Preservation Alternatives for Historic Metal Truss Bridges: Survey of Literature and Current Practices

by

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Preservation Alternatives for Historic Metal Truss Bridges: Survey of Literature and Current Practices

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Dedication

To my parents, Russell and Rae Ann, who have taught, and continue to teach me so much about life.

Acknowledgements

I would like to thank the individuals who have played key roles in the completion of this thesis. Firstly, to Dr Michael D. Engelhardt, for giving me the opportunity to work on this project and guiding it, and me, through these two years. Secondly to the Texas Department of Transportation for funding this study. Thirdly, to the faculty and staff of Ferguson Structural Engineering Laboratory, who have provided me both an excellent technical background and the support necessary to complete my studies.

On a personal note, I would also like to thank persons who have shaped my life over the past twenty-three years. Every person and experience in my life, has contributed to the person I am, and will become. My parents have instilled the knowledge of right and wrong, and continue to be a model which I will ever strive to reach. My friends and time at Washington University taught me to open my eyes to the variety of people and places around me. At the University of Texas, the professors have demonstrated a level of technical expertise which will be an example throughout my professional career. Finally together with my friends in Austin we have grown through the difficulties of life with faith, perseverance, encouragement, and humor.

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Abstract

Preservation Alternatives for Historic Metal Truss Bridges: Survey of Literature and Current Practices

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The University of Texas at Austin, 1998

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It is a well-known fact that the condition of the nations' bridges is poor at best. Surveys have revealed that up to 40% of the bridges currently in service are either structurally or geometrically deficient.

In response to the growing interest of the historical community in the preservation of Texas' older metal truss bridges, the Texas Department of Transportation (TxDOT) has been addressing each bridge rehabilitation on a case-by-case basis. To streamline this process, TxDOT commissioned the University of Texas at Austin to conduct a series of investigations to not only increase the information available to engineers, but also test current rehabilitation techniques as applied to metal truss bridges.

To complete the first task of the project three steps were taken, which are described in this paper. The first involved a literature search and cataloging of relevant information. The second was a survey of other transportation agencies to document current trends in truss bridge rehabilitation. The third task consisted of

a summary of the literature search and survey of DOTs to form an in-depth collection of common deficiencies in structures and possible solution alternatives.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

It is a well-known fact that the condition of the nations' bridges is poor at best. Surveys have revealed that up to 40% of the bridges currently in service are either structurally or geometrically deficient, [Ref. 5.9]. As an alternative to destroying inadequate bridges, a common solution involves rehabilitating the existing structure. The Texas Department of Transportation (TxDOT) is responsible for deciding whether replacement or rehabilitation is the best option for each bridge structure. This process is complicated when the bridge in question is historic in nature. In response to the growing interest of the historical community in the preservation of Texas' older metal truss bridges, TxDOT has been addressing each historic bridge rehabilitation on a case-by-case basis. The officials at TxDOT, wishing to formulate sound engineering decisions, as well as maintain the existing historic truss bridges of the state, commissioned The University of Texas at Austin to aid in the resolution of these difficulties.

1.2 PROJECT DESCRIPTION

The overall objective of this project is to maintain the historic metal truss bridges of Texas in continued vehicular service. The University of Texas at Austin had been commissioned by TxDOT to produce guidelines that will aid the Texas officials in the repair and rehabilitation of historic metal truss bridges. The researchers have identified tasks, which are presently being completed, to aid in the compilation of these guidelines. There are three steps of this research project, the first of which being a review and documentation of current rehabilitation techniques of other Departments of Transportation (DOTs) and an in-depth literature review of repair techniques. The second task is the examination of two case-study bridges. This examination will include the load testing and evaluation of possible retrofit options to strengthen the bridges. A third investigation will involve laboratory testing of repair and retrofit techniques as applied to bridge members. At the completion of this project, the researchers will produce a thorough compilation of strategies that will aid the TxDOT officials in preserving the historic metal truss bridges of Texas in vehicular service.

1.3 Scope of Report

This research report represents the completion of the first task identified above. To successfully carry out this step, the task was separated into three segments. The first step was a survey of DOTs to investigate the current level of rehabilitation undertaken by other agencies. The second step involved assembling a collection of articles and documents related to truss bridge rehabilitation. Thirdly, the elements from the first two steps are condensed to provide a summary of current rehabilitation techniques, supported with relevant literature and the experiences of other transportation officials. In the following paragraphs, a short introduction to each of these segments will be provided.

1.3.1 Survey of DOTs

This task involved sending mail questionnaires to other DOTs soliciting information on historic metal truss rehabilitation. The first step in completing this task involved the development of the survey. Through discussions with TxDOT officials and other researchers at the University of Texas at Austin, a collection of nine questions was assembled. This survey was mailed to sixty transportation agencies throughout the United States and Canada. Thirty-nine responses were received and transcribed into a computer database. A complete summary of the survey including the methodology and techniques utilized may be found in Chapter 3. A copy of the survey is located in Appendix A along with a complete listing of the responses from the DOTs in Appendix B.

1.3.2 Literature Review

The literature review sought to collect as much relevant information concerning metal truss bridge rehabilitation as possible. The documents recovered include journal articles, books, manuals, and product information. Each document was read and summarized. The collection of material will continue throughout the duration of the project. For this reason, a cataloging system was created that would allow for, not only easy access to the included materials, but also future expansion of the database. Chapter 2 provides further discussion of the materials collected, as well as, information on literature searching techniques. The database of literature summaries may be found in the Annotated Bibliography.

1.3.3 Summary of Literature Review and DOT Survey

To collect the information gathered in the first two parts of the project into a useful format, a synthesis of the information was undertaken. A collection of common rehabilitation topics related to metal truss bridges was assembled. Materials from the survey of DOTs, as well as, relevant documents discovered in the literature search, were assembled for each topic and presented in Chapter 4. General topics such as the Analysis and Testing of Bridges, Structural and Geometric Deficiencies, and Damage Repair are included in this chapter.

CHAPTER 2

LITERATURE SEARCH

2.1 GOALS OF LITERATURE REVIEW

A major component of this study consisted of an in-depth literature search. The purpose of this search was to collect, catalog, and summarize information related to metal truss bridge rehabilitation. This database of literature is intended to serve as a resource to engineers involved with truss rehabilitation projects, providing sources of information on technical issues pertinent to older truss bridges. The database also provides information on rehabilitation techniques which have been successfully implemented in other states, and for which experience and precedence of use already exist. Finally, the literature search served as a resource for the remainder of the study, an in particular, for the case study bridges.

This chapter describes the methods used to conduct the literature review, provides a summary of topics covered in the review, and provides guidance on methods to conduct more detailed searches to obtain publications. The results of the literature survey are summarized in the form of an Annotated Bibliography. A synthesis and discussion of information found in the literature is provided in Chapter 4.

2.2 METHODOLOGY

The methodology used during this phase of the project involved several steps to collect the desired information. First, a list of topics and keywords related to steel truss bridge rehabilitation was identified. The next step was to locate publications related to these topics.

The preliminary literature search was conducted using the University of Texas at Austin library database (UTCAT) which is a computerized listing of books and articles available at the university. A variety publications were found using the UTCAT system and retrieved for the database. A second database, namely the Engineering Index (EiCPX), was also extensively referenced. This database, available over the world-wide-web, lists articles published related to engineering topics from the 1970's to the present. Once the articles were obtained the articles were read, summarized, and a cited in the Annotated Bibliography.

2.3 SUMMARY OF THE DATABASE

In order to facilitate the use of the literature database, the publications have been categorized and cataloged into the following five major sections:

1. General Information
2. Rehabilitation Techniques
3. Evaluation
4. Testing
5. Reference

Within each major section, articles were then further categorized according to topic areas. To assist in locating articles in the database, a sequential numbering system is used. For example, an article dealing with the evaluation of fatigue and fracture in a bridge can be found at 3.2.X referring to Section 3 (Evaluation), Topic 2 (Fracture and Fatigue). Some articles have been placed into more than one group if warranted by the material and cross-referenced in the catalog. The major sections and topic areas are described in the following paragraphs.

2.3.1 General Information

The articles in this section provide an introductory presentation of bridge preservation, problems present in metal truss bridges, and solutions to some common deficiencies.

2.3.2 Rehabilitation Techniques

This section contains articles which focus on individual rehabilitation techniques. Many different techniques are included with a wide range of applications. Articles covering simple rehabilitation solutions such as the addition of coverplates, to complex rehabilitation efforts involving the replacement of pins in a truss are included. These articles should aid in considering the full range of available options for truss rehabilitation, as well as provide details of the various techniques. Topics in the Rehabilitation Techniques Section include:

1. General
2. Post Tensioning

3. Superimposed Truss
4. Coverplating
5. Rivet Replacement
6. Additional Members
7. Pin Replacement
8. Deck Replacement
9. Flame Straightening

2.3.3 Evaluation

The evaluation section is comprised of references dealing with the assessment of the bridge structure. In a rehabilitation project, the key first steps include structural analysis and load rating, as well as an inspection of the bridge. Articles in this section relate to appropriate methods for structural analysis of truss bridges, as well as introductory information on non-destructive inspection and evaluation techniques. Also included are articles on fatigue and fracture concerns. Topics in the Evaluation Section include:

1. Corrosion
2. Fatigue and Fracture
3. Truss Stability
4. Structural Analysis
5. Non-Destructive Testing
6. Reliability Analysis

2.3.4 Testing

The testing section of the catalog includes articles concerning either small or large-scale load testing of the bridge structure. To fully understand the response of a truss bridge it may be beneficial to load test either the entire structure or certain members. Articles in this section refer to some of the situations that might be presented to an engineer who would like to test a bridge, or individual members of a bridge. Topics contained in the Testing Section include:

1. Structure
2. Members
3. Connections
4. Deck

2.3.5 References

The final section of the catalog, References, encompasses the more general topics that may be of interest in truss bridge rehabilitation. A majority of the books found during the literature review are contained in this section. These documents provide a varied and broad discussion of the truss rehabilitation topics.

2.4 SEARCHING TIPS

Over the course of the literature search some obstacles in both finding pertinent references, as well as retrieving these documents were encountered. In retrospect, a discussion of literature searching techniques would have proved useful. From these experiences, this section of literature search suggestions has been assembled. Hopefully these suggestions will help future researches both at the University of Texas at Austin, and also engineers of the Texas Department of Transportation.

2.4.1 Finding Articles

As previously mentioned, the two main search engines used were the University of Texas system and the Engineering Index. Hundreds of article references were available and examined to determine which would be applicable to the research. The University of Texas library resources may be accessed via the wold-wide-web at "www.utexas.edu". By following the links to the library, the UTNetCAT system may be referenced. More in-depth article listings may be searched by linking to the "Indexes & Abstracts" then linking to the "Science/ Technology/ Health" page. The EiCPX may be accessed, as well as other article search engines including.

- Applied Science and Technology Abstracts
- ArticleFirst
- OCLC WorldCat
- CARL UnCover

Unfortunately, the resources mentioned in the previous paragraph are available to university students, faculty, or at the University of Texas Library. Therefore, engineers outside the university must find alternate means of document location. For engineers within close proximity of the University of Texas at Austin, access to many of these databases may be gained by visiting the library and using the computer terminals inside the library. If the engineer is not located near a library facility with search capabilities, another option is utilize various state databases and search engines. Engineers should check within the office for access to resources such as TRIS and other transportation information databases available to state agencies. If these services are not available, some databases are accessible for a charge, such as EiCPX.

2.4.2 Document Procurement

Once the article or book references were collected, it was necessary to obtain a hard copy of the document. It was checked if the article was available in The University of Texas at Austin using the electronic card catalog. If an article was not at the university, a document delivery service was employed. By completing a request form through the on-line library system at the university, the articles were requested. If a book was not contained in the university stacks, an Interlibrary Loan (ILL) form was completed. The ILL program lends books between member libraries at little or no cost to the patrons.

The document delivery services might not be available to practicing engineers. To collect articles, the following steps are suggested. The first task involves collecting a list of articles which are relevant to the project at hand. Information such as journal name, issue, number, and pages should be listed for each article. The second step would involve checking the available sources for the articles. The University of Texas at Austin system, or other local universities may house the articles. Typically the university catalogs may be accessed on-line, saving a trip to the library. The articles, which cannot be found locally, may be retrieved using a document delivery service. Many of the search engines listed in the previous section, including the Engineering Index and ArticleFirst, provide article reprints. Usually a fee is charged for the delivery of these documents.

To procure a copy of a specific book, the engineer may investigate ILL services at their local library. A copy of the book might also be available through the publisher, provided that the book is still in print.

CHAPTER 3

SURVEY OF DEPARTMENTS OF TRANSPORTATION

3.1 Survey Objectives

A mail survey of departments of transportation (DOTs), and other agencies, on their experiences with historic steel truss bridges was conducted. The main objective of the survey was to gather additional information on a variety of topics related to truss bridge evaluation and rehabilitation. The survey was intended to document current trends and attitudes concerning truss bridge rehabilitation, to identify practical application of rehabilitation techniques documented in the literature, and to identify new or innovative rehabilitation techniques that have not yet been documented in the literature. This chapter provides a compilation of the responses received in the survey. A copy of the actual survey is included in Appendix A.

3.2 Description of Survey

In assembling the survey, consideration was given to accommodate both the goals of this study, as well as the convenience of the survey recipients. The most difficult problem was to make the survey sufficiently in-depth to be useful, but at the same time, brief enough such that the survey recipients would not be burdened by a lengthy document. To this end, a short discussion will be included of the considerations taken to develop the survey.

3.2.1 Survey Overview

The two components of the survey were the coverletter and the main body of the survey. The coverletter summarized the goals of this research project and objectives of the survey. The survey itself was designed to be easy to comprehend, and complete, but technically relevant to the task at hand.

3.2.1.1 Coverletter

The coverletter, which accompanied each survey packet, served as an introduction of the research to the surveyed DOTs. An important primary issue involved contacting the appropriate individual at the various agencies. A book containing a listing of AASHTO members working at DOTs was invaluable in the creation of a mailing list for the survey [Ref. 5.12]. The survey was sent to individuals with titles related to bridge design or repair. A total of 60 surveys were sent, including the 49 other states, the District of Columbia, Puerto Rico, and 9 provinces in Canada.

The coverletter gave a short introduction to the research project, including its goals and how the survey would aid in the successful completion of the project. The coverletter also included contact persons at both The University of Texas at Austin and the Texas Department of Transportation. Inquiries about the survey could be made via phone, mail, or email to accommodate as many people as possible. As an incentive for the engineers surveyed, the research team offered to return a copy of the final report in exchange for their assistance.

3.2.1.2 Survey

A major consideration in designing the survey was to limit the number and intricacy of the questions so as to encourage the recipients to actually complete the survey. The questions were written to allow for simple answers however, adequate space was also included for a more involved discussion.

Questions asked in the survey related to many facets of bridge rehabilitation. Topics such as analysis techniques, non-destructive testing (NDT), railings, as well as general questions related to geometric clearances and structural strengthening were included. A final question asked the engineer to include their address to allow for future contacts and a location to send a copy of the final report.

3.3 RESULTS OF THE SURVEY

Responses to the survey were mailed to the researchers at the University of Texas at Austin. The responses to the questions were compiled in a Word document and may be found in Appendix B. Of the 60 surveys mailed, 39 responses were received, representing a 65% return rate. The responses collected from the DOTs varied in content and substance. Some responders gave brief answers only consisting of checkmarks without elaborating on the answers. Other engineers thoroughly discussed individual question by introducing examples and possible contacts. The graphs and charts in the following pages summarize the survey responses.

3.3.1 Question 1

Has your state developed any reports, guidelines, or other documents addressing the evaluation or rehabilitation of steel truss bridges?

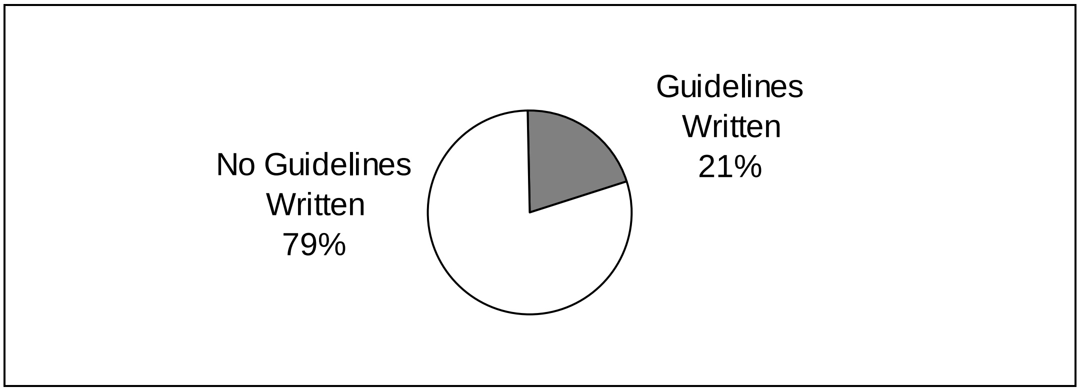

Figure 3.1: Response to Question 1

Figure 3.1 shows that a majority of DOTs have not developed standards or guidelines related to historic metal truss bridges. This is similar to the case in Texas where truss bridge rehabilitations have been dealt with on a case-by-case basis. The state with the most published work concerning truss bridges was Iowa. They have documented experience in load testing, as well as a research project produced by Iowa State University concerning the rehabilitation of truss bridges, [Ref. 5.9]. Other states have produced reports, but on smaller levels such as Washington's "Report on Steel Bridge Cracking" or Minnesota's "Bridge 4174 – Summary of Inspection for Reuse as a Pedestrian Bridge".

3.3.2 Question 2

Have you used advanced structural analysis techniques to provide improved estimates of the structural capacity of steel truss bridges?

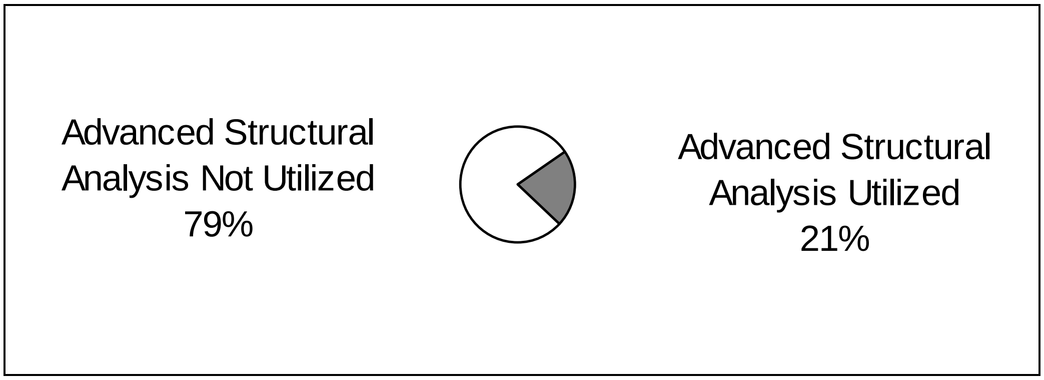

Figure 3.2: Response to Question 2

The most common technique reported by agencies was two-dimensional analysis. Only a few agencies, such as Connecticut, Arizona, and Newfoundland, indicated that more advanced, three-dimensional analysis have been used. Analysis programs used by these DOTs include GTSTRUDL, SAP90, and BRUFEM. Based on the survey responses, conventional frame analysis, using either hand methods, or commercial structural analysis programs, is the most common technique for analyzing truss bridges. A few agencies have employed more advanced finite element programs or other advanced analysis techniques for truss bridges.

