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Highway Accident Report

Interstate 35W Collapse Over the Mississippi River, Minneapolis, Minnesota

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NTSB/HAR-08/03

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NTSB: As a result of this accident investigation, the Safety Board makes recommendations to the Federal Highway Administration and the American Association of State Highway and Transportation Officials. One safety recommendation resulting from this investigation was issued to the Federal Highway Administration in January 2008.

CONCLUSIONS

NTSB: The initiating event in the collapse of the I-35W Bridge was a lateral shifting instability of the upper end of the L9/U10W diagonal member and the subsequent failure of the U10 node gusset plates on the center portion of the deck truss.



Barry B. LePatner Analysis: Lateral shifting is another way of saying lateral torsional buckling. Blaming the cause of the failure of the I-35W Bridge solely on the design of forty-year-old gusset plates that withstood daily traffic of up to 140,000 vehicles a day is not supported by the historical documentation of the bridge's history. The NTSB report totally ignores a discussion of major causative factors such as:

- the failure of MnDOT to remediate frozen bearings that prevented the bridge from needed movement due to thermal stresses;
- widespread "section loss" or corrosion throughout the bridge;
- the failure to prevent the redecking contractor from asymmetrically loading the bridge at a single point with 578,000 lbs. of construction material and trucks just prior to the collapse.

Even if the gusset plates were sized properly, they may not have been able to resist that load and the forces placed on the bottom chords of the steel trusses directly under the construction materials where independent structural engineering experts believe the failure occurred. In-depth analysis by the highly respected structural engineering firm of

Thornton Tomasetti and other experienced bridge engineers disclosed that the failure was initiated on a bottom chord of one of the adjacent steel trusses and that the NTSB finding was flawed from the outset.

Most importantly, the bridge was always acknowledged by MnDOT and its consultants as “fracture-critical” or “non-load-path-redundant.” This means that if just one critical load-bearing structural element failed, the bridge’s structural system would not be able to safely transfer the load from the failed member to another load-bearing element, and therefore the entire structure could collapse from the failure of a single critical element.

NTSB: Because the deck truss portion of the I-35W Bridge was non-load-path-redundant, the total collapse of the deck truss was likely once the gusset plates at the U10 nodes failed.

Barry B. LePatner Analysis: As noted above, as a fracture-critical bridge, when even one critical member fails, there is no redundant path to assume the transfer of the load that member was carrying. As a result, the statement by the NTSB that once a member failed, “total collapse of the deck truss was likely” is a euphemism. Failure in this situation was a certainty.

NTSB: The examination of the collapsed structure, the finite element analysis, and the video recording of the collapse showed that the following were neither causal nor contributory to the collapse of the I-35W Bridge: corrosion damage found on the gusset plates at the L11 nodes and elsewhere, fracture of a floor truss, preexisting cracking in the bridge deck truss or approach spans, temperature effects, or shifting of the piers.

Barry B. LePatner Analysis: What is not identified in the NTSB findings is any indication that URS (the outside consultant studying the bridge for three years prior to its collapse) had warned in a draft report to MnDOT that the bridge’s load conditions, with two earlier additions of dead load, had already exceeded its design capacity. Had that information been fully disseminated, coupled with the understanding that the bridge was fracture-critical (and this on a bridge that was inspected annually since 1991, and was given a condition rating of 4 or “poor”), then there would have been clear prohibitions to the redecking contractor in July and August 2007 not to load the bridge with 578,000 lbs. of eccentrically placed building materials that triggered the collapse.

NTSB: The initial emergency response to the bridge collapse by fire and rescue units was timely and appropriate, and the incident command system was well coordinated.

NTSB: The damage to bridge components that occurred during victim recovery did not, in this case, prevent determination of the collapse sequence.

NTSB: The gusset plates at the U10 nodes, where the collapse initiated, had inadequate capacity for the expected loads on the structure, even in the original as-designed condition.

Barry B. LePatner Analysis: The report fails to remark that the gusset plates didn’t fail for forty years. Yet, several improperly designed and installed gusset plates had withstood not only the original construction since 1967 but two modifications by MnDOT that added

significant additional loads before they allegedly failed in 2007. What then was the causative factor? MnDOT's inattention to the effect of added dead load from two subsequent additions to the original design, plus 578,000 lbs. of eccentrically stored materials, plus their insistence they didn't need advanced monitoring technology, which would have captured the excess loads in the truss members caused by dead loads and frozen bearings, all contributed to the failure. The NTSB failed to note MnDOT's unwillingness to adopt advanced technology that would have given them the necessary information to manage this structurally deficient, fracture-critical bridge.

