FEDERAL HIGHWAY ADMINISTRATION

BRIDGE INSPECTION TRAINING SPECIFIC TO GUSSET PLATES

(10 pages including this cover sheet)

NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF HIGHWAY SAFETY
WASHINGTON, D.C. 20594

FEDERAL HIGHWAY ADMINISTRATION
BRIDGE INSPECTION TRAINING SPECIFIC TO GUSSET PLATES

A. ACCIDENT

NTSB #: **HWY-07-MH-024**

Date and Time:	August 1, 2007 at 6:05 p.m.
Description:	Interstate 35W Bridge collapse
Location:	Interstate Highway 35W Bridge over the Mississippi River, Minneapolis, Hennepin County, MN.
Fatalities:	13
Injuries:	145

B. REPORT GROUP

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C. ACCIDENT SUMMARY

About 6:05 p.m. (CDT), on Wednesday, August 1, 2007, the 35W Interstate Highway Bridge over the Mississippi River, in Minneapolis, Minnesota experienced a catastrophic failure in the main span of the deck truss portion of the 1907-foot-long bridge. As a result, approximately 1,000 feet of the deck truss collapsed with about 456 feet of the main span falling into the river. An assessment of the gusset plates within the deck truss revealed that the connections at U10, U10 prime, L11 and L11 prime were under-designed. The bridge was comprised of eight traffic lanes, with four lanes in each direction. At the time of the collapse, a roadway construction project was underway that resulted in the closure of two northbound and two southbound traffic lanes causing traffic queues on the bridge. A total of 111 vehicles were documented as being on the portion of the bridge that collapsed. Of these, 17 vehicles were recovered from the water. As a result of the bridge collapse, 13 people died and 145 people were injured.

D. DETAILS OF THE REPORT

This report examines the currently available training material and guidance provided by the Federal Highway Administration (FHWA) regarding the inclusion of information specific to the evaluation and condition rating for gusset plates on steel truss bridges. Additionally, information regarding a FHWA technology initiative program designed to educate bridge inspectors on how to better utilize Non-Destructive Examination (NDE) techniques is also presented. Due to the specific nature of this report, it is not intended to provide an overview or assessment of current bridge inspection training programs or practices.

1. EXISTING TRAINNG INFORMATION

1.1 Bridge Inspector's Reference Manual

The Bridge Inspector's Reference Manual[1] *(BIRM)*, contains information for bridge inspectors about the different programs, procedures, and techniques for inspecting and evaluating various types highway bridges. The BIRM is used as a basis for the National Highway Institute's (NHI) three-week training program for bridge inspections. This program is comprised of a one-week course, "Engineering Concepts for Bridge Inspectors[2]," and a two-week course, "Safety Inspection of In-Service Bridges[3]". When combined, both of these courses meet the Federal Highway Administration's (FHWA) definition of a comprehensive training program in bridge inspection as defined in the National Bridge Inspection Standards.

The BIRM is divided into 13 sections, each dealing with a specific concept or evaluation area. Additionally, the manual includes a primer dealing with basic concepts. For this report, excerpts from the following sections are presented:

- Section 2, Bridge Materials (Topic 2.3 Steel)
- Section 8, Inspection and Evaluation of Common Steel Superstructures (Topic 8.1 Fatigue and Fracture in Steel Bridges)
- Section 8, Inspection and Evaluation of Common Steel Superstructures (Topic 8.6 Steel Trusses)

1.1.1 BIRM Topic 2.3 – Steel

Information pertinent to the properties of steel and other related aspects such as deterioration and inspection procedures are presented within this topic area. As such, this section was evaluated for content relating to gusset plate distortion or other information that would direct an inspector to specifically consider further evaluation regarding gusset plate bowing or deformation. While no explicit information was found that was specific to gusset plates, there were several areas related to distortion and deformation.

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[1] Volume One Publication Number FHWA NHI 03-001, and Volume Two Publication Number FHWA NHI 03-002, October 2002, revised December 2006 (applicable to both volumes).
[2] National Highway Institute Course No 130054
[3] National Highway Institute Course No 130055

1.1.2 BIRM Topic 2.3.5 – Types and Causes of Steel Deterioration

In this topic area, "*fatigue cracking*" related to distortion is presented as follows:

> *There are two basic types of bending in bridge members: in-plane and out-of-plane. When in-plane bending occurs, the cross section of the member resists the load according to the design and undergoes nominal elastic deformation. Out-of-plane bending implies that the cross section of the member is loaded in a plane other than that for which it was designed and undergoes significant elastic deformation or distortion. More correctly, out-of-plane bending should be referred to as out-of-plane distortion. Out-of-plane distortion is common in beam webs where transverse members, such as floorbeams, connect and can lead to fatigue cracking*[4].

