Learning the lessons from bridge collapses around the world

Mungo Stacy

Principal Engineer, Parsons Brinckerhoff

"Failure is central to engineering ... every single calculation that an engineer makes is a failure calculation.

Successful engineering is all about understanding how things break or fail."

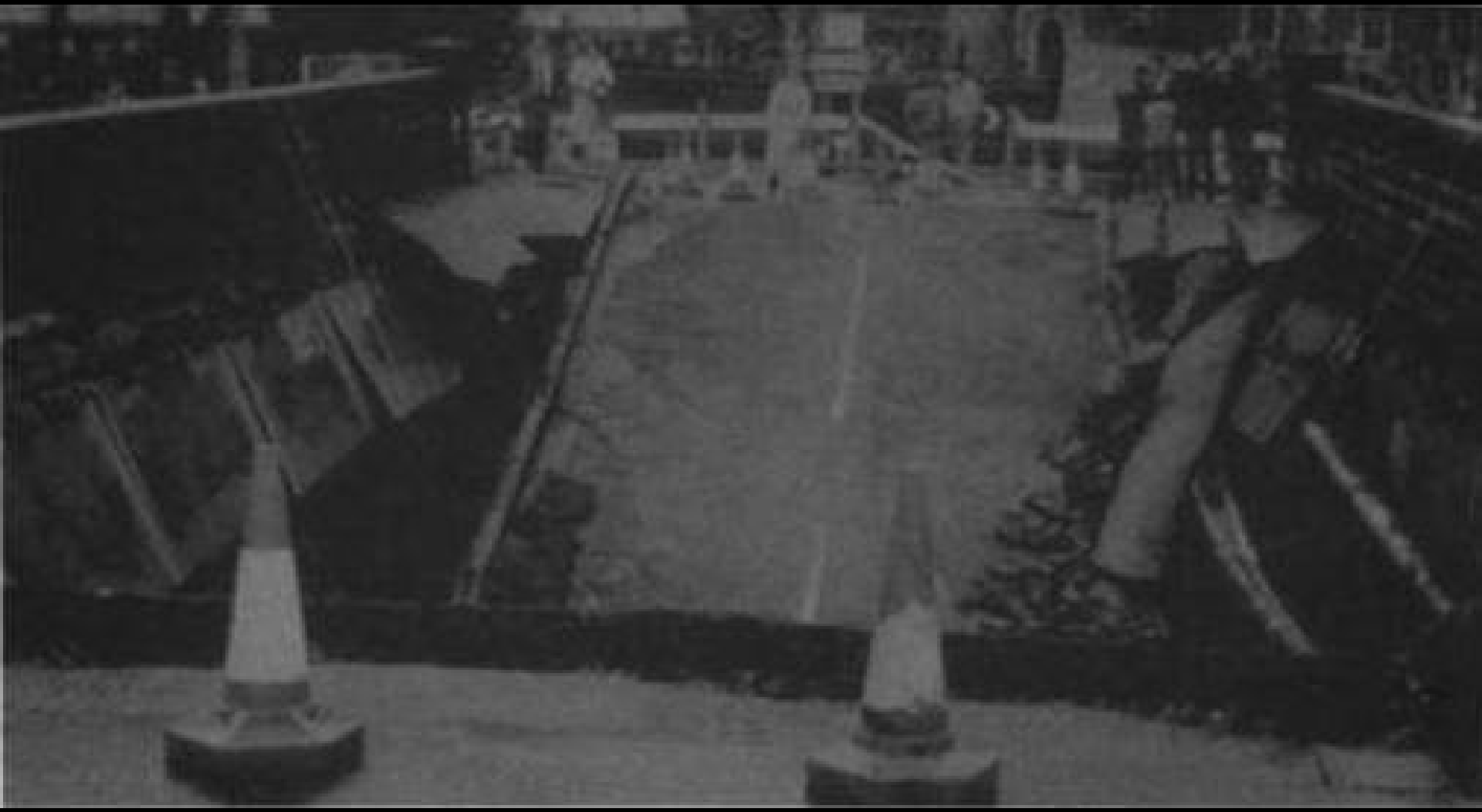
Henry Petroski

Tay bridge – 28 Dec 1879

Tacoma Narrows – 7 Nov 1940

Milford Haven – 2 June 1970

Ynys-y-gwas – 4 Dec 1985



MacArthur Maze – 29 Apr 2007

Cameroon – 1 July 2004

Montreal – 30 Sept 2006

Minnesota – 1 Aug 2007

Fenghuang, China - 14 Aug 2007

Can Tho, Vietnam – 26 Sept 2007