NTSB: Because the bridge's main truss gusset plates had been fabricated and installed as the designers specified, the inadequate capacity of the U10 node gusset plates had to have been the result of an error on the part of the bridge design firm.

NTSB: Even though the bridge design firm knew how to correctly calculate the effects of stress in gusset plates, it failed to perform all necessary calculations for the main truss gusset plates of the I-35W Bridge, resulting in some of the gusset plates having inadequate capacity, most significantly at the U4 and U4', U10 and U10', and L11 and L11' nodes.

Barry B. LePatner Analysis: Absolutely no mention is made that the MnDOT engineers who designed the two additions to the bridge in 1977 and 1994 failed to perform these calculations for added loads as part of their own design determinations. In addition, there was no attention paid to the potential impact of rusted and potentially frozen bearings, or the added weight and placement of stored construction materials.

NTSB: The design review process used by the bridge design firm was inadequate in that it did not detect and correct the error in design of the gusset plates at the U4 and U4', U10 and U10', and L11 and L11' nodes before the plans were made final.

Barry B. LePatner Analysis: No mention is made that it may have been appropriate for the original bridge contractor to question why only a small portion of the gusset plates were designed as such. Nor is there any mention that the original engineers failed to notice the thinner gusset plates during the construction phase when they should have been inspecting all critical connections. This finding clearly shows a failure of construction quality assurance by MnDOT, who undoubtedly had responsible employees present daily during the construction of this bridge in 1967.

NTSB: 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.

Barry B. LePatner Analysis: There also was no requirement for "peer review" at the time.

NTSB: While the U10 gusset plates would have required edge stiffeners, according to AASHTO specifications, the addition of stiffeners [that add additional support for the gusset plates] would not have made the U10 gusset plates adequate or prevented the gusset plates from yielding.

Barry B. LePatner Analysis: This finding is probably correct.

NTSB: Current federal and state design review procedures are inadequate to detect design errors in bridges.

Barry B. LePatner Analysis: This is an acknowledgment of critical importance—there is no process for ensuring quality control of bridge design in the nation, and leaving this to the subjectivity of each state transportation department does not ensure the protection of the traveling public, which travels each day over millions of miles of bridges that have been designated as “structurally deficient.” And the NTSB fails to note that the 1967 collapse of the Silver Bridge over the Ohio River was caused by failure of similar lack of inspection methods. So had the NTSB instituted a recommendation for increased inspection methods as a result of that collapse, the tragedy of the I-35W would not have occurred. Similarly, increased visual inspection procedures may not help, especially with fracture-critical bridges. The FHWA already discounted the efficacy of visual inspection ten years ago. What is needed is the use of advanced technology that can capture strain/stress data and support the development of a calibrated Finite Element Model (FEM), which can then be used to pinpoint areas of highest stress for more detailed investigation. Allowing continued operation of any fracture-critical bridge in the U.S. that has been classified as structurally deficient, without use of structural monitoring technology, is only inviting another tragedy.

NTSB: Because current American Association of State Highway and Transportation Officials 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.

Barry B. LePatner Analysis: The issue here is that there is no formalized requirement that load testing be done on all critical elements of a bridge either before, during, or after a bridge is designed and built. If the transportation agency implements a viable quality assurance program during construction, there is no need for load testing of a new bridge—they are significantly overdesigned from the start. Certainly, when bridge structures add dead load from additions and increased live (i.e., vehicular) loads from expansion projects, these calculations and a concomitant peer review should become imperative and probably mandated.

NTSB: Had the American Association of State Highway and Transportation Officials’ 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.

NTSB: Because bridge owners generally consider gusset plates to be designed more conservatively than the other members of a truss, because the American Association of State Highway and Transportation Officials 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.

Barry B. LePatner Analysis: This is inaccurate as gusset plates play a key role in the structural support system of a bridge and should have been included as part of the inspection process for decades. If NTSB concluded that an inadequate gusset plate caused the failure, wouldn't it be prudent to require that all gusset plates on steel truss bridges be inspected annually in the future? After the I-35W Bridge failure, MnDOT did check gusset plates on other Minnesota bridges and found more problems, which have been corrected.

NTSB: The loading conditions that caused the failure of the improperly designed gusset plates at the U10 nodes included substantial increases in the dead load from bridge modifications and, on the day of the accident, the traffic load and the concentrated loads from the construction materials and equipment; if the gusset plates had been designed in accordance with American Association of State Highway Officials specifications, they would have been able to safely sustain these loads, and the accident would not have occurred.