Within this section, the material is presented in general terms designed to familiarize an inspector with the condition of bending. Here, floorbeams are the only types of bridge members specifically identified. This topic area also contains information regarding *"overloads"*, which is presented as follows:

> *Overloads are loads that exceed member or structure design loads. Steel is elastic (i.e., it returns to the original shape when a load is removed) up to a certain point, known as the yield point (see Topic P.2). When yield occurs, steel will bend or elongate and remain bent or elongated after the load has been removed. This type of permanent deformation of material beyond the elastic range is called plastic deformation. Plastic deformations due to overload conditions may be encountered in both tension and compression members.*
>
> *The symptoms of plastic deformation in tension members are:*
>
> - *Elongation*
> - *Decrease in cross section, commonly called "necking down"*
>
> *The symptoms of plastic deformation in compression members are:*
>
> - *Buckling in the form of a single bow*
> - *Buckling in the form of a double bow or "S" type, usually occurring where the section under compression is pinned or braced at the center point*
>
> *An overload can lead to plastic deformation, as well as complete failure of the member and structure. This occurs when a tension member breaks or when a compression member exhibits buckling distortion at the point of failure*[5].

Similar to the topic of fatigue cracking, the information is presented in a general context regarding compression and tension members and is not intended to direct an inspector to a specific bridge member such as a gusset plate.

[4] BIRM, page 2.3.8
[5] BIRM, page 2.3.9

1.1.3 BIRM Topic 8.1.2 – Failure Mechanics

In this topic area, the *"Types of Fractures"* are presented and their relation to plastic deformation is also discussed as follows:

> *Ductile Fracture - Generally preceded by local plastic deformation of the net uncracked section. This plastic deformation results in distortion of the member, providing some visual warning of the impending failure[6].*

The information regarding deformation of bridge members is presented in general terms that would direct an inspector to examine any applicable deformation, but nothing uniquely directed toward gusset plates.

1.1.4 BIRM Topic 8.1.8 – Inspection Procedures and Locations

This topic area discusses issues specific to a Fracture Critical Member[7] (FCM). References are made to gusset plates at lateral bracing locations but the topic does not bring specific attention to gusset plates at panel points along the main chord members[8]. The information is presented as follows:

> *When a deficiency is encountered in a FCM, all relevant information should be recorded carefully and thoroughly, including:*
>
> - *The type of deficiency, such as cracks, notches, nicks, or gouges, defects in welds, excessive corrosion, or apparent distortion, mislocation, or misalignment of the member*
> - *Any noticeable conditions at cracks when vehicles traverse the bridge, such as opening and closing of the crack or visible distortion of the local area[9]*

And:

> *For out-of-plane distortion, inspect the following locations:*
>
> - *Girder webs at floorbeam and diaphragm connections*
> - *Ends of diaphragm connection plates in girder bridges*
> - *Box girder webs at diaphragms*
> - *Lateral bracing gusset plates on girder webs at floorbeam connections*
> - *Floorbeam and cantilever bracket connections to girders*
> - *Pin connected hanger plates and fixed pin plates[10]*

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[6] BIRM, page 8.1.8

[7] *Fracture critical member (FCM).* A steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse.

[8] Typically, connection components, such as gusset plates in the primary trusses of a two truss bridge, would be classified as fracture critical. As such, the guidance in the BIRM should apply to these gussets in the same manner as it would to any other FCM.

[9] BIRM, page 8.1.46

[10] BIRM, page 8.1.53

1.1.5 BIRM Topic 8.6.4 – Inspection Procedures and Locations

This topic area discusses issues related to Truss Bridges.

> *Tension Members*
>
> *For truss members subjected to tensile loads, special attention should be given to the following locations:*
>
> - *Check for section loss (corrosion) and cracks.*
> - *A member may not be acting as designed such as a buckled bottom chord member in s simply supported truss. Try to determine the cause of different loading and look at adjacent members. They may be overstressed*[11].

