Investigation Issues

• Inadequate load capacity due to a design error
• Why the collapse occurred
• Why the design error went undetected for 40 years
• Gusset plate issues related to distortion and corrosion
Summary of Collapse Events

2 closed outside northbound traffic lanes

2 closed inside southbound traffic lanes
Summary of Collapse Events

- Construction equipment and vehicles
- Piles of aggregate
- U10 west node
Summary of Collapse Events

Source: MPD
Summary of Collapse Events

North approach

Deck truss

South approach

North
Initial Investigation Activities

• Pre-collapse condition of bridge
  – Cracks
  – Corrosion

• History of bridge
  – Construction
  – Inspection
  – Fatigue evaluations
  – Prior maintenance projects
Initial Investigation Findings

• Most of the structure was in good condition
• Generally well maintained
• Significant attention given to fatigue issues
• Inspected more frequently than required
Initial Investigation Findings

• Two previous construction projects had significantly increased the dead load
• Construction activities on day of collapse had concentrated weight over node U10 west
• Physical evidence indicated that failure at U10 was initiating event
Initiating Event

• Analysis of surveillance camera collapse video
• Inspection of bridge components
  – Superstructure
  – Bearings
  – Piers
• Additional analyses corroborated inspection findings
Fracture and Deformation

Upper chord

Lower chords

U10E

U10W

North
Fracture and Deformation

Initial compression failure

Initial tension fracture
Initial Tension Fracture

L9/U10W

North

Up
Gusset Plate Thickness

1 3/8” thick gusset plate (100 ksi) → 2 of 29 gusset plates
1” thick gusset plate (50 ksi) → 13 of 29 gusset plates
5/8” thick gusset plate (50 ksi) → 4 of 29 gusset plates
1/2” thick gusset plate (50 ksi) → 10 of 29 gusset plates
Gusset Plate Shear Analysis

The diagram shows the Gusset Plate D/C ratio with points marked for U4, U10, and L11.
Finite Element Modeling

Orange and red shading: exceeds yield stress

Stress

Yield stress
Allowable

0

Tension diagonal

Compression diagonal
Factors That Did Not Contribute

• Corrosion damage
• Fracture of a floor truss
• Pre-existing cracking
• Bearings and piers
Increases in Dead Load

• 1977 Modification
  – Deck thickness increased
  – Added over 3 million pounds

• 1998 Modification
  – Barriers / deicing system
  – Added 1.2 million pounds

• August 1, 2007
  – Construction materials concentrated above U10
Concentrated Construction Loads

- Construction materials: 383,000 lbs
- Construction equipment: 195,500 lbs
- Center span combined: 578,500 lbs
Increasing Loads on U10W Gusset Plate

- Construction Materials and Vehicles
- Traffic
- 1998 Modified Barriers
- 1977 Added Deck (Less Milled-off Lanes)
- Dead Load of Original Bridge Design
Increasing Loads on U10W Gusset Plate

Expected capacity of gusset plates for proper AASHO design

Total load at collapse

Critical Load on U10W Gusset Plates

Dead Load of Original Bridge Design

Construction Materials and Vehicles

Traffic

1998 Modified Barriers

1977 Added Deck (Less Milled-off Lanes)

Missing reserve capacity for proper design
Accident Loads on ½-inch-Thick Gusset Plates

Orange and red shading: exceeds yield stress
Accident Loads on 1-Inch-Thick Gusset Plates

Stress

Yield stress

Allowable

Compression diagonal

Tension diagonal
Detection of Design Error

- Error not discovered during original checks and reviews by:
  - Design firm
  - State and federal transportation officials

- Other opportunities for detection
  - Load ratings
  - Annual inspections
Load Ratings

• Required when significant change occurs that affects load-carrying capacity
• First load rating performed in 1979
  – Pavement overlay project to increase thickness of bridge deck
• Additional load ratings performed in 1995 and 1997
  – Modifications to barrier system
Load Ratings

• Load rating programs do not include or consider gusset plate strength

• If gusset plates had been included in load ratings
  – Should have revealed improperly designed gusset plates
  – May have determined that improperly designed gusset plates were controlling members
Bridge Inspections

• Bridge was inspected at a frequency greater than required by NBIS

• Condition ratings
  – Deck
  – Superstructure
  – Substructure

• Evaluate condition, not design adequacy
Gusset Plate Distortion

- Bowed gusset plates not addressed through inspections
- At least one inspector had observed bowing but did not report it
- Lack of specific training references to bowing could cause bridge inspectors to give inadequate attention to this condition
Grand River Bridge, source: ODOT
Gusset Plate Corrosion

• Corrosion not a factor in I-35W bridge collapse
• Visual inspections alone are inadequate to detect or quantify gusset plate corrosion
• NDE can greatly enhance accuracy of inspections
• Use NDE when appropriate to evaluate gusset plates
Safety Recommendations

• The design error was not initially detected during
  – Reviews by the design consultant
  – Reviews by Federal or State transportation agencies

• The design error remained undetected
  – Through subsequent load ratings
  – Through annual bridge inspections