National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 21, 2008

In reply refer to: H-08-17 through -19

The Honorable Thomas J. Madison, Jr.
Administrator
Federal Highway Administration
1200 New Jersey Avenue, S.E.
Washington, D.C. 20590

About 6:05 p.m. central daylight time on Wednesday, August 1, 2007, the eight-lane, 1,907-foot-long I-35W highway bridge over the Mississippi River in Minneapolis, Minnesota, experienced a catastrophic failure in the main span of the deck truss.[1] As a result, 1,000 feet of the deck truss collapsed, with about 456 feet of the main span falling 108 feet into the 15-foot-deep river. A total of 111 vehicles were on the portion of the bridge that collapsed. Of these, 17 were recovered from the water. As a result of the bridge collapse, 13 people died, and 145 people were injured.

On the day of the collapse, roadway work was underway on the I-35W bridge, and four of the eight travel lanes (two outside lanes northbound and two inside lanes southbound) were closed to traffic. In the early afternoon, construction equipment and construction aggregates (sand and gravel for making concrete) were delivered and positioned in the two closed inside southbound lanes. The equipment and aggregates, which were being staged for a concrete pour of the southbound lanes that was to begin about 7:00 p.m., were positioned toward the south end of the center section of the deck truss portion of the bridge and were in place by about 2:30 p.m.

About 6:05 p.m., a motion-activated surveillance video camera at the Lower St. Anthony Falls Lock and Dam, just west of the I-35W bridge, recorded a portion of the collapse sequence. The video showed the bridge center span separating from the rest of the bridge and falling into the river.

The National Transportation Safety Board determined that the probable cause of the collapse of the I-35W bridge in Minneapolis, Minnesota, was the inadequate load capacity, due to a design error by Sverdrup & Parcel and Associates, Inc., of the gusset plates at the U10 nodes, which failed under a combination of (1) substantial increases in the weight of the bridge, which resulted from previous bridge modifications, and (2) the traffic and concentrated construction loads on the bridge on the day of the collapse. Contributing to the design error was the failure of Sverdrup & Parcel's quality control procedures to ensure that the appropriate main

[1] For more information, see *Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007*, Highway Accident Report NTSB/HAR-08/03 (Washington, DC: NTSB, 2008), which is available on the National Transportation Safety Board website at <http://ntsb.gov/publictn/2008/HAR0803.pdf>.

truss gusset plate calculations were performed for the I-35W bridge and the inadequate design review by Federal and State transportation officials. Contributing to the accident was the generally accepted practice among Federal and State transportation officials of giving inadequate attention to gusset plates during inspections for conditions of distortion, such as bowing, and of excluding gusset plates in load rating analyses.

The predecessor organizations of the Minnesota Department of Transportation (Mn/DOT) and the Federal Highway Administration (FHWA) were closely involved in some aspects of the design process for the I-35W bridge, which began with the bridge design firm's initial designs in 1962 and ended with acceptance of the final design in 1965.

In March 1964, based on Mn/DOT and FHWA concerns, the bridge design firm eliminated T-1 steel from all structural members. This change required a redesign of all the members originally specified as T-1 steel.

The FHWA also took issue with the design of a typical node. The agency was concerned about the lack of symmetry in the rivet patterns and about the configuration of the ends of some of the structural members at the node. The bridge design firm changed the design to address these concerns.

Although both Mn/DOT and the FHWA were closely involved with some specific features of the I-35W bridge design, neither organization detected the failure to perform the appropriate design calculations for the gusset plates in the main trusses. At that time, Mn/DOT had design review procedures that provided for checking of consultants' computations—but these procedures were not applied to gusset plates. Complex construction projects are often contracted out to design firms, such as Sverdrup & Parcel, because neither the State nor the FHWA has sufficient resources. This same lack of resources causes State and Federal authorities to rely on the stamp of a professional engineer to certify that all design computations are appropriate, complete, and accurate. The Safety Board concludes that neither Federal nor State authorities evaluated the design of the gusset plates for the I-35W bridge in sufficient detail during the design and acceptance process to detect the design errors in the plates, nor was it standard practice for them to do so.

