The Story Behind the Collapse of Minnesota's I-35W Bridge on August 1, 2007

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The I-35W Bridge was ultimately brought down by a long history of inadequate maintenance resulting from management and financial shortsightedness. Designed in 1964 by the St. Louis-based firm of Sverdrup & Parcel and opened in 1967, the bridge was built at a time when the bulk of the nation's freight moved by rail and not by massive eighteen-wheeler trucks. It was built at the time to carry approximately 60,000 cars per day.

The first thing it is important to understand about the design of this steel-truss bridge is that the structure is known as "fracture-critical," meaning that the failure of any one of its supporting structural members could result in the collapse of the whole bridge. In the years of the post-World War II boom in bridge building in the United States, fracture-critical steel bridge designs were common as a means of streamlining construction and saving costs. They remained common until the 1980s, when new specifications issued by the American Association of State Highway and Transportation Officials

(AASHTO) led to a requirement that called for greater load-path redundancy, i.e., the simple concept that if a structural support failed then the collapsing loads could be distributed amongst other supporting members in order to prevent sudden catastrophic collapse. When built, the I-35W Bridge was not unusual—there are approximately 12,600 fracture critical steel deck truss bridges still in use in the United States today.[1]

By 2007, the year the bridge collapsed, approximately 160,000 cars passed over it every day,[2] and the combination of increased dead load (the weight of the structure itself) resulting from the 1977 and 1998 modifications, and increased live load (owing to higher traffic volumes and heavier truck loads), represented a significant increase over the design load of the structure.[3] The story of the I-35W collapse represents a more alarming version of the same story. The most obvious starting point of this disaster must take note of the ongoing failure by Minnesota's Department of Transportation, (MnDOT) over a protracted period of time to provide needed maintenance for a bridge that was deteriorating for many years. The basic facts, supported by the voluminous record of the bridge's inspection teams, tell a simple tale. In 1991, based upon a litany of reported signs of deterioration, I-35W Bridge inspectors downgraded the bridge's previous rating of "satisfactory", to "poor" or "structurally deficient". Such a drop in rating entitled MnDOT to receive federal funding for the bridge's remediation. While accepting federal funding for ongoing repairs during the 16 years until its collapse on August 1, 2007 the bridge never improved upon its "poor" rating. Despite repeated warnings from outside consultants from 2001 to 2006 that this "fracture-critical" bridge needed strengthening to avoid collapse if even one structural member failed, MnDOT officials continued to treat the bridge as one that was safe for the 160,000 plus vehicles that traveled across its span on a daily basis.

The November 2008 NTSB report, which followed 15 months of investigation, tellingly ignored the maintenance record for the I-35W Bridge. Pursuing an entirely different course, a surprisingly different picture emerges. Simply put, the NTSB advised the public and all other state and federal transportation officials that this was a one-time only occurrence caused by a simple design error that went undetected at the time of construction. As such, the NTSB treated the I-35W collapse – a collapse the resulted in the deaths of 13, injuries to 145 others and massive economic disruption to the Twin Cities' metropolitan area (plus $278 million for an entirely new bridge) – as a one-off from which no lessons could be learned to avoid future failures. When carefully analyzed, the NTSB report masked far more

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1 *Popular Science*, *http://www.popsci.com/john-brandon/article/2008-10/bridge-monitors-itself*.

2 *Bridge 9340, I-35W Over Mississippi River, Fatigue Evaluation and Redundancy Analysis, Draft Report,* URS Corporation, July 2006, p. 2-15.

3 The "design load" of a bridge represents the amount of "dead load", i.e. the physical weight of the bridge plus its intended expectancy to handle "live load" i.e. the anticipated loads representing the traffic to be borne by the bridge plus a factor of safety built into the design to handle unexpected contingencies.

than it revealed about how the I-35W Bridge was maintained, funded, and operated. This failure to address the ongoing deterioration of a forty-year-old fracture critical bridge – not a design failure at the time of construction – brought this bridge to its tragic and preventable end. Moreover, the story of the I-35W is not an isolated tale of one state's transportation agency. It is an apocryphal tale of a pervasive culture of neglect that permeates our national transportation system.