I35E Minnesota – 26 July 2008

Czech republic – 8 Aug 2008

Delhi Metro – 20 Oct 2008

Minnesota – 15 Nov 2008

Hanoi, Vietnam – 10 Mar 2009

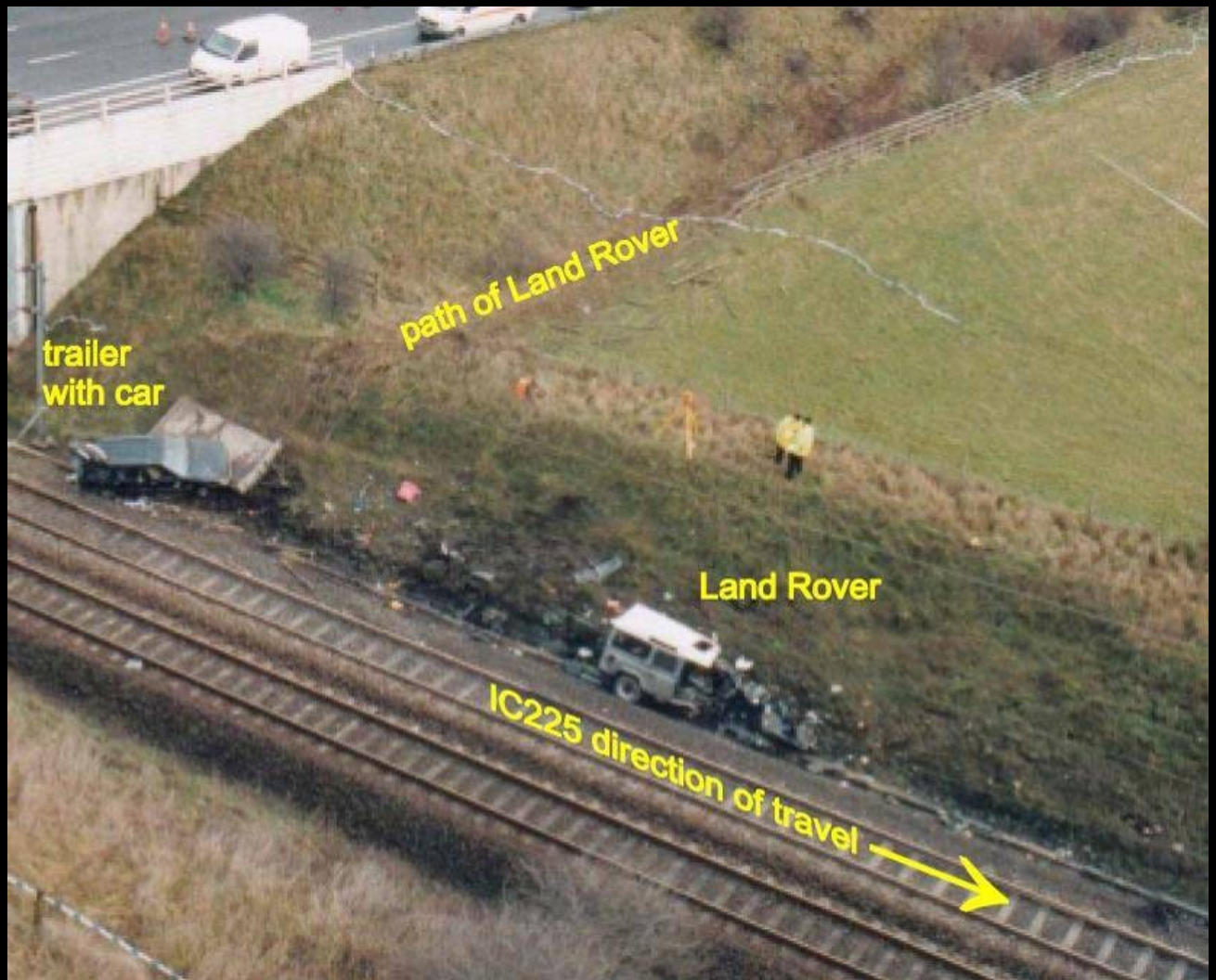
Zhuzhou, China – 17 May 2009

Kerry – 7 Feb 2007

Ludlow – 26 June 2007

Shropshire – 22 Oct 2008

Selby - 2001


path of Land Rover
trailer
with car
Land Rover
IC225 direction of travel

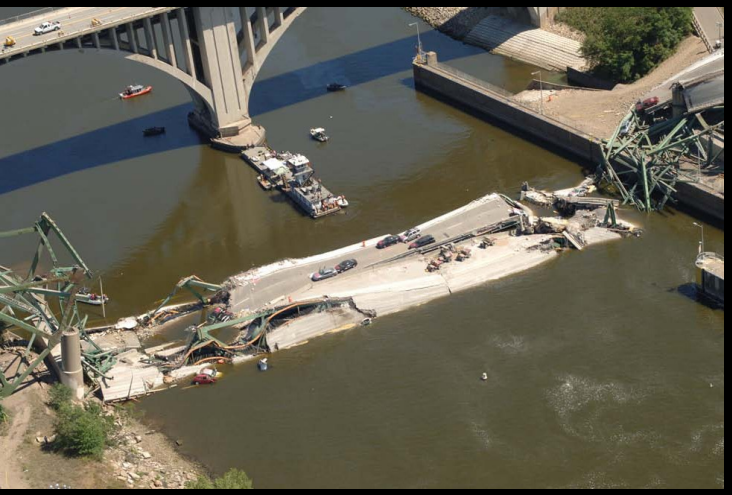
Gerrards Cross – 30 June 2005

Millennium Bridge – 12 June 2000

Liverpool St GE19 – 28 May 2008

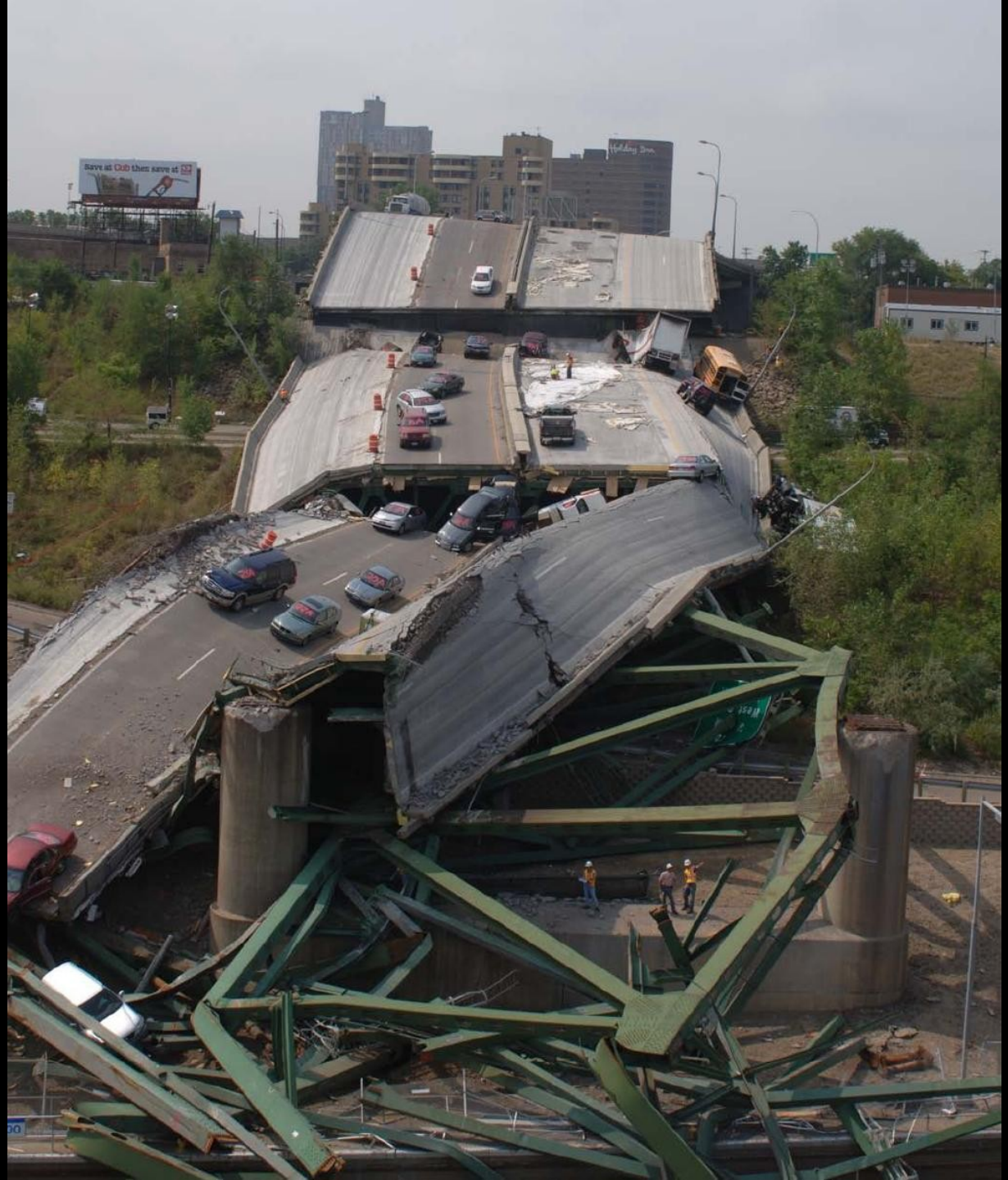
Clyde Arc – 14 Jan 2008

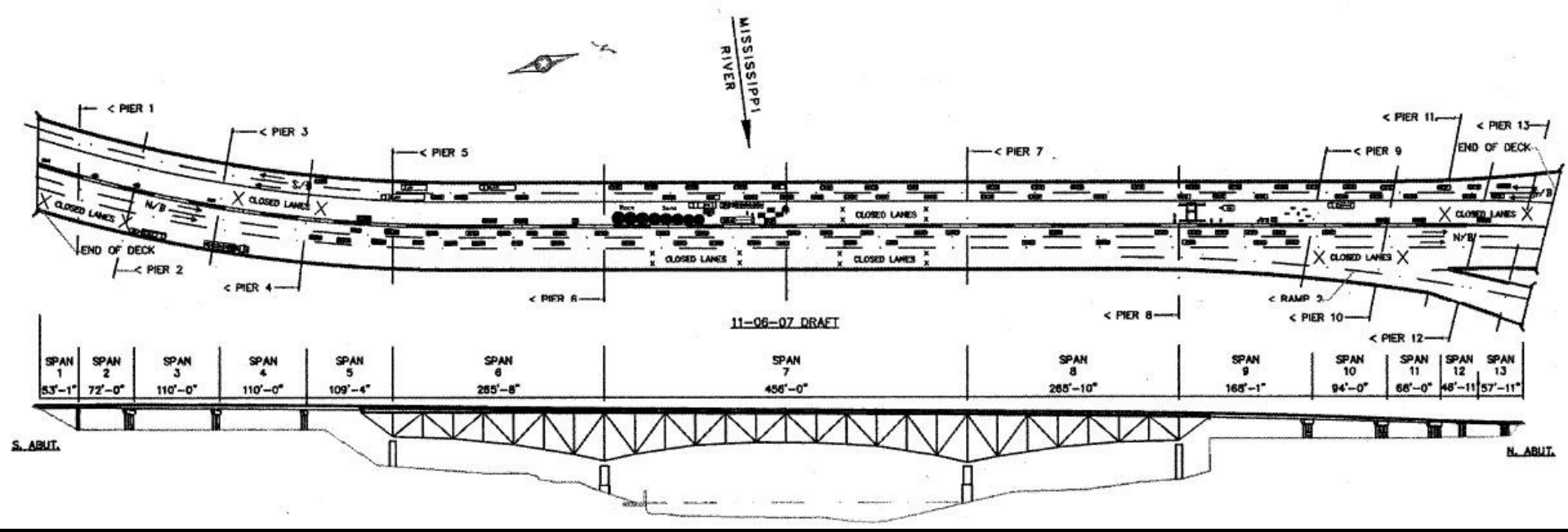
Learning the lessons from bridge collapses

