASH compliance may not be feasible due to constraints related to aesthetics, cultural preservation, and structural limitations. The reviewed documents collectively focus on rehabilitation, preservation, and enhancement of bridge railings and barriers on historic bridges, emphasizing compliance with current crashworthiness standards while preserving historical integrity and aesthetics.

Rails and Barriers: A Reference Guide for Transportation Projects in the Coastal Zone[1]

The document emphasizes the collaborative relationship between Caltrans and the California Coastal Commission, highlighting the importance of balancing structural safety, aesthetics, environmental considerations, and regulatory compliance. The guide identifies the particular challenges faced in coastal zones, notably the need to preserve scenic and visual quality as mandated by the Coastal Act, which includes preserving views, minimizing alterations to natural landforms, and ensuring design compatibility with local context. A significant portion of the guide is dedicated to illustrating and describing a variety of specific railing and barrier designs, classified by test-level performance (TL-2 and TL-4). TL-4 railings and barriers are mandated for bridges with higher speed limits (above 45 mph), while TL-2 is for bridges with lower speeds. Each railing type includes precise specifications related to design, material, height, and spacing, complemented by renderings and photographs of completed and proposed bridge projects. The document underscores the necessity of context-sensitive solutions, urging Caltrans to align safety and structural standards with coastal policy mandates and aesthetic considerations. It also outlines the regulatory framework established by the Coastal Act, AASHTO, and FHWA crash-testing standards that must be adhered to during the design and construction of bridge railings.

Development and Crash Testing of a Concrete Post-and-Beam Bridge Railing, California Type 86H[2]

This document is a detailed research report conducted by the Caltrans Roadside Safety Research Group. The study's primary objective is to design, develop, and evaluate a new concrete bridge rail—California Type 86H—that meets the MASH 2016 Test Level 4 standards. The report outlines the complete development process, from design through construction and crash testing. Three crash tests (Test 4-10, 4-11, and 4-12) were performed to meet the MASH Test Level 4 criteria, evaluating barrier performance using three vehicle types: a small passenger car, a pickup truck, and a single-unit truck. The Type 86H concrete bridge rail demonstrated compliance with MASH 2016 TL-4 safety standards. This barrier is suitable as a replacement for some of the existing non-compliant rails on historic and aesthetically sensitive bridge projects within California.

Guardrails for Use on Historic Bridges: Volume 1—Replacement Strategies[3]

This document is a detailed technical report developed in collaboration between Purdue University's Joint Transportation Research Program (JTRP) and the Indiana Department of Transportation (INDOT).

[1] https://dot.ca.gov/-/media/dot-media/programs/design/documents/caltrans-bridge-rails-and-barriers-a11y.pdf
[2] https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/type-86h-bridge-rail-report-final-version-11-26-24-a11y.pdf
[3] https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3154&context=jtrp

The primary objective of the research was to develop effective strategies to upgrade railings on historic bridges. The study found that Indiana had 658 historic bridges in service as of January 2014, featuring 61 different types of historic railings, with only a handful of railing types being significantly common. Researchers successfully developed retrofit strategies addressing approximately two-thirds of the state's historic railings, demonstrating that historic appearance could be effectively preserved or closely replicated while substantially improving safety. The document provides detailed practical solutions for rehabilitating railings on historic bridges while preserving their historical and aesthetic integrity. Three main strategies were proposed:

1. **Inboard Retrofit**: This strategy involves installing a modern, crash-tested railing inside the original historic railing. This approach is advantageous as it allows the original railing to remain visually undisturbed, thus preserving the historic appearance. This solution works particularly well when sufficient bridge deck width is available, ensuring historic integrity without compromising safety standards.

2. **Curb Retrofit**: This method involves installing a modern railing directly onto the existing curb, particularly suitable for bridges that feature sidewalks. This new railing serves both as pedestrian protection and as a vehicular barrier. Similar to the inboard retrofit, it retains the visual presence of the original railing structure and is suitable for bridges with sidewalks and lower vehicle speeds.

3. **Simulated Historic Railing Replacement**: This solution involves completely replacing the original railing with new crash-tested railings specifically designed to replicate the aesthetic features of the original historic railings. Using modern materials and crash-tested geometries, these replacement railings retain visual authenticity and aesthetic value while meeting current safety standards. Researchers successfully developed designs that simulated 42 historic railing types found in Indiana, covering approximately two-thirds of historic bridges in the state.