3.3.3 Question 3

Have you used advanced non-destructive evaluation techniques (e.g. acoustic emission monitoring) to assist in evaluating the condition of steel truss bridges?

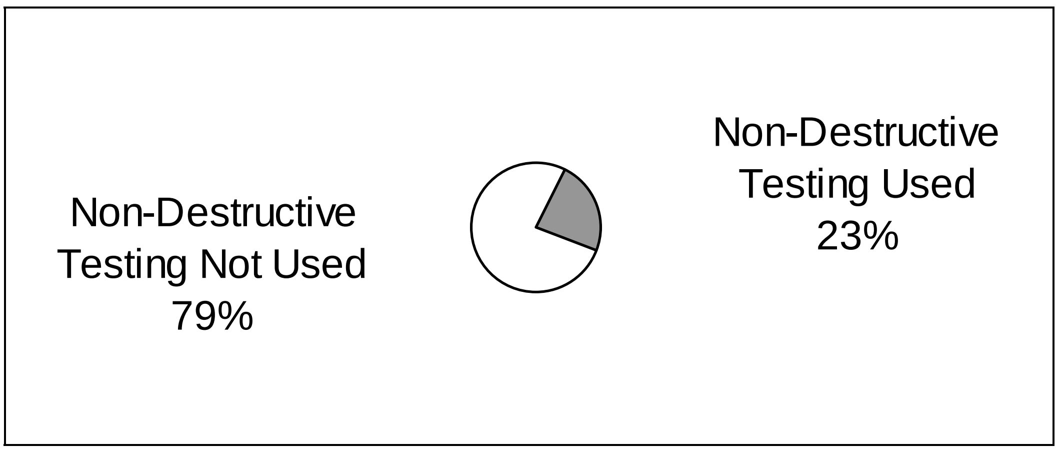

Figure 3.3: Response to Question 3

Figure 3.3 shows that, most agencies have not conducted in-depth investigations by non-destructive methods. The most common NDT method indicated in the survey was the use of ultrasonic evaluation to test pins for flaws. Further discussion of this topic may be found in Chapter 4.2.2.2.

3.3.4 Question 4

Have you used load testing to assist in the evaluation of the structural capacity of steel truss bridges?

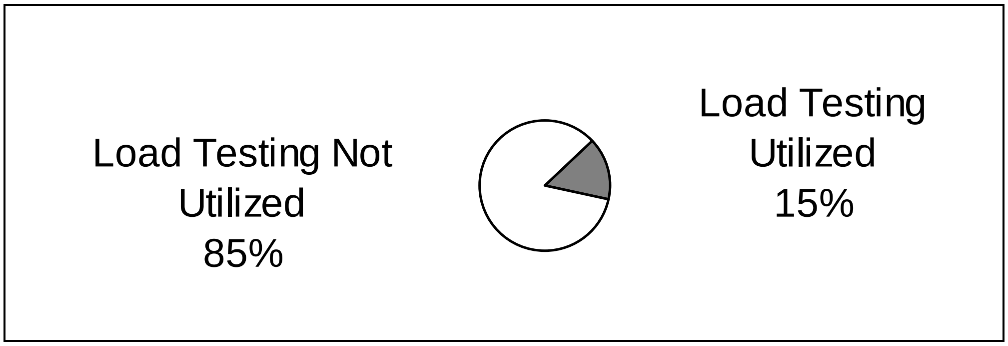

Figure 3.4: Response to Question 4

Load testing as a method of bridge evaluation is a very time-consuming and expensive endeavor. Figure 3.4 demonstrates that very few agencies employ load testing to aid in the evaluation of a bridge. A majority of load tests conducted in the United States were conducted as part of research projects. In other words, universities have conducted many experiments for DOTs since these institutions have the time, equipment, and expertise for load tests. Overall though, most DOTs in the United States do not appear to perform load testing on a routine basis. However, most provinces in Canada use load testing to rate their bridges. Many examples were found in the literature of "proof loading" of truss bridges. Further discussion of this topic can be found in Chapter 4.2.1.2.

3.3.5 Question 5

What are the most common structural strengthening techniques your department has used in rehabilitating steel truss bridges?

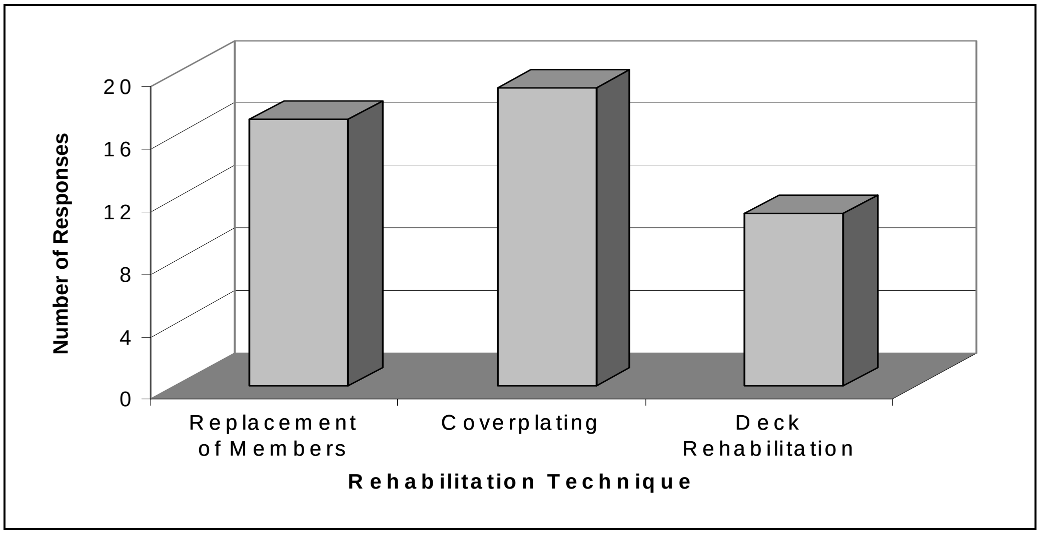

Figure 3.5: Response to Question 5

These responses indicate that most rehabilitation efforts focus on individual members instead of the whole structure. In rehabilitating a structure, the most common techniques involve repairs to the critical portion of the system. Very few responses indicated rehabilitation of an entire system as the most common solution which can be attributed to the fact that most bridges are deficient in only a few locations, while other elements may be substantially overstrength and do not require repair or strengthening. Most main truss members generally appear to have adequate strength, while floorbeams and decks are usually often deficient. The rehabilitation of these members usually involve techniques such as replacement of members, coverplating, or deck replacement.

3.3.6 Question 6

Please check any other structural strengthening techniques you have used.

______Superimposed trusses

______Post-tensioning bottom chord

______Joining simple spans into continuous span

______Replace floor deck with a lighter system

______Other (please explain)

______Addition of longitudinal beams

______Providing additional supports

______Adding king or queen posts post-tensioned tendons

______Pin replacement

______Attach cover plates to members

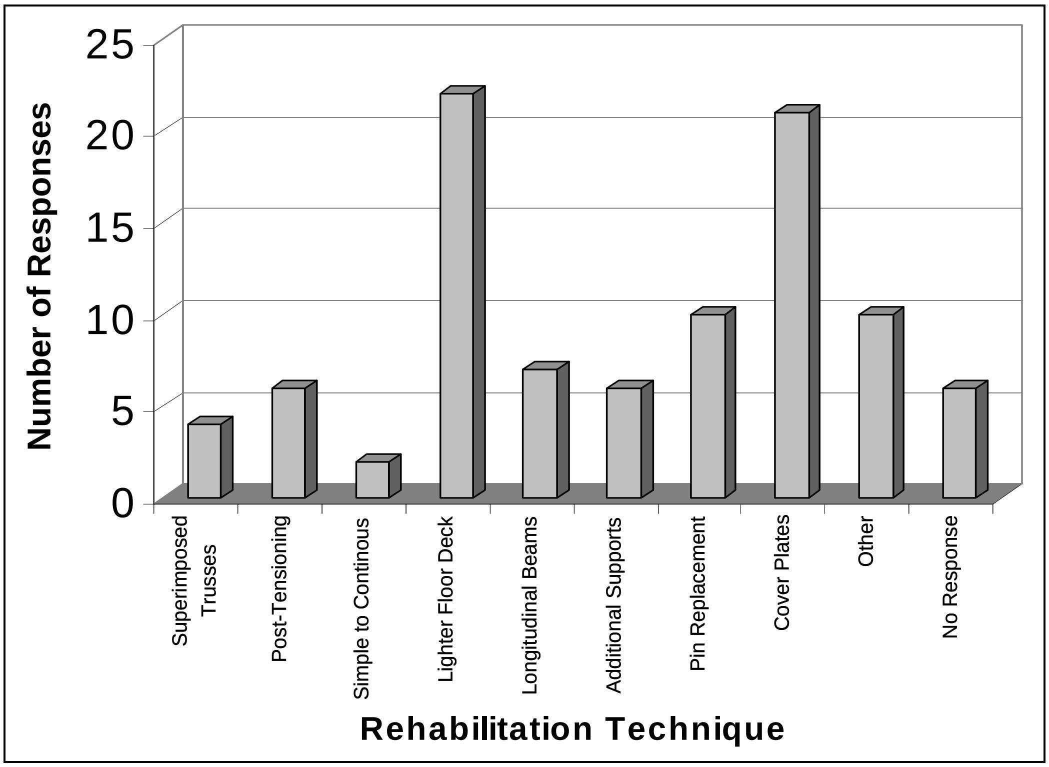

Figure 3.6: Response to Question 6

Figure 3.6 shows that a wide variety of techniques have been used successfully. Coverplating and deck replacement are the two most common rehabilitation techniques. The coverplating technique is useful when a few members are understrength. By utilizing a lighter deck system, the dead load of the structure is reduced and the live load capacity is increased. However, deck replacement might also be warranted to repair a deficient deck.

3.3.7 Question 7

For bridges with geometric deficiencies, either inadequate height or width, please check any solutions you have used:

______Relaxing geometric standards for historic bridges
______Widening bridge
______Increasing portal height by removing or altering overhead members
______Convert bridge to one-way traffic
______Other (please explain)

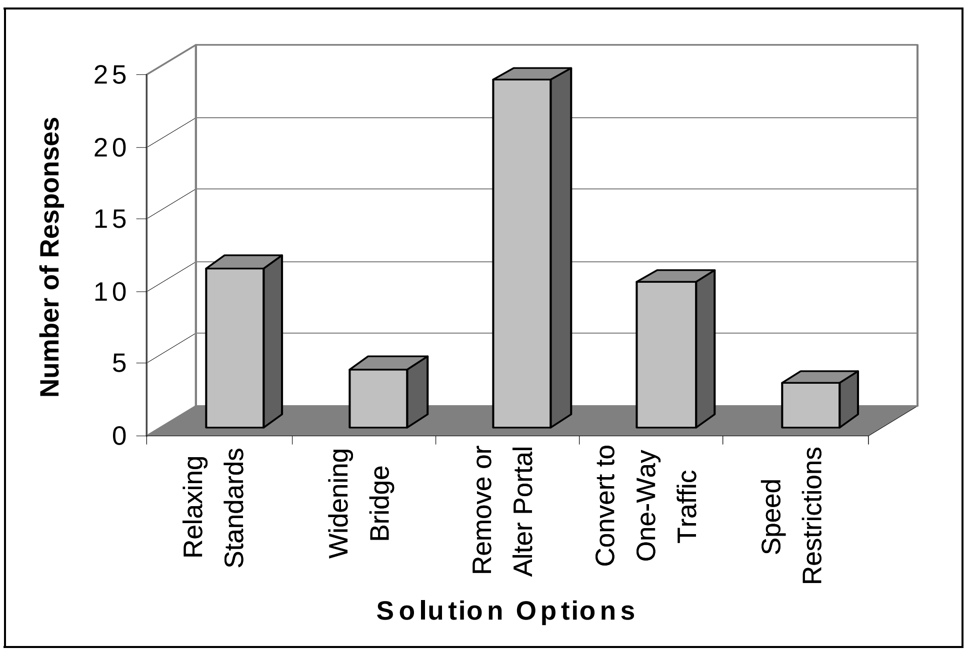

Figure 3.7: Response to Question 7

The issue of geometric standards, as they relate to truss bridges, is a very difficult topic. Figure 3.7 shows that most agencies prefer to alter the portal dimensions, which is a valid solution for height considerations. A larger problem is the issue of width requirements. Figure 3.7 also shows that conversion to one-way traffic and relaxing geometric standards are the most common solutions for width problems. Some states such as Arizona, Nevada, and Oklahoma, have widened truss bridges to meet with current requirements. Further discussion of this topic can be found in Chapter 4.3.1.1 and 4.3.1.2.

3.3.8 Question 8

What methods, if any, have you used to improve railings on historic steel truss bridges? We are particularly interested in information on crash tested railings which have been added to historic steel truss bridge.

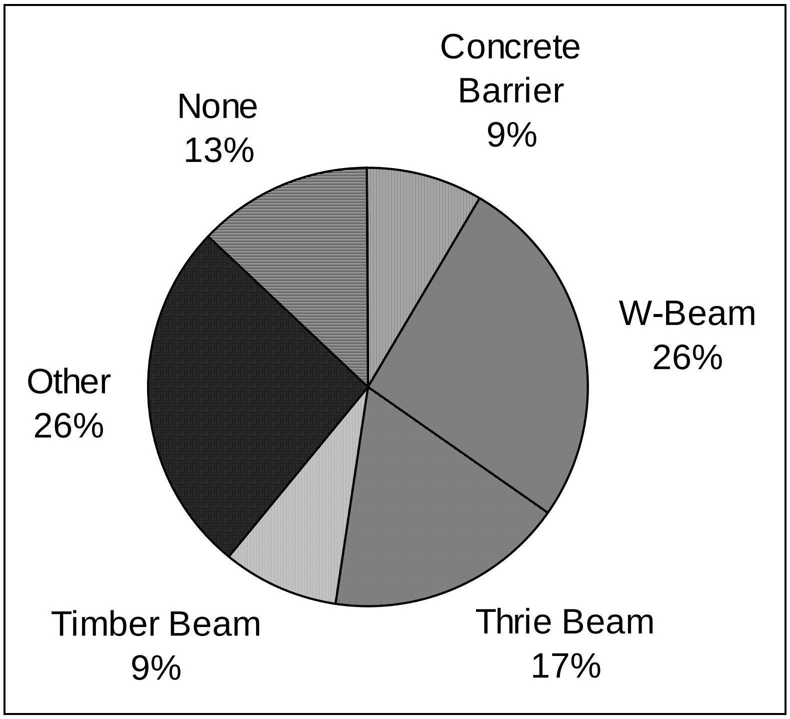

Figure 3.8: Response to Question 8

The responses to this question were varied. Sixteen of the DOTs that returned their survey did not respond to this question. In comparison, for questions 5, 6, and 7 no response was given by only 6, 5, and 5 DOTs respectively. This suggests that the issue of railings is a difficult rehabilitation topic. Of the 23 DOTs which did respond, no clear solution was the favorite. Figure 3.8 indicates that the W-shape was the most popular retrofit, but not a majority solution. This topic will be discussed more thoroughly in Chapter 4.2.1.3

3.3.9 Question 9

What methods have you used to deal with the presence of lead based paints on historic steel truss bridges:

______Remove old lead paint (with appropriate disposal techniques) and repaint bridge
______Apply sealer to encapsulate lead based paint
______Other (please explain)

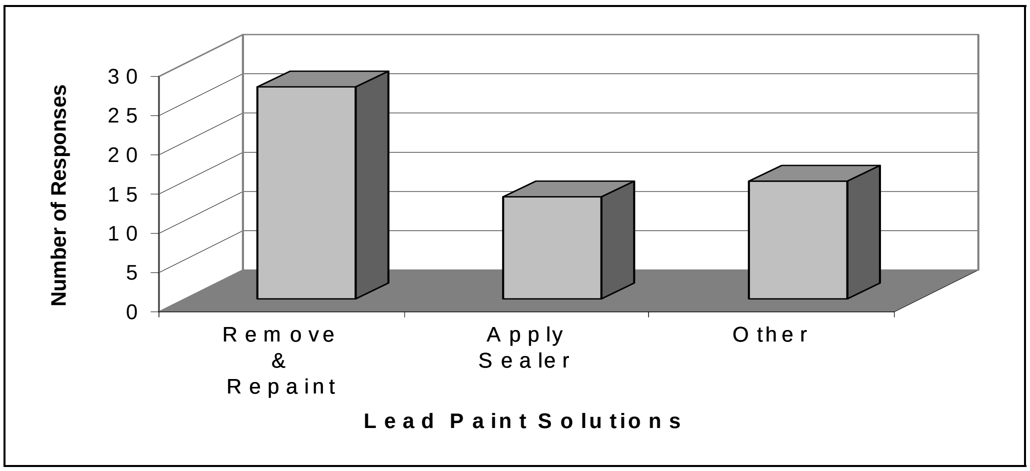

Figure 3.9: Response to Question 9

Lead paints are often a problem for older metal bridges. Figure 3.9 shows that the most common solution involves removing the existing paint and repainting the structure. The responders who indicated "Other" included comments concerning the first two options and other suggestions such as spot painting.

3.4 Follow-Up

After the results of the survey were compiled some of the responders, who indicated the use of new railing techniques in their survey response, were contacted. From these follow-up calls, some innovative solutions were discovered; a hollow tube railing used in Vermont, insight on methods to attach the bridge railings to the deck, and a method of utilizing a concrete barrier with a simulated rail. These solutions are discussed further in Chapter 4.3.1.3.

3.5 FINAL COMMENTS

A wide range of information and examples were gathered on a variety of topics related to metal truss bridge rehabilitation. Information collected in the survey is also used in Chapter 4, to provide practical applications of the rehabilitation techniques. The survey also uncovered new rehabilitation techniques that are also discusses in Chapter 4.

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CHAPTER 5

SUMMARY & RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

The three tasks which were identified for this portion of the research included a literature search, survey of Departments of Transportation (DOT)s, and a summary of the literature review and DOT survey related to truss bridge rehabilitation. The literature search yielded approximately 100 documents related to the repair or rehabilitation of metal truss bridges. The literature was summarized to expedite future reference. A numbering system was implemented to allow for further expansion of the catalog.

The survey of DOTs was sent to 60 agencies to enlist their help in documenting current trends in truss bridge rehabilitation. Thirty-nine responses were received and recorded. This information was used to provide practical examples of rehabilitation techniques documented in the literature. The survey also uncovered some rehabilitation techniques which have not yet been documented in the literature.

The objective of the summary chapter of this thesis was to provide a collection of information and examples related to a wide range of rehabilitation topics. Evaluation, geometric and structural deficiencies, damage scenarios, and many other topics were included encompassing a collection of issues present in many bridge rehabilitation projects.

5.2 RECOMMENDATIONS FOR FUTURE INVESTIGATION

As information was collected, it was realized that much more information is available. Future study should included continued investigation into topics discussed, further investigation of topics which little information was found, and the investigation of other media.

Topics which should be focussed on in the future include:

- Non-destructive Testing Methods
- Retrofit Railings
- Flame Straightening
- Painting repairs and other coating systems

Continued investigation of article databases, which are expanded daily should also be undertaken. Other media such as the Internet, might also hold additional information concerning the rehabilitation of metal truss bridges.

ANNOTATED BIBLIOGRAPHY

DESCRIPTION OF ANNOTATED BIBLIOGRAPHY

This appendix serves as a collection of information concerning many facets of metal truss bridge rehabilitation. The author has collected articles, books, and product information on a wide range of topics. Further discussion of the topics discussed herein may be found in Chapter 2.