Barry B. LePatner Analysis: See comments above. This NTSB comment fails to mention the effects of frozen bearings on stress concentrations that were reported on by a consultant to MnDOT in 2001 as existing on the I-35W Bridge and that went uncorrected. These concentrations can be significant, but unless the owner uses structural monitoring technology, there is no way to know that from visual inspection.

NTSB: 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.

Barry B. LePatner Analysis: This is another "smokescreen" by the NTSB. The I-35W Bridge was fracture-critical and lacked any designed load path redundancy from the date it was constructed. In 1990 when the bridge's rating was dropped from a "7" to a "4" (i.e., it was rated as being in "poor" condition), every inspector at MnDOT had to be aware that any overloading of the bridge over its critical structural elements would create a potential for collapse. This was reiterated in the University of Minnesota and the URS reports and had to be considered on all annual visual inspection reports by MnDOT. This "finding" highlights the impotence of state DOTs, in that NTSB thinks they have to be "told" how to execute their responsibilities for bridge management. Any halfway competent bridge engineer should have the knowledge and foresight to know that adding 578,000 lbs. of construction material (eccentrically) on a structurally deficient, fracture-critical bridge represented a potentially serious addition of dead load and should have been evaluated and either approved by MnDOT or denied before the contractor was allowed to place those materials.

NTSB: Although the I-35W Bridge had been inspected in accordance with the National Bridge Inspection Standards and more frequently than required by the standards, these inspections would not have been expected to detect design errors.

Barry B. LePatner Analysis: Another smokescreen to hide the active malfeasance of MnDOT. In 2003 (and in 1999) photos were taken of the bowing gusset plates and were ignored by MnDOT. See the transcript of the MnDOT inspector who acknowledged seeing them but not deeming the bowing as significant. Gusset plates are meant to carry load from one truss member to another in one plane only. The fact that any bowing was noticed shows the inspector didn't understand how gusset plates are supposed to function. This is indicative of the overreliance by state DOTs and FHWA on visual inspections by minimally trained personnel.

NTSB: Although the I-35W Bridge had been rated under the National Bridge Inspection Standards as *structurally deficient* for sixteen years before the accident, the conditions responsible for that rating did not cause or contribute to the collapse of the bridge.

Barry B. LePatner Analysis: Over that entire length of time, MnDOT failed to take any remedial steps to ever secure any improvement to the poor rating for the bridge. Acknowledgment that the bridge deck would have to be replaced was made by MnDOT in 2006, and the actual work was deferred to 2020. Again, one has to wonder why any structurally deficient, fracture-critical bridge in the U.S. isn't monitored using advanced technology. Granted that a visual crack didn't cause the failure, but there was no way short of structural monitoring to understand the significance of frozen bearings on stress concentrations.

NTSB: The bowing of the gusset plates at the U10 and U10 nodes was symptomatic of the inadequate capacity of the plates and occurred under an undetermined load condition before 1999.

Barry B. LePatner Analysis: See above. True, but again, there should have been no bowing. Any bowing was cause for alarm and immediate investigation.

NTSB: 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 non-destructive evaluation technologies when evaluating gusset plates.

Barry B. LePatner Analysis: There is evidence of some section loss to these gusset plates, but there appears to be no acknowledgment that this factor or the bowing of the plates was significant. Nor was there any active attempt to employ ultrasonic or other non-destructive testing. In a conversation one week before the collapse of I-35W, the MnDOT chief bridge engineer told Peter Vanderzee of LifeSpan Technologies that MnDOT didn't need structural monitoring technology. The reality is that distortion such as bowing is a sign of an out-of-design condition that should be identified and subjected to further engineering analysis to ensure that the appropriate level of safety is maintained.

NTSB: 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.

Barry B. LePatner Analysis: This is another smokescreen by NTSB in that even if gusset plates were not customarily inspected, certainly by 1999 when MnDOT files showed photos of the bent gusset plates, the warning signs should have been heeded and analysis of the structural integrity of the gusset plates for this bridge should have been tested. Again, NTSB is excusing MnDOT because they weren't specifically instructed to conduct inspections on gusset plates. This is symptomatic of too much reliance on minimally trained technicians who perform visual inspection.

NTSB: 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.

Barry B. LePatner Analysis: As the National Bridge Inspection Standards (NBIS) emphasize the importance of giving significant attention to fracture-critical bridges, it seems anachronistic that gusset plates found to be distorted would not be treated with great attention. Again, this proves the shortcomings of visual inspection.

PROBABLE CAUSE

The National Transportation Safety Board determines 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 [the original designer'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.

Barry B. LePatner Analysis: See comments listed above.