Meanwhile, concerned about the possibility of fatigue cracking on the deck truss, MnDOT hired the University of Minnesota to "evaluate the potential for fatigue cracking in the deck truss, and estimate the remaining life if fatigue cracking was a potential" and "recommend increased inspection or retrofitting, if necessary." The University's report, issued in March 2001, provided good news: fatigue cracking on the deck truss was not to be expected during the remaining life of the bridge.[4] The University of Minnesota researchers recommended that certain areas of the main truss and floor trusses be frequently inspected, and sounded a cautionary note, in some ways prescient, in the report's concluding comments where they recognized the fragility of the Bridge's fracture critical design: "Concern about fatigue cracking in the deck truss is heightened by a lack of redundancy in the main truss system. Only two planes of the main trusses support the eight lanes of traffic… Therefore, if one member were severed by a fatigue crack, that plane of the main truss would, theoretically, collapse."[5] The key finding of this consultant was that if any one crack severed a critical member, the entire fracture critical bridge was at risk.

In 2003, MnDOT hired URS Corporation to perform evaluations of the I-35W. It hired URS because Flemming was a former head of MnDOT's Central Bridge division as well as State Bridge Engineer from 1986 to 2000 who, while still at MnDOT, had spoken to colleagues about the need to add redundancy to the I-35W Bridge.[6] At URS, not surprisingly, Flemming became "a primary contact for MnDOT."[7]

URS began work on its second contract with MnDOT on the I-35W Bridge in January 2004. The work took longer than expected and the date for its completion was extended several times owing to circumstances "arising in part from the unique complexity of the project."[8] By spring, 2006 however, MnDOT was evaluating three recommendations that URS would present in a preliminary report in

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4 Gray Plant Mooty, *Investigative Report*, p. 26.

5 University of Minnesota Fatigue Evaluation of the Deck Truss of Bridge 9340 Final Report, March, 2001, p. 4.

6 Gray Plant Mooty, *Investigative Report*, pp. 57–58.

7 Gray Plant Mooty, *Investigative Report*, p. 27.

8 Gray Plant Mooty, *Investigative Report*, p. 28.

July 2006. These recommendations were that MnDOT: 1) completely redeck the bridge in order to provide added structural redundancy; 2) retrofit fracture critical truss members with steel plating — including eight "fracture critical members" specifically identified as such by URS[9], six of which were located in the portion of the bridge that would eventually collapse first; and 3) continue to inspect the bridge.

In an August 2006 response to the URS draft report, MnDOT staff supported the consultant's recommendations and seemed to show every intention of following up on them, asking for advice, for example, on how the recommended redecking should be staged. Don Flemming's successor as State Bridge Engineer, Dan Dorgan, also asked for an important clarification of URS's recommendation about how to retrofit the eight fracture critical members identified by the URS report. He cited to a section that indicated that "failure of five of the eight critical members would 'cause instability of the structural system'" He wanted it made explicit even to "others in MnDOT that are not knowledgeable in structures" that this phrase must not be understood. "*If the conclusion is the instability would likely lead to collapse of the bridge that should be state* [sic] *clearly.*[10]*"*

In effect, what Dorgan was instructing URS to make clear was that when dealing with a fracture critical bridge such as I-35W, every government official involved in decision making must be capable of fully understanding that "instability likely to lead to a collapse" is merely a euphemism and that any report likely to become a part of the public record must state clearly that a failure of a critical structural member will automatically result in a total collapse of the bridge.

But there was a clear reluctance on the part of MnDOT to address these longstanding problems despite the sense of urgency reflected in the reports by the consultants. MnDOT asked URS for a detailed analysis to determine the number of lanes that could be kept open to traffic during the redecking and where and how much construction material, vehicles and equipment could be staged on the bridge.[11] Precisely what happened to this question and the answer provided by URS is not known. What is known is that these concerns about "asymmetric loading," i.e., the need to avoid an imbalanced loading of a fracture critical bridge would, one year later, prove to have been critical. Whether or not the response provide by URS was correct, the contract and specifications provided by MnDOT to the redecking contractor in 2007 failed to provide clear instructions to avoid an asymmetric overload of materials being used for the repaving out of fear for the fragility of the structure.

