National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 21, 2008

In reply refer to: H-08-20 through -25

Mr. John Horsley
Executive Director
American Association of State Highway and
Transportation Officials
444 North Capitol Street, N.W.
Suite 249
Washington, D.C. 20001

The National Transportation Safety Board is an independent Federal agency charged by Congress with investigating transportation accidents, determining their probable cause, and making recommendations to prevent similar accidents from occurring. We are providing the following information to urge your organization to take action on the safety recommendations in this letter. The Safety Board is vitally interested in these recommendations because they are designed to prevent accidents and save lives.

These safety recommendations address insufficient bridge design firm quality control procedures, lack of guidance for bridge owners with regard to the placement of construction loads on bridges during repair or maintenance activities, exclusion of gusset plates in bridge load rating guidance, lack of inspection guidance for conditions of gusset plate distortion, and inadequate use of technologies for accurately assessing the condition of gusset plates on deck truss bridges. The recommendations are derived from the Safety Board's investigation of the collapse of the I-35W highway bridge in Minneapolis, Minnesota, on August 1, 2007, and are consistent with the evidence we found and the analysis we performed. As a result of this investigation, the Safety Board has issued nine safety recommendations, six of which are addressed to the American Association of State Highway and Transportation Officials (AASHTO). Information supporting the recommendations is discussed below. The Safety Board would appreciate a response from you within 90 days addressing the actions you have taken or intend to take to implement our recommendations.

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

[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>.

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 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.

Bridge Design Quality Assurance/Quality Control

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 AASHTO should work with the FHWA to develop and implement 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.

Revision of *Manual for Bridge Evaluation*

Bridge load ratings are most commonly performed when relevant changes in condition are observed or when any new weight (dead load) is added to the structure. Initially, the design firm provided Mn/DOT with the capacity for each member in the truss and for both approach spans (however, no data were found regarding the capacity of the gusset plates); this information was most likely used as the basis for the 1979 load rating that was performed in conjunction with the 1977 construction project, which had added dead weight to the bridge. Mn/DOT performed another load rating that coincided with the 1998 modifications to the bridge's median barrier and outside traffic railings. Both of these load ratings were believed to have been conducted in accordance with the National Bridge Inspection Standards and adhered to the requirements for following AASHTO guidance. However, because the guidance did not consider the connections (gusset plates) and did not provide information on how to evaluate gusset plates, the gusset plates were never evaluated over the life of the bridge. In 2007, Mn/DOT instituted a policy under which a load rating must be performed on any new bridge before it is opened to traffic. This requirement is in contrast to AASHTO guidance, which directs bridge owners to load rate their bridges only when a significant change occurs.

Following its opening in 1967, the I-35W bridge became subject to the AASHTO load rating guidance in conjunction with the newly established National Bridge Inspection Standards, which had been put forth in 1971. As a result, Mn/DOT performed the first load rating of the I-35W bridge in 1979, 12 years after the bridge was put into service. Had a load rating been performed before the bridge was opened, and had it included an evaluation of the connections (gusset plates), the design error might have been detected, and this accident would not have occurred. The Safety Board concludes that, because current AASHTO guidance directs bridge owners to rate their bridges when significant changes occur but not before they place new bridges in service, the load-carrying capacity of new bridges may not be verified before they are opened to traffic. The Safety Board believes that AASHTO should revise its *Manual for Bridge Evaluation* to include guidance for conducting load ratings on new bridges before they are placed in service.

Had an evaluation of gusset plate capacity been included in any of these load ratings, the analyses should have revealed the improperly designed gusset plates, but such ratings did not consider the strength of the connections. The Safety Board concludes that, had AASHTO guidance included gusset plates in load ratings, there would have been multiple opportunities to detect the inadequate capacity of the U10 gusset plates of the I-35W bridge deck truss.

The fact that gusset plates were not considered in load ratings is probably reflective of the tendency to assume that they are stronger than the members they connect, an assumption supported by the apparent lack of previous bridge collapses involving gusset plates. This tendency also probably explains why two of the more commonly employed bridge load rating software programs—the Bridge Analysis and Rating System (BARS) and Virtis—do not incorporate the strength of connections in their analyses. The exclusion of variables not considered important to load rating, such as gusset plates, allows programmers and engineers to simplify the analysis without seemingly affecting its accuracy.