This investigation revealed a number of other instances, not involving gusset plates, in which questionable bridge designs have been certified by a designer and reviewed and approved at both the State and Federal levels. For example, of the 14 State departments of transportation surveyed by the Safety Board with regard to their design review and approval processes, 10 acknowledged having approved bridge designs that were later found to be deficient. All but one of these deficient designs had been approved within the past 10 years, most within the past 6 years. The design errors ranged from girder sections that had substandard capacity due to errors in design calculations, to incorrect loading assumptions in the design of box girders, to inaccurate shop drawings. In most cases, the errors were revealed during initial construction; however, in one case, a deficiency was not discovered until the bridge had been in service for several years. In each case, redesigns or retrofits were required to address the errors. The Safety Board concludes that current Federal and State design review procedures are inadequate to detect design errors in bridges.

The number of deficient bridge designs identified through the Safety Board's relatively limited sampling suggests that design errors in bridges are not restricted to a particular bridge type, a particular State, or a particular time frame, and instead reflect a deficiency in the processes used for reviewing and approving the designs. The Safety Board believes that the FHWA should develop and implement, in conjunction with the American Association of State Highway and Transportation Officials (AASHTO), a bridge design quality assurance/quality control program, to be used by the States and other bridge owners, that includes procedures to detect and correct bridge design errors before the design plans are made final; and, at a minimum, provides a means for verifying that the appropriate design calculations have been performed, that the calculations are accurate, and that the specifications for the load-carrying members are adequate with regard to the expected service loads of the structure. The Safety Board notes that, as a result of this accident, Mn/DOT has revised its *LRFD* [load and resistance factor design] *Bridge Design Manual* to require an independent review of all major bridges designed by consultants.

The I-35W bridge was only one of a number of steel truss bridges that were found to have gusset plate corrosion and section loss that had been overlooked or underestimated by State bridge inspectors. In 1996, gusset plates on the eastbound Lake County Grand River bridge in Ohio failed while the bridge was undergoing maintenance. The failure was attributed to corrosion and section loss, which had completely penetrated the gusset plates at some locations. The amount of section loss had been masked by corrosion products to the extent that it could not be adequately assessed solely through visual bridge inspections.

Similarly, the Ohio Department of Transportation discovered in October 2007 that visual inspections of the gusset plates on the Cuyahoga County Innerbelt bridge in Cleveland had significantly underestimated the amount of section loss. The actual degree of section loss in the gusset plates was determined only through the use of nondestructive evaluation methods, specifically hand-held ultrasonic thickness gauges.

More recently, in the wake of the collapse of the I-35W bridge, Mn/DOT conducted detailed inspections and analyses of 25 other truss bridges in the State and found significant corrosion and section loss on the Highway 43 bridge in Winona, Minnesota. The amount of section loss in some of the plates was sufficient to prompt Mn/DOT to close the bridge until an analysis could be performed to determine the safe capacity of the bridge in light of the deteriorated gusset plates. A fracture-critical inspection had been completed on this bridge on August 1, 2007, the day the I-35W bridge collapsed. The report of this inspection noted severe deterioration in some of the gusset plates but nonetheless concluded that the bridge had no critical structural deficiencies. The report recommended that some cracked welds in the bottom chord of the deck truss be monitored during future inspections, but it made no recommendation for more frequent or in-depth inspection or monitoring of the deteriorated gusset plates.

A routine inspection of the bridge in Winona had been conducted less than 4 months before the fracture-critical inspection, but it too had identified no critical findings with regard to the bridge superstructure. The report did note the presence of rust between some of the gusset plates and their steel members but concluded that "the connections are still functioning." Although this statement was accurate in that the bridge had not fallen, the Safety Board is concerned that inspectors did not attempt either to address the reduction in load-carrying

capacity that might have resulted from the existing section loss or to assess the potential effects of any further deterioration of the gusset plates.

The detection of corrosion in gusset connections is often hampered by the configuration of the connection. The insides of gusset plates, which are perhaps the most susceptible to corrosion, are often difficult to inspect visually even if a concentrated effort is made beforehand to clean or remove debris from the connection. Further, when corrosion is found, its surface appearance often belies the actual amount of section loss that has occurred. Thus, State departments of transportation whose inspectors rely solely on visual examination to quantify the amount of corrosion on gusset plates or to assess its potential to weaken the connection do not have sufficient information to make accurate quantifications or assessments. The Safety Board therefore concludes that because visual bridge inspections alone, regardless of their frequency, are inadequate to always detect corrosion on gusset plates or to accurately assess the extent or progression of that corrosion, inspectors should employ appropriate nondestructive evaluation technologies when evaluating gusset plates.