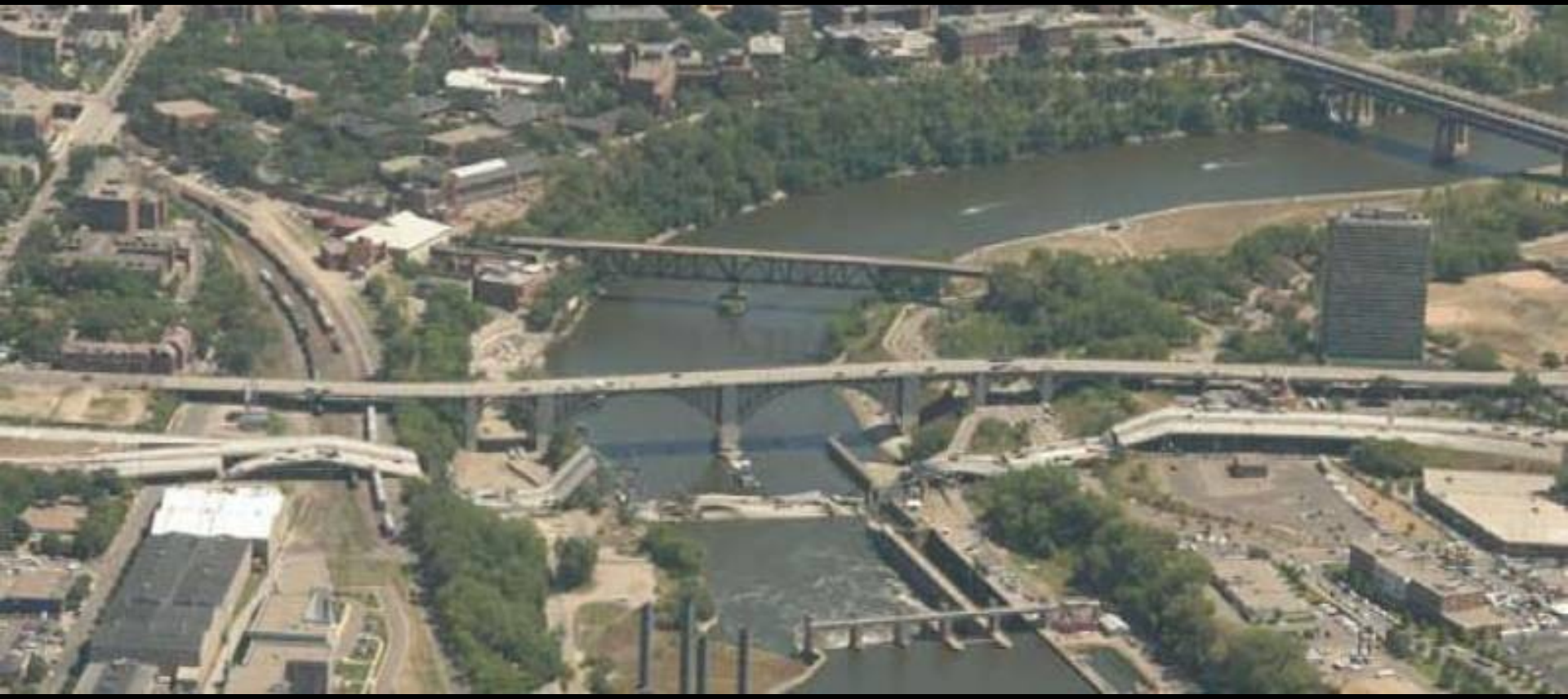


Minnesota *I35W Highway bridge*	Built 1967	Collapsed Aug 2007

Montreal *de la Concorde overpass*	Built 1971	Collapsed Sept 2006


Save at Dub then save at


MISSISSIPPI RIVER
< PIER 1
< PIER 2
< PIER 3
< PIER 4
< PIER 5
< PIER 6
< PIER 7
< PIER 8
< PIER 9
< PIER 10
< PIER 11
< PIER 12
< PIER 13
< RAMP 2
END OF DECK
END OF DECK
S/B
N/B
CLOSED LANES
11-06-07 DRAFT
SPAN 1 53'-1"
SPAN 2 72'-0"
SPAN 3 110'-0"
SPAN 4 110'-0"
SPAN 5 109'-4"
SPAN 6 265'-8"
SPAN 7 456'-0"
SPAN 8 265'-10"
SPAN 9 168'-1"
SPAN 10 94'-0"
SPAN 11 66'-0"
SPAN 12 48'-11"
SPAN 13 57'-11"
S. ABUT.
N. ABUT.



Bridge owning agency

"…recognised nationally and internationally as a leading Transportation Agency and a model for both the nation and other countries"

"…consulted by several European countries regarding best practices"

Bridge owning agency

"…from fiscal year 2001 to 2007, the number of Department staff declined by 19%"

"…departure of professional staff, particularly senior engineers"

"The Department and other similar departments around the county have lost engineers to more lucrative or interesting positions in the private sector"

Bridge owning agency

"...various organisational structures during the years since its creation..."

"...many people commented on the low moral that currently exists in the Department..."

"...the agency has lost substantial administrative infrastructure support, which has placed a greater burden on the professional staff to perform administrative and clerical tasks"

Inspections

Form 17108 (12-71)

Minnesota Department of Highways

1972 BRIDGE INSPECTION REPORT

Prepare 4 copies:
- ☐ *Original to District Engineer*
- ☐ *First copy to Area Maintenance Engineer*
- ☐ *Second & Third copies to Central Operations*

Bridge No. 9340	Check One: ☒ annual inspection ☐ special inspection	Date 11-29-72	Year Built 1967
Maintenance Area 5A	T. H. No. 35W	Mile Post 18.43	Location 2 Mi. N. of I94
Type B.S. & 3 Slab Spans	☒ Over ☐ Under Miss. Rv. & Rwy.	Bridge Posted For	Tons

I	ITEM	RATING
	Substructure	8
1	Footing	
2	Abutments	8
3	Wing Walls	8
4	Piers	8
5	Bridge Seats	8
	Superstructure	7
6	Trusses	8
7	Girders	8
8	Floor Beams	8
9	Stringers	8
10	Bearing Devices	8
11	Paint (Yr. Ptd. 1968)	7
	Decks	7
12	Expansion Joints	7
13	Railing	8
14	Structural Slab	
15	Wearing Surface	
16	Curb & Walk	
	Drains	7
	Channel & Protection	8
18	Area Under Bridge	8
19	Stream Bed	
20	Slope Protection	8
	Culverts	
21	Barrel & Floor	
22	Apron Wing Wall	
23	Retaining Wall	
24		
25		
26		
27		

COMMENTS AND SKETCHES
Refer to item number in comments and sketches
Use additional sheets if necessary

(10) The south expansion hinge should be checked for excessive expansion at 90° or higher.

(11) Light rusting under the open hinge joints.

(12) The joints at the cover plates are leaking. 500 L.F. of the 1" median joint has fallen out.

(14 & 15) N.B.L. has been sealed but 800 L.F. of add'l cracks should be sealed and 8,000 L.F. of leaking transverse cracks in the S.B.L. should be sealed.

(17) Drains over the south bank are plugged and need cleaning. (Sand gets traped in the horiz. troughs.

Condition rating from 9 (very good) to 0 (very poor) for conditions noted
Rating of 9 ---- new condition
Rating of 8 ---- good condition - no repair necessary
Rating of 7 ---- minor items in need of repair by maintenance forces
Rating of 6 ---- major items in need of repair by maintenance forces
Rating of 5 ---- major repair contract needs to be let
Rating of 4 ---- minimum adequacy to tolerate present traffic - immediate rehabilitation necessary to keep open
Rating of 3 ---- inadequacy to tolerate present heavy load - warrants closing bridge to trucks
Rating of 2 ---- inadequacy to tolerate any live load - warrants closing bridge to all traffic
Rating of 1 ---- bridge repairable, if desirable to reopen to traffic
Rating of 0 ---- bridge conditions beyond repair - danger of immediate collapse
Place dash where item is not rated

Inspec [redacted] Date: 11-29-72

Form 17108A (1-74)

Minnesota Department of Highways

BRIDGE INSPECTION REPORT

- ☐ *Original to Area Maintenance Engineer*
- ☐ *First copy to Bridge Maint. Supv.*
- ☐ *Second copy to Bridge Inventory Group*