As part of the survey of 14 representative State departments of transportation, Safety Board investigators obtained information on the types of bridge load rating computer programs currently in use. (See appendix B of investigation report.) The survey revealed that as many as 15 bridge rating programs, in addition to BARS and Virtis, are in common use. At the time of the collapse, none of these computer programs considered the strength of connections (gusset plates). The assumption that gusset plates are stronger than their members appears to prevail despite the fact that, as indicated in the problem statement to the proposed FHWA–AASHTO joint study of gusset plates, the complex geometry and stress in those connections present bridge engineers with special analytical and design challenges that have not previously been adequately addressed.

The Safety Board is not aware of a previous highway bridge collapse that resulted from improperly designed gusset plates; however, the I-35W bridge had been in service for 40 years before the deficiency became known. If gusset plates are left out of a load rating analysis, bridge owners do not have the opportunity to verify the original design of these critical components or to account for deterioration of the gusset plates, such as might have occurred through corrosion. Had gusset plates been included in the 1979 and 1997 load rating analyses of the I-35W bridge, Mn/DOT might have determined that the gusset plates at U10 and L11 were in fact the weakest points of the bridge. Instead, Mn/DOT believed that the weakest point of the bridge was in the south approach span and not on the truss portion of the bridge. The Safety Board therefore concludes that because bridge owners generally consider gusset plates to be designed more conservatively than the other members of a truss, because AASHTO provides no specific guidance for the inspection of gusset plates, and because commonly used computer programs for load rating analysis do not include gusset plates, bridge owners typically ignore gusset plates when performing load ratings, and the resulting load ratings might not accurately reflect the actual capacity of the structure.

On January 15, 2008, the Safety Board[2] issued the following safety recommendation to the FHWA:

> H-08-1
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> For all non-load-path-redundant steel truss bridges within the National Bridge Inventory, require that bridge owners conduct load capacity calculations to verify that the stress levels in all structural elements, including gusset plates, remain within applicable requirements whenever planned modifications or operational changes may significantly increase stresses.

Safety Recommendation H-08-1 is currently classified "Open—Acceptable Response."

Also on January 15, 2008, the FHWA issued Technical Advisory T 5140.29, "Load-carrying Capacity Considerations of Gusset Plates in Non-load-path-redundant Steel Truss Bridges," which referenced Safety Recommendation H-08-1 and advised bridge owners to take certain actions to supplement the AASHTO *Manual for Condition Evaluation of Bridges*.

[2] As discussed in appendix C of the investigation report, Safety Board accident investigations and the resulting safety recommendations have played a prominent role in the development of Federal bridge inspection requirements and procedures.

For new or replaced non-load-path-redundant steel truss bridges, bridge owners were "strongly encouraged to check the capacity of gusset plates as part of the initial load ratings." For existing non-load-path-redundant steel truss bridges, bridge owners were "strongly encouraged to check the capacity of gusset plates" when performing load ratings as a result of changes in bridge condition or dead load, before making permit or posting decisions, or when necessary to account for bridge alterations that would increase stress levels in the structure. Finally, bridge owners were advised to review previous load rating calculations to ensure that the capacities of gusset plates had been adequately considered.

In May 2008, the FHWA and AASHTO proposed a joint study of gusset plates, with the intent, among other things, of further developing and refining the guidance for bridge engineers in the proper design and rating of gusset plates, and of developing "guidelines, specifications, and examples for the load and resistance factor design and rating of gusset connections."

The Safety Board finds both of these timely responses commendable and takes particular note of the efforts of both the FHWA and AASHTO in providing technical assistance and guidance to FHWA field offices, bridge owners, and State departments of transportation in the load rating and evaluation of gusset plates of steel truss bridges. But while acknowledging the short-term effectiveness of the FHWA technical advisory, the Safety Board is concerned about the long-term implementation of the second action item in the advisory:

> (2) **Future recalculations of load capacity on existing non-load-path-redundant steel truss bridges.** Bridge owners are strongly encouraged to check the capacity of gusset plates as part of the load rating calculations conducted to reflect changes in condition or dead load, to make permit or posting decisions, or to account for structural modifications or other alterations that result in significant changes in stress levels.