And:

> *Compression Members*
>
> *For truss members subjected to compressive loads, special attention should be given to the following locations:*
>
> - *End posts and web members, which are vulnerable to collision damage from passing vehicles. Buckled, torn, or misaligned members may severely reduce the load carrying capacity of the member.*
> - *Check for local buckling, an indication of overstress.*
> - *Wrinkles or waves in the flanges, webs or cover plate are common forms of buckling*[12].

Also, within this topic area a discussion regarding the floor system contains the following information and guidance:

> *Floor System*
>
> *The floor system on a truss contains floorbeams and, possibly, stringers. These members function as beams and are subjected to bending, shear and out-of-plane bending stresses. Distortion induced fatigue cracks have also developed in the webs of many floorbeams at connections to truss bridge lower chord panel points when the stringers are placed above the floorbeams. The webs of these floorbeams at the connections and adjacent to flanges and stiffeners need to be inspected routinely*[13].

As with other sections in the manual, the presentation of material is designed to provide an inspector with a general knowledge of conditions such as corrosion (section loss) and buckling, as well as where and how these conditions may be detected. Additionally, the material discusses areas warranting special attention. Attention is given to the members and to specific locations such as the floor system, but nothing in the material specifically addresses gusset plates.

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[11] BIRM, page 8.6.27
[12] BIRM, page 8.6.32
[13] BIRM, page 8.6.34

The Inspection Procedures and Locations topic area also contains information on other members and problem locations. These discussions are as follows:

> *Secondary Members*
>
> *Investigate the diaphragms, if present, and the connection areas of the lateral bracing for cracked welds, fatigue cracks, and loose fasteners. Check the lateral bracing gusset plates for corrosion. These horizontal plates typically deteriorate more rapidly than other elements on a truss because they are exposed to, and retain, moisture and deicing salts. Inspect the bracing members for any distortion, or corrosion and rust packing. Distorted or cracked secondary members may be an indication the primary members may be overstressed or the substructure may be experiencing differential settlement*[14].

And:

> *Areas that Trap Water and Debris*
>
> *Check horizontal surfaces that can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration. Areas that trap water and debris can result in active corrosion cells and excessive loss in section. This can result in notches susceptible to fatigue or perforation and loss of section.*
> *On steel truss bridges check:*
>
> - *lateral bracing gusset plates*
> - *inside built-up chord members (horizontal surfaces)*
> - *areas exposed to drainage runoff*
> - *pockets created by floor system connections*
> - *tightly packed panel points*
> - *pin and hanger assemblies*
> - *bottom flanges of chord members and floor system*[15]

Here, the emphasis regarding secondary members appears to be the propensity of horizontal plates to succumb to corrosion. Additionally, information is provided to other areas that are susceptible to trapping water and debris and "tightly packed panel points" are defined as being one of those areas. While this is applicable to gusset plates there is no guidance as to what constitutes such a condition within a panel point.

[14] BIRM, page 8.6.45
[15] BIRM, page 8.6.47

2. NATIONAL HIGHWAY INSTITUTE

The two-week training course, *Safety Inspection of In-Service Bridges* is a component of the FHWA's training program for bridge inspections within the National Bridge Inspection Standards. This course is provided to bridge inspectors by the National Highway Institute (NHI), which through the FHWA is responsible for training and education. The NHI was established by Congress in 1970, to provide training, resource materials, and educational opportunities to personnel involved in surface transportation. The mission of the NHI is:

> *To educate, train, and develop the current and future transportation workforce to improve the safety, efficiency, effectiveness, and quality of America's surface transportation system. We actively pursue partnerships with public and private organizations and educational institutions to more effectively meet our mission goals.*

As described in section one of this report the Bridge Inspector's Reference Manual is used as the primary reference for the NHI course on Safety Inspection of In-Service Bridges. The Instructors Guide[16] and the Participant's Workbook[17] were both examined for references specific to gusset plate corrosion or deformation. The applicable guidance presented in the NHI material was the same as what was found in the BIRM.

Another course provided by the NHI is *Fracture Critical Inspection Techniques for Steel Bridges*[18]. This three and one half day long course includes training and hands-on workshops for nondestructive testing equipment as well as a case study on preparing an inspection plan for a fracture critical bridge. The course curriculum also includes inspection procedures and reporting for common fracture critical members, such as problematic details, I-girders, floor beams, trusses, box girders, pin and hanger assemblies, arch ties, eyebars, and cross girders/pier caps.

