CORRODED GUSSET PLATES ON OHIO BRIDGES

FACTUAL REPORT

(8 pages including this cover sheet)

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

CORRODED GUSSET PLATES ON OHIO BRIDGES FACTUAL REPORT

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

The Ohio Department of Transportation (ODOT) has previously experienced incidents where extensive corrosion and related section loss of gusset plates on two steel truss bridges required intervention by the ODOT for the bridges to remain open to traffic. The first incident occurred in 1996 when a gusset plate on the eastbound Lake County Bridge over the Grand River failed as maintenance crews were working on the structure. The second instance took place in 2007 and involved emergency repairs to the Innerbelt Bridge over the Cuyahoga River Valley. In this report, the corrosion issues associated with each bridge and the actions and events initiated by the subsequent section loss will be presented. Additionally, inspection issues for each structure, as well as the Ohio bridge inspection program and qualifications of bridge inspectors were examined.

1. LAKE COUNTY GRAND RIVER BRIDGES

1.1 BRIDGE DESCRIPTION

The Lake County Grand River Bridges[1] were twin structures located approximately 30 miles east of Cleveland, in Lake County, Ohio. Each structure was comprised of five spans totaling 863 feet. Spans #1 and #5 were 75-foot-long simply supported approach spans. Spans #2, #3, and #4 were approximately 208, 297, and 208 feet respectively. Spans #2 and #4 were arched cantilevered deck trusses supporting a suspended truss section in span #3.

Each structure was comprised of two traffic lanes for Interstate 90 and incorporated a deck width of 44 feet. The bridges were designed in 1958[2] and the project was constructed and the bridges opened to traffic in 1960. The design consultant of record was Capitol Engineering Associates, Dillsburg, PA

1.2 GUSSET PLATE FAILURE

On Friday, May 24, 1996, the structure carrying eastbound traffic experienced a gusset plate failure. At the time of the failure, contractors were proceeding with a maintenance project to repaint the bridge. Vehicles and equipment related to the painting project were occupying the right shoulder of the structure in the area over node L8 prime. To facilitate the project, a temporary work zone had been established by closing the right lane and shoulder to traffic. However, the left lane remained open allowing vehicular traffic access on the bridge. The gusset plates reportedly buckled when a truck drove across the bridge in the left eastbound lane.

The inner and outer 7/16-inch thick gusset plates of both truss lines of the bridge carrying eastbound traffic buckled causing a 3-inch lateral displacement, which in turn allowed the compression members at the connections to move downward about 3-inches. The failure occurred at node L8 prime on each truss line and comprised two gusset plates at each node for a total of four gusset plates.

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[1] Identified in the Ohio Department of Transportation Bridge Inventory as LAK-90-2342 L&R.
[2] The plan sheets had been signed and dated in July and August of 1958.

Following the failure, the bridge was closed to traffic and an investigation was initiated by the ODOT. The source of the failure was attributed to corrosion resulting in significant section loss that had penetrated completely through the plates at some locations. The investigation revealed that the extent of the corrosion had not been adequately assessed through visual inspections. ODOT reported that a leaking joint above panel point U9 prime had allowed salt contaminated water to run down diagonal U9 prime - L8 prime to the lower chord gusset plates. The years of corrosive run-off had allowed crevice corrosion and the byproduct of the corrosion had manifested itself in thin sheets of layered rust. Additionally, oxygen rich corrosion cells had started to take root along the vertical faces at the inside of the gusset plates. The blooms of oxidation concealed the perforations in the base metal and the result was a line of section loss that rendered the load capacity of the gusset plates incapable of handling the additional loads created by the maintenance project on the day of the failure.

1.3 POST - FAILURE EVENTS

The ODOT notified the Ohio Division Office of the FHWA regarding the incident. As a result, assistance was provided through the FHWA's Turner Fairbank Highway Research Center, where a failure analysis of the structure was preformed. The ODOT also solicited assistance from other parties including Richland Engineering Limited, which also conducted an independent analysis of the gusset plates.