In the view of the Safety Board, this guidance would go further in preventing another gusset-plate-related catastrophic bridge collapse if it were codified through rulemaking or through appropriate guidance documents. Because the National Bridge Inspection Standards incorporate by reference[3] the AASHTO *Manual for Condition Evaluation of Bridges*, in 23 *Code of Federal Regulations* 650.313(c), a provision in that manual would have, for State bridge authorities, the force of a regulation. However, though the *Manual for Condition Evaluation of Bridges* was current at the time of the bridge collapse, it has since been replaced by the recently adopted *Manual for Bridge Evaluation*. The Safety Board therefore believes that AASHTO should modify the guidance and procedures in its *Manual for Bridge Evaluation* to include evaluating the capacity of gusset plates as part of the load rating calculations performed for non-load-path-redundant steel truss bridges. The Safety Board further believes that, when the findings of the FHWA–AASHTO joint study on gusset plates become available, AASHTO should update the *Manual for Bridge Evaluation* accordingly.

[3] *Incorporation by reference* is a technique Federal agencies use to include and make enforceable material published elsewhere without republishing those materials in full within the regulations. This technique is typically used to incorporate widely used industry-developed codes and guidance.

Guidelines for Construction Loads and Stockpiled Raw Materials

Mn/DOT specifications required that the low-slump concrete used for the roadway overlay be mixed on site. The quick set-up time for the materials and time limits for pouring and screeding that were built into the specifications argued for mixing the concrete as close to the pour site as possible. On August 1, 2007, the pour was to extend from the center of the bridge (node 14 of the center deck truss span) to the north end of the deck truss. For the sake of efficiency, personnel from Progressive Contractors, Inc. (PCI), the contractor adding the overlay on the day of the accident, decided to stage the construction aggregates and equipment near the south end of the center span, just over node 10. Although Mn/DOT had no policy that specifically required contractors to obtain approval before stockpiling materials on a bridge, contractor employees indicated that on a previous occasion they had asked a Mn/DOT construction inspector about such stockpiling and had been given a response that they interpreted as permission.

According to PCI, the previous request for approval of stockpiling of materials on the deck reflected a concern about the time and effort that would be involved in moving the materials to another location if Mn/DOT were to later determine that they should be positioned elsewhere. No evidence was found that contractor personnel were concerned about the weight of the materials. Nor would the weight itself have been an obvious consideration in that the weight of the aggregates that were added to the deck truss portion of the bridge was less than the weight of the concrete that had been previously milled off.

When the aggregates were delivered, they occupied a space 101 feet long and 20–26 feet wide. To facilitate traffic and construction work, they were later rearranged into an area 115 feet long and 12–16 feet wide. If the overlay project had been completed as planned, much of the weight of the aggregates (and the cement that would have been added to them) would have been spread over an area 530 feet long and 24 feet wide, and the undersized gusset plates would not have been overloaded. The problem with the construction loads was thus not the weight of the aggregates but the concentrated nature of the loading of the aggregates and associated construction equipment.

Mn/DOT officials told the Safety Board after the accident that they would probably have denied a request to stockpile materials as they were on the day of the collapse because of the concentrated loads. But because the contractor was not required to, and did not, formally ask for permission, it is impossible to know with certainty what the Mn/DOT response would have been. If PCI had made a written request to the project engineer regarding the stockpiling, one option for Mn/DOT would have been to base its decision on the result of load analysis, which would have indicated whether the proposed loads exceeded the allowable load limit of the structure. At the Safety Board's request, Mn/DOT performed such an analysis, which—though not addressing the capacity of the gusset plates—indicated that the structure should have been able to safely support the additional load. Had Mn/DOT made a decision based solely on such an analysis, it likely would have approved the stockpiling.