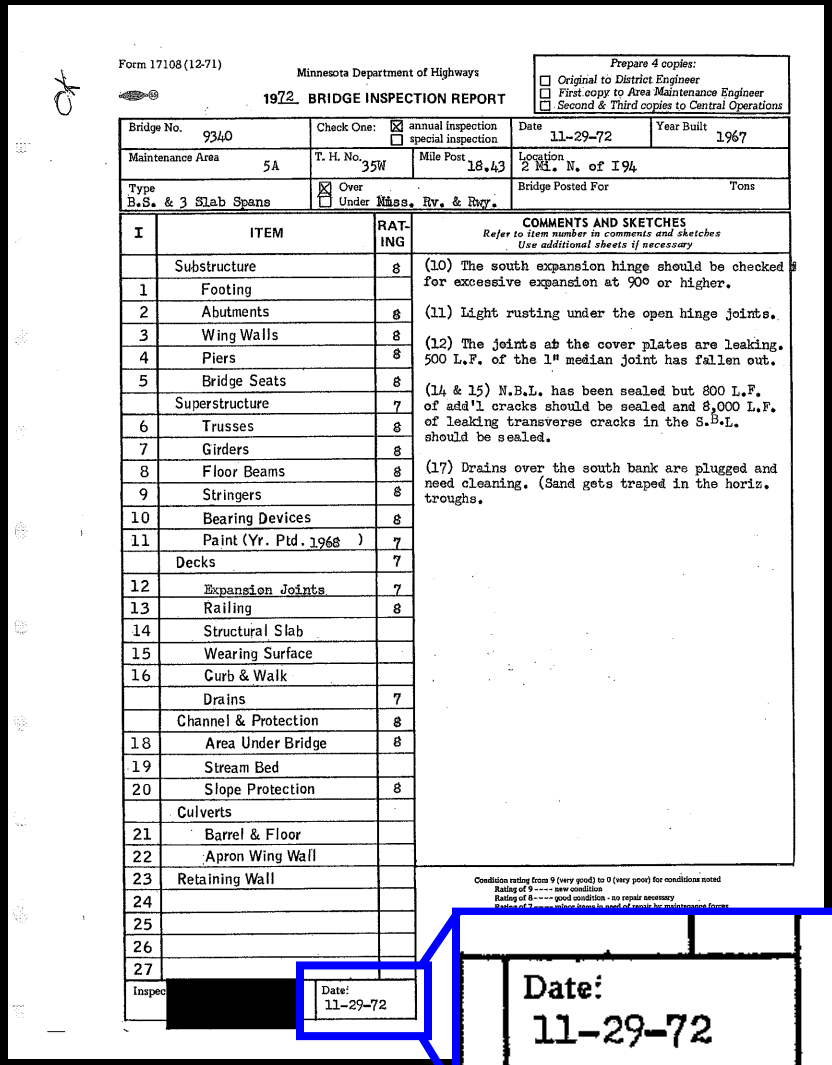
Bridge No. 9340 5 9340A	T.H. No. 35W	Mile Post 18.5A	Location 0.5 MI. NO. OF JCT. TH 12	Maintenance Area 5A
Type (304) 11 APPR. SPANS 3 CONT. ST. DK. TRUSS	☒ Over ☐ Under MISS. RIVER		Posted Limit in Tons	☒ annual inspection ☐ special inspection

I	ITEM	RATING				COMMENTS AND SKETCHES (Refer to item number in comments and sketches; Use additional sheets if necessary)
	SUBSTRUCTURE	6	6	6	6	1) So. ABUT. BRIDGE SEAT - CRACKING AND DISCOLORED.
1	Abutments	7	7	7	7	2) PIER 7 (FIXED PIER ON NO. EDGE OF RIVER) WEST COLUMN IS CRACKED VERTICALLY COMPLETELY THROUGH COLUMN.
2	Piers	6	6	6	6	3) SMALL AREAS OF SEVERE CORROSION OCCURING ESPECIALLY UNDER MEDIAN JOINT AND A SMALL AMOUNT OF CORROSION ON LOWER FLANGE (EAST) JUST SOUTH OF PIER 8
	SUPERSTRUCTURE	7	7	7	7	4) SEE 3) ABOVE. -
3	Trusses	7	7	7	7	5) SOME OF THE JOINTS TOO TIGHT.
4	Girders	N	N	N	N	7) DIRT & DEBRI UNDER ROLLER BEARINGS - NO INDICATION THAT BRGS ARE MOVING AS MUCH AS DESIGNED TO MOVE.
5	Floor Beams	7	7	7	7	9) 15-20% OF CONC. RAIL BASE IS UNSOUND. -
6	Stringers or Beams	8	8	8	8	11) 2000-3000 L.F. OF TRANSVERSE CRACKS IN LOW SLUMP OVERLAY -
7	Bearing Devices	7	7	7	7	12) FACE OF CURB STARTING TO SPALL IN SPOTS.
	DECKS	6	6	6	6	13) SEE 5) ABOVE - MAY BE A PAVEMENT PRESSURE PROBLEM.
8	Expansion Joints	7	7	7	7	20) NO HAZARD MARKERS
9	Railing CODE 12	6	6	6	6	21) 4-5% PAINT UNSOUND
10	Structural Slab	8	7	6	6	22) DRAINS PERENNIALLY PLUGGED. -
11	Wearing Surface	7	7	7	7	1968
12	Curb & Walk	7	7	7	7	1) 2) 5) 7) 9) 11) 12) 13) 20) 21) 22) NO CHANGE.
	AREA UNDER BRIDGE	8	8	8	8	2) SEE 3) ABOVE. SOME OF THE PIER JOINTS AT THE NORTH END OF THE BRIDGE - ASSOCIATED WITH THE SLAB SPANS ARE MODERATELY DETERIORATED -
13	Channel & Protection	8	8	8	8	3) SEE 5) ABOVE. - ALSO STRIP SEAL GLAND IS COMING OUT OF THE RETAINING SLAB IN SEVERAL PLACES (NORTH END OF BRIDGE)
14	Roadway, Railway, Other	8	8	8	8	10) BOTTOM OF SLAB, CAPING, & MEDIAN DETERIORATING IN MANY PLACES - ESPECIALLY NORTH END
15	Slopes & Berms	8	8	8	8	
	CULVERTS	N	N	N	N	
16	Barrel & Floor	N	N	N	N	
17	Apron & Wings	N	N	N	N	
	OTHER		7	7	7	
18	Retaining Wall	N	N	N	N	
19	Approaches	7	7	7	7	
20	Signing	7	7	7	7	
21	Paint (yr. ptd.) 1968	7	7	7	7	
22	Drainage	7	7	6	6	
23	Guard Rail #5	8	8	8	8	
24	CONDUIT	8	8	8	8	
25						

Inspected by [redacted] Date 6/14/73; Date 5/7/83; Date 5/17/84; Date 11/7/85

ESTIMATED COST OF REPAIR (1981)				REVIEWED
Labor	Material	Equipment	Total	By Engineer
				[illegible]
				[illegible]

Inspections



Form 17108 (12-71)

Minnesota Department of Highways

1972 BRIDGE INSPECTION REPORT

Prepare 4 copies:
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- ☐ Second & Third copies to Central Operations

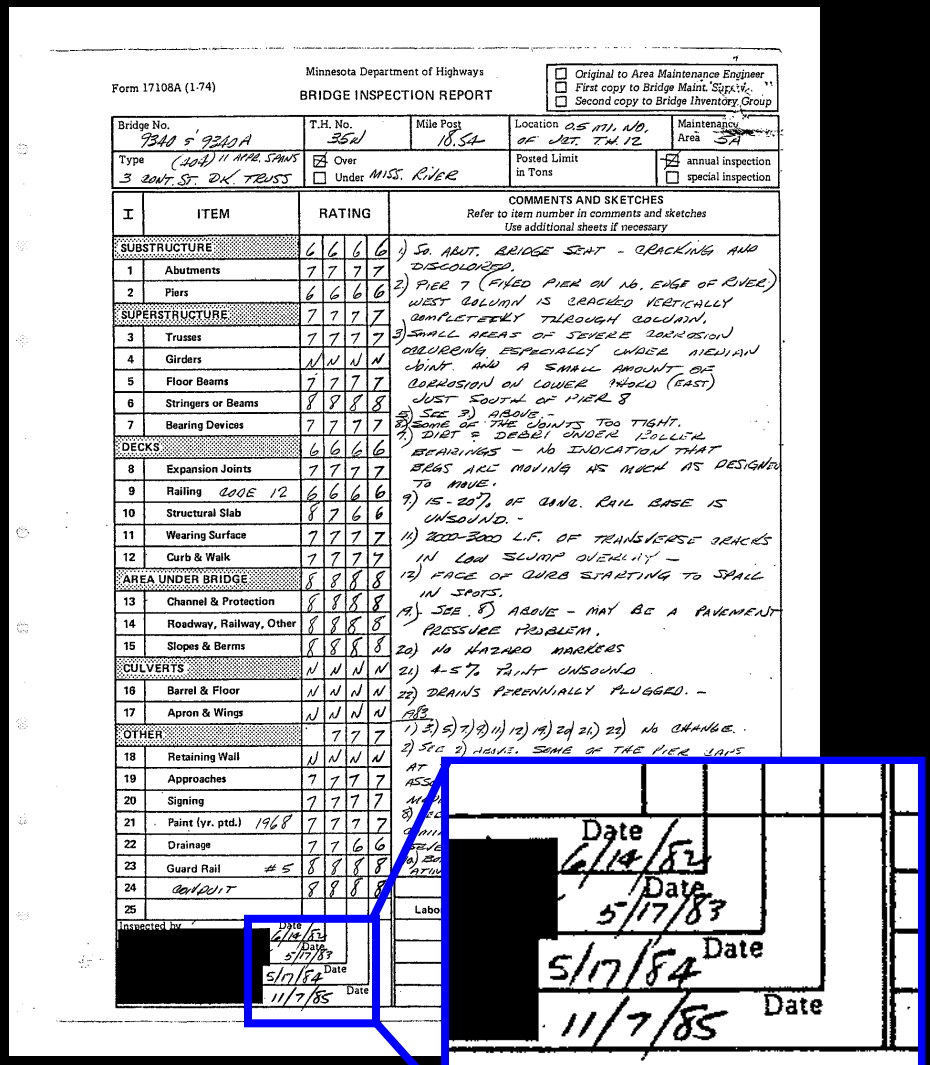
Bridge No.	Check One:	Date	Year Built
9340	☒ annual inspection ☐ special inspection	11-29-72	1967
Maintenance Area 5A	**T. H. No.** 35W	**Mile Post** 18.43	**Location** 2 Mi. N. of I94
Type B.S. & 3 Slab Spans	☒ Over ☐ Under Miss. Rv. & Rwy.	**Bridge Posted For**	Tons

