Analysis of the 2007 Interstate-35 Bridge Collapse in Minneapolis, MN

Civil Engineering and Architecture

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At 6:05 p.m. CDT on Wednesday, August 1, 2007, during rush hour traffic, the central span of the I-35 Mississippi River Bridge (pictured to the right) suddenly collapsed into the river below it, followed by the adjoining spans. 13 people were killed, 145 were injured, and 111 vehicles were involved in the collapse. The bridge's design was a continuous truss bridge, with a total length of 1907 ft, and a width of 113.3 ft. Construction began in 1964, and the bridge opened in November, 1967. There are several possibilities of what might have caused the collapse of the bridge:

1. Stress and fatigue cracking: There was quite a lot of fatigue and stress cracking. The cross girders at the end of the approach spans were cracking. The main trusses connected to these cross girders, and resistance to motion at the connection point bearings lead to distortion of the cross girders and subsequent stress cracking.
2. Lack of redundancy: There was also a lack of redundancy in the main truss system, which means that the bridge had a greater risk of collapse in the event of any single structural failure.

3. Steel gusset plates: The steel gusset plates were undersized and inadequate to support the load. The gusset plates at eight different joint locations in the main center span were fractured (see picture on right).

Some gusset plates were bowed, and others were corroded from rust and other reasons. In December, 2006, a steel reinforcement project was planned for the bridge. However, it was revealed that drilling for the retrofitting would weaken the bridge, so the project was cancelled.

4. Bearings: The roller bearings for the bridge (see picture below) were severely

corroded, and didn't really allow the bridge to expand and contract a lot during different weather conditions.

5. Increased dead and live loads: Concrete was added over the years on the bridge's road surface. This ended up in increasing the dead load by 20%. The bridge originally carried four lanes of traffic, two in each direction. But in 1998, the bridge was remodeled to allow 8 lanes of traffic (four in each direction) to flow over the bridge. This increased the live load tremendously. A few weeks before (and during) the time of the collapse, the bridge was undergoing some construction, such as joint work, resurfacing, and the replacement of lighting, concrete, and guard rails. At the time of the collapse, four of the eight lanes were closed for resurfacing. There were 578,000

pounds of construction supplies and equipment sitting just above the weakest point of the bridge.

6. Black ice problem: On December 19, 1985, the temperature in the area of the bridge reached -30°F. Cars experienced black ice, which caused several pile-ups and collisions on the bridge. In 1996, the bridge was identified as the single most treacherous cold-weather spot in the Twin Cities freeway system. They solved the black ice problem by setting a system (similar to a sprinkler system) up on the bridge. This system sprayed Potassium Acetate on the surface of the bridge when the temperature reached below zero to prevent the black ice from forming. The problem of the black ice was solved, but it is very possible that the Potassium Acetate corroded the structural support of the bridge.

Of course after the bridge collapsed (pictured to the right), fingers pointed at who was to blame for this fatal accident. MnDOT (Minnesota Department of Transportation) was responsible for the inspection and maintenance of the bridge. I believe that they were partially responsible for the collapse of the bridge. MnDOT did not adequately document inspection report findings, such as the bowed steel gussets. The action taken by MnDOT to correct the bridge did not improve the “poor” rating of the bridge’s structure. They did not conduct an analysis in response to the bridge’s deteriorating condition, and they did not effectively follow through on the advice of their experts on the condition of the bridge. I believe they did not do their job properly and thoroughly.

If I was to go back in time to prevent the collapse of this bridge, I would make sure that the steel gussets are strong enough and thick enough before construction. I would also increase the amount of redundancy in the bridge structure. I would forbid the addition of traffic lanes on the bridge, as this would increase the live load. I would conduct thorough inspections of the structure of the bridge at least once or twice a year.

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REFORMING STRUCTURAL INTEGRITY OF BRIDGES:

ANALYSIS ON THE COLLAPSE OF I-35W

With over six and a half million kilometers of roads[1] and over two hundred fifty million registered vehicles,[2] the United States must maintain the structural integrities of its roads and prevent the unnecessary loss of lives. On August 1 of 2007, at precisely 6:05 PM, the I-35 West Bridge collapsed in Minneapolis, Minnesota, killing 13 people and injuring another 145.[3] The incident left the entire nation in both shock and doubt of the safety of its roads.[4] Their doubts are not unwarranted. Structural engineer experts reveal that over eight thousand bridges in the United States alone are in need of remodeling.[5] In order to assess fully the requirements of sustaining structurally sound roads in America, this report will provide an analysis on the causes of the Interstate 35 West Bridge's collapse. The analysis sheds light on the inadequacy of proper planning and calculations, including the failure to apply adequate sized gusset plates[6] and the failure to provide restrictions on the maximum load capacity of the bridge.[7]