The Instructors Guide[19] and the Participant's Workbook[20] for this training course were both examined for issues specific to gusset plates. Each set of training material contained general references to gusset plates and the most significant finding for plates at panel points was found under *Session 4, Topic 3, Inspection Procedures: Trusses*. This topic area contained the following paragraph:

> *Gusset Plates - The other mechanical connection common on truss members is their connection at the* ***truss panel points****. If not pin connected,* ***gusset plates*** *are used to transfer loads at panel points. A positive connection can be made using* ***rivets, bolts*** *or a combination of both. During inspection, the fasteners and the surrounding gusset plate area should be examined closely.*

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[16] Publication Number NHI 03-005 (volume 1) and NHI 03-006 (volume 2), October 2002
[17] Publication Number NHI 03-004, October 2002
[18] NHI Course Number 130078
[19] Publication Number FHWA-NHI 02-036, January 2002, Revised August 2003, March 2006
[20] Publication Number FHWA-NHI 02-036, January 2002, Revised August 2003, March 2006

3. FHWA TECHNOLOGY INITIATIVE

In Section 8 of the BIRM, *Inspection and Evaluation of Common Steel Superstructures*, Topic Area 8.1.8 discusses *Inspection Procedures and Locations*. Within this section, under the subsection of *Procedures*, the following guidance is presented:

> *The inspection of steel bridge members for defects is primarily a visual activity. Most defects in steel bridges are first detected by visual inspection. In order for this to occur, a hands-on inspection, or inspection where the inspector is close enough to touch the area being inspected, is required. More exact visual observations can also be employed by cleaning suspect areas, removing paint when necessary, and using a magnifying unit.*

There is additional material related to inspection practices, and this topic area includes a list of *Advanced Inspection Techniques*. However, these techniques are included to educate the inspector of other methods that may be employed to enhance their findings beyond a visual inspection. The manual does not go into detail concerning their use, benefits or limitations.

Following the I-35W Bridge collapse, significant attention was focused on the procedures and tools used for inspecting bridges. To address concerns regarding bridge inspection technology, a group representing the various bridge program offices within the FHWA met and mapped out short and long-term plans for improving the tools and approaches available to bridge owners for inspecting and assessing their highway structures, and for educating and training owners and field personnel on the availability and application of these technologies.

Among the short-term initiatives was the development of the FHWA **B**ridge **I**nspector's **N**DE **S**howcase (BINS)[21]. This one-day training program was developed to demonstrate five advanced bridge evaluation and inspection tools that are commercially available, but may be under-utilized in many State bridge inspection programs. The BINS training is targeted at both the managers of a bridge inspection program, and the inspectors in the field. The training is intended to provide an opportunity for managers and inspectors to become familiar with each of these five technologies, two of which are focused on steel bridge components and three on concrete bridge components. The training also demonstrates how each tool can be used in the field, the type of information each provides, as well as their strengths and limitations for different bridge inspection and detailed assessment situations. The five technologies presented in the BINS are:

[21] NDE is defined as Nondestructive Evaluation.

- **Eddy Current (EC)**
  Utilizes electromagnetic induction to assess surface flaws, material thickness, and coating thickness. Typically used on metals with painted or untreated surfaces.

- **Ultrasonics (UT)**
  Utilizes high frequency sound energy to assess flaws (surface and subsurface) and make dimensional measurements. Typically used on metals with untreated or cleaned surfaces.

- **Infrared Thermography (IR)**
  Measures of the amount of infrared energy emitted by an object to calculate temperature. Typically used to assess deterioration damage, surface and subsurface flaws, and moisture intrusion.

- **Impact Echo (IE)**
  Utilizes impact generated stress waves to assess subsurface flaws and material thickness in concrete and masonry.

- **Ground Penetrating Radar (GPR)**
  Utilizes electromagnetic waves to assess subsurface flaws and to image embedded reinforcement or tendons in concrete, asphalt, timber or earthen structures.

At the time of this report, the BINS has been pilot tested with the New York State Department of Transportation and based on their feedback is being revised before being fully implemented. It is anticipated that BINS will be available for all State departments of transportation by the early fall of 2008.

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