I	ITEM	RATING	COMMENTS AND SKETCHES (Refer to item number in comments and sketches. Use additional sheets if necessary)
	Substructure	8	(10) The south expansion hinge should be checked for excessive expansion at 90° or higher.
1	Footing		
2	Abutments	8	(11) Light rusting under the open hinge joints.
3	Wing Walls	8	
4	Piers	8	(12) The joints at the cover plates are leaking. 500 L.F. of the 1" median joint has fallen out.
5	Bridge Seats	8	
	Superstructure	7	(14 & 15) N.B.L. has been sealed but 800 L.F. of add'l cracks should be sealed and 8,000 L.F. of leaking transverse cracks in the S.B.L. should be sealed.
6	Trusses	8	
7	Girders	8	
8	Floor Beams	8	(17) Drains over the south bank are plugged and need cleaning. (Sand gets traped in the horiz. troughs.
9	Stringers	8	
10	Bearing Devices	8	
11	Paint (Yr. Ptd. 1968)	7	
	Decks	7	
12	Expansion Joints	7	
13	Railing	8	
14	Structural Slab		
15	Wearing Surface		
16	Curb & Walk		
	Drains	7	
	Channel & Protection	8	
18	Area Under Bridge	8	
19	Stream Bed		
20	Slope Protection	8	
	Culverts		
21	Barrel & Floor		
22	Apron Wing Wall		
23	Retaining Wall		
24			
25			
26			
27			

Condition rating from 9 (very good) to 0 (very poor) for conditions noted
Rating of 9 ---- new condition
Rating of 8 ---- good condition - no repair necessary

Inspec[redacted] Date: 11-29-72

Date: 11-29-72



Form 17108A (1-74)

Minnesota Department of Highways

BRIDGE INSPECTION REPORT

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- ☐ First copy to Bridge Maint. Supv.
- ☐ Second copy to Bridge Inventory Group

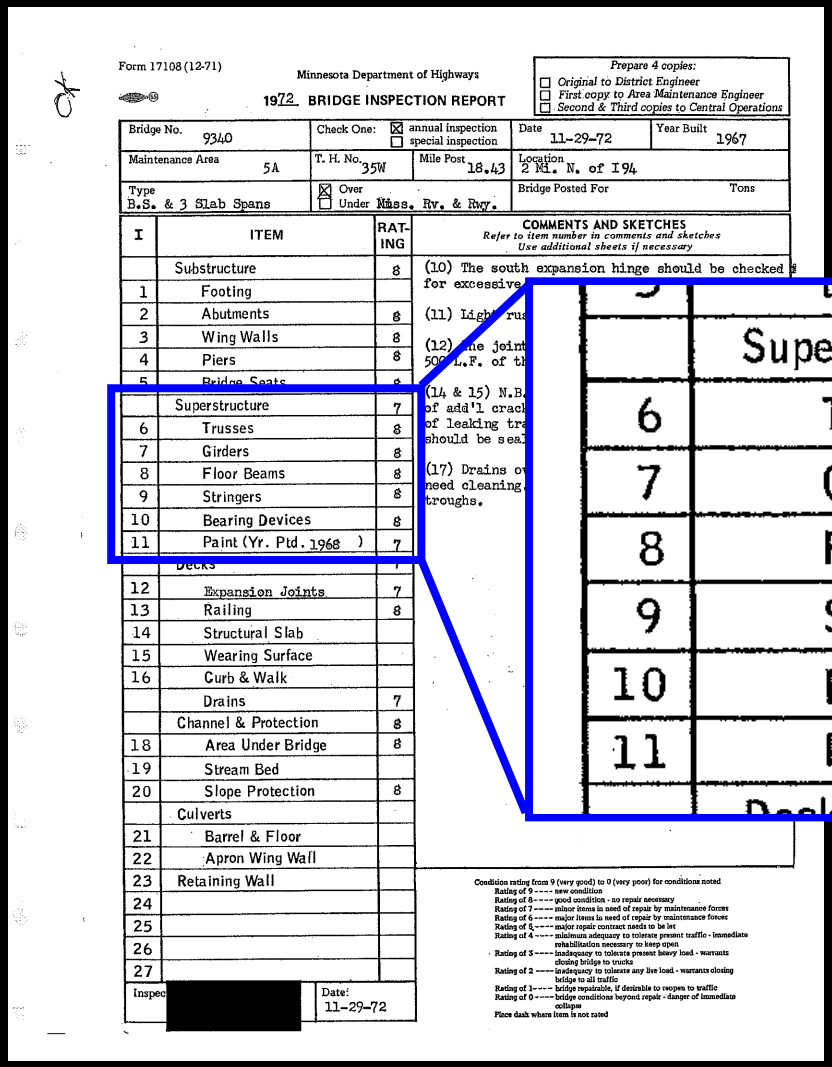
Bridge No.	T.H. No.	Mile Post	Location	Maintenance Area
9340 & 9340A	36W	18.5A	0.5 MI. NO. OF JCT. TH 12	5A
Type (304) 11 APPR. SPANS 3 CONT. ST. DK. TRUSS	☒ Over ☐ Under MISS. RIVER		**Posted Limit in Tons**	☒ annual inspection ☐ special inspection

I	ITEM	RATING				COMMENTS AND SKETCHES (Refer to item number in comments and sketches. Use additional sheets if necessary)
	SUBSTRUCTURE	6	6	6	6	1) So. ABUT. BRIDGE SEAT - CRACKING AND DISCOLORED.
1	Abutments	7	7	7	7	2) PIER 7 (FIXED PIER ON NO. EDGE OF RIVER) WEST COLUMN IS CRACKED VERTICALLY COMPLETELY THROUGH COLUMN.
2	Piers	6	6	6	6	3) SMALL AREAS OF SEVERE CORROSION OCCURING ESPECIALLY UNDER MEDIAN JOINT AND A SMALL AMOUNT OF CORROSION ON LOWER INSIDE (EAST) JUST SOUTH OF PIER 8
	SUPERSTRUCTURE	7	7	7	7	4) SEE 3) ABOVE.
3	Trusses	7	7	7	7	5) SOME OF THE JOINTS TOO TIGHT.
4	Girders	N	N	N	N	7) DIRT & DEBRI UNDER ROLLER BEARINGS - NO INDICATION THAT BRGS ARE MOVING AS MUCH AS DESIGNED TO MOVE.
5	Floor Beams	7	7	7	7	9) 15-20% OF CONC. RAIL BASE IS UNSOUND. -
6	Stringers or Beams	8	8	8	8	11) 2000-3000 L.F. OF TRANSVERSE CRACKS IN LOW SLUMP OVERLAY -
7	Bearing Devices	7	7	7	7	12) FACE OF CURB STARTING TO SPALL IN SPOTS.
	DECKS	6	6	6	6	13) SEE 5) ABOVE - MAY BE A PAVEMENT PRESSURE PROBLEM.
8	Expansion Joints	7	7	7	7	20) NO HAZARD MARKERS
9	Railing CODE 12	6	6	6	6	21) 4-5% PAINT UNSOUND
10	Structural Slab	8	7	6	6	22) DRAINS PERENNIALLY PLUGGED. -
11	Wearing Surface	7	7	7	7	1968
12	Curb & Walk	7	7	7	7	1) 2) 5) 7) 9) 11) 12) 13) 20) 21) 22) NO CHANGE.
	AREA UNDER BRIDGE	8	8	8	8	2) SEE 3) ABOVE. SOME OF THE PIER JOINTS AT ASS[illegible]
13	Channel & Protection	8	8	8	8	
14	Roadway, Railway, Other	8	8	8	8	
15	Slopes & Berms	8	8	8	8	
	CULVERTS	N	N	N	N	
16	Barrel & Floor	N	N	N	N	
17	Apron & Wings	N	N	N	N	
	OTHER		7	7	7	
18	Retaining Wall	N	N	N	N	
19	Approaches	7	7	7	7	
20	Signing	7	7	7	7	
21	Paint (yr. ptd.) 1968	7	7	7	7	
22	Drainage	7	7	6	6	
23	Guard Rail #5	8	8	8	8	
24	CONDUIT	8	8	8	8	
25						