According to Roman Wolchuk, a structural engineer and bridge expert, an investigation lead by the National Transportation Safety Board (NTSB) uncovered a shocking miscalculation of undersized gusset plates in the I-35W Bridge – a root cause of its catastrophic collapse.[8] The Washington State Department of Transportation states that gusset plates are used to connect two or more structural members at a joint in a steel truss and need to be strong enough to accommodate the loads and stresses that a bridge will experience throughout its lifetime.[9] The undersized gusset plates on the I-35W Bridge in Minneapolis evidently did not fulfill its purpose. Experts and analysts suggest that the gusset

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[1] The World Bank Data, *Roads, Total Network (km)*, 2014, http://data.worldbank.org/indicator/IS.ROD.TOTL.KM
[2] Statista, The Statistics Portal, *Number of Vehicles in the United States Since 1990*, http://www.statista.com/statistics/183505/number-of-vehicles-in-the-united-states-since-1990/
[3] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[4] Roberts, Charles C., (PhD from Worcester Polytechnic Institute and engineering consultant in the areas of accident reconstruction, failure analysis, structural analysis, heat transfer, fire origin analysis, computer analysis, mechanics, and biomechanics), *Minneapolis Bridge Collapse*, http://www.croberts.com/minneapolis-bridge-collapse.htm
[5] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[6] Hao, S. (PhD Structural Engineer) and Roman Wolchuk (Structural engineer and steel bridge expert), *I-35W Bridge Collapse*, August 13, 2010, http://suhao-acii.com/files/I35W_note.pdf
[7] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[8] Hao, S. (PhD Structural Engineer) and Roman Wolchuk (Structural engineer and steel bridge expert), *I-35W Bridge Collapse*, August 13, 2010, http://suhao-acii.com/files/I35W_note.pdf
[9] Washington State Department of Transportation, *Washington State Bridge Construction Practices and Gusset Plates*, http://www.wsdot.wa.gov/Accountability/GussetPlates.htm

plates needed to be at least twice its original half inch size in order to have sustained the bridge adequately.[10]

The scant gusset plates, however, were not the only factor that triggered the collapse of the bridge. Further exacerbating the pressure on these already deficient gusset plates were numerous additions to the original bridge. These modifications increased both dead loads – unmoving loads that do not change over time[11] – and live loads, – moving loads that change over time.[12] Charles C. Roberts, a PhD engineer from Worcester Polytechnic Institute reports that the I-35 West Bridge, constructed in 1964 and completed in 1967, had a total length of 1,907 feet intended to carry three lanes in each direction and two auxiliary lanes for emergencies, allowing only approximately sixty thousand vehicles to cross daily.[13] In stark contrast, at the time of its collapse, the bridge's weight was increased by twenty percent, expanded to include eight lanes, and carried over one hundred forty thousand vehicles daily.[14]

The first load that was added onto the bridge in 1997 was an extra layer of concrete overlay. This layer was required by the Minnesota Department of Transportation with the purpose of protecting the road from harsh chemical corrosion that could possibly damage the roads' steel rebar.[15] What the Minnesota Department of Transportation failed to recognize was the three million extra pounds that were placed on the bridge. Those three inches of extra layers increased the dead load of the bridge by more than thirteen percent.[16] The next year, 1998, an anti-icing system was installed, again by the Minnesota Department of Transportation, that intended to prevent corrosion from both natural weather and also traffic impact. With thirty eight valve units and seventy six spray nozzles that applied potassium acetate to the roadway, the result was another one million pounds weighted on the bridge; an additional six percent increase of the bridge's dead load.[17] The third and final major renovation of the bridge was in fact in progress at the time of the bridge's collapse. The project performed by the Progressive Contractors Incorporation (PCI) of St. Michael, Minnesota, intended to replace two inches of concrete overlay in order to remove unsound concrete from the curb, reconstruct expansion joints, and replace the anti-icing system. At the time the bridge collapsed, an extra one

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[10] Hao, S. (PhD Structural Engineer) and Roman Wolchuk (Structural engineer and steel bridge expert), *I-35W Bridge Collapse*, August 13, 2010, http://suhao-acii.com/files/I35W_note.pdf

[11] Pie Global Consulting and Engineering, *Live Loads vs Dead Loads: Determining Building Design Loads for Structural Claims*, http://www.pieglobal.com/live-loads-vs-dead-loads-determining-building-design-loads-for-structural-claims/