Each reference is followed by a short discussion of the content of the document. A sequential numbering system has been implemented to permit easier access to the references, and allow for further expansion of the database.

Introductory Information

INTRODUCTORY INFORMATION [1.1]

Burke, Martin P., Jr. "Enduring Symbol of American Endeavor." Transportation Research News (March-April 1989): 3-8 (TE 1 H57) (C).

This article describes the first cast iron bridge built in America. The bridge was built on the National Road (Cumberland), originally built to encourage settlement to the west. The author tells the history of the design and construction of the bridge.

INTRODUCTORY INFORMATION [1.2]

Nichols, G., and R. McGee. "A Management Plan for Richmond Bridge, Tasmania." Road & Transport Research 4, no. 2 (June 1995): 4-14 (TE121 A922) (C).

Summary of the management plan developed for Australia's historic bridges. This article outlines the following topics which are included in a typical historical report: 1) Historical record: includes construction, repairs, and major events 2) Statement of Significance: significance of bridge to national and local history 3) Condition of bridge: material conditions and properties 4) Terrestrial Photogrammetry: pictures to measure quantities on and around bridge 5) Hydraulic Analysis: assessing flood risks at bridge 6) Structural Analysis: bridge analyzed for different types of loading on superstructure and substructure 7) Review Process: request for outside agencies or committees to comment on findings and make recommendations 8) Recommendations: recommended immediate, continual, and future work on the bridge.

INTRODUCTORY INFORMATION [1.3]

Bigelow, Lawrence N. "Fifty-Year Development-Construction of Steel Truss Bridges." Journal of the Construction Division, Proceedings of American Society of Civil Engineers 101, no. C02 (June 1975): 239-257 (TA 630 A447) (C).

This article provides general background information for the history of metal truss bridges in America. The author discusses many bridge types and construction techniques. Simple, Cantilever, and Continuous truss bridges are also described in this article.

INTRODUCTORY INFORMATION [1.4]

Lichtenstein, Abba G., and Mary Elizabeth McCahon. "Historic American Bridges." In Structural Preservation of the Architectural Heritage: Proceedings of the Symposium in Rome, Italy, 1993, by the International Association of Bridge and Structural Engineering. Italy, 1993 573-80 (C).

In this paper, the author gives a brief overview of bridge preservation in America. Firstly, a discussion of what constitutes a historic bridge is presented along with examples of historic bridges. Secondly, examples of bridges that were repaired and some that were destroyed are given. In conclusion, the author states that the preservation of bridges should be dealt with on a case-by-case basis.

INTRODUCTORY INFORMATION [1.5]

Watson, Sarah Ruth. "Some Historic Bridges in the United States." Journal of Professional Activities, Proceedings of the American Society of Civil Engineering 101, no. 3 (July 1975): 383-390 (ILL) (C).

This article is a brief checklist of famous bridges in America. The author discusses the requirements for a bridge to be deemed historic. In eloquent language, the author describes the significance of many bridges that relate to not only engineering feats, but also significant times in U.S. history. The author also focuses on the symbol of a bridge being used in many cultures, folklore, and history.

INTRODUCTORY INFORMATION [1.6]

Lichtenstein, Abba G. “Historic Bridges: Conflict Ahead.” Civil Engineering 7, no. 5 (May 1987): 64-6 (620.5 C499) (C).

This article briefs a few preservation conflicts/solutions the author has been involved with. A 75 year old steel truss in Hawaii, after much input from the public, was converted to a one-way bridge, two-way traffic pattern. A 90 year old lenticular truss in Somerset County New Jersey was rehabbed by replacing some deteriorated members and adding high strength beams inside existing built up members. A bridge in Califon, New Jersey was widened by cutting it in half and new floorbeams were added. A bridge in West Virginia was dismantled and moved to a golf course. The worst case was a chain link suspension bridge in New York which was judged structurally deficient and was removed for fear of sudden collapse due to flooding. Detailed drawings and certain details were saved for future reference. A list of “rules of thumb” of bridge preservation are given.

INTRODUCTORY INFORMATION [1.7]

Lichtenstein, Abba. “Impact Fracture in Historic Bridges.” In Structures Congress XIII: Proceedings of papers presented at the Structures Congress '94, Atlanta, Georgia, April 24-28, 1994, sponsored by the Structural Division of the American Society of Civil Engineers. Atlanta, Georgia, 1994, 1289-1292 (TA630 S86 1995) (C).

This article outlines failures that have occurred to historic truss bridges and the outcome of each situation. The first bridge discussed was a suspension truss bridge that collapsed after a car impact. Pieces of the bridge were salvaged from the river and an investigation into reconstructing the bridge was undertaken. Because of monetary constraints, the bridge was not restored. The second bridge, a wrought iron Phoenix truss, suffered extensive damage to one truss but did not collapse due to the other truss accepting the additional dead load. The bridge was repaired at a minimal cost compared to a new structure. The last bridge suffered a partial collapse due to an overload caused by a power generator placed on the bridge during a repair. The rehabilitation involved hiding new members inside the old members to reduce the stresses.

INTRODUCTORY INFORMATION [1.8]

Report of the Secretary of Transportation to the United States Congress. <u>The Status of the Nation's Highways and Bridges: Condition and Performance and Highway Replacement and Rehabilitation Program 1989</u>. Washington D.C.: Government Printing Office, June 1989 (Y4.P96/11:101-2) (PCL).

This report outlines many factors which effect the nations bridges. Chapters on Highway Finance, Conditions and Performance, and Highway and Bridge Needs for the Future are presented. These chapters detail the inner workings of how the national government views the status of the bridges on the highway system. A second part of the report focuses on the bridge replacement and rehabilitation program. An explanation of the goals and methodology of the replacement program is included. The report also describes the various funding types available for bridge rehabilitation or replacement. This report was very helpful in explaining how the government is dealing with the problem of deficient bridges.

Rehabilitation Techniques

GENERAL [2.1.1]

Morf, Ulrich. "Investigation of Obsolete Structural Elements and Retrofit of Old Steel Structures." International Association of Bridge and Structural Engineering: 547-52 (C).

The characteristics of old steel structures are different than modern steels making evaluation of such structures difficult. This article suggests methods of repairing a variety of joints using high strength bolts, welding, and external prestressing. However, first an evaluation of the material must be completed to determine its properties. The author suggests ultrasonic, magnetic particle or penetration testing. A discussion of the fracture characteristics of old bridge steel is included with formulae to quantify Charpy tests.

[A page is missing in the copy of the article, therefore some information has been lost]

The author suggests requirements for the use of external tendons on existing bridges

-Design shall allow for inspection and monitoring

-Tendons should be replaceable and restressable

-Check on the response to lateral forces

-Include fretting corrosion fatigue test if tendons are encased in metal pipe

-In riveted structures, tendons should be bolted to the main structure

GENERAL [2.1.2]

“Bridge Rehabilitation Saves a Lost Art.” Modern Steel Construction (October 1997): 58-62 (691.705) (C).

This article describes a rehabilitation effort completed on a lenticular truss built in 1886. The wrought iron bridge had been closed to vehicles in 1969 and converted into a pedestrian bridge. Repairs to the bridge included: replacement of fracture critical elements with high strength steel, replacement of bearings at abutments, substructure repair, removal of existing concrete deck and replacement with concrete filled steel grid deck, floorbeam repairs, and repainting.

GENERAL [2.1.3]

Stolldorf, Dennis W. “Fire Damaged Bridge Requires Major Repair.” Public Works 121, no. 12 (December 1990): 32-3 (TD1 P8) (C).

A bridge in Washington D.C. was badly damaged due to a ruptured fuel tanker below the bridge. Concrete of the piers was spalled, as well as severe damage to many of the steel components. The repair consisted of demolishing the damaged concrete and replacing it. Damaged portions of the steel girder were removed and new plates welded in their place. It should be noted that the bridge was not historic, therefore welding was not difficult on the modern materials.

POST-TENSIONING [2.2.1]

Ayyub, Bilal M., Ahmed Ibrahim, and David Schelling. “Post-tensioned Trusses: Analysis and Design.” Journal of Structural Engineering 116, no. 6 (June 1990): 1491-1506 (TA 630 A483) (C).

This article describes a structural stiffness analysis method of evaluating post-tensioned trusses. Post-tensioning allows a gain of strength, as well as, introducing redundancy into the design. Post-tensioning increases the elastic range and reduces the force on members. Stiffness matrices are developed for straight, one-drape, and two drape configurations. It is possible to use either internal or external tendons. Internal tendons, as the name implies, are contained inside the truss system. Internal tendons lessen tension member forces with no, or slight increase, in compression member stresses. External tendons are placed on the exterior of the truss system usually below the bottom chord. These tendons are more effective in reducing both tensile and compressive forces, but might unacceptable due to geometric clearances. A statically determinate and indeterminate bridge with internal tendons and a statically determinate truss with external tendons were both analyzed in this study.

Truss 1: Statically determinate truss with (a) a straight tendon (b) a one-drape tendon (c) a two-drape tendon. The straight and two-drape tendons reduced the tensile stresses on members which coincided with the tendon. The one-drape tendon, while reducing all tension stresses, caused increases in some compression members.

Truss 2: Statically indeterminate truss with (a) two straight tendons, one two-drape tendon (b) a two-drape tendon (c) a straight tendon. Again, all three cases saw a reduction in tension members which coincided with the cable layout. The redundant members of the truss experienced a reversal of stresses which should be accounted for in the design.

Truss 3: Statically determinate truss with external two-drape tendons. Three cases were investigated for different distance (h) between the bottom chord of the truss and the post-tensioned tendon. In all three cases both compression and tension members are relieved of some of their stress. With increasing (h), the reduction in stresses increased.

Conclusions: Tension members can be strengthened by using internal coincidental tendons. Both tension and compression members may be strengthened by using external tendons. This study was theoretical and dependent upon assumptions such as: a) linear elastic materials b) frictionless joints c) constant tendon forces throughout the member d) 2-D geometry.

POST-TENSIONING [2.2.2]

"Cables Rejuvenate Old Truss Span." Engineering News Record 223 (September 7, 1989): 21 (TA 1 E6) (C). (find copy)

A pin-connected, camelback through truss in Tennessee was closed in 1978 and saved by local historical group. The local DOT proposed replacing deteriorated members for a cost of $8 million. A.G. Lichtenstein & Assoc. Inc. Proposed $4 million post-tensioned cable solution. Pairs of 0.6 inch tendons were placed coincidentally to existing diagonal members and the bottom chord to relieve dead load and account for the live load of proposed trolley and pedestrian traffic.

POST-TENSIONING [2.2.3]

Ayyub, Bilal M., and Ahmed Ibrahim. "Post-Tensioned Trusses: Reliability and Redundancy." Journal of Structural Engineering 116, no. 6 (June 1990): 1507-1520 (TA 630 A483) (C).

The concept of post-tensioned trusses has been used in many rehabilitation efforts. Most studies and experiments focus on stress level reduction or increases in stiffness and fatigue resistance. This paper focuses on reliability and redundancy changes due to post-tensioning a bridge. Three tendon layouts including one-drape, two-drape, and straight were investigated. It was confirmed that the tendons work to reduce stresses in coincidental members. External tendon layouts (e.g. king post) reduce stress levels in most of the members in the structure.

System reliability was determined by using an event-tree analysis. The study demonstrated that a post tensioned structure with a classic definition of redundancy of one, actually has a higher level of redundancy dependent upon the tendon layout. For example, a redundancy factor of over three was calculated for the straight tendon layout.

POST-TENSIONING [2.2.4]

Belenya, E. I., and D. M. Gorovskii. "The Analysis of Steel Beams Strengthened by a Tie Rod." International Civil Engineering Monthly 2, no. 9 (1971/72): 412-419 (TA1 I7465) (C).

This article presents a straightforward analysis of steel beams strengthened by pre-stressing rods. The authors describe very clearly their analysis methods. Equations are developed which relate tie rod placement, tension in the rod, length of rod, and number of rods. Using these equations the stress resultants for different configuration may be found. The authors also discuss deflection calculations. An example problem is worked out to show these techniques in practice. General conclusions include: (1) the load carrying capacity of a rolled section may be increased by 80-90% (2) the length of the tie should be between 0.5-0.7 the length of the beam (3) the initial deformations of the beam should be taken in to account if h/l is less than 1/20 and if the length of the tie is to be between 0.8-1.0 the length of the beam.

POST-TENSIONING: SEE ALSO [2.4.5]

SUPERIMPOSED TRUSS [2.3.1]

Kim, Jai B., Robert J. Brungraber, and Robert H. Kim. “Recycling Bridges.” Civil Engineering (November 1988): 58-9 (620.5 C499) (C).

This brief article describes the use of a superimposed arch to strengthen an existing bridge. It provides general information on the concerns and advantages of this system.

SUPERIMPOSED TRUSS [2.3.2]

“Old Truss Bridge Rehabilitated.” Highway and Heavy Construction 128 (Feb 1985): 74-5 (TE 1 H5525) (C).

A truss bridge with buckled floor beams and a posted 3 ton load limit was strengthened to a 20 ton limit. Superimposed steel arches and floor beams of

A572-50 steel were added to the old truss. Cost of rehab approximately $62,000 compared to estimated cost of new bridge (about $200,000). "Underlying concept of their technique...the combination of a reinforcing arch with an existing truss system can carry a significant extra load if it is well supported laterally". This rehabilitation solution was proposed by Brungraber and Kim of Bucknell.

SUPERIMPOSED TRUSS [2.3.3]

Kim, Jai B., Robert J. Brungraber, and John M. Yadlosky. "Truss Bridge Rehabilitation Using Steel Arches." Journal of Structural Engineering 110, no. 7 (July 1984): 1589-97 (TA 630 A483) (C).

1:7 scale model of a truss bridge was fitted with steel arches to investigate this type of strengthening technique. The model consisted of steel tubes, eyebars, and rods while actual bridge was channels, laced members, etc. Connections of bridge were represented in the model with a combination of pins and welds. Two arches made of channels back-to-back were placed on the outside of the truss to carry total dead and live load. This apparatus was subjected to four testing stages: (1) model without arch (2) model with arch and ends restrained (3) #2 with one member of bottom chord of original truss removed (4) #2 with two bottom chord members removed. Load was applied to different panel points and deflections were measured. Results yielded that deflections were decreased by 30-40% on average. When members were removed from the truss (tests (3) & (4)) arches prevented collapse of system. Discussion of benefits of superimposed arches. Written by Brungraber and Kim of Bucknell.

SUPERIMPOSED TRUSS [2.3.4]

Brungraber, Robert J., and Jai B. Kim. "Rehabilitation of Steel Truss Bridges Using a Superimposed Arch System." Transportation Research Record 950 (1984): 113-120 (TE 1 T7357) (C).

The article described a rehabilitation project for a 74 ft. Pratt truss in Pennsylvania. The superimposed arch method was used, which acted to accept all live loads of the bridge and increased the rating to HS-20. The project saved the historic bridge and was completed in only 3 weeks at a cost of $62,000. New floor beams were added which aided in reducing the load resisted by the pre-existing floor beams. Floor beam were repaired while the bridge was still in service. After the completion of the project, a load test of the repaired bridge was conducted by running a 22.5 ton truck across the bridge. Midspan deflections were measured to be 0.2 inches and deemed adequate.

COVERPLATING [2.4.1]

Bakht, Baidar, and Paul F. Csagoly. "Strengthening and Widening of Steel Pony Truss Bridges." Canadian Journal of Civil Engineering 4 (1977): 214-225 (TA 1 N17513) (C).

Lateral buckling behavior of pony trusses and repair options are discussed in this article. The authors give a short history of the analysis of pony trusses and then present a modified solution to the analysis. A computer program was developed to predict the capacity of pony trusses. Two full scale tests were run to check the accuracy of the program. The failure loads of the bridges were within 10% of the computer prediction.

To increase the portal rigidity of a pony truss, intuitively, either, or both, the floor beams or vertical members may be strengthened. It was shown that by only increasing the rigidity of the vertical members, the portal rigidity was actually decreased. The authors, therefore, recommend strengthening only the floor beams. Several rehabilitation techniques are discussed and their effects on portal stability are presented. The addition of longitudinal plate girders to widen the bridge had little effect on stability. If only the floor beams are lengthened, the article states that the variation in load carrying capacity is usually detrimental, and therefore should be avoided. A third option is adding a Bailey truss to the interior of the pony truss. This solution increased the load carrying capacity, but does decrease the width of the bridge. A final technique involves the addition of cover plates to the existing top chord. This method is presented as a good solution for bridges with stability plane concerns.

COVERPLATING [2.4.2]

Beauchamp, J. C., M. Y. T. Chan, and R. H. Pion. "Repair and Evaluation of a Damaged Truss Bridge-Lewes, Yukon River." Canadian Journal of Civil Engineering 11, no. 3 (September 1984): 494-504 (TA1 N17513) (C).

This article describes a series of repairs, evaluations, and tests completed on a Warren truss that had been damaged due to an overheight collision. The bridge, built in 1955 using A7 steel, consists of two 250-foot spans and was designed for HS20-S16 loadings. A flat bed trailer carrying a backhoe struck the bridge in January of 1982. All bottom struts of the sway frames were severed which lead to progressive failures including the brittle fracture of the bottom chord. The bridge did not collapse completely, but was closed to traffic immediately. The article describes the temporary repair and subsequent permanent repair and evaluation. The repair of the bottom chord involved attaching four Dywidag bars and pre-stressing then to transfer the stresses back to the bottom chord. A splice was installed while the Dywidag bars held the bottom chord in place. The bridge was instrumented and computer models were used in verifying the success of the repair. After the bottom chord was repaired, the bridge was opened to one lane of traffic while the sway frames and other repairs were completed. Coverplates were added to strengthen the bottom chord and improve fatigue capacity.

Physical and chemical tests were also conducted on materials taken from the bridge. The tests revealed low Charpy values and good yield and elongation characteristics. A proof load test of the repaired bridge confirmed that the rehabilitation was a success. Conclusions from the study included the restatement of the importance of the integrity of the bottom chord in a truss bridge. Response of the bridge deck, in redistributing and relieving some of the stresses lost in the failure of the bottom chord, should also be noted. The authors state that older structures are just as susceptible to overheight damage as overweight damage due to the general trend of low toughness in older steels.

COVERPLATING [2.4.3]

Biller, Benjamin J. "Economical Flange Replacement for Built-up Steel Sections." In <u>Structures Congress XIII: Proceedings of papers presented at the Structures Congress '94, Atlanta, Georgia, April 24-28, 1994</u>,

sponsored by the Structural Division of the American Society of Civil Engineers. Atlanta, Georgia, 1994, 811-814 (TA630 S86 1995) (C).

This article describes four rehabilitation alternatives investigated for the strengthening of deteriorated floor beam members of the Eads bridge in St. Louis. The 120-year-old structure was being upgraded to allow a light rail system to pass over the bridge. The floorbeams were determined to be a critical component in the rehabilitation. Four schemes were investigated including: (1) total floorbeam replacement (2) full bottom flange replacement (3) partial bottom flange coverplating (4) partial bottom flange coverplating and angle replacement. Cost estimates for each type of repair were determined. It was found that the full bottom flange replacement and partial coverplating were the most economical solutions depending on the level of deterioration in the beams. Over 200 floor beams were replaced using one of these two methods saving over $200,000 compared to total floorbeam replacement.

COVERPLATING [2.4.4]

Schwendeman, Louis P., and Arthur W. Hedgren, Jr. "Bolted Repair of Fractured I-79 Girder." Journal of Structural Engineering 104, no. ST10 (October 1978): 1657-1670 (TA 630 A483) (C).