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9 *Fatigue Evaluation and Redundancy Analysis, Bridge No. 9340 I-35W Over Mississippi River,* URS Corporation, July 2006 , p. 10 which sets out that "five of the eight critical members are fracture critical, i.e., their failure would result in the failure of at least one other mai truss member and thus cause instability of the structural system."

10 Gray Plant Mooty, *Investigative Report*, p. 60. Emphasis in original.

11 Gray Plant Mooty Report, p. 60, citing D. Dorgan comments to URS Report.

Regardless of the support from MnDOT's engineers for pursuing URS's recommendations, or their recognition of the potential gravity of the issues at hand, there would be plenty of reservations expressed at MnDOT when it came to budgeting funds to carry them out. By the time that an investment strategy meeting was held in July 2006, MnDOT officials, in fact, had decided that any complete redecking of the bridge would not occur until 2022. The decision to postpone deck replacement—which was estimated to cost a financially unobtainable $15 million—sixteen years into the future was a major inflection point that would lead directly to the bridge disaster in August 2007. Despite MnDOT's clear recognition that adding redundancy to the I-35W Bridge was a critical step for ensuring its safety, as well as URS' determination that "replacing the existing deck with one that was continuous throughout would decrease live stress loads by 20% in some of the critical fatigue-prone members and improve the structural redundancy of the Bridge,"[12] that option was pushed sixteen years into the future even before it was formally presented.

The financially unobtainable option of completely redecking the bridge, however, was not the only one that was discussed, and deferred, by MnDOT officials at the July 2006 investment strategy meeting. Also under discussion was URS's second, much less expensive recommendation for retrofitting steel members. Judging from the meeting minutes, MnDOT officials clearly understood that such retrofitting would significantly reduce the risk of further fatigue cracking until the bridge could be redecked no later than 2022. They were reluctant to act as a result of the cost. Officials also understood the risks entailed in opting for nothing more than conducting further inspections, even if their worst-case scenario would eventually prove to fall far short of the real danger. If a crack were to be found after a decision to forego retrofitting, it would take months to order steel for the reinforcement and the bridge would have to be closed for the duration of the remedial work. It would be even more problematic if the bridge were so badly compromised that it had to be condemned and closed until a replacement had to be rebuilt. In effect, MnDOT officials, by 2006 had been fully briefed by their bosses that their principal job was to balance all bridge assets amongst a transportation budget that put new projects ahead of remediation while requiring more costly remediation to take a secondary role to those that enabled the most projects (as opposed to the most necessary) to be addressed.

In October 2006, MnDOT finally did budget the money for a retrofitting that was scheduled to go out for bids in the fall of 2007. But that work would never be performed owing to a series of additional decisions involving both budget considerations and an apparent reluctance on URS's part to speak more directly about the perceived risks detailed in its reports. That December, URS presented MnDOT with new recommendations for retrofitting the bridge, Specifically, URS determined that acoustical or magnetic testing was sufficient to detect fatigue cracks of a size necessary to give cause for concern.

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12 Gray Plant Mooty, *Investigative Report*, p. 65.

URS recommended that MnDOT: (1) retrofit all 52 critical tension members to add redundancy, (2) conduct non-destructive examination (NDE) testing of all 52 members with the use of technological sensors, or (3) implement a combination of both those recommendations. URS even obtained bids from testing companies, informing the state that a complete examination of the bridge with what appeared to be the latest available technology would cost less than $200,000.

On December 6, MnDOT staff members met to begin planning the prep work that would be entailed in performing a retrofitting of the bridge. Then on January 17, 2007, a conference call took place in which URS consultants surprisingly warned MnDOT that drilling for the retrofit that URS itself had recommended could weaken the bridge. The same day, MnDOT decided that, instead of hiring out this work to consultants as URS had recommended, it would rely on visual inspections performed by MnDOT personnel (combined, if necessary, with ultrasound technology) to determine whether there were any cracks in the bridge large enough to justify a retrofitting. However, once again MnDOT failed to show a sense of urgency as to addressing a known series of problems that threatened the structural integrity of the bridge. When inspection efforts were initiated in May 2007, only half the bridge was inspected and no URS personnel were asked to participate. MnDOT employees assigned to the job later acknowledged that not only did they have different understandings of the purpose for their work but had not even consulted with URS prior to performing their inspection.