Inspected by [redacted] Date 6/14/82 Date 5/17/83 Date 5/17/84 Date 11/7/85

Date 6/14/82 Date 5/17/83 Date 5/17/84 Date 11/7/85

Inspections



Form 17108 (12-71)

Minnesota Department of Highways

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Bridge No. 9340	Check One: ☒ annual inspection ☐ special inspection	Date 11-29-72	Year Built 1967
Maintenance Area 5A	T. H. No. 35W	Mile Post 18.43	Location 2 Mi. N. of I94
Type B.S. & 3 Slab Spans	☒ Over ☐ Under Miss. Rv. & Rwy.	Bridge Posted For	Tons

I	ITEM	RATING
	Substructure	8
1	Footing	
2	Abutments	8
3	Wing Walls	8
4	Piers	8
5	Bridge Seats	8
	Superstructure	7
6	Trusses	8
7	Girders	8
8	Floor Beams	8
9	Stringers	8
10	Bearing Devices	8
11	Paint (Yr. Ptd. 1968)	7
	Decks	7
12	Expansion Joints	7
13	Railing	8
14	Structural Slab	
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16	Curb & Walk	
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18	Area Under Bridge	8
19	Stream Bed	
20	Slope Protection	8
	Culverts	
21	Barrel & Floor	
22	Apron Wing Wall	
23	Retaining Wall	
24		
25		
26		
27		

COMMENTS AND SKETCHES
Refer to item number in comments and sketches
Use additional sheets if necessary

(10) The south expansion hinge should be checked for excessive

(11) Ligh rus

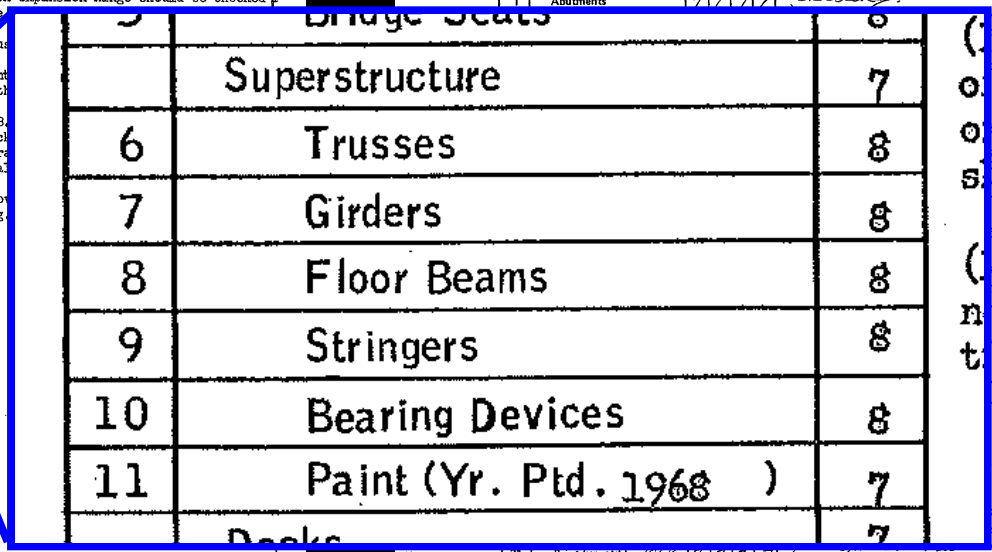
(12) he joint 500 L.F. of th

(14 & 15) N.B. of add'l crack of leaking tr should be sea

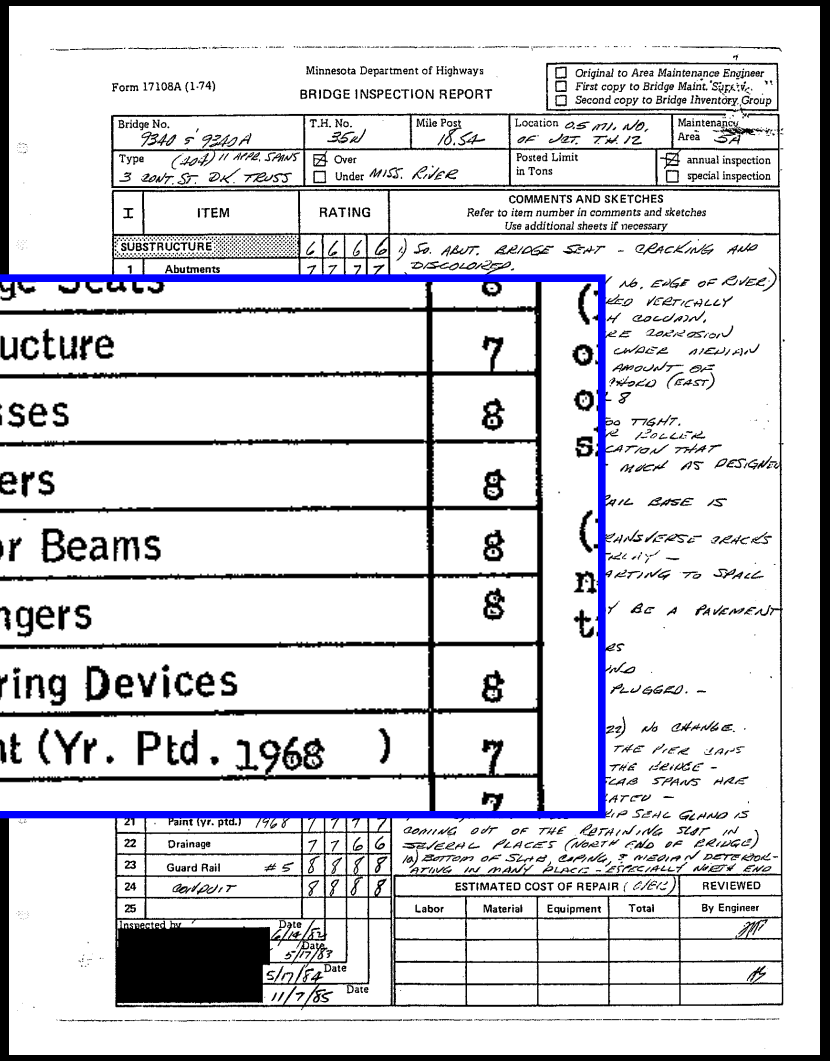
(17) Drains o need cleaning troughs.

Condition rating from 9 (very good) to 0 (very poor) for conditions noted
Rating of 9 ---- new condition
Rating of 8 ---- good condition - no repair necessary
Rating of 7 ---- minor items in need of repair by maintenance forces
Rating of 6 ---- major items in need of repair by maintenance forces
Rating of 5 ---- major repair contract needs to be let
Rating of 4 ---- minimum adequacy to tolerate present traffic - immediate rehabilitation necessary to keep open
Rating of 3 ---- inadequacy to tolerate present heavy load - warrants closing bridge to trucks
Rating of 2 ---- inadequacy to tolerate any live load - warrants closing bridge to all traffic
Rating of 1 ---- bridge repairable, if desirable to reopen to traffic
Rating of 0 ---- bridge conditions beyond repair - danger of immediate collapse
Place dash where item is not rated

Inspec [redacted] Date: 11-29-72



	Bridge Seats	8
	Superstructure	7
6	Trusses	8
7	Girders	8
8	Floor Beams	8
9	Stringers	8
10	Bearing Devices	8
11	Paint (Yr. Ptd. 1968)	7
	Decks	7



Form 17108A (1-74)

Minnesota Department of Highways

BRIDGE INSPECTION REPORT

- Original to Area Maintenance Engineer
- First copy to Bridge Maint. Supv.
- Second copy to Bridge Inventory Group

Bridge No. 9340 5 9340A	T.H. No. 36W	Mile Post 18.5A	Location 0.5 MI. NO. OF JCT. TH 12	Maintenance Area 5A
Type (304) 11 APPR. SPANS 3 CONT. ST. DK. TRUSS	☒ Over ☐ Under MISS. RIVER		Posted Limit in Tons	☒ annual inspection ☐ special inspection