A brittle fracture occurred at the midspan of a 350 ft. steel girder over the Ohio River in Pennsylvania. The girder was cracked through its entire 11 ft height causing a deflection of 5 inches in the roadway. The bridge was immediately closed to traffic. Several repair schemes were investigated but the final solution involved using a floating barge, jacking the girder back together, and splicing the fractured girder. Jacks were used to reintroduce the dead loading of the bridge into the girder. Detailed analysis of stresses on the splice and bolting ensured a conservative rehabilitation design. The girder was strain gauged to check the stresses in the girder throughout the operation. A detailed description of the entire process is included in the paper. No rehabilitation was needed for the deck or parapets of the bridge. At the conclusion of the repair, elevations were shot of the roadway a showed that the slab was only ¼ of an inch below the original alignment. The entire process from closure of the bridge, to being reopened for traffic, took slightly over two months.

COVERPLATING [2.4.5]

Martin, Robert A., and Jerome S. B. Iffland. "Marine Parkway Bridge Truss Member Replacement." Journal of Structural Engineering 109, no. 7 (July 1983):1603-1616 (TA 630 A483) (C).

This article gives a detailed description of repair efforts on a damaged tension chord, and the replacement of vertical hangers in a truss. The structure is a lift-span truss with a clear span of 500 ft. A barge travelling underneath the bridge struck the tension chord, badly damaging it. The engineers decided that flame straightening would not be a viable option due to the severe damage to the member. The solution consisted of affixing a temporary load carrying assembly, consisting of stressable bars, to the bottom chord. Once the bars were in place, the damaged section was removed and new material was spliced to the tension chord. A similar repair was used in replacing the corroded vertical hangers.

Tension rods were attached to the truss to accept the load of the hangers. The vertical hangers were removed, and new hangers were installed.

RIVET REPLACEMENT [2.5.1]

"Riveting Experience." Modern Steel Construction (Sep 1993): 34-37 (691.705 M72) (C).

Description of recreation of riveted truss bridge. Original structure was fabricated in the shop then shipped to the sight and assembled. References are included to riveting processes and suppliers who completed work. The new bridge met HS20 loading requirements.

RIVET REPLACEMENT [2.5.2]

Reemsnyder, Harold S. "Fatigue Life Extension of Riveted Connections." Journal of Structural Engineering 101, no. ST12 (December 1975): 2591-2608 (TA 630 A483) (C).

To extend the fatigue life of riveted connections, this article describes a study in which rivets were replaced with high strength bolts. Two connections were taken from an actual bridge, while 16 other specimens were modeled using comparable materials. A series of constant and variable amplitude fatigue tests were run on the specimens. When damage (cracking) was observed in the specimen, the rivet was removed using field techniques, and a high strength bolt was installed. The benefit of the bolt was the increased clamping force between the members. From the experiments, it was determined that this technique increased the fatigue life from two to six times the base life estimated from a nonrehabilitated specimen. Crack lengths of less than one inch, prior to rehabilitation, showed the best performance. This confirms that early detection and rehabilitation are paramount to extending the service life of structures.

RIVET REPLACEMENT [2.5.3]

Baker, K. A., and G. L. Kulak. "Fatigue of Riveted Connections." Canadian Journal Civil Engineering 12 (1985): 184-191 (TA 1 N17513) (C).

This article summarizes previous work on the fatigue of riveted connections, as well as, adds to the available data with additional tests. The authors have compiled the results from many researchers and provide a short commentary on each study. In their study, ten specimens were examined. Three of which were models of completely loose rivets. Another three were simulated using high strength bolts to replace rivets. The final four specimens were taken from a riveted bridge structure to examine the fatigue safety of the members. The loose rivet specimens were prepared by punching holes in a steel beam. This was to simulate a lower bound of riveted connections. The bolted specimens used ¾ inch A325 bolts. The actual bridge members were comprised of pairs of angles with lacing between them, forming an I shaped member.

The three "loose rivet" beams failed below AASHTO Category D loading. The bolted beams failed between Categories A and B. The in-service specimens were highly scattered but all tested higher than Category D. A duty spectrum was established, and it was determined that previous loadings on the bridge had minimal, if any, effect on the results. In conclusion, by comparing the new test results with previous studies, it was determined that AASHTO Category D rating is a conservative designation for riveted structures. The study confirmed that the replacement of rivets with high strength bolts greatly improves the fatigue rating.

ADDITIONAL MEMBERS [2.6.1]

"Rehabbed Trusses Shed Load." Engineering News Record (November 6, 1995): 21 (TA 1 E6) (C).

Two 110 year old Pratt pony trusses were saved by supporting the bridge using hidden steel girders. The bridges consisted of a single 58' span and two 98' spans. The timber decks in both had deteriorated causing a significant loss in capacity. Approximately $3 million was spent to install the new steel girders and decks for both bridges. The steel girders are shallow enough to be hidden by the bottom members of the truss. Vertical slip connections were added to allow the deflection of the new girders without transferring force to the trusses. The beams are braced against each other and by the truss superstructure.

ADDITIONAL MEMBERS [2.6.2]

Dodds, N. M. S., L. A. Locke, and R. N. Welsford. "Recent Strengthening Work to Cleveland Bridge, Bath." The Structural Engineer 73, no. 5 (7 March 1995): 69-75 (TA 680 I512) (C).

This article describes a cast iron bridge built in 1827 and strengthened in the 1920's. The new work included the addition of pedestrian sidewalks. The span of the bridge is 30.4 m. The main structural system is comprised of seven arch ribs. In 1925 it was determined that the 5 ton load limit was unsafe and the bridge should be strengthened. Four reinforced concrete trusses were added between the arched ribs as well as a new reinforced concrete deck. An examination of the structure before the present rehabilitation determined that while the load capacity of the bridge was still fairly good, the footpaths and parapets were unsafe and the concrete trusses impeded the view of the original structure. Beginning in 1988, an assessment and feasibility study for the repair of the bridge were undertaken. A load assessment yielded that the combined structure could handle a 40t C&U load (two loads of 205 and 236t). A detailed description of the analysis techniques can be found in the article. From the analysis, it was determined that the main portion of the bridge was adequate but the footways and parapets were in need of strengthening. A solution of "hidden portals" was adopted to strengthen the footways, but remain out of view. The added portals bear on original spreader plates and are tied into rock abutments. The footway slab is reinforced concrete able to resist all loading conditions including impact forces. In placing the new girders between the two pre-existing cast iron members, the cross bracing and attachment to the footpath was lost. Bracing was added between the old and new girders to provide adequate lateral support. The original parapets were left in place, but strengthened to provide safety.

ADDITIONAL MEMBERS [2.6.3]

Bondi, Robert W. "Adding Redundancy to Fracture Critical 2-Eyebar Members in a Cantilever Truss Bridge." In Proceedings 2nd Annual International Bridge Conference in Pittsburgh, Pennsylvania, June 17-19, 1985, by the Engineers' Society of Western Pennsylvania, 1985, 47-53 (ILL) (C).

A truss bridge built in 1926-27 connecting Ambridge and Aliquipa, PA was investigated and repaired for fracture critical concerns. Following the Point Pleasant Bridge collapse, investigation of non-redundant tension eye-bar members for high strength steel truss bridges became a topic of much discussion. The high strength steels of the 1920's prove susceptible to stress corrosion and corrosion fatigue cracking. An in-depth analysis of this bridge revealed 72 locations at which the failure of one member would lead to a catastrophic collapse. It was also recommended, that the bridge should be strengthened from a 10 ton rating, to HS20. A detailed description of the failure investigation and solution are presented in this paper. A third member was added to strengthen the existing 2 eye-bar members. A new deck of pre-cast, post-tensioned concrete was implemented which reduced the dead loads on the bridge. A railing system was also added to meet specifications. The rehabilitation, costing $2.3 million was completed in 1983.

PIN REPLACEMENT [2.7.1]

Taavoni, Shahin. "Upgrading and Recycling of Pin-Connected Truss Bridges by Pin Replacement." <u>Transportation Research Record</u> 1465 (1994): 16-21 (TE 1 T7357) (C).

This article describes the rehabilitation of a 113 year old wrought iron Pratt through truss in Maryland. All members, connections, and pins were evaluated to determine if the bridge could take additional loads. From site visits some tension members were found to be unsymmetrical due to dynamic effects, repairs, fatigue, or corrosion. It was determined that the pins were the critical members in the repair. Four rehab alternatives were examined: (1) superposition of an arch (2) supplementary girders under the truss (3) pre-stressing the bottom chord (4) replacing pins. The solution included dismantling each truss and moving it to a working space, to replace pins. Material tests were done on removed pins $f_y \approx 26$ ksi. The total cost of the repais was$300,000. The rating of the bridge was increased to HS23.

PIN REPLACEMENT [2.7.2]

Bondi, Robert W. "Pin Replacement on a 100 Year Old Whipple Truss Bridge." In Proceedings 2nd Annual International Bridge Conference in Pittsburgh, Pennsylvania, June 17-19, 1985, by the Engineers' Society of Western Pennsylvania, 1985, 218-223 (ILL) (C).

The author describes the procedure used in the rehabilitation of a wrought iron truss bridge built in 1884. The bridge consists of two 200 ft spans with an 18.3 ft roadway and a six foot sidewalk on one side. An inspection of the bridge in 1977 identified corrosion in the diagonals, verticals, floor beam hangers, and stringers. As a result of the investigation, repairs including adding redundancy to eye-bar members, U-bolt hanger replacement, frame repairs, addition of a steel railing, and repairs to abutments. Five pins were replaced in the structure. The author outlines the repair procedure for the pins in nine steps. The new pins were longer to accommodate new vertical and horizontal strengthening members. The U-bolt hangers were replaced with a more reliable floor beam hanger system. The replaced pins showed minor wear and corrosion damage. It was speculated that the damage occurred due to the eccentricity induced by the single U-bolt hanger type connection. The pins on the sidewalk side were not replaced due to the fact a double U-bolt connection on that side of the structure did not have the eccentricity associated with the single U-bolt connection.

DECK REPLACEMENT [2.8.1]

"New Aluminum Decks Cut Loads, Add Life." Civil Engineering (August 1996): 12 (620.5 C499) (C).

Two bridges, one in Pennsylvania, another in Virginia have used pre-cast aluminum panels to replace the decks. The dead load of the 55 ft. span in Virginia was reduced between 30-40%. A cost analysis between replacing the bridge with a new steel/concrete equivalent and adding a new aluminum deck were comparable. On the Pennsylvania project, a 320 ft suspension bridge built in the 1930's, new aluminum panels reduced the deck weight by 50%. An increase of load rating from 7 tons to 24 was realized. Construction time was reduced, as well as keeping traffic disruption to a minimum.

DECK REPLACEMENT [2.8.2]

Mangone, Ronald W. "Weldless Decking Expands Bridge Options." Modern Steel Construction 12 (November 1997): 14-17 (691.705) (C).

This article provides a discussion of a deck product which has been utilized in West Virginia. A truss span which has been in service since the 1920's was rated poor to critical for the bridge deck. The new decking material, which was attached to the floorbeams and stringers using Nelson studs, achieved a lighter construction than conventional methods. The rehabilitated bridge rated at HS23 for the truss and the new deck system. The project also came in under cost.

DECK REPLACEMENT [2.8.3]

Holm. "Structural Lightweight Concrete for Bride Redecking." <u>Concrete Construction</u> 30 (August 1985): 668-672 (TA 680 C745) (C).

This article provides introductory information on lightweight concrete. The author uses a case study bridge in New York which was widened from two lanes to three. Only 20% of the steel framing was strengthened due to the lowered dead weight of the lightweight concrete. The author further praises lightweight concrete for its durability and ease of placement. The durability of lightweight concrete is attributed to the similar moduli of the cement grout and the lightweight aggregate. Less cracking is observed since freeze/thaw cycles induce smaller stresses between grout and aggregate as compared to normal aggregate. Some simple guidelines are presented which discuss topics such as changes in water content due to a change in entrained air or fine aggregate. The author discusses placing techniques and states the lightweight concrete is, in fact, easier to place than normal weight concrete. An example mix design is also included.

DECK REPLACEMENT [2.8.4]

Exodermic Bridge Deck Institute, Inc. "Exodermic Bridge Deck Handbook." Scarsdale, New York: Exodermic Bridge Deck Institute, Inc., 1996 (C).

This handbook provides an overview of exodermic bridge decking provided by the Exodermic Bridge Deck Institute. A discussion of the theory, design, and construction of this system is included. A presentation of related laboratory tests completed on exodermic systems is offered. A listing of design criteria and assumptions is included to provide guidance for design engineers. Design examples using both pre-cast and cast-in-place concrete are provided. A tabular listing of calculations provide quick reference for the capacities of various configurations of bridge decks. Finally, structural details are presented to aid in the completion of design drawings.

DECK REPLACEMENT [2.8.5]

Buffalo Specialty Products, Inc. "Bridge Flooring." Allentown, Pennslyvania: Buffalo Specialty Products, Inc., (C).

This document is a product guide for a galvanized decking system. The deck is comprised of a saw-tooth floor of either 10 or 12 gauge material with a bituminous wearing surface on top. The weight of the floor system varies from 35-52 psf dependent upon the depth of wearing surface applied. Typical attachment details to existing bridge members are included to aid the engineer in design drawings.

DECK REPLACEMENT [2.8.6]

Reynolds Metals Company. "Reynolds Aluminum Bridge Decks." Richmond, Virginia: Reynolds Metals Company, 1996 (C).

This decking system consists of hollow aluminum sections welded together to form panels. The panels are toped with a thin epoxy wearing surface to provide the necessary skid resistance. The system weighs approximately 22 psf, significantly reducing the dead loads on the bridge. A discussion of design for the decking is included, as well as, material properties. The document also discusses corrosion, thermal expansion, and costs relative to other decking systems.

DECK REPLACEMENT [2.8.7]

Laminated Concepts Inc. "Longitudinal Truss Concept." Elmira, New York: Laminated Concepts Inc. (C).

This document is introduction to a glue-laminated deck system. The paper presents various deck thickness for different spans which will meet current AASHTO standards. Sample drawings are included to aid in the visualization of the system. The paper also includes a timber railing detail, which may be fixed to the new deck. No indication is given whether the railing system was crash tested.

DECK REPLACEMENT [2.8.8]

Bridge Grid Flooring Manufacturers Association (BGFMA). Collected Articles, Mount Pleasant, Pennsylvania.

"Design of Grid Reinforcement Concrete Bridge Decks." March 1997 (C).

This technical brief outlines the analysis of concrete grid decks as orthotropic systems, instead of the conventional beam strip method of analysis. The result is better live load distribution and thereby lower stresses.

"Enhancing Grid Performance & Service Life through Integral Overfills." Issue 13, Spring 1997 (C).

This paper discusses the use of concrete overfills as opposed to flush filled grids in bridge deck rehabilitation. Primary advantages include better riding surfaces and protection for the gridding. A list of ten bridge rehabilitation projects which used metal grid, with concrete overfills, is included along with comments on each repair.

"Design of Grid Reinforcement Concrete Bridge Decks Using AASHTO's 16th Edition." Spring 1997 (C).

This short brief contains a typical design example for grid decking. The example is of a 4.25 inch metal grid with stringer spacing of twelve feet.

"Corrosion Protection for Grid Reinforced Concrete Bridge Decks" Issue 14, Summer 1997 (C).

This article discusses the current research on corrosion resistance for steel gridding. The paper presents the findings of Donald Timmer, an engineer in Ohio, who has specified different types of corrosion protection for metal grids. Four case studies are presented in which either galvanized, or epoxy coated gridding was used in the replacement deck. The article concludes that galvanizing, while slightly more expensive than painting, provides very good resistance to corrosion of steel gridding.

DECK REPLACEMENT: SEE ALSO [2.1.2]

FLAME STRAIGHTENING [2.9.1]

Holt, Richard E. "Primary Concepts for Flame Bending." Welding Journal 50 (June 1971): 416-24 (671.06 AM35) (C).

This article provides a very thorough introduction to flame bending. A discussion of the theory of flame bending is included. The author discusses spot, vee, line, and strip heats. Each of these discussions included theory and applications of the various heats to bridge members. The author also describes heating processes for plate girders and other larger built up members. The author provides examples of repairs using heat straightening for tension and compression members. The author also discusses damage to joints and the interaction of truss members with one another. I would strongly recommend reading this article prior to utilizing flame bending in practice.

FLAME STRAIGHTENING [2.9.2]

Post, Jeffrey, W. "Flame Straightening Repairs Bridge." Welding Innovation Quarterly Vol. 13, No. 3 (1996): 4-6 (C).

This article gives a brief overview of flame straightening, as well as, an example of its use in the field. A compression member on the I-93 Bridge crossing the Charles River was damaged due to an impact of wood which fell off of a truck. The column had an 18-inch bend in a 25-foot length. The options in repairing the bridge consisted of flame straightening or replacement. A replacement member would take three weeks to fabricate; therefore the decision was made to use flame straightening. For 40 hours, people were working on the member with torches to remove the damage. At the end of the repair, over one-million dollars was saved in material costs and the bridge was back in service in less than a week after the collision.

Volume 2

Evaluation

CORROSION [3.1.1]

Fisher, John W., Ben T. Yen, and Dayi Wang. "Corrosion and Its Influence on Strength of Steel Bridge Members." Transportation Research Record 1290 (1991): 21-219 (TE 1 T7357) (C).

This paper reports on a study which tested the strength and performance of corroded, riveted bridge members. A discussion of the causes of galvanic and pitting corrosion is included. The first part of the study involved the fatigue strength of corroded notched members. Eight girders with area losses ranging from 5-40% failed at equivalent AASHTO fatigue categories C, D, and E. The second set of tests concerned the strength of corroded hangers. Two specimens (losses of 39-41% area) were loaded to a failure load which was about 5% less than that calculated using net areas and ultimate strength. This small difference was attributed to shear lag. The hangers did not fail by sudden fracture, rather by ductile elongation. Conclusions arrived at by this paper include: (1) corrosion notch effects relate to AASHTO fatigue categories ranging from C to E depending on the severity of the corrosion (2) the ultimate strength of corroded tension members is about equal to the tensile strength multiplied by the remaining net area (corrosion did not affect ductility)

FATIGUE & FRACTURE [3.2.1]

Keller, Andreas, Eugen Brühwiler, and Manfred A. Hirt. "Assessment of a 135 Year Old Riveted Railway Bridge." International Association of Bridge and Structural Engineers 1029-1034 (C).

A wrought iron railroad bridge connecting Switzerland and Germany was assessed for continuing service of passenger trains. The structure, built in 1859, was designed to carry two trains, but has only carried one line throughout its life. Three stages of analysis were completed. The first involved checking the structural safety, fatigue safety, and serviceability of the structure. All the members were determined to be adequate. Secondly, a fatigue analysis using the approximated loadings was completed. Stress ranges for the freight and passenger trains were calculated and compared to the damage limit stress range. It was found that some damage has occurred due to freight trains, but the effects were small. By comparing the stress range for the proposed new passenger trains, to the damage limit stress range, it was determined that the bridge would not incur more damage in the future. As a final step, the critical crack size prior to failure was determined using fracture mechanics methods. This value provides guidance for inspection procedures in the future. Fatigue crack propagation was investigated and also found not to be critical. In conclusion, the author states that the bridge can continue in service, with inspection and normal maintenance, for many years to come.

FATIGUE & FRACTURE [3.2.2]

Szeliski, Z. L., I. A. Elkholy. "Fatigue Investigation of a Railway Truss Bridge." Canadian Journal of Civil Engineering 11 (1984) 625-631 (TA 1 N17513) (C).