The Safety Board believes that the FHWA should require that bridge owners assess the truss bridges in their inventories to identify locations where visual inspections may not detect gusset plate corrosion and where, therefore, appropriate nondestructive evaluation technologies should be used to assess gusset plate condition.

The primary guidance document for bridge inspectors is the FHWA *Bridge Inspector's Reference Manual.* A number of topics and subtopics in the manual are applicable to the inspection of steel truss bridges. Although these sections address types of steel and steel deterioration, steel failure mechanics, and procedures and locations for inspecting bridge structural members, including fracture-critical members, none of them specifically refer to gusset plates on main truss members.

The minimum qualifications for bridge inspectors, including the requirements for experience and training, are spelled out in the National Bridge Inspection Standards. All bridge inspection project managers and team leaders must complete a bridge inspection training program approved by the FHWA. The National Highway Institute provides a 3-week training program for bridge inspectors that consists of a 1-week "Engineering Concepts for Bridge Inspectors" course and a 2-week "Safety Inspection of In-Service Bridges" course. When combined, these courses, which are based on the *Bridge Inspector's Reference Manual*, meet the requirements for a comprehensive training program as defined in the National Bridge Inspection Standards. The National Highway Institute also offers a 3.5-day course for bridge inspectors, "Fracture Critical Inspection Techniques for Steel Bridges."

Safety Board investigators reviewed the training materials for these courses and found only a few, very general references to gusset plates. None of the materials emphasized the importance of gusset plates as structural members or identified deficiencies, such as distortion, that should be of particular concern to inspectors. This lack of emphasis on gusset plates in the FHWA primary bridge inspection reference document and in the National Highway Institute training courses could, in part, explain the apparent lack of due attention to gusset plate condition exhibited by bridge inspectors in several States and identified during this accident investigation. The Safety Board concludes that the lack of specific references to gusset plates in the *Bridge*

Inspector's Reference Manual and in National Highway Institute bridge inspector training courses could cause State bridge inspectors during routine or fracture-critical bridge inspections to fail to give appropriate attention to distortions, such as bowing, in gusset plates.

The Safety Board believes that the FHWA should modify the approved bridge inspector training as follows: (1) update the National Highway Institute training courses to address inspection techniques and conditions specific to gusset plates, emphasizing issues associated with gusset plate distortion as well as the use of nondestructive evaluation at locations where visual inspections may be inadequate to assess and quantify such conditions as section loss due to corrosion; and, (2) at a minimum, include revisions to reference material, such as the *Bridge Inspector's Reference Manual*, and address any newly developed gusset plate condition ratings in the AASHTO commonly recognized (CoRe) structural elements.

As a result of its investigation, the National Transportation Safety Board makes the following recommendations to the Federal Highway Administration:

> Develop and implement, in conjunction with the American Association of State Highway and Transportation Officials, a bridge design quality assurance/quality control program, to be used by the States and other bridge owners, that includes procedures to detect and correct bridge design errors before the design plans are made final; and, at a minimum, provides a means for verifying that the appropriate design calculations have been performed, that the calculations are accurate, and that the specifications for the load-carrying members are adequate with regard to the expected service loads of the structure. (H-08-17)
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> Require that bridge owners assess the truss bridges in their inventories to identify locations where visual inspections may not detect gusset plate corrosion and where, therefore, appropriate nondestructive evaluation technologies should be used to assess gusset plate condition. (H-08-18)
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> Modify the approved bridge inspector training as follows: (1) update the National Highway Institute training courses to address inspection techniques and conditions specific to gusset plates, emphasizing issues associated with gusset plate distortion as well as the use of nondestructive evaluation at locations where visual inspections may be inadequate to assess and quantify such conditions as section loss due to corrosion; and, (2) at a minimum, include revisions to reference material, such as the *Bridge Inspector's Reference Manual*, and address any newly developed gusset plate condition ratings in the American Association of State Highway and Transportation Officials commonly recognized (CoRe) structural elements. (H-08-19)

The Safety Board also issued six new safety recommendations to the American Association of State Highway and Transportation Officials.

In response to the recommendations in this letter, please refer to Safety Recommendations H-08-17 through -19. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our Tumbleweed secure mailbox. To avoid

confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

Acting Chairman ROSENKER and Members HERSMAN, HIGGINS, SUMWALT, and CHEALANDER concurred in these recommendations.

[*Original Signed*]

By: Mark V. Rosenker
Acting Chairman