Although Mn/DOT officials stated that they would probably not have approved the concentration of loads as they were on the day of the collapse, there is no formal guidance that would have led them to that decision. AASHTO guidance on construction loading advised only

that such loads should not exceed the load-carrying capacity of the structure. The technical advisory issued by the FHWA a week after the accident suggested that bridge owners should "ensure that any construction loading and stockpiled raw materials placed on a structure do not overload its members." Neither the advisory nor the existing guidance suggested how such an assurance was to be achieved.

A Safety Board survey of 10 State departments of transportation revealed that almost all rely heavily on the contractor for determining the safe placement of construction loads, and almost all are primarily concerned with oversized vehicles rather than with the potential stockpiling of raw materials. Of the 39 States that responded to an AASHTO survey, only 22 reported having procedures in place for the review of construction loads, including loads from stockpiled materials and construction equipment. Of these 22 States, the majority stated that the operation and storage of equipment/materials would be required to follow the State truck size and weight statutes.

In the absence of formal and specific guidance, decisions about the placement of construction materials may be made on an ad hoc basis or may be considered in the same way as an overweight vehicle permit, and may not take into account all the considerations necessary to ensure that temporary loads do not damage the structure or possibly even exceed the load-carrying capacity of the structure at its most highly stressed location.

The Safety Board concludes that without clear specifications and guidelines to direct bridge owners regarding the stockpiling of raw materials, they may fail to conduct the appropriate engineering reviews or analyses before permitting raw materials to be stockpiled on a bridge. The Safety Board believes that AASHTO should develop specifications and guidelines for use by bridge owners to ensure that construction loads and stockpiled raw materials placed on a structure during construction or maintenance projects do not overload the structural members or their connections.

Gusset Plates as Commonly Recognized (CoRe) Structural Elements

The majority of States base their bridge inspections on the Pontis bridge management software program. But Pontis, like other bridge management systems, does not include gusset plates because the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* does not include gusset plates as a bridge structural element requiring specific attention and subsequent condition rating during bridge inspections. Gusset plates can be noted using the "smart flag" system, but no specific action is required if a gusset plate condition is so noted. By not including gusset plates as separate inspection elements with specific condition rating guidelines, the AASHTO guidance (and the bridge management systems that are based on it) may lead bridge owners and inspectors to give inadequate attention to these critical bridge components. The Safety Board concludes that because the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* does not include gusset plates as a separate bridge inspection element, bridge owners may fail to adequately document and track gusset plate conditions that could threaten the safety of the structure. The Safety Board believes that AASHTO should include gusset plates as a CoRe structural element and develop guidance for bridge owners in tracking and responding to potentially damaging conditions in gusset plates,

such as corrosion and distortion; and revise the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* to incorporate this new information.

Therefore, as a result of its investigation, the National Transportation Safety Board makes the following recommendations to the American Association of State Highway and Transportation Officials:

> Work with the Federal Highway Administration to develop and implement 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-08-20)
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> Revise your *Manual for Bridge Evaluation* to include guidance for conducting load ratings on new bridges before they are placed in service. (H-08-21)
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> Modify the guidance and procedures in your *Manual for Bridge Evaluation* to include evaluating the capacity of gusset plates as part of the load rating calculations performed for non-load-path-redundant steel truss bridges. (H-08-22)
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> When the findings of the Federal Highway Administration–American Association of State Highway and Transportation Officials joint study on gusset plates become available, update the *Manual for Bridge Evaluation* accordingly. (H-08-23)
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> Develop specifications and guidelines for use by bridge owners to ensure that construction loads and stockpiled raw materials placed on a structure during construction or maintenance projects do not overload the structural members or their connections. (H-08-24)
>
> Include gusset plates as a commonly recognized structural element (CoRe) and develop guidance for bridge owners in tracking and responding to potentially damaging conditions in gusset plates, such as corrosion and distortion; and revise the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* to incorporate this new information. (H-08-25)

The Safety Board also issued three new safety recommendations to the Federal Highway Administration.

In response to the recommendations in this letter, please refer to Safety Recommendations H-08-20 through -25. 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