A thorough investigation of a railway truss bridge was conducted to determine the fatigue life, as well as, if any rehabilitation effort were needed. The bridge, built in 1906, was designed for an E-48 Cooper train. Increased traffic raised concerns of the bridge's safety. Strain gauges were placed on the bridge members and data was taken for several days of normal operation. Computer analysis was also run to determine the best modeling technique for the structure. Conclusions included: the stringers and floor beams behaved like simple beams, hangers behaved somewhat like a plane truss and somewhat like a space frame.

An estimate of the past, present, and future traffic was complied and a fatigue damage model was assembled. A root-mean-square model was used to estimate the damage the bridge had sustained. Field investigation revealed small cracks at some rivet holes, however, these cracks were not considered critical. The investigators concluded that if critical rivet areas were replaced with high strength bolts, the fatigue life of the structure could be extended past 1998. A similar conclusion, that of replacing the rivets, was drawn for floor beams and stringers. As a result of the investigation, all critical rivets were replaced with high strength bolts.

FATIGUE & FRACTURE [3.2.3]

Idriss, R. L., K. R. White, C. B. Woodward, and D. V. Jauregui. "Evaluation and Testing of a Fracture Critical Bridge." Non-Destructive Testing & Evaluation International 28, no. 6 (1995): 339-347 (ILL) (C).

This article reports on a series of tests of a two girder, steel bridge. This fracture critical structure, as defined by AASHTO, was tested with a man-made flaw, to examine the post-fracture response. The bridge showed very good reserve strength with moment redistribution occurring in the damaged span. The rigid concrete floor system, floor beams, and stringers contributed in a secondary manner. The important point of hidden redundancy in "fracture critical" structures (e.g. truss bridges) was reinforced in the article.

FATIGUE & FRACTURE [3.2.4]

Fisher, John W., and J. Hartley Daniels. "An Investigation of the Estimated Fatigue Damage in Members of the 380-ft Main Span, Fraser River Bridge." American Railway Engineering Association Bulletin 658 577-597 (C).

This article investigates the remaining fatigue life of a railroad truss bridge. The bridge, constructed in 1904, is along an important route carrying traffic to and from Vancouver. The critical member investigated was a vertical hanger comprised of four angles with a filler plate forming an I-section. The web plate was replaced with latticing in 1923. To analyses the structure, a simple truss model and 3-D model were both used. The pin-plates, which connected the hanger to the floor beam were also investigated using simple analysis and a more complicated 3-D model. The 3-D model predicted that the stresses in the plates were unequal, which agreed with field tests on the pin-plates.

For fatigue calculations, the capacity of the riveted members was taken to be AASHTO Category D. This conclusion stemmed from previous work done by others. The fatigue strength of the pin-plates were determined using fracture mechanics and a finite element analysis. It was found that AASHTO Category E would predict the fatigue capacity of the pin-plates with a reasonable initial flaw size.

The damage assessment was determined using both Miner's solution and RMS and the loading spectrum determined by Sweeny in previous work. The hangers were found to be adequate until the year 2000. The pin-plates, due to their unequal sharing of the load, were determined to be critical by 1985. The stringers were found to be critical by 1979. In conclusion, the authors point out that the field investigation lead to a stress range reduction of between 15-20%. This translated into over a 33% change in the allowable stress for future calculations.

FATIGUE & FRACTURE [3.2.5]

Kunz, Peter M., Eugene Brühwiler, and Manfred A. Hirt. "Evaluation of the Remaining Fatigue Life of Steel Bridges." In Developments in Short and Medium Span Bridges Engineering 1994 edited by Aftab A. Mufti, Baidar Bakht, and Leslie Jaeger (August 1994): 1219-1230 (ILL) (C).

In this paper, the authors discuss the calculation of the fatigue life of a bridge. Critical details must first be assessed to determine the members which are subjected to a maximum stress. A fatigue calculation can then be performed using past, present, and anticipated loadings. Finally, the bridge should be monitored to verify calculated results. The authors concern themselves with the second step in the process, the evaluation of fatigue life, and developed a computer program to aid in damage accumulation calculations. Damage accumulation using fatigue strength curves is a widely accepted method employed by the European and US codes. Damage accumulation utilizing crack propagation calculations based on fracture mechanics, is a less used procedure, but yields longer remaining life. Using the American, European, and fracture mechanics methods, the authors compare the predicted remaining fatigue life of a railway girder bridge built in 1900. As predicted, the fracture mechanics method yielded the longest remaining fatigue life. A sensitivity study was performed to determine the parameters which effect the various methods. It was found that the fracture mechanics method displayed vastly different results from the fatigue strength curves in low fatigue loading, but similar results in high fatigue loading.

FATIGUE & FRACTURE [3.2.6]

Schindler, Hans-Jakob and Ulrich Morf. "Toughness and Fracture Behavior of Obsolete Wrought Bridge Steel." International Association of Bridge and Structural Engineers Workshop, Lusanne, Switzerland (1990) 85-93 (ILL) (C).

In this article, the authors discuss the performance of wrought iron in fracture situations. The fibrous nature of wrought iron contains many impurities and any type of welding repair could change the composition of the material possibly leading to a more brittle structure. To determine the fracture mechanics properties, a series of compact tension tests were performed and the results analyzed. Dynamic fracture toughness was also measured using pre-cracked Charpy specimens. It was concluded that the fracture toughness of the material was approximately 5000 N/mm^(3/2) for in-service cases. A series of experiments were performed to verify these conclusions. A failure assessment diagram was constructed using the R6 procedure and an assumed toughness of 4000 N/mm^(3/2). The failures of the specimens corresponded to points outside, near the R6 curve which verifies the predictions of the tests. In conclusion, the authors state that wrought iron is not as crack-sensitive as previously thought, and members with small cracks (e.g. hidden by rivet heads) should not be considered critical.

FRACTURE & FATIGUE: SEE ALSO [2.4.2]

TRUSS STABILITY [3.3.1]

Csagoly, Paul F. And Baidar Bakht. "In-Plane Buckling of Steel Trusses." Canadian Journal of Civil Engineering 5, no. 4 (December 1978) 533-541 (TA 1 N17513) (C).

This paper discusses buckling phenomena associated with truss structures. The authors state that buckling in a truss might occur due to one member failing, or an instability of a joint. A computer program was developed which takes into account the change in rotational stiffness of a member due to an applied loads. A thorough explanation of the mechanics behind the methods is stated in the paper. Two frames were fabricated to test the results of the analysis using this program. The results of the tests were in agreement with the predictions of the computer program. Estimates of failure loads were also computed using other published results. Again, the computer predictions were similar to the test results.

TRUSS STABILITY [3.3.2]

Bober, Marlene N., ed. "Investigation of Historic Bridges." Forensic Engineering in Construction By Zallen Engineering 3, no 2 (October 1996) (C).

This article gives a brief description of the investigation of a 71' Pratt pony truss. Field observation was used to determine member sizes due to the lack of construction drawings. A discussion of the lateral resisting system for a pony truss is included. A rating of 2.5 tons was given to the bridge. Since there is only light traffic on the bridge, removal was not warranted.

TRUSS STABILITY [3.3.3]

Alibe, Bunu. "Characteristics of Columns with Uncertain End Restraint." Journal of Structural Engineering 116, no. 6 (June 1990): 1522-1534 (TA 630 A483) (C).

This article examines a probabilistic approach of determining the buckling load of a column with uncertain restraints. The author summarizes other studies which use deterministic methods to solve similar problems. This paper proceeds to derive equations for partially end-restrained columns. This paper might be helpful if a detailed analysis of members is desired.

TRUSS STABILITY [3.3.4]

Tarnai, T. "Lateral Buckling of Plane Trusses with Parallel Chords and Hinged Joints." Acta Technica Academiae Scientiarium Hungaricae 85 (1977) 179-196 (605 AC81 Library Storage) (C).

In the analysis of trusses, the buckling behavior of the structure is often an intricate, difficult problem. The two widely accepted continuum models for trusses include a cross-section with a deformable web, and a hinged cross-section with non-torsional flanges. The author, using the second method, derives a series of differential equations for the laterally buckled shape. Boundary conditions for various truss layouts are discussed. This article is very in depth as far as mathematical computations, and probably would not be helpful in the design arena.

TRUSS STABILITY [3.3.5]

Machaly, El-Sayad Bahaa. "Buckling Contribution to the Analysis of Steel Trusses." Computers and Structures 22, no. 3 (1986): 445-458 (TA 641 C65) (C).

This article deals with the stability of semi-rigid steel trusses in flexure. The author outlines previous work related to the topic and suggests that the effects due to partial rigidity have not been investigated. A series of differential equations and stability functions are used to model trusses with one to six panels.

For practical cases it was found that stresses due to moment were approximately 12% that of normal stresses in the web members. This article would probably not be helpful in the design arena.

STRUCTURAL ANALYSIS [3.4.1]

Adeli, H. and K. V. Balasubramanyam. "A Heuristic Approach for Interactive Analysis of Bridge Trusses Under Moving Loads." Microcomputers in Civil Engineering 2 (March 1987): 1-18 (ILL) (C).

The authors have developed a method for determining the maximum stresses using influence line diagrams (ILD). ILD's are generated for each member and like shapes are grouped together. A logic tree for calculating maximum stresses due to AASHTO loadings of uniform lane loading, two axle, and two axle plus one axle are presented. By following the steps in the procedures, maximum forces can be found. However, this procedure seems catered to an expert system which can analyze many parameters to recommend an optimal structure. The procedure noted is valid for only Pratt trusses.

STRUCTURAL ANALYSIS [3.4.2]

Adeli, H. and K. V. Balasubramanyam. "Heuristic Analysis of Bridge Trusses Under AASHTO Live Loads." Microcomputers in Civil Engineering 2 (June 1987): 1-18 (ILL) (C).

This article expands upon the study presented in the previous work. The analysis is extended to include determinate K-trusses and indeterminate Parker trusses. Generalized ILD types are recommended for various members of a truss.

Maximum forces due to uniform lane loading, two axle loading, and two axle plus one axle can be calculated by following the flowcharts created by the authors. This method lends itself to new construction and requires the use of a computer.

STRUCTURAL ANALYSIS [3.4.3]

Trautner, Janice J. and Dan M. Frangopool. "Computer Modeling and Reliability Evaluation of Steel Through Truss Bridges." Structural Safety 7 (March 1990): 255-267 (TA 656 S92) (C).

Many forms of analysis have been used in evaluating old truss structures including 2D, 3D, and Finite Element methods. This paper analyses a through truss bridge built in 1935 to determine which modeling technique is the most applicable. The bridge is a 150' Pratt through truss connected by riveted gusset plates. The steel used in the truss is A7 with a f_y of 30ksi with a reinforced concrete deck with f´c of 2 ksi. Live loads of a HS20-44 trucks were applied asymmetrically to produce a worst case scenario, as well as, torsion on the bridge. Four modeling methods were run: (1) 2D all truss elements (2) 2D beam and truss elements (3) 3D beam and truss elements (4) 3D beam and truss elements including the deck. Corrosion effects were analyzed with damage factors.

A detailed probabilistic analysis identified each member as either redundant or non-redundant. 2D truss elements: A table of maximum load carried by the system under each loading is presented. Ductile and brittle scenarios were considered.

2D beam and truss: Top and bottom chord and posts were modeled as Euler-Bernouilli beams. All other members were identified as truss elements. It was found in general that the beam model induced slightly smaller stresses in the diagonal members than the truss model. However, post and chord members saw an increase in stresses, some up to 15%. The load magnification factor at failure was larger than the truss model, but not substantially. The paper did not discuss the 3D models.

STRUCTURAL ANALYSIS [3.4.4]

Seong, C. K., B. A. Ward, B. T. Yen, and J. W. Fisher. "Behavior of Truss Bridges as Three Dimensional Structures." In Proceedings 1st Annual International Bridge Conference in Pittsburgh, Pennsylvania, 1984, by the Engineers' Society of Western Pennsylvania, 1984, 203-207, (ILL) (C).

In this article, the authors investigate the modeling techniques which can be used in analyzing truss bridges and compare these results to actual tests. In the study three analysis methods includeding 2D truss, 2D frame, and 3D frame were compared with the actual readings on the bridge. The authors conclude that the 3D frame model is the most accurate predictor of the actual stresses in the members. A second part of the investigation looked at the effects of a damaged member on the stresses in the other members. It was found that members near the damage experienced large changes in stress, while distant members saw little change.

STRUCTURAL ANALYSIS [3.4.5]

Korol, R. M., A. Rutenberg, and D. Banariol. "On Primary and Secondary Stresses in Triangulated Trusses." Journal of Construction Steel Research 6 (1986): 123-142 (TA 684 J68) (C).

This article investigate the contribution of secondary stresses in the failure of a truss structure. The authors provide an informative history of the discussion on secondary stresses which covers the entire 20th century. The authors state that secondary stresses may be disregarded if: (1) the joints are stronger than the members and allow for moment redistribution (2) the joints are weaker than the members than they must be ductile enough to allow redistribution.

In their investigation, two Pratt trusses with welded connections were loaded to failure. An analytical model which accounted for secondary stresses was used to predict the failure loads. End restraints of pin-pin and pin-roller were investigated and compared with actual results. The models also analyzed the structure using the average yield strength and lowest yield strength of the members. From the test results, it was concluded that the trusses did experience secondary stresses and responded between pin-pin and pin-roller end restraint conditions. The lowest yield strength predicted the collapse of the truss more accurately than the average value. The fixity of the joint provided approximately 5% more capacity than the simple truss model.

STRUCTURAL ANALYSIS [3.4.6]

Tabsh, Sami W. "Simple Live Load Factors for Girder Bridges." In Structures Congress XII: Proceedings of the Papers Presented at the Structures Congress '94 Held in Atlanta, Georgia 24-28 April 1994, edited by N. C. Baker and B. J. Goodno, 497-502. New York: American Society of Civil Engineers, 1994 (TA 630 S86 1994) (C).

In the analysis of a bridge with concrete on steel girders, distribution factors are often used. The current AASHTO factors do not account for such factors as span length, number of girders, and the stiffness of the girders. The author has developed an approximate method for distributing live load to the girders. An example for composite and non-composite girders is include in the article. The results were checked by performing similar calculations using the OHBDC code, a method developed using more exact techniques. The simple method developed by the author mimicked the complex calculations for the cases shown.

NON-DESTRUCTIVE TESTING [3.5.1]

Clemena, Gerardo G. and Wallace T. McKeel, Jr. "Non-Destructive Inspection of Steel Bridge Members." Nondestructive Inspection 1014-1019 (C).

This article is a thorough list of current non-destructive inspection techniques. The author briefly describes each method. Comments on cost, difficulties, and advantages of each method are included. Techniques discussed include visual inspection, Dye-Penetrant, Magnetic Particle, Ultrasonic, Radiographic, Magnetic Flux Leakage, and Acoustic Emission. This article contains good basic information on the methods available for bridge engineers.

NON-DESTRUCTIVE TESTING [3.5.2]

Pope, C. W. and K. J. Card. "The Detection of Lamellar Tearing by Ultrasonic Testing." Non-Destructive Testing-Australia. (November/December 1976): 19-22 (ILL) (C).

This article describes some techniques in using ultrasonics to find lamellar tearing damage in welds. Examples of compression and shear wave tests are described along with the necessary considerations and possible complications associated with each. Although it is not discussed in the article, I believe that ultrasonic testing could be used in damage detection in bridge members. More particularly wrought iron, which has a fibrous nature which leads to lamellar tearing. This paper could provide valuable background information if ultrasonic testing was to be used in examining wrought iron bridge members.

NON-DESTRUCTIVE TESTING [3.5.3]

Maurenbrecher, A.H.P., and G. Pernica. Review of Non-Destructive Test Methods for Assessing Strength, Serviceability and Deterioration in Buildings. Canada: National Research Council, March 1993 (C).

This report is a synopsis of NDT methods which are applicable to steel, concrete, and masonry. The authors present a very sound introduction to ND methods by first breaking them down into visual, mechanical, electromagnetic, sonic, and radiographic categories. The following chapters contain summaries of NDT methods for different situations. Although this document is geared towards buildings, many of the NDT method are also used in bridge inspection. Sections discussing methods for investigating geometrical, strength and physical, and moisture properties are included. Manufacturers, advantages, disadvantages, applications, and required equipment are listed for each method. This report is a very good introductory source for information on NDT.

RELIABILITY ANALYSIS [3.6.1]

Ebrahimpour, A., E. A. Maragakis, and S. Ismail. "Point Distribution Methods for Bridge Reliability Analysis." Forensic Engineering 3, no 2/3 (1991): 137-145 (ILL) (C).

This article describes a complicated method to analyze bridges using probabilistic methods. The author describes the use of 2n point estimates and three point estimates. Applications on continuous beams, steel girders, reinforced concrete and pre-stressed concrete are presented. However, this article is very in depth and probably out of the scope of normal bridge analysis.

RELIABILITY ANALYSIS [3.6.2]

"A Fatigue Reliability Model for Railway Bridges" Proceedings of the Specialty Conference, Proceedings of the 6th ASCE Specialty Conference on Probabilistic Mechanics, and Structural and Geotechnical Reliability, Jul 8-10, 1992, Pg. 320-323, (TA 349 P73 1992) (C). <missing paper>

An equation is developed utilizing the Miner damage theory to quantify the remaining fatigue life of a railway bridge. The bridges examined were riveted truss bridges built near the turn of the century. The equation contains six variables that represent material and loading variability and analysis uncertainty. A random number generator was used to input various distribution factors for the variables. A sensitivity analysis was conducted to determine which variables affect the computations significantly. It was found that traffic volume and the fatigue linear model did not significantly affect the results.

RELIABILITY ANALYSIS [3.6.3]

Frangopool, Dan M., and Rachid Nakib. "Effects of Damage and Redundancy on the Safety of Existing Bridges." Transportation Research Record 1290 (1991): 9-15 (TE 1 T7357) (C).

The authors provide a summary of methods and theories used in the analysis of redundancy in bridges. Both deterministic and probabilistic methods are discussed. Terms such as redundancy factor, reserve strength factor, and redundancy factor with respect to a given damaged state of the system are well defined. A composite steel girder/concrete deck bridge was modeled using a finite element analysis program named ABAQUS. Corrosion and accidental damage were introduced into the model and redundancy factors were calculated using deterministic and probabilistic methods.

Testing

STRUCTURE [4.1.1]

Choros, John, and Vinaya Shama. "Testing Railway Bridges for Increasing Life and Service Loads." In Structural Faults and Repairs: Proceedings of the 5th International Conference on Structural Faults and Repairs at the University of Edinburgh, July 1, 1993, by the International Conference on Structural Faults and Repairs, 1993, 35-42 (TA 656 I58 1993 V.1) (C).

This article describes a large collection of tests conducted on various types of railroad bridges. Both concrete and steel bridges were evaluated in this study. Included in the study were the investigation of a riveted truss and a pin-connected truss. Both bridges spanned approximately 150 feet and were built in the early part of the 20th century. The article describes in detail, the monitoring equipment used in the study including strain gauges, data acquisition techniques, and various non-destructive methods. The results of the investigations are printed in separate reports referenced in the bibliography.

STRUCTURE [4.1.2]

Grundy, P. "Capacity of a Wrought Iron Lattice Girder Bridge After 117 Years in Service." Civil Engineering Transactions 28 (1986): 195-200 (TA 1 C454) (C).