RECOMMENDATIONS

NTSB: As a result of its investigation of the collapse of the I-35W Bridge in Minneapolis, Minnesota, the National Transportation Safety Board makes the following safety recommendations:

NEW RECOMMENDATIONS

To the Federal Highway Administration:

NTSB: 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. (H08-XX)

Barry B. LePatner Analysis: These are recommendations addressed only to initial design error and, with the state of sophisticated computer analysis and peer review for modern bridge design, are highly unnecessary. Also these are only recommendations and do not have the impact of imperatives to the state agencies to implement these procedures, which in many instances will not be implemented if states contend that they lack the funding to provide detailed investigative inspections to all structurally deficient bridges. Just as the Federal Aviation Agency is responsible for investigating airplane crashes, Congress should be called upon to mandate that a federal agency such as the Federal Highway Administration be responsible for investigating infrastructure failures and mandating corrective work on all bridges across the nation when it appears that causation may have commonality with others throughout the states. This type of clearinghouse will be able to provide greater assurance to the traveling public that uniformity in inspections, reporting, and action upon directives to correct defective conditions will be carried out immediately after a failure occurs.

Ten years ago, the FHWA published a study that explained the subjectivity and variability of NBIS visual bridge inspection, which was demonstrated by the I-35W collapse, when bowed gusset plates were ignored. Perhaps it's time for FHWA to mandate use of structural monitoring and other advanced condition assessment technologies when a bridge superstructure or deck is rated as 4 or below (structurally deficient) and/or the bridge is fracture-critical. Visual inspections, no matter how often they are conducted, cannot and will not find and diagnose problems that cannot be seen.

NTSB: 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 non-destructive evaluation technologies should be used to assess gusset plate condition. (H-08-XX)

NTSB: 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 Guide for Commonly Recognized (CoRe) Structural Elements*. (H-08-XX)

Barry B. LePatner Analysis: The federal government must begin to acknowledge that we have a shortage of experienced engineers to conduct inspections and implement remedial design changes for the hundreds of billions of dollars of remediation that must be addressed. The FHWA needs to mandate use of technically appropriate structural monitoring and other advanced condition assessment technologies when the superstructure is rated 4 or below and/or when the bridge is fracture-critical. Then, we need to train these engineers to know how and when to use advanced technology to detect structural problems before they are visible to the naked eye.

To the American Association of State Highway and Transportation Officials:

NTSB: 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-XX)

NTSB: Revise your *Manual for Bridge Evaluation* to include guidance for conducting load ratings on new bridges before they are placed in service. (H-08-XX)

Barry B. LePatner Analysis: This increases expense with minimal return on investment. There is little likelihood of a failure in design if a construction quality assurance program is in place (see above).

NTSB: 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-XX)

NTSB: 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-XX)

NTSB: 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-XX)

Barry B. LePatner Analysis: Discussed above.

NTSB: Include gusset plates as a commonly recognized (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. (H-08-XX)

Barry B. LePatner Analysis: Discussed above.

PREVIOUSLY ISSUED RECOMMENDATION RESULTING FROM THIS ACCIDENT INVESTIGATION

NTSB: As a result of its investigation of this accident, the Safety Board issued the following safety recommendation to the Federal Highway Administration on January 15, 2008:

NTSB: 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. (H-08-1)

Barry B. LePatner Analysis: Yes, but...these load calculations are not based on actual stress/strain data from the bridge but rather from subjective visual inspection data. Using subjective, highly variable visual inspection data to “calculate” a load capacity is the equivalent of asking your doctor to diagnose lung cancer by looking at your skin.

CONCLUSION

In conclusion, for the NTSB to characterize the failure and collapse of the I-35W Bridge as a “one-off” without any reference to the myriad other factors that contributed to this tragic occurrence is an abdication of its role as an advisory agency. While it is true that there was a design error in the bridge’s original design, to ignore the documented history of minimal maintenance by MnDOT is a grievous error of judgment. To ignore the many warning signals embodied in both the agency’s own inspection reports as well as the reports of outside consulting engineers is malfeasance. To fail to highlight the fragility of the bridge’s fracture-critical design and the implicit recognition that a failure of even one critical member could lead to collapse of the entire structure as if it were an unimportant factor is inexcusable.

What the NTSB report should have identified as the lesson to be learned from this tragedy was the pure engineering construct that all fracture-critical and structurally deficient bridges in the nation—which currently total 7,980 according to FHWA records—should automatically be tagged for immediate corrective work. Each of these bridges has already reached a mode of failure. Waiting for a calamity is not acceptable. The time for action is now. What every engineer knows is that gravity always wins out.