[12] Fisette, Paul R. (Associate Dean, College of Natural Sciences at the University of Massachusetts, Amherst, MA, past Department Head of Environmental Conservation and past Director of the Building & Construction Technology program, currently a Professor of Building & Construction Technology, and a Professor of Architecture at the University of Massachusetts, Amherst, University of Massachusetts in Amherst, *Understanding Loads and Using Span Tables*, June 4, 2009, http://bct.eco.umass.edu/publications/by-title/understanding-loads-and-using-span-tables/

[13] Roberts, Charles C., (PhD from Worcester Polytechnic Institute and engineering consultant in the areas of accident reconstruction, failure analysis, structural analysis, heat transfer, fire origin analysis, computer analysis, mechanics, and biomechanics), *Minneapolis Bridge Collapse*, http://www.croberts.com/minneapolis-bridge-collapse.htm

[14] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx

[15]Department of Transportation (DOT) and National Transportation Safety Board (NTSB), Minnesota, *Collapse of I-35W Highway Bridge Minneapolis, Minnesota August 1, 2007*, November 14, 2008, http://www.dot.state.mn.us/i35wbridge/ntsb/finalreport.pdf

[16] Department of Transportation (DOT) and National Transportation Safety Board (NTSB), Minnesota, *Collapse of I-35W Highway Bridge Minneapolis, Minnesota August 1, 2007*, November 14, 2008, http://www.dot.state.mn.us/i35wbridge/ntsb/finalreport.pdf

[17] Department of Transportation (DOT) and National Transportation Safety Board (NTSB), Minnesota, *Collapse of I-35W Highway Bridge Minneapolis, Minnesota August 1, 2007*, November 14, 2008, http://www.dot.state.mn.us/i35wbridge/ntsb/finalreport.pdf

million pounds were exerted on the bridge from both additions already made and also extra cement, trucks, and water required for the planned construction.

Despite these daunting figures, the bridge managed to sustain its weight and additional ones for over forty years. Experts attribute this feat to the steel that was used to build the bridge. The steel allowed a further ten percent plastic strain ultimately creating a total bridge strength of 86 ksi (kilopounds per square inch), which is a seventy percent increase from the bridge's predicted yield limit of 50 ksi.[18] This steel's ductile property sustained the bridge for forty years until the many accumulated loads and inadequate gusset plates were beyond the safety margin, leading to inevitable failure.

The collapse of this I-35W Bridge soaked up more than four hundred fifty million taxpayer dollars from the government – expenses that amounted from increased commuting expenses, direct losses to the economy, and most severely, replacement of the bridge itself[19] – expenses that neither the government nor the taxpayers were in any condition to pay. What can future engineers and bridge builders change to prevent such unnecessary costs? ThinkReliability, a consultant group that studies root cause analysis focusing on problems and processes, gives a few suggestions. The first reform that must be made is to limit the amount of weight concentration of construction materials on bridges.[20] Moreover, staging materials on bridges must require written permission, so that the concentration of weight can be calculated and, if necessary, prevented. The second action is to ensure that bridge inspectors receive formal bridge construction training, ensuring that they can accurately assess the conditions of the bridge.[21] Thirdly, a weight analysis should be required after every major renovation or increase of dead weight on a bridge. This will provide a more realistic understanding of the bridge's load capacity and safety margin. The fourth and final change regards the careful application of gusset plates on bridges. The weight capacity of gusset plates must be calculated in order to determine whether they can sufficiently support their designated bridges.[22] In addition, construction workers and bridge designers must be educated on the vital role that gusset plates have on structural integrity because currently the plates are not viewed as essential parts to a bridge.[23] Furthermore, gusset plates need to be listed as specific separate elements during inspections, allowing reviewers to evaluate them individually and with more attention.[24] Had these policies been put into place before the I-35W Bridge collapse, the incident may have been prevented.[25]

In summation, bridge builders and structural engineers in America have failed to properly plan and calculate the stress capacity and maximum load of

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[18] Hao, S. (PhD Structural Engineer) and Roman Wolchuk (Structural engineer and steel bridge expert), *I-35W Bridge Collapse*, August 13, 2010, http://suhao-acii.com/files/I35W_note.pdf
[19] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[20] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[21] Department of Transportation (DOT) and National Transportation Safety Board (NTSB), Minnesota, *Collapse of I-35W Highway Bridge Minneapolis, Minnesota August 1, 2007*, November 14, 2008, http://www.dot.state.mn.us/i35wbridge/ntsb/finalreport.pdf
[22] Hao, S. (PhD Structural Engineer) and Roman Wolchuk (Structural engineer and steel bridge expert), *I-35W Bridge Collapse*, August 13, 2010, http://suhao-acii.com/files/I35W_note.pdf
[23]Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[24] Department of Transportation (DOT) and National Transportation Safety Board (NTSB), Minnesota, *Collapse of I-35W Highway Bridge Minneapolis, Minnesota August 1, 2007*, November 14, 2008, http://www.dot.state.mn.us/i35wbridge/ntsb/finalreport.pdf
[25] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx

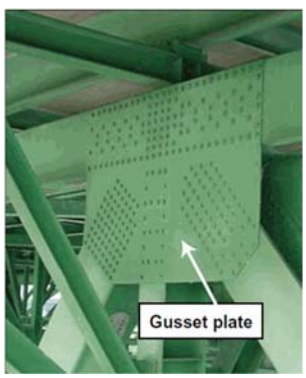
bridges – miscalculations that have lead to the deaths of 13 people and another 145 injured.[26] With over eight thousand other bridges potentially suffering the same structural deficit, a change in the structural integrity of bridges is sorely required. [27] The collapse of the I-35W Bridge in Minneapolis, Minnesota is a clear warning. Its collapse was caused by a combination of structurally inadequate gusset plates, a twenty percent increase of dead loads, and also at least a two hundred percent increase in live loads – namely traffic. Solutions have been proposed to resolve these devastating issues; restrictions on weights applied on bridges, formal bridge construction training for inspectors, detailed analysis of future bridge renovations, and careful planning for applications of structurally sound gusset plates. If these four fundamental steps are rigorously enforced in the construction sector, the United States will have a chance at restoring safety to its roads.

[26] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx
[27] Think Reliability, *Root Cause Analysis of the I-35 Bridge Collapse*, 2011 http://thinkreliability.com/CM-I35.aspx

Analysis of the 2007 Interstate-35 Bridge Collapse in Minneapolis, MN

Principles of Engineering 12/5/2014 - Nathan Nakoski

Most-Likely Causes



- Undersized steel gusset plate
  - The design calculations were not done correctly by the original design firm making it ½' instead of 1".
- Increased load on the bridge.
  - Bridge was reconfigured from 4 lanes to 8 lanes.
  - 500,000lbs (250 tons) of construction material piled on the bridge (Over the gusset plate).
  - High volume of traffic because of increased use of the bridge and rush hour.
  - Increased dead load because of previous repairs.
- Insufficient inspection

(According to an investigation done by the National Transportation Safety Board, corrosion damage in gusset plates at the L11 nodes, fracture of a floor truss, preexisting cracking, temperature effects, and pier movement were ruled out.)

Who was Responsible?

The firm that paid to inspect the bridge every year was partially responsible because of inadequate inspection of the buckling gusset plates.

The contractor who piled 500,000lbs of materials on the bridge was less responsible because of the lack of guidance for the placement of construction materials and equipment during repairs or maintenance.

The original design firm is responsible for not following the review process properly and making inaccurate calculations (including the load rating calculations).

The Government and state legislature of Minnesota and/or department of transportation were responsible for not fixing multiple problems that had been documented, inadequate procedures for reviewing and approving bridge design plans and calculations and lack of certain regulations.

What Could Have Prevented the Bridge Collapse?

There are multiple things that could have prevented the collapse of the bridge

- Proper inspection of gusset plates.
- Proper guidance for placement of construction materials.
- Limit Weight Concentration of Construction Materials
- The design firm should have followed the review process and done proper calculations on the load bearing capacity of the bridge.

Other research found on the web site ThinkReliability listed these as possible things that could have prevented the accident:

- Require Written Permission for Staging Materials on Bridges.
- Ensure Bridge Construction Inspectors Receive Bridge Instruction Training
- Recheck Weight Analyses After Dead Weight Increases
- Add Gusset Plates to Design Review
- Checklist to Make Sure All Calculations Have Been Performed
- Make Preliminary Designs Clearly.
- Require Load Calculations before Use.
- Analyze Capacity of Gusset Plates
- Educate on the Importance of Gusset Plates
- Verify Strength of Gusset Plates is Greater than the Parts that Depend on It (Members)
- List Gusset Plates as Specific, Separate Inspection Elements.
- Add Specific Training on Gusset Plate Inspections

The NTSB identified the following issues.

- Insufficient bridge design firm quality control procedures for designing bridges, and insufficient Federal and State procedures for reviewing and approving bridge design plans and calculations.

- 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.
- Inadequate use of technologies for accurately assessing the condition of gusset plates on deck truss bridges.