Post-failure analysis revealed that many gussets did not adhere to the code requirements for unsupported edge lengths. In addition to this, at other connections, the members were not mitered causing a condition where excessive plate length was left in the middle where the member centerlines met. Calculations performed by ODOT revealed that other members had excessive unbraced lengths for the Whitmore stress block[3]. A finite element analysis (FEA) was conducted by the Federal Highway Administration (FHWA) on the as-built condition of the failed gusset plates. The FHWA analysis concluded that:

> ...the design thickness of the original gusset plate was marginal, at best, and its load carrying capacity was further exacerbated by loss of section due to corrosion…

In addition to the emergency repairs to the four corroded L8 prime gusset plates on the eastbound bridge, a plan was developed to add stiffeners to 92 other gusset plates. For each bridge, a total of 46 gusset plates were modified by adding stiffeners resulting in a combined total of 96 repaired gusset plates for both bridge structures. The four L8 prime gusset plates on both truss lines of the eastbound structure were the only gusset plates that required the replacement of structural material.

[3] Whitmore, R.E. 1952. Experimental Investigation of Stresses in Gusset Plates. Bulletin No. 16, Engineering Experiment Station, University of Tennessee.

Information about the gusset plate failure was presented during a technical session[4] of the 1997 *International Bridge Conference* held in Pittsburg, Pennsylvania. Additionally, an article on the subject was published in the September 1997 issue of *Civil Engineering Magazine*[5].

According to personnel from the FHWA, no follow-up actions or advisories were issued by the agency. The failure of the gusset plates was attributed to section loss resulting from corrosion and bridge inspection standards were already in place mandating the examination of structures for this type of condition.

2. <u>CUYAHOGA COUNTY INNERBELT BRIDGE</u>

2.1 BRIDGE DESCRIPTION

The Innerbelt Bridge[6] was located in Cleveland, Cuyahoga County, Ohio, and spanned the Cuyahoga River Valley on the north side of the city. The bridge carried eight lanes of Interstate 90 traffic thru the downtown area.

Including the approach spans, the overall length of the structure was 5,079 feet. The main truss spans were comprised of a reinforced concrete deck with steel curbs, safety walks, and railings; and a concrete safety shape median barrier supported by steel stringers and floor beams carried by nine cantilevered, arched deck truss spans. The total length of the trussed spans was 2,722 feet.

The bridge was designed in 1955[7] and was opened to traffic on August 15, 1959. The design consultant of record was Howard, Needles, Tammen & Bergendoff (HNTB), Cleveland, Ohio

2.2 GUSSET PLATE CORROSION

Unlike the Lake 90 Bridge over the Grand River, the Innerbelt Bridge did not experience a gusset plate failure. However, following a 2007 inspection of the structure the ODOT became extremely concerned about the extent of the corrosion reported on many gusset plates. Additionally, a follow-up evaluation of the structure found multiple gusset plates exhibiting various amounts of deformation

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[4] The presentation was made by personnel from Richland Engineering Limited.
[5] Grand Gusset Failure, Civil Engineering; September 1997; 67, 9, page 50.
[6] Identified in the Ohio Department of Transportation Bridge Inventory as CUY-90-1524.
[7] The plan sheets had been signed and dated in May and June of 1955.

A consultant[8] had inspected the structure in October of 2007. The inner and outer gusset plates at many connections had exhibited crevice corrosion along the vertical face of the gusset plate and the top of the lower chord. Following the inspection, members from the ODOT performed an additional evaluation of the bridge using *Non Destructive Evaluation* (NDE) methods. The structure was comprised of 468 gusset plates and all were measured for section loss. Section loss was determined by using hand-held ultrasonic thickness gauges. The NDE revealed that visual estimates from the original inspection had grossly underestimated the loss of section in the gusset plates. Moreover, at some locations the corrosion was associated with deformation of the gusset plates. The magnitude of the deformation, or bowing, of the gusset plates had been documented by placing a straightedge along the gusset plates at various locations and measuring the gaps between the straightedge and the gusset plate.

2.3 EMERGENCY REPAIR OF GUSSET PLATES

The ODOT immediately initiated an emergency repair program that was completed in April of 2008. To accomplish this, those plates having the most corrosion and greatest amount of section loss were renovated by bolting an additional plate to the outside of the original gusset plate. In all, 21 gusset plate locations were repaired in this manner and these locations were further reinforced by adding stiffening angles to the plates. An additional 12 gusset plate locations were repaired by adding stiffening angles. The ODOT plans to continue addressing the gusset plate problems on the Innerbelt Bridge and additional gusset plates will be strengthened during a project planned for later in 2008.