Guardrails for Use on Historic Bridges: Volume 2—Bridge Deck Overhang Design[4]

The research includes experimental testing of both half-scale and full-scale bridge deck overhang specimens and evaluates real-world bridge railing failures to assess their performance under collision conditions. Findings indicate that the current AASHTO guidelines, which rely heavily on yield-line analysis, can be overly conservative. Instead, the study demonstrates that punching shear, rather than yield-line mechanisms, typically governs failure. The report recommends revised design methods that account for the actual force distribution observed during testing, suggesting that lateral impact forces distribute over a larger deck length than currently considered. By adopting the proposed recommendations, bridge decks can be designed more efficiently, significantly reducing reinforcement needs, improving cost-effectiveness, and simplifying construction without compromising safety.

Historic Bridge Section 4(f) Programmatic Evaluation Guidelines[5]

This document offers comprehensive guidelines and documentation standards to assist the Texas Department of Transportation (TxDOT) in completing Programmatic Section 4(f) Evaluations specifically related to historic bridge projects. An extensive segment of the guide focuses on outlining alternatives

[4] https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3164&context=jtrp
[5] https://ftp.txdot.gov/pub/txdot-info/env/toolkit/423-04-gui.pdf

analysis, presenting detailed criteria to assess the feasibility of various options. Alternatives explored include the "no build" scenario, building on a new location to avoid the historic bridge, rehabilitation alternatives that preserve historic integrity, and replacement alternatives when avoidance is impractical. The document carefully explains how to evaluate each alternative's viability in terms of structural, functional, geometric deficiencies, safety, economic impacts, community disruptions, and environmental considerations. Another vital component covers measures to minimize harm, providing strategies for planning efforts to reduce adverse effects on historic bridges, such as modifying bridge design elements and consulting with public and stakeholders. The section also discusses various mitigation strategies if avoidance is impossible, including bridge relocation, thorough documentation, interpretative educational materials, and aesthetic considerations for replacement bridges. Incorporating specific measures can help mitigate adverse impacts on historic bridges during rehabilitation. For instance, using aesthetic railings that meet modern safety standards is particularly beneficial when working on historic structures. Additionally, installing crash-tested rails designed to harmonize with the original bridge features effectively balances preservation goals with safety compliance. One example mentioned in the document is the addition of crash-tested rails on the interior side of a historic bridge, allowing continued use without significantly compromising its historic integrity.

2024 Management Plan for Historic Highway Bridges[6]

This document is a detailed Management Plan for Historic Highway Bridges prepared for the Maryland Department of Transportation State Highway Administration by AECOM. This updated version revises and enhances the previous 2012 Management Plan. It outlines strategies and best practices for maintaining, rehabilitating, and preserving historic highway bridges in Maryland, especially those listed or eligible for listing in the National Register of Historic Places (NRHP). Specifically, the document addresses the preservation needs of 17 priority bridges chosen based on their historical, architectural, and engineering significance, including various bridge types such as reinforced concrete arches, steel trusses, stone masonry arches, and movable bridges. For each of the 17 priority bridges, the document provides an individual preservation plan detailing their historical significance, existing conditions based on recent inspections, previous repairs, modifications, and recommendations for ongoing preservation and future rehabilitation. Preservation recommendations primarily focus on routine inspections, vegetation control, debris removal, and minor repairs to prevent deterioration. Rehabilitation recommendations are more extensive, addressing structural issues, drainage improvements, waterproofing measures, and integrating safety features such as modern traffic barriers that are context-sensitive and compliant with current safety standards.

It advocates for barriers that comply with current standards outlined in AASHTO's Manual for Assessing Safety Hardware (MASH), recommending visually appropriate solutions such as solid barriers with architectural features that mimic historic designs, preserving original railings behind new protective installations whenever possible. The plan also advises considering design waivers for bridges with low traffic volumes or speeds to retain historic elements undisturbed. Successful examples within the document, notably the Patapsco River Bridge, demonstrate the effective blending of contemporary safety requirements and historical aesthetics by incorporating barriers designed to closely resemble original architectural details.

[6] https://www.roads.maryland.gov/OPPEN/Management_Plan_for_Historic_Highway_Bridges_2024_Final.pdf

Summary of Findings

General Findings

Historic bridges, including their railings, are protected under federal and state preservation laws due to their cultural and aesthetic significance. Such bridges present specific challenges as their original railings typically do not comply with current crash-test requirements or modern standards. Rehabilitation and preservation efforts require balancing current safety standards with preserving historic integrity, especially since railing designs often contribute significantly to the aesthetic character of historic bridges.