I	ITEM	RATING				COMMENTS AND SKETCHES
						Refer to item number in comments and sketches *Use additional sheets if necessary*
	SUBSTRUCTURE	6	6	6	6	1) SO. ABUT. BRIDGE SEAT - CRACKING AND DISCOLORED.
1	Abutments	7	7	7	7	
2	Wing Walls	8	8	8	8	
3	Piers	8	8	8	8	
4	Bridge Seats	8	8	8	8	
	SUPERSTRUCTURE	7	7	7	7	
6	Trusses	8	8	8	8	
7	Girders	8	8	8	8	
8	Floor Beams	8	8	8	8	
9	Stringers	8	8	8	8	
10	Bearing Devices	8	8	8	8	
11	Paint (Yr. ptd.) 1968	7	7	7	7	
22	Drainage	7	7	6	6	
23	Guard Rail #5	8	8	8	8	
24	CONDUIT	8	8	8	8	
25						

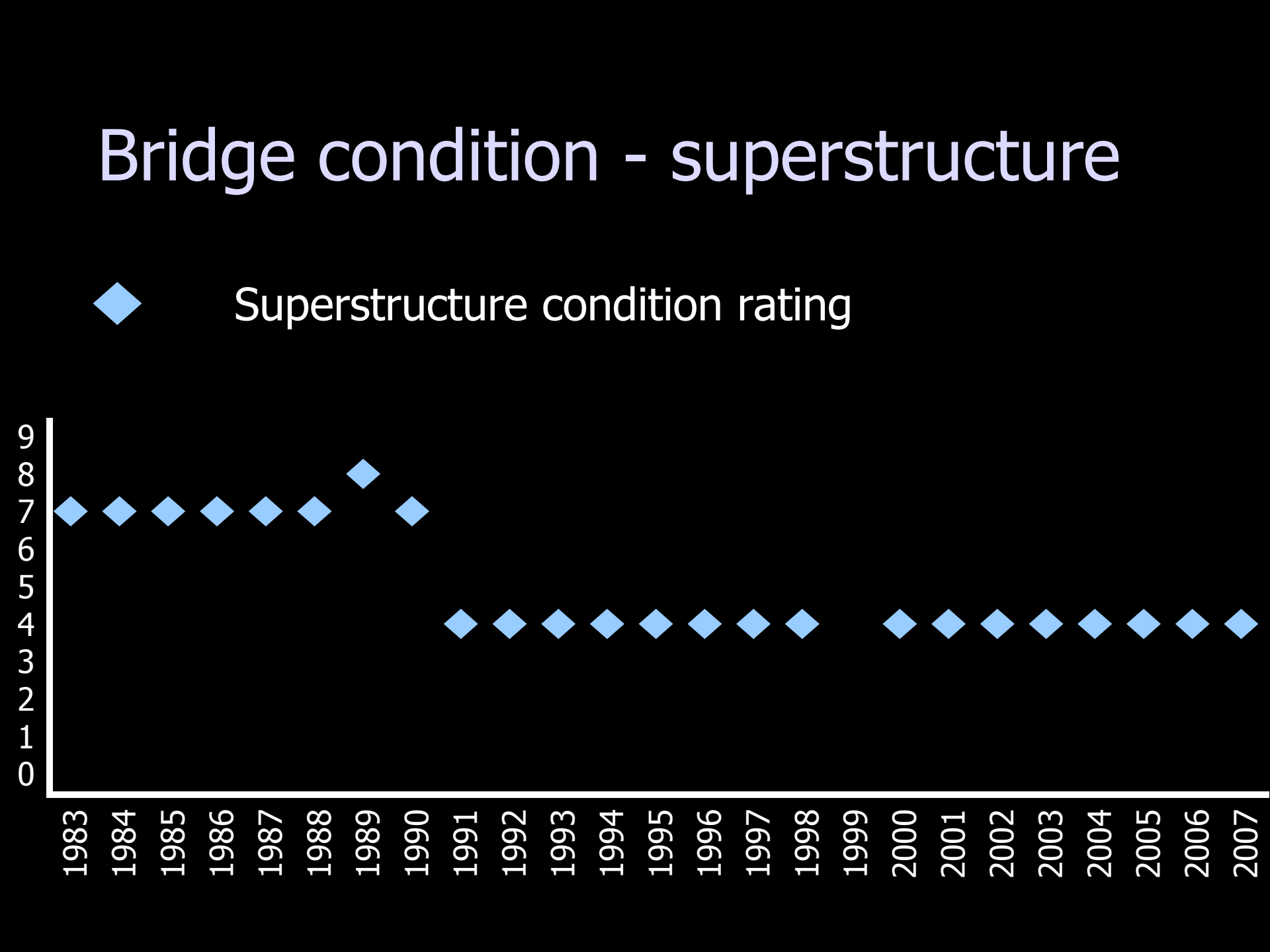
Inspected by [redacted]
Date 6/14/83
Date 5/7/83
Date 5/17/84
Date 11/7/85

ESTIMATED COST OF REPAIR (1984)

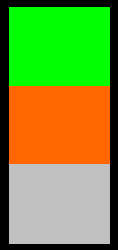
Labor	Material	Equipment	Total	REVIEWED By Engineer

(NO. EDGE OF RIVER)
RED VERTICALLY
H COLUMN.
RE CORROSION
UNDER MEDIAN
AMOUNT OF
WARD (EAST)
L 8
OO TIGHT.
R ROLLER
CATION THAT
MUCH AS DESIGNED
AIL BASE IS
RANSVERSE CRACKS
TALLY -
RTING TO SPALL
Y BE A PAVEMENT
ES
AND
PLUGGED. -
22) NO CHANGE.
THE PIER CAPS
THE BRIDGE -
LAB SPANS ARE
ATED -
IP SEAL GLAND IS
COMING OUT OF THE RETAINING SLAT IN
SEVERAL PLACES (NORTH END OF BRIDGE)
10) BOTTOM OF SLAB, CAPING, & MEDIAN DETERIORATING IN MANY PLACES - ESPECIALLY NORTH END