3. OHIO BRIDGE INSPECTION PROGRAM

3.1 GENERAL DESCRIPTION

The ODOT complies with and participates in the National Bridge Inspection Program as set forth by the FHWA in their National Bridge Inspection Standards (NBIS)[9]. Both ODOT inspectors and private consultants perform bridge inspections within the state of Ohio. For example, during the past 26 years inspections of the Innerbelt Bridge have been performed by a variety of consultants. However, the ODOT plans to use state inspectors for the 2008 inspection.

All bridge inspectors must successfully complete a comprehensive bridge training program. In addition, ODOT conducts annual meeting with all state (ODOT employees) bridge inspector. Due to the cost of the inspection school we have many of the inspectors retake the course, but have no written policy on refresher training requirements.

The ODOT does not have a requirement for bridge inspectors to be a professional engineer. However, when employed by the ODOT consultants typically use professional engineers in the field to conduct inspections. While this is typical for state owned bridges, this is not always the case when a consultant has been hired by a county or other local entity to perform bridge inspections.

[8] Richland Engineering Limited.

[9] For detailed information on the National Bridge Inspection Program and the National Bridge Inspection Standards see the Bridge Design Group Chairman's Factual Report.

3.2 UPDATES TO TRAINING

The ODOT conducts in-house bridge inspection training seminars for all bridge owners and consultants within the state. The ODOT believes there are many benefits gained by addressing their training needs in this manner including:

- Better participation from local bridge owners
- Uniform collection of inspection and inventory information
- Training is focused on Ohio bridges
- Expertise is maintained within the department
- Course content is continuously updated
- Training is free to all participants

The ODOT still must meet regulations within the NBIS. As such, in 2006 the ODOT submitted the course content for their bridge inspection training to the FHWA for their review and approval. FHWA personnel in both the Ohio Division Office and the Office of Bridge Technology in Washington, D.C. reviewed the training material. Both offices approved the course content in early 2007. It is important to note that the material in the submittal packet included information regarding the gusset plate issues the ODOT has encountered.

In response to the Minneapolis I-35W Bridge collapse and the associated FHWA Technical Advisories that have been issued as the investigation has progressed, the ODOT has developed a strategy to inspect and analyze all truss bridge gusset plates by 2010. This strategy includes inspection techniques that have been incorporated from *lessons learned* though their experiences with the Lake County Grand River Bridges and the Cuyahoga County Innerbelt Bridge. The following are excerpts from an ODOT inter-office communication[10] distributed to the District Bridge Engineers within the state:

- The technical advisory warns of design related issues. Prudent analysis of the gusset plates must be accompanied by a field investigation of the existing condition. Field inspection of gusset plates need to focus on corrosion, distortions, and connections.

- Corrosion is the deterioration of the metal due to a chemical or electrochemical reaction with the environment resulting in section loss. Typically, large amounts of section losses can occur along the top of the lower chord. Visual inspection can be impeded from proper evaluation due to debris built-up on the member or from the byproduct of the corrosion process, rust. Areas that trap debris or hold water need to be cleaned adequately to evaluate any section losses. In addition, rust blooms can form on the outside of the plate causing localized pitting. Areas with surface rust should be mechanically cleaned and evaluated. All section losses need to quantified and documented in the inspection report. Section losses can be deceiving when performing a visual inspection. The use of ultrasonic thickness gauges or calipers is highly recommended to determining section losses.

[10] Dated February 24, 2008, authored by Mike Loeffler, P.E., Office of Structural Engineering and distributed through Tim Keller, P.E., Administrator, Office of Structural Engineering.

- Distortion in the gusset plate can be caused by overstressing of the plate due to overloads or inadequate bracing. A straight edge should be used to evaluate and quantify any distortion of the un-braced gusset plate edges between members. An additional area to survey on the gusset plate is located below the compression members. All bows or distortions shall be documented in the inspection report.

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