A railroad bridge built in 1860 of iron lattice girders was statically tested an described in this article. The iron was corroded in many places including flanges and connections. Four tests were conducted (1) Static test of girder (2) Tensile coupon tests (3) Riveted splice tests (4) Fatigue tests. Results: (1) Girder Test: A bending moment equivalent to Cooper train was applied to the girder and failed at Cooper M218, without impact loads. Failure mechanism was rupture of tension flange which was not corroded. Compression flange which was corroded did not buckle prematurely as was expected. (2) Tensile test: elongation of 10%; mean yield stress 231 Mpa; 14 specimens were cut from the tension flange. (3) Riveted Splice Test: Two splices were tested. Tensile load was applied which placed the splices in double shear. Failure occurred on the net section in one section and an "endsplit" failure in the second. It was concluded that the capacity of the rivets were not less than 153 kN in double shear (7/8" rivets). (4) Fatigue test: 19 specimens. Failures occurred by fracturing of laminae. Test results lie above fatigue category C (AISC). The conclusion was made that the fatigue life of these specimens is comparable to mild steel.

STRUCTURE [4.1.3]

Aktan, A. E., K. L. Lee, R. Naghavi, and K. Hebber. "Destructive Testing of Two 80-Year-Old Truss Bridges." Transportation Research Record 1460 62-72 (TE 1 T7357) (C).

Two decommissioned bridges were tested using non-destructive methods. An investigation of connection retrofitting by welding plates to critical connections was also undertaken. Objectives of this project included: (1) survey of existing similar bridges (2) investigation of simple methods to retrofit bridges (3) better understanding of condition assessments due to two main problems (a) inability to locate damage in hidden or hard to see members (b) a lack of reliable analytical modeling.

Bridges: Pratt through truss span of 46.4 m; members were built up riveted. The second bridge was a Camelback through truss with a span of 76.2 m. Both bridges were inspected on site to check construction drawings, locate deteriorated members, connections, etc., and to identify any pre-existing repairs. Both bridges were judged to be in fair to poor repair. Extensive explanation of these investigations are found in the article. Deteriorated members which would not affect vertical loading (e.g. wind bracing) were removed to conduct material testing. An account of the loading frames and testing methods, as well as, a list of instruments used can be found in the article. The bridges were tested at service loads. Static tests used the shakedown technique with peak loads of 12.8 HS20-44 and 20 HS20-44 trucks for the Pratt and Camelback bridges respectively.

Graphs of load/deflection, strain histories, and failure patterns are given for each truss.

Conclusion: If bearings, abutments, and floor members are adequate, deterioration in some truss members or connections did not affect the load capacity of the bridge. This conclusion may not hold true for non-gusseted bridges (e.g. eye-bar connections). Frozen rollers may cause the bridge to act in an arch manner until significant load frees the joints. Retrofit of welded plates proved very successful.

STRUCTURE [4.1.4]

Nowak, Andrzej S., and T. Tharmabala. "Bridge Reliability Evaluation Using Load Tests." Journal of Structural Engineering 114, no. 10 (October 1988): 2268-79 (TA 630 A483) (C).

This article investigate the evaluation of existing bridges using a reliability analysis. A reliability study was conducted along with load testing on a 110 ft. steel truss bridge built in 1948. A discussion of bridge reliability methods is included with a description of series and parallel systems, correlated and uncorrelated, and the probability equations associated with each. In testing a bridge behavior, proof, and ultimate loading methods are described with a discussion of the useful data obtainable with each type of test. The researchers proposed to use a proof test to modify the distributions associated with the bridge properties, to come to a better understanding of the bridge's capacity. To this end, the bridge was instrumented and loaded to determine the member forces and these values were compared to theoretical values. Reliability indices were modified from published values using the data previously obtained, and the reliability analysis was re-run. The load carrying capacity of the bridge was more accurately evaluated using the modified approach. By justifying some correlation (or load sharing) by bridge members, the capacity of the members could be enhanced by 30-55% thereby increasing the allowable loads on the bridge in the future.

STRUCTURE [4.1.5]

Bakht, Baidar, and Leslie Jaeger. "Bridge Testing-A Surprise Every Time." Journal of Structural Engineering 116 no. 5 (May 1990): 1370-1383 (TA 630 A483) (C).

This paper draws on the experiences in testing a variety of bridges in Canada. The authors consider slab on girder, steel truss, and concrete bridges. Five unusual characteristics are documented in the article pertaining to steel truss bridges. These qualities include:

The various components of the tension chords of pin-connected trusses share loads so unevenly that only one component should be considered in the calculations for bridge evaluation.

In pony-truss and through-truss bridges, the floor system participates with the bottom chords of the trusses only if the stringers are connected effectively with all the nodes of the trusses.

In calculating the capacity of a compression chord, account should be taken of the potential sources of weakness introduced by the rippling of the cover plate between rivets, which may be caused by the buildup of rust between the cover plate and other components of the compression chord.

In some bridges advantage can be taken of the floor system of substantial flexural rigidity that can themselves take a sizable portion of the load directly spanning the truss supports

Component interaction can, in certain cases, be used to advantage in upgrading the analytical bridge capacity.

The authors suggest that the best way to determine the capacity of the bridge is by applying a proof test load.

STRUCTURE [4.1.6]

Elleby, Hotten A., Wallace W. Sanders, Jr., F. Wayne Klaiber, and M .Douglas Reeves. "Service Load and Fatigue Tests on Truss Bridges." Journal of Structural Engineering 102, no. ST12 (December 1976): 2285-2300 (TA 630 A483) (C).

Two bridges in Iowa, constructed near the turn of the century were field tested. The bridge was comprised of eyebar tension members, steel posts, and built up members. The first part of the test involved a service load testing on the truss components. It was found that the pin connected analysis conservatively predicted the response of the bridge. Secondly, a service load test was performed on the floor beams. It was found that the deflections of the floor beams fell in between the predictions of pinned and totally fixed, determined by theoretical calculations. A third test was a service load test on the timber decking. In this case, the pin ended calculation provided a good estimate of the experimental results.

Eyebars were taken from the bridge to perform fatigue tests. A total of 30 eyebars were tested. Some of these were intentionally damaged and repaired. Highly scattered results were obtained from these tests, however, the stress ranges that these bridges were subjected to, would not conceivably cause problems in the future. Static tests were also performed on 17 eyebars. Yield stresses were about 30 ksi, while ultimate strengths were consistently over 40 ksi.

STRUCTURE [4.1.7]

Bakht, Baidar, and Leslie G. Jaeger. "Behavior and evaluation of pin-connected steel truss bridges." Canadian Journal of Civil Engineering 14 (1987): 327-335 (TA 1 N17513) (C).

Two pin-connected bridges in Ontario were proof tested to investigate the behavior of these bridges to loading. Both bridges were subjected to a load of 300 kN and monitored. The most unusual behavior observed was the unequal sharing of load in the bottom tension chords pairs. The chord forces were influenced by the floor system accepting a substantial portion of the load. However, in the end panel, the floor system did not participate in accepting part of the load. This was attributed to the lack of a floor beam at the truss support. From these tests, it was also concluded that the reserve strength usually associated with truss bridges, cannot be counted on in pin-connected systems. A technique for determining the dead load supported by the pairs of members is outlined. The frequency of the two bars are measured, and from the differences in responses, a ratio of force can be found. A conversion of proof test results to recommended load postings is also provided. However, these calculations only apply to Canadian codes, but possibly could be adjusted for AASHTO specifications.

STRUCTURE [4.1.8]

See also Evaluation Fracture & Fatigue

Szabó Gy. "Examination for the determination of load-carrying capacity of the bridge over the Sebes-Körös at Vészto." Periodica Polytecnica Ser. Civil Engineering 35, no. 3-4 (1991): 361-388 (ILL) (C).

This article describes the research conducted on a 100 year old wrought iron railway bridge. The history of the bridge includes a renovation 30 years ago to strengthen the bridge. It was necessary to examine the bridge to determine whether further service should be allowed. Material from the rivet plates and stringers was removed and tested statically and dynamically. The average yield and maximum stress observed were approximately 230 and 325 N/mm^2 respectively. Impact values were also presented. A fatigue test was conducted on samples with conclusions including: 1) longitudinal and transverse direction responses were similar 2) previous loading did not affect the tests 3) a larger standard deviation was noted than current materials. A fatigue test was also completed on a stringer from the trussed section of the bridge. Failure was initiated at the rivet holes, one of which had been damaged by the torching process to remove the rivet. A computer analysis using second order theory noted that stress levels in members are significantly lower than an analysis by a simple truss model.

The bridge was instrumented and a series of locomotives were passed over the bridge. Stress levels from the tests are included in the paper. The conclusions of the report include: no damage during its 100 years of previous service, the stringers could withstand very severe fatigue damage, including partial failure, and still carry service loads for long periods of time, the yield properties of the wrought iron were somewhat lower than current materials and variability was more pronounced.

A series of recommendations were made including:

A reduction of maximum speed to limit dynamic effects on the bridge

Inspection of the bridge every six months to identify possible areas of distress

Repairs should be made with care to prevent damage such as flame-widening a rivet hole

MEMBERS [4.2.1]

Brühwiler, E., I. F. C. Smith, and M. A. Hirt. "Fatigue and Fracture of Riveted Bridge Members." Journal of Structural Engineering 116, no. 1 (January 1990): 198-214. (TA 630 A483) (C).

The purpose of the paper is to provide fatigue data on riveted connections. Almost all fatigue studies are done on bolted or welded connections. Three full scale bridge girders were tested in the investigation. One was a mild-steel girder that was built as a temporary structure but never loaded. Six wrought-iron girders of which two had experienced corrosion damage formed the second test group. It was estimated that the girders had experienced approximately 100 million cycles in its 100 years of service. The third set of test specimens consisted of three latticed, wrought-iron girders built in 1891. 20 million cycles of constant amplitude loading were applied to all specimens.

Results: Yielding and tensile strengths were about equal for wrought-iron and mild steel specimens. Wrought-iron had a fracture strain of 15% compared to 40% for the mild steel. The Young's Modulus of the wrought-iron was about 15% lower than for mild steel. It was noted that by observing polished macro sections mild steel had a homogenous nature while wrought-iron was lamellar. Fatigue results: Steel girders (test set 1) all but one failed above ECCS 90 (AASHTO C) levels. Wrought iron girders and latticed members (sets 2 & 3) all but two failed above AASHTO C. Corroded members did not have a lower fatigue results due to the fact that most failures occurred in the rivet holes. Rivets in corroded members were fine. The author concluded that wrought-iron elements have similar fatigue strengths to mild steel members.

Fatigue Strength under shear loads was tested and a conservative constant amplitude limit of 15ksi was estimated.

Fracture strength: High variability was found in tests. Table of results show that Charpy test results do not undergo drastic changes from -20 to 20 degrees Celsius. A discussion of determining critical crack length follows.

Other conclusions included using AASHTO D as a conservative estimate of fatigue strength and the critical crack length is smaller in wrought iron than mild steel.

MEMBERS [4.2.2]

Schindler, Hans-Jakob. "Toughness Evaluation and Assessment of Old Bridge Steel." International Association of Bridge and Structural Engineers (1313-1318) (C).

The fracture toughness of wrought iron is very low. Evaluations of structures made of these steels often use standard Charpy V-notch tests which may be misleading in the case of wrought iron. Wrought iron, due to its anisotropic structure, tends to produce a wide scatter in V-notch tests, but also resists crack propagation. This article seeks to reach a better understanding of these two phenomena. Wrought iron's fracture behavior differs markedly from that of normal steel. Wrought iron has a large brittle to ductile transition temperature range and low upper shelf energies which indicate stable crack growth behavior. This behavior is due to the lamellar structure of wrought iron. The fibrous nature of wrought iron tends to arrest local cracking and allow for delamination and crack branching.

The author presents equations to relate standard V-notch quantities to an approximation of toughness. An equation is also presented to correct the impact testing values to lower loading rates, which the structure is subjected to. Finally, required toughness equations are presented which provide general yielding before fracture.

MEMBERS [4.2.3]

Szittner, A., L. Kristóf, and L. Kaltenbach. "Fatigue tests on the old stringers of the railway bridges." Periodica Polytechnica Ser. Civil Engineering 35, no. 3-4 (1991): 345-360 (C).

Members from the bridges in Hungary were tested to examine their fatigue capacity. The bridges examined included a continuous multi-span girder built in 1948 and a trussed bridge built in 1911-12. The truss bridge had experienced some damage during WWII, but it was unknown which members were replaced. From the stringers in the bridges, four types of samples were cut. One being material from the flange plates and web plates which included the edge of the rivet holes (A). A second type of sample contained a rivet hole in the center of the specimen (B). The third type of specimen consisted of undisturbed material from the middle of the web plate with new holes drilled in the middle (C). Charpy specimens were removed from the flange plates and web plates both near rivet holes and undisturbed material (D).

Charpy tests of the 1948 bridge showed poor results with brittle failure possible. The trussed bridge showed better results in Charpy testing. A series of fatigue tests were run on the specimens. Results showed that (A) samples performed the best (180-200 N/mm2), (C) samples averaged between 130-150 N/mm2, (B) samples performed the worst at 100-130 N/mm2. A fatigue test was also run on a full stringer. The testing machine's capacity was reached before any sign of fatigue distress was observed. Cumulative damage theory was applied and determined that both bridges could remain in service with a closely monitored schedule of replacement.

MEMBERS [4.2.4]

Keating, Peter B., John W. Fisher, Ben T. Yen, and William J. Frank. "Fatigue Behavior of Welded Wrought-Iron Bridge Hangers." Transportation Research Record 950 (1984): 113-120 (TE 1 T7357) (C).

This paper deals with the fatigue evaluation of welded wrought iron bridge components. The bridge investigated was a railroad bridge crossing the Mississippi built in 1888. To correct the problem of eyebar loosening, a practice of removing part of the eyebar and welding it back together with lap splices had been performed. This repair was undertaken in 1937 when welding techniques were first being developed. The primary question facing the investigators was, if the bridges could continue in service safely, or would fatigue concerns warrant closing the bridge. A series of field inspections and measurements were conducted to give preliminary information. To test the repair, three specimens were fabricated to replicate the conditions on the bridge. Actual specimens were also taken from a decommissioned truss span, replaced years ago due to a barge accident. All tests indicated that the welded joint was adequate for AASHTO fatigue category D and E loadings. To asses the likelihood of a future fracture, a traffic study was completed to estimate the damage which has, and will occur to the bridge. Predicted stress ranges showed that the bridge will be able to stay in service for many year to come. Conclusions arrived at due to this study include:

Cracks at the toe of the splice plate were arrested by the slag inclusions inherent in the wrought iron matrix.

Splice connection was determined to be a category D detail, but category E should be used for evaluation.

3) Fatigue crack growth could not be arrested in the edge welded wrought iron splices.

CONNECTIONS [4.3.1]

Yamamoto, Kazuyuki, Narioki Akiyama, and Toshie Okumura. "Buckling Strength of Gusseted Truss Joints." Journal of Structural Engineering 114, no. 3 (March 1988): 575-590 (TA 630 A483) (C).

Investigation of the buckling modes of eight gusseted joints is presented. A detailed account of the buckling phenomena is documented for each test. A proposed design formula is also recommended. This paper might only be useful if the case study bridge has gusseted joints.

CONNECTIONS [4.3.2]

Yamamoto, Kazuyuki, Narioki Akiyama, and Toshie Okumura. "Elastic Analysis of Gusseted Truss Joints." Journal of Structural Engineering 111, no. 12 (December 1985): 2545-2563 (TA 630 A483) (C).

Experiments were performed to find the stress distributions of gussted plates. Design formulae for finding required plate thickness are derived by the authors. This paper might only be useful if the case study bridge has gusseted joints.

CONNECTIONS [4.3.3]

Leon, Roberto, Roeder, Charles W., and F. Robert Preese. "A Comparison of the Cyclic Performance of Bolted and Riveted Connections." In Proceedings of the Symposium on Structural Engineering in Natural Hazards Mitigation, Apr 19-21, 1993, 415-420 <find call #> (C).

This article reports the results of tests that compared three connections including A307 bolts, A325 bolts, and A502 rivets. Connection details were replicated using a T-stub connection common in building construction in the 1920‘s. Results showed poor performance by the riveted connection and good performance from the A325 bolts. It is concluded that under severe cyclic conditions, riveted connections lose their clamping force and therefore their dissipative capacity.

CONNECTIONS [4.3.4]

van Maarchalkerwaart, H. M. C. M. "Fatigue Behavior of Riveted Joints." International Association of Bridge and Structural Engineers 37 691-698 (ILL) (C).

In this article, the author discusses a few variables which influence the fatigue characteristics of riveted joints. A variety of type of steel are tested with varying clamping forces, bearing-tension ratios, and shear tension ratios on double angle lap joints. Data was compiled from a variety of tests performed all over the world. A scatterband suggested by W.H. Munse was used in comparing the different tests. The clamping force results showed that as the grip of the rivet increases, the clamping force increases, and therefore the fatigue resistance increases. Other conclusions of this work suggest that as the ratio of minimum stress to maximum stress approaches one, the fatigue capacity decreases. Single lap joints with eccentric connection were tested with the largest eccentricity displaying the poorest performance. The author suggests a series of S-N curves to be used in the prediction of fatigue life for various combinations of single and double splices with different stress range factors. A discussion of riveted wrought iron connection is also presented. The wrought iron displays poorer fatigue resistance than steel. A S-N curve for wrought iron is also proposed.

CONNECTIONS: SEE ALSO [2.5.3]

DECK [4.4.1]

Sanders, Wallace W., F. Wayne Klaiber, Hotten A. Elleby, and Leonard W. Timm. "Ultimate Load Test of Truss Bridge Floor System." Journal of Structural Engineering 102, no. ST7 (July 1976): 1383-1397 (TA 630 A483) (C).

A timber deck of a truss bridge built in 1909 was tested to failure. This article compares the test results to the theoretical capacity of the deck. A test set-up which loaded the bridge at four points was used. The first test positioned the load cell in the center of the deck. The second test eccentrically loaded the structure. It was found that the deck behaved elastically to approximately half its ultimate load. The theoretical capacity was very near the experimental in both tests. An AASHTO rating of H32 was determined from the ultimate load. However, this rating applied only to the deck and not the entire bridge.

Reference

REFERENCE [5.1]

Sanders, Wallace W. "Bridge Repair and Rehabilitation, North American Codes and Practice." In Structural Faults and Repairs: Proceedings of the 5th

International Conference on Structural Faults and Repairs at the University of Edinburgh, July 1, 1993, by the International Conference on Structural Faults and Repairs, 1993, 9-12 (TA 656 I58 1993 V.1) (C).

This article provides an introduction to the codes that govern or provide guidance for bridge repair. References to strengthening both concrete and steel bridges are given. A discussion of whether existing codes should apply to old structures is presented. An extensive bibliography lists research projects relating to various topics in bridge repair and rehabilitation.

REFERENCE [5.2]

Zuk, William, and Wallace T. McKeel, Jr. "Adaptive Use of Historic Metal Truss Bridges." Transportation Research Record 834 1-6 (TE 1 T7357) (C).

Twenty bridges in Virginia were surveyed for different methods of preservation. Two major options were proposed: (a) continued vehicular use (b) convert to non-vehicular use. Four sub-options for continued use include: (1) upgrade by strengthening (2) widening (3) convert to on way traffic and build secondary bridge (4) move bridge to less demanding traffic location. Article focused on strengthening techniques which included: (1) join simple spans to form continuous span (2) add pylons and cable stays to bridge (3) posttension bottom chord of individual trusses (4) add queen post under individual trusses (5) place additional supports under trusses (6) add longitudinal beams under trusses (7) add an additional truss on the outside of old truss. A discussion of non-vehicular options such as conversion to a footbridge, restaurant, museum, etc. was offered in the article.