Specific Strategies Identified for Upgrading Historic Bridge Railings

Three main retrofit strategies were developed for preserving historic railings while ensuring safety. The first strategy, the Inboard Railing, involves installing a modern railing behind the original one, allowing the historic rail to remain visually intact. The second, the Curb Railing, is suitable for bridges with sidewalks and places the railing on the curb to protect pedestrians while preserving the original railing. Lastly, the Simulated Historic Railing strategy involves creating crash-tested railings that replicate the appearance of the original historic railings. These railings maintain the necessary crash-resistant geometry while incorporating design elements from the original structure.

86H Concrete Post-and-Beam Bridge Railing (California Case)

Caltrans developed the Type 86H railing, compliant with the MASH 2016 Test Level 4 standards, to serve both aesthetic and safety purposes, specifically targeting historic bridges and new projects requiring historically appropriate designs. The Type 86H railing successfully passed rigorous crash testing (MASH TL-4), ensuring compliance with current safety standards while maintaining historical aesthetics.

General Guidelines and Regulatory Context

Caltrans, in collaboration with the California Coastal Commission, developed comprehensive guidelines for bridge railings within California's coastal zones. This guide provides a range of design standards and examples, focusing on visual cohesion, safety, ease of maintenance, and contextual compatibility. Early collaboration is encouraged to streamline rail selection and permitting processes.
Historic bridges require thorough evaluation when projects impact their structural or aesthetic features. The TxDOT guidelines detail methods for documenting the justification for rehabilitation or replacement alternatives and outline the necessary documentation standards for assessing alternatives to minimize harm to historic integrity.
Maryland's Management Plan also emphasizes the importance of context-sensitive rehabilitation, highlighting treatments specific to various types of historic bridges. Best practices include specific treatments for moisture penetration, stone masonry repointing, rust prevention, and preservation of concrete and steel structural integrity, but only briefly address barrier-specific issues.

Recommendations for Caltrans

Caltrans requires a comprehensive catalog of tested and historically compatible railing designs that can be adapted to various bridge typologies and regional aesthetics. To address unique cases, additional guidelines are needed for bridges with rare or specialized railing types that cannot easily accommodate existing standardized designs. Early-phase coordination with relevant regulatory bodies can also be established to streamline the project approval process. Clear documentation and standardized best practices for maintaining the long-term integrity, aesthetics, and safety performance of historic bridge

railings are also helpful. Furthermore, there is a need for improved methodologies to assess the economic feasibility, lifecycle costs, and environmental impacts of railing replacement or rehabilitation projects. In addition, detailed long-term maintenance guidelines can be created to address environmental factors and ensure that historical and safety standards are consistently met.

Gaps in Findings

Comprehensive Design Catalogue

While the documents provide examples and references to historically compatible designs, there is no unified, comprehensive catalog or database of historically appropriate barrier designs suitable for different bridge types and regional contexts.

Specific Criteria for Historical Integrity Assessment

The reviewed documents frequently emphasize balancing aesthetics with safety standards, yet they lack detailed guidelines or standards for determining acceptable levels of visual impact or historic integrity loss.

Lack of Specifics on Non-standard Conditions

Limited guidance is offered for bridges that have unique or uncommon railings. There is a need for more explicit guidance on handling these unique cases.

Material-specific Preservation Techniques

Though various bridge preservation practices are outlined, details specific to the preservation of original rail materials in the context of safety compliance remain sparse.

Economic and Environmental Impacts

Economic analysis of implementing recommended barrier strategies and the broader environmental impacts of different rehabilitation options are not thoroughly addressed.

Lifecycle and Maintenance Considerations

Guidance for long-term maintenance, lifecycle performance, and sustainability of replacement or simulated railings, especially considering environmental stresses like coastal conditions or freeze-thaw cycles, is minimal or lacking.

Detailed Guidance on Compatibility with Pedestrian and Bicycle Uses

Limited focus on integrating pedestrian and bicycle barriers effectively while maintaining historical and aesthetic standards.

Concrete Recommendations on Barrier Integration Techniques

Limited explicit recommendations are provided regarding effective integration of new crash-tested barriers to historic bridge decks, particularly for bridge deck overhangs, which have unique structural demands.