Following the May inspection of half the bridge, MnDOT scheduled a meeting with URS that would never take place—it was slated for August 20, nearly three weeks after the bridge collapsed—to discuss the inspection results. As a result, at the time of the I-35W collapse, MnDOT had been working for eight years with teams of consultants seeking information on fatigue cracks and securing recommendations for remediating a seriously deteriorated bridge. During that time, with efforts that ranged from detailed studies by the University of Minnesota, HNTB and URS the net result was a tentative plan to address the serious issues presented by the consultants a decade hence and the authorization to proceed with a cosmetic paving project. Any action to add critical redundancy was either deferred or rejected.[13]

Even the simple project to provide new paving for the bridge turned into an aggregation of errors. In February 2006, while MnDOT was working with URS on proposed plans for redecking the entire bridge to add structural redundancy, its Central Bridge construction unit was preparing the paperwork for approval of another, previously budgeted project that would replace the top two inches of concrete on the bridge's deck, a largely non-structural, cosmetic operation. Shortly thereafter, the Central Bridge engineer called URS to express concern that MnDOT was planning for deck and joint

13 p. 63.

repairs without considering recommendations for a more permanent repair. The URS representative responded, "personally, I would defer the proposed deck work and plan for a deck replacement and strengthening project."[14]

The proposed deck overlay would have improved drivability but would have done nothing to improve the superstructure rating.[15] By contrast, the deck replacement that URS was recommending would have gone a long way to improve the integrity of the bridge's structural support system. It would have decreased the live stress-loads in some of the critical fatigue-prone members of the superstructure and improved the structural redundancy. In April 2006, MnDOT officials met to discuss these two options. A third option—replacing the entire bridge—was also discussed but immediately ruled out at this time, owing to the prohibitive $75 million cost estimate, although it is unclear from MnDOT records how this sum was computed or whether it merely reflected the state's portion after anticipated federal funding.

Several conclusions can be drawn from MnDOT's internal dialogue involving funding for this work. First, MnDOT ruled out any project for the short term that required a commitment in excess of $3.5 million. This limited MnDOT's choices to the non-structural deck overlay option promoted by Central Bridge. Acknowledging the financial handcuffs that constrained its choice of options for remediation, officials noted that the two chief benefits for the overlay scenario were that "it delays bridge replacement the most" and "allows time to acquire the funds needed for the deck replacement [structural redundancy] and the bridge replacement." Officials used the term "budget-buster," an internal phrase that referred to projects for which there was no short-term likelihood of finding sufficient funding. The option to replace the entire deck at an anticipated cost of $15 million was deferred to the period between 2017 and 2022 notwithstanding the fact that this option incorporated strengthening of members to this fracture critical bridge. Finally, they relegated the acknowledged need for total replacement of the bridge (at an estimated cost of more than $75 million) to a far distant time between 2057 and 2062.[16]

In order to choose between these two options—the more provisional, though less expensive, deck overlay, and the deck replacement, which would have partially fulfilled the objective of adding redundancy to the bridge as contemplated since 1999—MnDOT decided that it needed to perform a ground penetrating radar survey, at an estimated cost of $40,000. This costs was comparable to a previous survey performed in 1999 used to determine the rate at which the deck was deteriorating. The radar

14 p. 64–65.
15 Gray Plant Mooty, *Investigative Report*, p. 46–47.
16 P. 65–66.

survey was scheduled for August 2006 but then—in a pennywise decision comparable to the one the following winter to forego high technology testing for determining the extent of fatigue cracking on the bridge—it was "not completed due to funding."[17] In July, MnDOT made the decision to go ahead with the non-structural deck overlay and postpone the redecking until 2022.