References : Virginia Highway and Transportation Research Council

VHTRC 78-R29 and VHTRC 80-R48

REFERENCE [5.3]

Heins, Jr., Conrad P, and Charles F. Galambos. “Highway Bridge Field Tests in the United States, 1948-1970.” Public Roads 36, no. 12 (February 1972): 271-291 (625.705 P96) (C).

This article lists tests conducted on various types of bridges over a span of 22 years. Two truss bridges, one in Maryland, the other in Indiana, are documented. References to available materials concerning each bridge are listed in the bibliography.

REFERENCE [5.4]

White, Kenneth R. Bridge Maintenance Inspection and Evaluation. New York: M. Dekker, 1981 (TG 315 B742).

This book provides an introductory description of bridge inspection and evaluation. It covers timber, steel, and concrete bridges as well as documentation techniques and equipment needed. A very short discussion is included concerning bridge maintenance and rehabilitation. Calculation examples are included for stress determination in various bridge types. However, this reference is very general and only provides the introductory information in the repair and rehabilitation arena.

REFERENCE [5.5]

NATO Advanced Research Workshop on Bridge Evaluation, Repair, and Rehabilitation and Andrzej S. Nowa, ed. Bridge Evaluation, Repair and Rehabilitation. Dordrecht, Boston: Kluwer Academic, 1990 (TG 315 N33 1990).

This book presents articles related to different topics in bridge repair. Major issues covered include: Bridge Management, Diagnostics and Monitoring, Loads and Analysis, Evaluation and Tests, and Repair and Rehabilitation. Only a few of the articles use metal truss bridges as case studies. The most informative article related to truss bridges is titled “Rehabilitation of Steel Truss Bridges in Ontario”. The article outlines four bridges and the solution to each of the bridges’ deficiencies. The Burlington Skyway Bridge’s floorbeam trusses were strengthened using Dywidag bars. The South Muskota River Bridge was rehabilitated by adding a new deck truss to halve the existing span. The Buskegau River Bridge was replaced after extensive cost analysis was completed. A new bridge was found to be much more economical. The Confederation Drive Bridge was rehabilitated by removing the existing deck and replacing it with a lightweight, pre-stressed timber bridge.

REFERENCE [5.6]

Silano, Louis G., ed. Bridge Inspection and Rehabilitation: A Practical Guide. New York: John Wiley & Sons Inc., 1993 (TG 315 B72 1993).

This book discussed many topics concerning the repair of concrete and steel bridges. Chapters on Bridge Inspection, Steel Structures, and Deck Reconstruction, would be of particular interest for an engineer working on a rehabilitation project. The Steel Structures chapter provides an introductory discussion of topics including damage and strengthening, as related to bridges. This book is an excellent reference for an explanation of repair schemes used in steel bridges.

REFERENCE [5.7]

Horn, W. B., G. O. Shanafelt. Guidelines for Evaluation and Repair of Damaged Steel Bridge Members. Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program 271, June 1984 (TE 7 N25) (C).

This report is a very good review of repair methods for members subject to impact, fire, or other damage. Chapters dealing with inspection, assessment, repair selection, and guidelines of repair methods, are included. Repair techniques such as flame straightening, welding, hot mechanical straightening, and bolting are covered as repair techniques. This document was referred to extensively during the writing of this thesis, and the author would strongly recommend any engineer approaching a rehabilitation to have a copy of this document on hand.

REFERENCE [5.8]

University of Virginia Civil Engineering Department, Virginia Highway and Transportation Research Council, and the Virginia Department of Highways and Transportation. Bridges on Secondary Highways and Local Roads. Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program 222, 1980 (TE 7 N25) (C).

This report deals with common bridge deficiencies on secondary roads or highways. This report included repair and replacement procedures for concrete, steel, and timber bridges. Topics such as railing retrofits, and geometric clearances are discussed. Information is also given on the repair of bridge substructures. A complete section of replacement schemes is also included for a variety of bridge members. During the writing of this thesis, many examples, and figures were taken from this report. The author would strongly recommend any engineer approaching a rehabilitation to have a copy of this document on hand.

REFERENCE [5.9]

Klaiber, F. W., K. F. Dunker, T. J. Wipf, and W. W. Sanders, Jr. Methods of Strengthening Existing Highway Bridges. Washington, D. C.: Transportation Research Board, National Cooperative Highway Research Program 293, 1987 (TE 7 N25) (C).

This report is an excellent reference for any engineer seeking information on a wide range of rehabilitations. The authors examined over 300 references related to bridge repair. The referenced were grouped into general classifications including member replacement, stiffness modification, member additions, and port-stressing. The authors also discuss economic analysis as related to bridge replacement versus repair. A bibliography is included of references used, and would be helpful to an engineer.

REFERENCE [5.10]

Mishler, H. W., and B. N. Leis. Evaluation of Repair Techniques for Damaged Steel Bridge Members. Washington, D. C.: Transportation Research

Board, National Cooperative Highway Research Program 12-17, 1981 (ILL).

This report provides information on four common techniques of repairing damaged bridge members including welding, cold mechanical straightening, hot mechanical straightening, and flame straightening. A majority of the document investigates hot mechanical straightening and flame straightening. The authors concluded that the effects of these procedures are very variable and rely primarily on the skill and expertise of the person using the technique.

REFERENCE [5.11]

Zuk, William, Howard Newlon, Jr., and Wallace T. McKeel, Jr. Methods of Modifying Historic Bridges for Contemporary Use. Charlottesville, Virginia: Virginia Highways & Transportation Research Council, 1980 (C).

This report focuses on the rehabilitation options for 21 bridges in Virginia. A detailed investigation into each bridge structure was undertaken including history, architecture, and structural aspects. Continued vehicular service as well as conversion to non-vehicular uses were investigated. A bibliography of related articles is also included. This report provides a good introduction to bridge preservation.

REFERENCE [5.12]

American Association of State Highway and Transportation Officials. AASHTO Reference Book of Member Department Personnel and Committees. Washington, D.C., 1996-1997 (C).

This book contains names and addresses of individuals who work at transportation departments. Information is also included for transportation departments in Canada. This document was used to compile a mailing list for the survey.

OTHER REFERENCES

Rhode Island Department of Transportation. “Plan, Profile and Sections of Proposed Rehabilitation of the Albion Bridges Nos. 163 & 164.” Gordon R. Archibald, Inc. Professional Engineers, 1994. Photocopied.

U. S. Department of Transportation. Federal Highway Administration. Retrofit Railings for Narrow Through Truss and other Obsolete Bridge Structures Report FHWA RD-82/099, by M.E. Bronstad, L. R. Calcote, C. E. Kimball, Jr., of the Southwest Research Institute. San Antonio, Texas, 1986, (copy available on microfiche).

Xanthakos, Petros. Bridge Strengthening and Rehabilitation. Upper Saddle River, Ney Jersey: Prentice Hall PTR, 1996, (TG 315 X36 1996).

APPENDIX A

SURVEY OF DEPARTMENTS OF TRANSPORTATION

The following letter was mailed to 49 state Departments of Transportation, as well as, Washington D.C, and 10 Canadian provinces. The words enclosed in double arrows are fields from a mail merge that included the names and addresses of the parties to be contacted at the transportation agency. A copy of the survey sent to each agency follows the letter. Further discussion of the survey can be found in Chapter 3.

April 27, 1997

«FirstName» «LastName»
«JobTitle»
«Company»
«Address1»
«Address2»
«City_State»
«PostalCode»

Dear «FirstName» «LastName»:

The Texas Department of Transportation (TxDOT) is currently sponsoring a research project through the University of Texas at Austin to investigate preservation alternatives for historic metal truss bridges. The bridges under consideration were constructed in the late 19^{th} to early 20^{th} centuries, and often suffer from structural and geometric deficiencies. The goal of this project is to research typical historic metal truss bridges in Texas and provide guidance for future rehabilitation efforts undertaken by TxDOT that will permit these bridges to remain in vehicular service.

As a preliminary step in this project, our team is currently collecting information concerning all aspects of metal truss bridge investigation and rehabilitation projects in other states. Any information you can provide on this subject would greatly help our project. This information will aid our research team to create a database of knowledge to be used in rehabilitating historic metal truss bridges.

If you would please fill out the enclosed survey and return it to us by June 30,1997, it would be of tremendous help to our project. If you do not have the information or time to complete all portions of the survey, please feel free to return the form only partially completed. We would prefer to have a partial response, rather than none at all.

If you have any questions, please feel free to call Matthew Thiel, research assistant at (512) 323-5934; Dr. Michael Engelhardt, research supervisor at (512) 471-0837; or Barbara Stocklin, TxDOT point of contact at (512) 416-2628. The researchers may also be reached via email at mthiel@mail.utexas.edu and mde@uts.cc.utexas.edu respectively. We would be happy to send you a copy of our final report at the completion of our project.

Thank you for your attention.

Sincerely,

Dianna F. Noble, P.E.
Director of Environmental Affairs

Preservation of Historic Metal Truss Bridges Survey

The University of Texas at Austin is currently investigating preservation of steel truss bridges under a project sponsored by the Texas Department of Transportation. To this end, we are asking your assistance in providing information which will aid our research team, and provide guidance for future rehabilitation efforts undertaken by TxDOT. A variety of issues have been identified as particularly relevant to our investigation including: 1) structural evaluation, repair, and strengthening techniques 2) dealing with geometric deficiencies 3) funding of rehabilitation projects 4) obtaining design exceptions for rehabilitation efforts.

As a preliminary step in this project, our team is currently collecting information concerning all aspects of steel truss preservation underway in other states. As such, we would appreciate your time and effort in filling out this survey. If you do not have the information or time to complete all portions of the survey, please feel free to return the form only partially completed. We would prefer to have a partial response , rather than none at all. In exchange for your assistance, we would be happy to send you a copy of our final report at the completion of our project.

Note: For any question which falls outside of your specialty, instead of providing an answer, would you please indicate the name and phone number of an individual we can contact for further information.

1. Has your state developed any reports, guidelines, or other documents addressing the evaluation or rehabilitation of steel truss bridges?

Yes_______ No_______

If yes, we would greatly appreciate receiving a copy of any pertinent reports returned with this survey.

Name, address or phone number of

Report Name & Date	individual to contact to obtain a copy of the report

2. Have you used advanced structural analysis techniques to provide improved estimates of the structural capacity of steel truss bridges?

Yes_______ No_______

If yes, please explain or provide contact for additional information.

3. Have you used advanced non-destructive evaluation techniques (e.g. acoustic emission monitoring) to assist in evaluating the condition of steel truss bridges?

Yes_______ No_______

If yes, please explain or provide contact for additional information.

4. Have you used load testing to assist in evaluation the structural capacity of steel truss bridges?

Yes_______ No_______

If yes, please explain or provide contact for additional information.

5. What are the most common structural strengthening techniques your department has used in rehabilitating steel truss bridges?

6. Please check any other structural strengthening techniques you have used.

_______ Superimposed trusses	_______ Addition of longitudinal beams
_______ Post-tensioning bottom chord	_______ Providing additional supports
_______ Joining simple spans into continuous span	_______ Adding king or queen posts and post-tensioned tendons
_______ Replace floor deck with a lighter system	_______ Pin replacement
	_______ Attach cover plates to members
_______ Other (please explain)	

7. For bridges with geometric deficiencies, either inadequate height or width, please check any solutions you have used:

_______ Relaxing geometric standards for historic bridges
_______ Widening bridge
_______ Increasing portal height by removing or altering overhead members
_______ Convert bridge to one-way traffic
_______ Other (please explain)

8. What methods, if any, have you used to improve railings on historic steel truss bridges? We are particularly interested in information on crash tested railings which have been added to historic steel truss bridges?

9. What methods have you used to deal with the presence of lead based paints on historic steel truss bridges:

______ Remove old lead paint (with appropriate disposal techniques) and repaint bridge.
______ Apply sealer to encapsulate lead based paint
______ Other (please explain)

10. Has your department been involved with the rehabilitation of a historic steel truss bridge that has involved a particularly interesting, unique, or innovative approach?

Yes_______ No_______

If yes, please state the name or location of the bridge, and the name and phone number of an individual that can provide additional information.

11. At the completion of our project on the rehabilitation of historic steel truss bridges for TxDOT, would you like to receive a copy of the reports?

Yes_______ No_______

If yes, please provide a name and address to which the reports should be sent.

12. Additional Comments:

13. Please provide your name, address, and phone number.

APPENDIX B

RESPONSES TO HISTORIC METAL TRUSS BRIDGE SURVEY

This appendix contains the responses received from the survey. The responses for each question have been grouped together for easier reference. Any phrase or word surrounded with square brackets [] indicate notes or modifications made by the author.

QUESTION 1:

Has your state developed any reports, guidelines, or other documents addressing the evaluation or rehabilitation of steel truss bridges?

Yes:

AZ : In-Depth Steel Bridge Inspection Program, July 20, 1996
IA : Ultimate Load Behavior of Full Scale Highway Truss Bridges, Aug. 1975, Sept. 1975
MN : Bridge 4175 - Summary of Inspection for Reuse as a Pedestrian Bridge, 4/97 Wabasha Street Bridge Fatigue Analysis, 8/89
NE: [“Evaluation and Retofitting of Historic Truss Bridge”, University of Nebraksa at Lincoln, 1996]
VT : [see Additional Comments]
WA : Research project w/ U. Of W. “Steel Bridge Cracking” Report due Phase I August, 1997, Phase II, 1999; Contact Harvey Coffman (360) 753-6076
[Alberta] AB : Bridge Truss Rating System - A computer system for load capacity rating of truss bridges; Contact Raymond Yu (403) 415-1016 email: ryu@tu.gov.ab.ca
[Nova Scotia] NS : We use Clause 12 of the Canadian Highway Bridge Design Code to evaluate our structures.

No (with note):

MD : We haven't developed any official guidelines pertaining to truss rehabilitation since the State of Maryland doesn't have any pin connected, iron or steel trusses, however several counties in Maryland do have pin connected trusses. We get involved in the review of ISTEA funded, local government projects and suggest, on a case by case basis, a similar theme. The major points that we suggest are as follows: [see question 12 additional comments]

No: AK, AL, AR, CA, CT, DE, DC, FL, GA, HI, IN, KS, KY, MS, MO, MT, NV, NH, NJ, NM, NY, NC, OH, OK, RI, TN, [Manitoba] MB, [New Brunswick] NB, [Newfoundland] NF, [Saskatchewan] SK

QUESTION 2:

Have you used advanced structural analysis techniques to provide improved estimates of the structural capacity of steel truss bridges?

Yes:
AL: Developed a truss analysis program that used the stiffness method of analysis. Accounts for stiffness at each joint and performs analysis
CT: BAR 7 - Analysis for rating; On occasion GTSTRUDL has been used for 3-D finite element modeling
FL: Bridge Rating of Girder - Slab Bridger Using Automated Finite Element Technology (BRUFEM) was used to analyze the deck girder portion of the bridge. Space frame analysis was used to determine forces in secondary and primary members.
KY: We have used STRUDL and analyzed trusses as a space frame for LL distribution.
NE: [BARS, SAP 90 utilized in research project]

No (with note):
AZ: Used conventional 2D & 3D elastic analysis methods to verify behavior and load distribution
OH: ODOT has accepted finite element from a consultant for truss rating. We don't normally do it.
NF: Normal methods. M-STRUDL.

No: AK, AR, CA, DE, DC, GA, HI, IN, IA, KS, MD, MN, MS, MO, MT, NV, NH, NJ, NM, NY, NC, OK, RI, TN, VT, WA, AB, MB, NB, NS, SK

QUESTION 3:

Have you used advanced non-destructive evaluation techniques (e.g. acoustic emission monitoring) to assist in evaluating the condition of steel truss bridges?

Yes:
AK: We use ultrasonic testing equipment to check the pins at connections
CT: Ultrasonic testing of pins for a truss bridge carrying metro-north railroad over Washington and Main Street in Norwalk Conn. Was performed in 1996. Contact Mr. Robert Brown at ConnDOT (860) 594-3207.
Eye bars have also been tested. Contact Mr. Richard Van Allen (860) 594-3172.
MD: We use ultrasonic testing to determine if defects are present in pins.
MN: Ultrasonic testing of pins and welds.
NJ: Non-destructive testing of pins.
NY: New York City DOT did use non-destructive "X-ray Diffraction Technique" to determine the load distribution in the eyebars at specified pin locations. The testing was done by PROTO Manufacturing Limited, 2175 Solar Crescent, Oldcastle, Ontario, NOR 1L0 Canada. The contact person is R. Mayrbaurl, Weidlinger Associates, 375 Hudson St., New York, N.Y. 10014-3656.
OH: No, specifically on a Ohio DOT bridge but did assist a county (Sandusky) with a truss bridge. This structure was load tested to validate the finite element results; the finite element revised; recommendations made for strengthening; and a final rating defined for the structure.
OK: We use Ultrasonic Testing to inspect the pins of pin-connected trusses.

No (with note):
AZ: Used conventional non-destructive testing techniques such as ultrasonic testing of pins, eyebars and impacted members; ultrasonic techniques for determining member thickness; and electronic in-situ hardness testing for material confirmation. Also used pachometer testing and coring for evaluation of concrete substructure, and seismic refraction methods and geotechnical borings to evaluate subgrade conditions for seismic and scour vulnerability. Contact : Rob Turton at Cannon & Associates (602) 470-8477

No: AL, AR, CA, DE, DC, FL, GA, HI, IN, IA, KS, KY, MS, MO, MT, NV, NH, NM, NC, RI, TN, VT, WA, AB, MB, NB, NF, NS, SK

QUESTION 4:

Have you used load testing to assist in evaluation the structural capacity of steel truss bridges?

Yes:
MD: We used load testing to evaluate the capacity of a gusset connected, steel truss in addition to concrete girder and slab bridges and an open spandrel, concrete arch. URS Greiner of Baltimore, MD completed the study in 1996.
MN: The Wabasha Bridge (see report) was instrumented and load tested to determine stress ranges.
NE: [see research report]
OH: [See answer for question 3]

No (with note):
AZ: Used observation of behavior under load, but no formal testing procedure
MO: Years ago a heavily used truss bridge was load tested with strain gauges on the floor system. (The floor system nearly always control our ratings) As I recall the capacity was determined to be appreciably higher than the theoretical values. It was thought at the time that the concrete slab which replaced the timber floor was acting compositly even though shear connectors were not present.

No: AK, AL, AR, CA, CT, DE, DC, FL, GA, HI, IN, IA, KS, KY, MS, MT, NV, NH, NJ, NM, NY, NC, OK, RI, TN, VT, WA, AB, MB, NB, NF, NS, SK

QUESTION 5:

What are the most common structural strengthening techniques your department has used in rehabilitating steel truss bridges?

AK: Replacement in kind of damaged or corroded members
AL: Addition of cover plates. Attached by longitudinal welds to increase the section.
AZ: Old Colorado River Bridge in Yuma County (SN 08533) [Report included]
Airport Road Wash Bridge in Cochise County (SN)08116) [Report included]
Cedar Canyon Bridge in Navajo County (SN 00215) - Though an arch bridge an identical historic arch (Corduroy Creek) was disassembled and reassembled to create a stronger wider bridge.
CA: Cover Plates
CT: Plating to replace lost section. Member replacement. Bearing replacement to decrease bottom chord longitudinal stresses due to thermal forces. Reinforcing eye bars. Light weight deck replacement to reduce dead load.
DE: Use of heavier or higher strength steel components.
FL: Replacing members and adding section as needed.

GA: Member replacement for damaged members, cover plates for damaged areas, etc. High strength bolts to replace rivets, etc.
IA: Bolting/Welding new material to existing members. Replace concrete deck with lighter weight steel grid deck. Add new bracing to reduce L/R of compression members. Add wire rope and turnbuckles to strengthen pin-connected eye-bar tension members.
KS: Lighten load by replacing concrete deck with metal grid deck.
KY: Tension tighteners on eye bar members. Additional members added. Building up of members using plating.
MD: Frequently, floorbeams and compression members in the truss have been strengthened by bolting plates or rolled shapes to their weds.
MN: Replacing members. Reinforcing members with additional plates and angles
MO: Most truss bridges in Missouri are functionally obsolete (too narrow, low overhead clearance) and many are posted. General practice is to replace these structures. We have a major river crossing currently being rehabbed and redecked. The longitudinal stringers are being made composite to increase the load rating.
MT: replacing deck, stringer and floorbeams
NE: [post-tensioning used in research project]
NV: We have manually rated a metal truss bridge and then widened it to one side using different truss members but the same truss configuration.
NH: Replace deck and deteriorated members.
NJ: Replace deck system with a lighter system. Install coverplates to strengthen members.
NM: We have done very little work in strengthening old trusses.
NY: An individual evaluation of each structure must be made to determine if one or more of the following techniques is (are) appropriate.

- Decrease dead load to provide additional live load capacity
- Repair or replace deteriorated material
- Post-tensioning elements which have low load capacity (i.e. floor beams)
- Adding a superimposed load carrying system (i.e. steel arches)

Generally these techniques are used to restore lost load carrying capability rather than add additional capability to the original design.
NC: Bridge replacement.
OH: Add plates, reconstruct, when required. Have not used composites or post tensioning. Have pulled a concrete deck to use open grid for increasing live load capacity.
OK: Redecking with a composite concrete deck. Welding steel plates to truss chords.
RI: Heat Straightening. Replace Members and Pins.

TN: Replace members. Add section to members for strengthening. Replace gusset plates.
VT: Replace weak or deteriorated members. Weld additional metal to weak members. Replace existing concrete decks with lighter timber decks.
WA: Replacement of decks (making them composite in some cases)
AB: Cover plates. Post-tension bottom chord with Dywidag rods. Member replacement.
MB: Replace deficient or damaged members. Add cover plates.
NB: Lightweight concrete deck. Composite floor action with concrete decks. Post-tensioning bottom chords. Member replacement, strengthening.
NS: Replacement or strengthening of members and connections is commonly used.
SK: installed additional longitudinal stringers. Installed additional members to lower chord and verticals/diagonals to strengthen deficient members. Gusset plates have generally been adequate, so involved replacement of rivets with longer high strength bolts to accommodate the additional members.

No Response: AR, DC, HI, IN, MS, NF

QUESTION 6:

Please check any other structural strengthening techniques you have used.

Superimposed trusses: CA, HI, NY*, AB

* Superimposed arch/hanger/transverse floorbeam system

Post-tensioning bottom chord: CT, KS*, [NE], VT, AB, NB

*This method was considered and analysis was done but final decision was to replace structure.

Joining simple spans into continuous span: KY, NY

Replace floor deck with a lighter system: AR, AZ, CA, CT, DE, FL, IA, KS, KY, MD, MT, [NE], NH, NJ, NY, NC, OH, TN, AB, NB, NF, NS

Addition of longitudinal beams: AZ, CT, NJ, RI, TN, AB, SK

Providing additional supports: CA, CT, NJ, RI, TN, NB

Adding king or queen posts and post-tensioned tendons:

Pin replacement : CT, FL, GA, KY, MD, MN, NJ, NY, RI, NS

Attach cover plates to members : AL, AZ, CA, CT, FL, GA, IA, KY, MD, MN, [NE], NH, NJ, OH, OK, RI, TN, AB, MB, NS, SK

Other:
AZ : Considered or proposed: Airport Wash Bridge draft documentation attached for reference but County chose to replace bridge due to cost of rehabilitation. Old Colorado River Bridge structural rehabilitation recommendations are presently being considered. (Drafts are attached for reference) Other techniques include strengthening existing deck by removing existing AC and providing structural concrete (reinforced) overlay and seismic retrofitting (bearing anchorages and pier strengthening).
CA: The strengthening techniques used above have mostly been used on local agency bridges.
MD: It has been our goal in working with the Maryland Historical Trust that we do as little modification to the truss as possible. When needed we will strengthen or replace members, use a lighter floor system, and replace pins but shy away from superimposed arches and trusses and post-tensioning.
MO: Although I am unaware of any trusses rehabbed with cover plates we have strengthened a number of beam bridges using this method.
NM: We've replaced floor decks but not to add strength.
NY: Post-tensioning of floorbeam.
NC: Additional stringers.
OK: Attaching threaded rebar to lower chord. Placing shims under floorbeams at abutments.
WA: Elimination of fracture critical hangers by adding secondary hangers.
NB: Composite stringers with concrete deck.

No Response: AK, DC, IN, MS, NV

QUESTION 7:

For bridges with geometric deficiencies, either inadequate height or width, please check any solutions you have used:

Relaxing geometric standards for historic bridges: CT, FL, IN, KY, [MD (see other)], NH, NJ, NY, OH, VT, NF

Widening bridge: AZ, [NE (tested in research)], NV, OK

Increasing portal height by removing or altering overhead members: AK, CA, DE, FL, GA, IA, KS, KY, MN, MO, MT, NH, NC, OH, OK, TN, VT, WA, AB, MB, NB, NF, NS, SK

Convert bridge to one-way traffic: AZ (Considered or proposed on Old Colorado bridge), [CT (see other)], FL, [MO (see other)], NJ, OK, RI, WA, AB, NB

Other:
AK: Replaced highway bridge and retained truss bridge for pedestrian use
CA: Placing speed restrictions. Placing electronic sensing devices prior to bridges to prevent overheight loads from entering bridge
CT: Convert to pedestrian traffic. Alternating one-way traffic.
GA: Posted low clearances. Relocation of truss.
MD: We believe that narrow structures having low speed limits are not vulnerable to the railing loads prescribed in AASHTO, therefore we grant design exceptions on those trusses having low incidence of accidents.
MO: On some low traffic roadways we have limited some structures to one lane. These bridges are usually narrow and re-striped to direct traffic to the center of the structure.
NM: Build an adjacent bridge and preserve the existing structure. This is what we usually do.
NY: Convert the bridge to alternate uses such as cars only, pedestrian and/or bicycle use.
OK: Post a reduced speed limit.

No Response: AL, AR, DC, HI, MS

QUESTION 8:

What methods, if any, have you used to improve railings on historic steel truss bridges? We are particularly interested in information on crash tested railings which have been added to historic steel truss bridges?

AK: We have added the “f” shape concrete barrier
AL: Have added 12” metal W-beam guardrail on inside
AZ: On Cedar Canyon used concrete jersey shaped barrier with architectural treatment on the outside to simulate metal rail

Considered or proposed: Extension of existing concrete curbs; concrete jersey-type barriers where feasible from loading standpoint (and acceptable to SHPO); crash-tested open metal railing system; non-standard open metal railing systems that may suit existing framing; and strengthening or providing additional members in existing system where operations permit (such as with one-way traffic of low volume/lowspeed/no truck facilities.
CA: We have used thrie-beam railing. Some 2 members high and blocked out a small amount.
CT: We have used W-beam rail systems with backing plates and rub rails and concrete AASHTO safety shapes.
DE: We have used glue-laminated timber rails as shown on the enclosed drawing. This detail is not crash tested. [Drawing can be found in collection of responses]
FL: Replace rail and post with Iowa Block railing.
KY: We use Ohio's curb & guardrail details when they will fit.
MD: We feel that the railing should be in harmony with the truss' appearance, however we recommend adequate protection for the endposts and smooth transition between approach barrier and the railing on the structure. We also recommend a heavy 12 inch tall timber rubrail attached to the deck to take the brunt of the wheel load and deflect the vehicle back into the roadway before striking truss members or hand railing.
MN: We added thrie beam rail to one truss to achieve a crash tested design.
MO: We have used thrie beams on truss bridges
MT: We have used the Texas T101 and Wyoming box beam.
NH: No crash tested rails used.
NJ: Guide rail carried across structure.
NY: No new crash tested railing systems have been used. However, by reducing speed limits, introducing higher curb/barrier curb lines and eliminating all but delivery and necessary access vehicles to a historic area, new and similar to original steel railing and parapet details have been used.
NC: Add 12" guardrail to pony truss.
OK: We have not improved the railings on historic metal trusses.
RI: Bolt guardrail thru deck.
TN: If we repair the structure by contract, we will specify the 10 gauge W shape guardrail be mounted to the lattice rail in the truss section of the structure. To my knowledge this application has not been crash tested. However, we fell that it is better than the existing condition.
VT: We have used steel box beam tube rails and also W-beam guard rail sections to supplement existing rails. None have been crash tested.
AB: HSS 6" x 8" rail.
NF: None. We use steel beam W guide rail or none. We do have some damaged truss members.

SK: We do not have any historic metal truss bridges. On some older bridges we have installed a heavy angle along the traffic face of lattice type railing, and then installed W. Beam in front of the angle.

No Response: AR, DC, GA, HI, IN, IA, KS, MS, [NE], NV, NM, OH, WA, MB, NB, NS

QUESTION 9:

What methods have you used to deal with the presence of lead based paints on historic steel truss bridges:

Remove old lead paint (with appropriate disposal techniques) and repaint bridge: AK, AL, AZ, CA, CT, DE, FL, GA, IN, IA, KY, MN, MO, NH, NJ, NM, NY, OH, OK, RI, TN, VT, WA, AB, MB, NB, NS

Apply sealer to encapsulate lead based paint: AZ, CT, IN, KY, MO, NH, NM, OH, OK, RI, TN, WA, AB

Other:
AZ: Considered or proposed. Also considered scrape bad areas with proper containment (partial removal) and overcoat.
Cedar Canyon Bridge - existing members were steam cleaned and painted over.
CA: Preventive Maintenance painting is also used to overcoat existing coating.
CT: Sealers are not used anymore
KS: We have no trusses on the State Highway System now classified as historic, but if we did we would recommend removal with appropriate disposal. The county system has some historic trusses, but they rarely get painted. We would recommend paint removal and appropriate disposal also.
KY: Currently we are hand cleaning loose paint & rust and encapsulating most of our bridges.
MD: We have been successfully using a moisture cured urethane coating that does not require 100% removal or near white cleaning. We remove the existing coating down to sound paint and tight mill scale. Lead abatement, containment, and worker protection is our highest priority.
MN: We have spot painted with primer and top coat.
MO: We have used both systems depending on life expectancy of bridge.
Aluminum or calcium sulfanate overcoats are used for short term bridges.
MT: We tried to let one contract to fully remove the lead paint. The cost was so high that we rejected all bids. We have one more project that we will try full removal on. This will go to contract in early 1998.

NV: Have not yet had to repaint a metal truss bridge.
NM: We have done both. Encapsulation is the most common.
NC: Spot clean (hand tools) and paint as necessary.
OK: A combination of removal and encapsulation. We did removal at the joint regions for the stringers and floor beams and we did full removal for the lower portion of the truss (bottom 10') and encapsulation every where else.
TN: Removal & Repaint: Normal Abrasive blast (SSPC SP-10) of steel followed with an inorganic zinc, epoxy tie coat and a urethane topcoat. Total containment with negative pressure.

Encapsulation: Surface prep. Include pressure washing (3000-4000 psi) existing steel and grinding rusted areas. The waste is collected, tested and disposed according to EPA standards. Overcoating is done with universal primers or epoxy mastics based on existing paint system.
SK: No recent projects. Some repainting projects in the past involved removal of old paint and repainting but without containment. We would have to use different procedures if we were to handle these projects today.

No Response: AR, DC, HI, MS, [NE], NF

QUESTION 10:

Has your department been involved with the rehabilitation of a historic steel truss bridge that has involved a particularly interesting, unique, or innovative approach?

Yes:
CA: Our department administered H.B.R.R. funds on a local agency bridge project where the structure was historic; it was unique in that the bridge was essentially replaced in kind, element by element.

Bridge Name : Deer Creek (#17C-0001) @ Pine St., Nevada City, CA. (Gault Bridge)
Type : Three Hinged Deck Truss Arch (150' Main span)
Date of Construction : 1903
Owner : City of Nevada City
Contact : William Falconi, City Engineer & Project Resident Engineer
Ph. (916) 265-2496
317 Broad St.
Nevada City, CA 95959

CT:

- We replaced the deck of bridge #1487 with precast concrete panels during off peak hours (nightly) to accommodate high traffic flows.
- Some have been left in place but no longer support traffic.
- Route 1?Patchogue River, Westbrook #349. This truss was scheduled for rehabilitation under a painting project. Department of Environmental Planning regulations made the painting cost prohibitive so a larger truss will be built and swapped with the existing. Bob Zaffetti or Sowatei Lomotey (860) 594-3402.
- East Haddam swing bridge #1138 - proposed deck replacement on a 456' swing span. Replacing the existing light-weight concrete filled steel grid with "Alumadeck" (A light-weight extruded aluminum decking system).

FL: Yes, but simply utilizing more advanced analyses.
NM:

- NM -502/ Rio Grande
- San Juan Pueblo Rio Grande Bridge
- Montezuma Bridge
- Old US-66/ Rio Puerco Bridge

  Jose Rojas NMSH&TD Bridge Engineer
  (505) 827-5465

TN: Walnut Street Bridge over Tennessee Rive, Chattanooga, TN
A.G. Lichtenstein & Assoc., Inc.
45 Eisenhower Drive
Paramus, NJ 07652

No (with comments):
AL: Just deck replacement, member replacement and cleaning and painting
AZ: Cedar Canyon Bridge was an innovative solution but was a steel arch not a truss bridge. The bridge is located on US 60 at mile post 323.44 south of ShowLow. Contact James R. Pyne (602) 255-8601
MD: Frederick County in Maryland has performed many ground up restorations of historic trusses. Contact Mr. Tom Meunier, Divsion Chief at (301) 696-2950. Also, Baltimore County, Mayland has rehabbed several trusses. Contact Mr. James Arford, Division Chief at (410) 887-3764. These gentlemen, being directly responsible for the projects should provide you with the information desire. We consult frequently with Mr. Aba G. Lichtenstein of Tenafly, NJ. He can be reached at (201) 567-7381
NY: See the attached article on Stuyvesant Falls Bridge.

Ryan - Biggs Associates P.C.
291 River Street
Troy, New York 12180
Contact : H. Daniel Rogers

Jai B. Kim, P.E., PhD
Bucknell University
Department of Civil Engineering
Lewisburg, Pennsylvania 17837

Phone: (518) 272-6266 Phone: (717) 524-1112

No: AK, AR, DE, DC, GA, HI, IN, IA, KS, KY, MN, MS, MO, MT, [NE], NV, NH, NJ, NC, OH, OK, RI, VT, WA, AB, MB, NB, NF, NS, SK

QUESTION 12:

Additional Comments:

AR: In general, when metal truss bridges are retained for historical purposes vehicular traffic is prohibited.

CA: The most extensive work Caltrans has done was by the Toll Bridge Unit on the San Francisco-Oakland Bay Bridge in 1960-61. The upper deck was designed for H10 with trucks and rail transit on the lower deck. The rails were removed and the decks were converted to 5 lanes each direction. The upper deck was strengthened by adding high strength cover plates to the floor beams and adding stringers between the existing stringers. The decks are lightweight concrete.

IN: Indiana has on the state highway system: 64 steel thru trusses, 22 steel pony truss, 3 deck trusses, 1 Bailey truss. This does not include metal truss bridges on city or county roadways.

KS: The State Highway System had one bridge removed several years ago and had to document, photograph and preserve it in the records. The counties have done this a few times.

MD:

- Replace only those members that do not rate out to desired load. Since most trusses were designed for 100 psf of deck, the top and bottom chords almost always rate out at or higher than H15 in the inventory stress range. Intermediate vertical members typically rate out well above H15 also. Take coupons from batten plates and have them tested for yield strength. The allowable stress derived from the yield values are typically higher than those recommended in AASHTO and other texts. Diagonals, hip verticals and pins are occasionally under capacity as joint loads from concentrated axle loads often exceed those resulting from the original, uniform design load even when using higher allowable values.
- Consider using glue-laminated timber decking in the replacement deck. This type of deck matches or exceeds the life span of plank decking, is typically less thick and therefore lighter than plank decking and virtually eliminates debris and moisture build-up on the steel framing below.
- When replacing the existing stringers, design the new ones as continuous. The design is slightly more economical and adds an additional level of redundancy to the bottom chord.

- Reuse the floorbeams by bolting channels to their weds provided they are in good condition. Floor beams will typically fail in bending due to axle loads not originally designed for. However, when you decide to replace the floorbeams, it becomes necessary to dismantle the bottom diagonal bracing and the U-hangers to the pins. By salvaging the floorbeams the overall project cost can be reduced and the number of original members to be incorporated in the rehabilitated structure increased.
- Try to salvage pins. Ultrasonically test them beforehand to verify that excessive wear or grooving is not a problem. Rate them for bending and shear. We typically increase the allowable stress by 50% over what was determined by testing batten plate material.
- Avoid truss disassembly as much as possible. Many trusses are especially unique as a result of odd details which are often destroyed in the dismantling process. The contractor's methods must be careful reviewed to ensure that in the process of completing necessary repairs, the integrity of these details is not compromised.

MS: Sorry that we could not be of help.

MT: We have rehabilitated 2 truss bridges but have several more in the future. We look forward to your final report.

NM: We've had a fair amount of discussion about these bridges lately. We've mainly been building a parallel new bridge & rehabilitating the existing bridge for pedestrian and horses. We've tried to build up a large enough bank of this type of bridge so that we can remove & destroy the existing bridge where building a parallel bridge isn't possible.

NY: A list of persons that nay provide additional information follows:

Abba Lichtenstein	William P. Chamberlain
26 Trafalgar St.	1046 Shave Court
Tenafly, New Jersey	Schenectady, New York 12303
07670	Project Manager NCHRP Topics 28-08
	"Historic Highway Bridge Preservation Practices"

NC: There are approximately 100 truss bridges in North Carolina most of which are small 1 lane bridges. Fifty of these are scheduled to be replaced within the next 5 or 6 years. Only 5 truss bridges are of any size (i.e. large), and are not scheduled for replacement or repair.

VT: We have had a consultant study done on approximately 110 truss bridges. This study, at a cost of approx. $10,000 per bridge, did not include a detailed structural capacity study of each bridge but did give overall recommendations for each site. Enclosed is a copy of a draft of one report. Obviously, it is not practical to send you a copy of all 110 reports, but this one will give you an idea of what was done.

WA: [on enclosed letter]

Our Department commissioned a multi-discipline independent team (GAER-Historic American Engineering Record) to conduct a Historic Washington Bridge Recording project i 1993 that documented 30 of the most historically significant bridges in the state. The majority of these historic bridges have steel truss construction and pre-date 1940. While “historic” rehabilitation has not been commonplace, timely maintenance and painting of mainspans to extend bridge service life; such a project is currently under development for the 1911 City Waterway Bridge in the city of Tacoma, Washington.

Aside from providing redundancy to certain fracture critical bridge elements, and replacement of deteriorated decks (and some steel members where section loss due to corrosion warrants), our Department does not have a policy or program to perform bridge strengthening to improve live load capacity. The Department does not have guidelines regarding the preservation of historically aesthetic features of these older steel structures (such as ornamental rails).

NF: We have no historic steel trusses on the present Highway System - just some trusses built in the sixties which are in the main galvanized and have served us well. However we have a now deficient railway with many trusses. These are now the responsibility of the Province and this is why we have an interest in rehabilitation of old trusses. Some of these trusses could be classed as historic.