The decision to forego a surface penetrating radar survey would have further implications for the cosmetic overlay project. By choosing another "very inferior" method in preparation for the deck overlay, it would not be until the top two inches of concrete were removed from the deck of the I-35W Bridge that MnDOT would discover that the inner portion of the deck was so badly deteriorated that more than the top two inches would have to be replaced in several locations.[18] That decision is important less for its literal consequences than for its illustration of the corner cutting, in ways large and small, that characterized MnDOT's maintenance of the bridge over much of its lifetime.

Like the later decision to rely primarily on visual inspection for determining the extent of the fatigue cracking on the superstructure, MnDOT left in place a bridge that had been identified as lacking needed redundancy in the event of a failure to a structural member. It took no action from amongst the many recommended by a series of consultants. It ignored photographic evidence from 1999 and 2003 showing that several gusset plates had bowed from excessive pressures indicative of incipient failure that went unattended for 40 years. It failed to act on the information provided by its consultants to make decisions crucial to the safety of the traveling public. Finally, without including the services of URS who had been studying the bridge for over four years, it pursued a largely non-structural interim repair in lieu of longer-term remediation. Finally, MnDOT permitted a contractor to load 587,000 pounds of construction material atop a fracture critical bridge fully understood to be unable to carry this unanticipated additional load.[19]

The National Transportation Safety Board would later dismiss any connection between MnDOT's maintenance of the I-35W Bridge, or the "poor" condition of the bridge itself for sixteen years prior to its failure "for no apparent reason." The NTSB report was silent as to MnDOT's decision-making

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17 Internal MnDOT e-mail quoted in Gray Plant Mooty, *Investigative Report*, p. 67.

18 Gray Plant Mooty, *Investigative Report*, p. 68.

19 Referring to the conditions at the time of the collapse, WJE, the consultant hired by MnDOT to do a detailed investigation in conjunction with that being performed by the NTSB, stated, "The dead load carried by the critical elements, both at the time of the collapse and in the previous years, represented a large fraction of available capacity. Therefore, small changes in strength, such as those associated with static versus dynamic loading, would cause a relatively large change in load capacity. Conversely, the static nature of the construction loads made them significantly more severe than moving loads of a comparable magnitude.'" *I-35W Bridge Over the Mississippi River: Collapse Investigation Bridge 9340 Minneapolis, Minnesota,* Final Report, Wiss, Janney, Elstner Associates, Inc., November 2008, p. 154.

process and whether MnDOT acted prudently in light of the URS recommendations to protect the well-documented fragility of the Bridge.

The story of the I-35W Bridge raises a number of "what ifs." What if MnDOT had tackled the problem of the bridge's lack of load-path redundancy head-on instead of avoiding the issue for eight years? What if it had undertaken the high-tech testing that URS recommended and discovered that the condition of the deck truss required either retrofitting or deck replacement to be performed as soon as possible, and that some lanes—if not the bridge itself—should be closed to reduce the likelihood of failure? What if MnDOT had agreed to retain HNTB who had offered to furnish an analysis of the fatefully mis-designed gusset plates? What if HNTB identified the bowed gusset plates as a "critical deficiency" that would have led to an immediate posting (closure of lanes) of the Bridge and/or a definitive decision to immediately prepare for deck replacement? Finally, and most importantly, what if the engineers at URS had stated their findings about the bridge's condition more plainly and demanded, as professionals sworn to protect the interests of the public over any other interests, that officials find the funding necessary to address the critical structural problems they had identified? And what if the engineers and other management officials at MnDOT, who clearly understood the technical analyses and warnings of the various consultant reports they had commissioned, had heeded the directive of the Deputy Commissioner/Chief Engineer who, a year earlier, had issued his directive for immediate action on "critical deficiencies" and sounded the alarm?

In the two years following the I-35W Bridge collapse, MnDOT has increased the number of bridge inspectors and crews to oversee its 14,000 state city and county bridges. And while the state has added 281 new maintenance workers, critics point to the fact that the state legislature transferred $35 million from MnDOT operations to reserves that cover construction cost overruns for new projects. Most importantly, MnDOT closed several other major bridges reporting similar deterioration that may have avoided future failures. Much of this was accomplished as the result of the state legislature's override of Governor Tim Pawlenty's veto of a badly needed transportation funding bill.