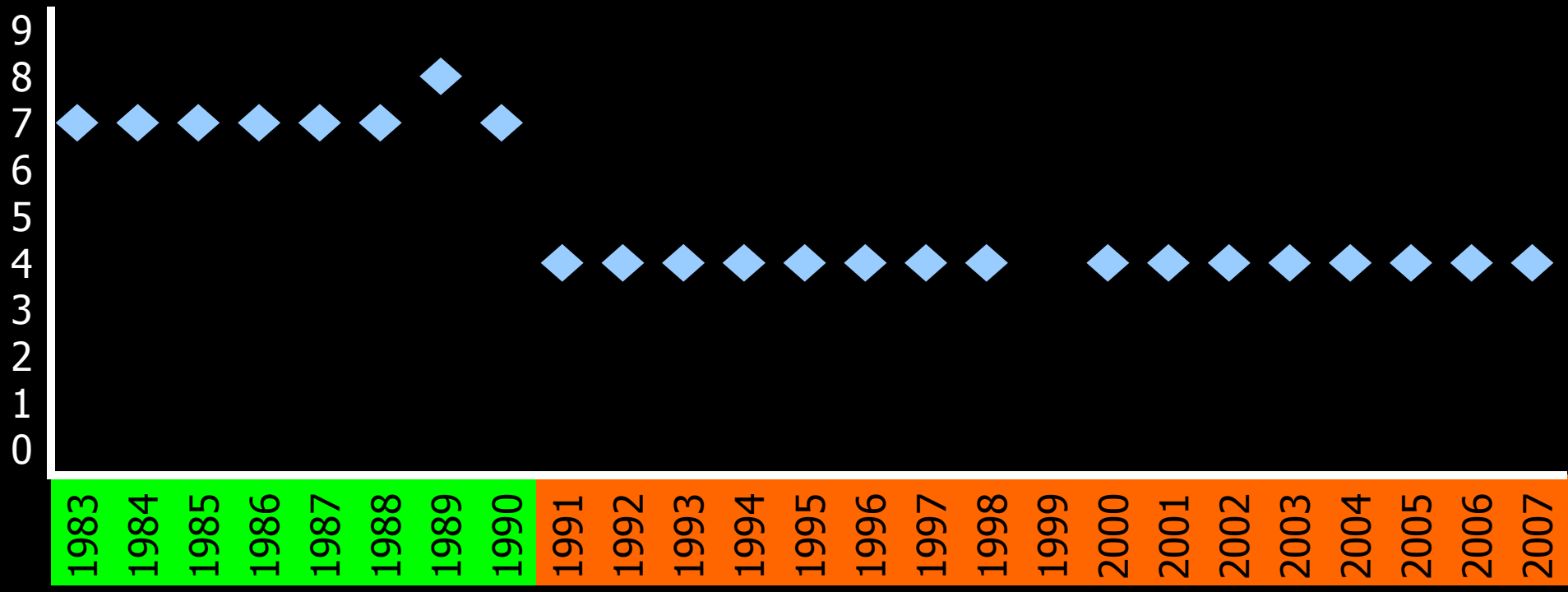
Bridge condition - superstructure



Bridge condition - status

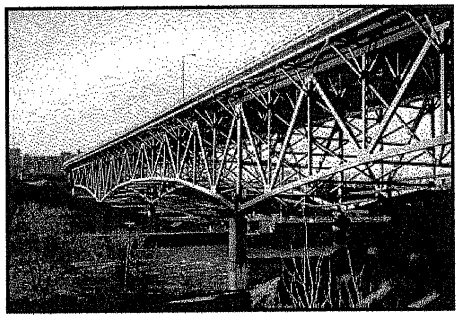


Not deficient
Structurally deficient
Functionally obsolete



Inspections – fracture critical

Fracture Critical
Bridge Inspection Report

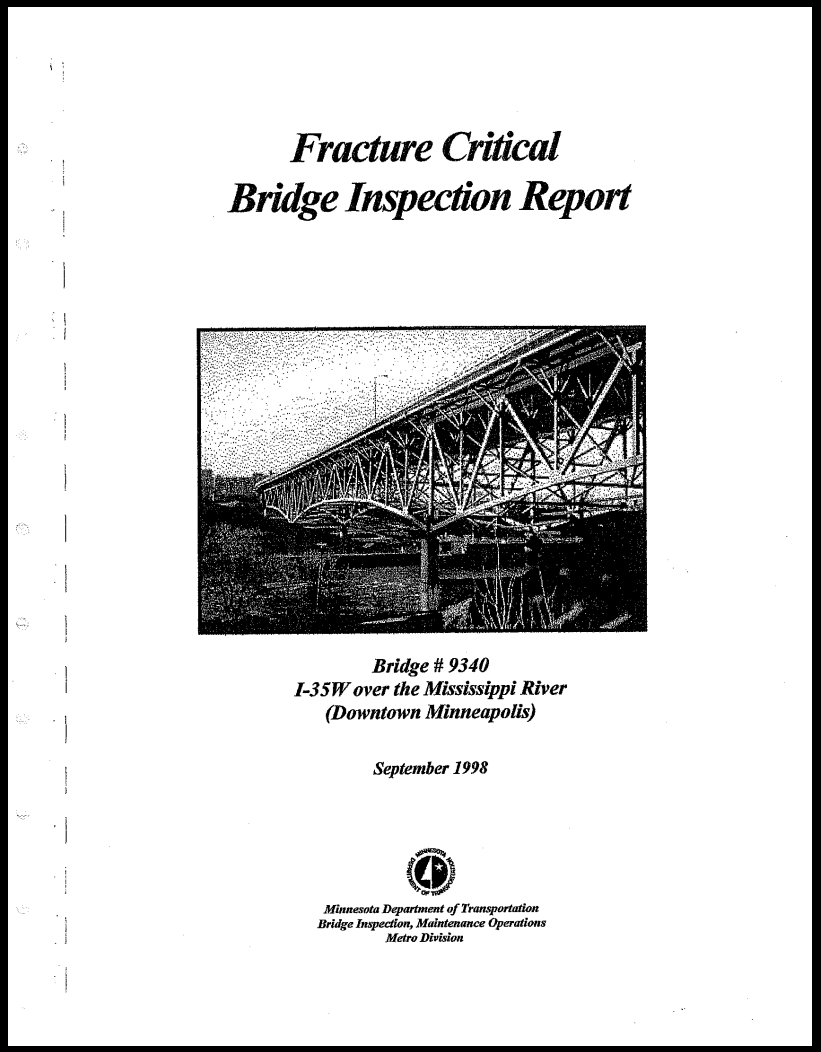


Bridge # 9340
I-35W over the Mississippi River
(Downtown Minneapolis)

September 1998

Minnesota Department of Transportation
Bridge Inspection, Maintenance Operations
Metro Division

Inspections – fracture critical



Fracture Critical
Bridge Inspection Report

Bridge # 9340
I-35W over the Mississippi River
(Downtown Minneapolis)

September 1998

Minnesota Department of Transportation
Bridge Inspection, Maintenance Operations
Metro Division

1994: Bridge classed as 'fracture critical' and 'non-load-path-redundant'

Failure of critical member expected to result in collapse of bridge

Fatigue / redundancy studies

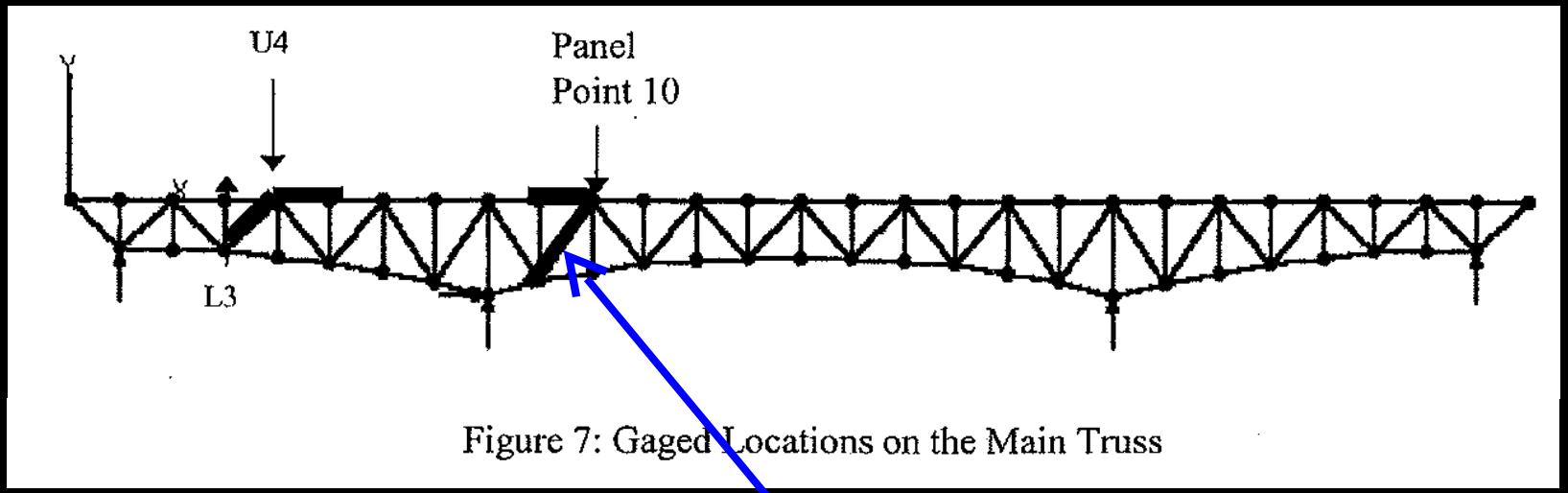
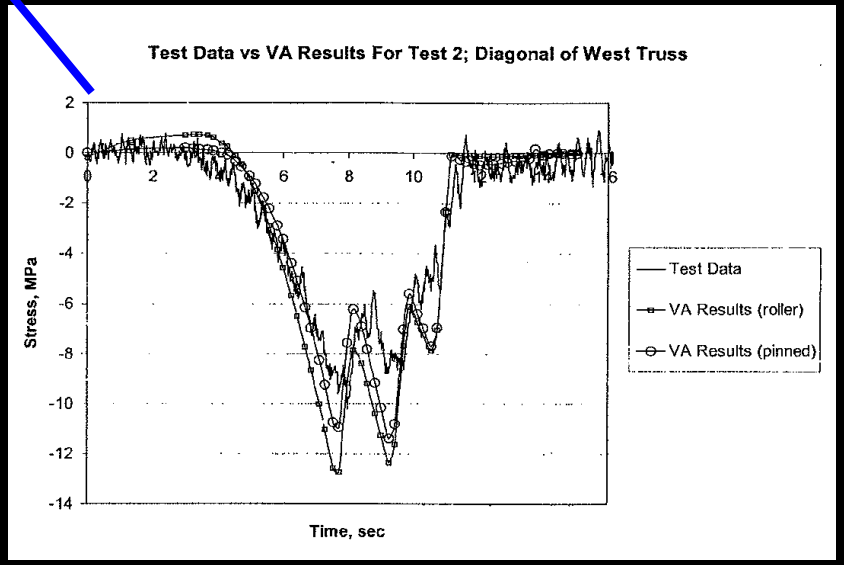


Figure 7: Gaged Locations on the Main Truss

Physical testing and modelling conducted by University of Minnesota



"Budget Buster"
Major TH Bridges Requiring Replacement or Renovation in the Next 10 Years

D7	TH 169/Minnesota at Le Sueur	2005
Metro	TH 36/St Croix at Stillwater	2007
D2	TH 11/Red River at Robbin	2008
Metro	TH 52/Mississippi in St Paul - Lafayette	2010
D6	I90/Mississippi at Dresbach	2010
Metro	I 35E/Cayuga St & RR in St Paul	2010
Metro	I35W/Mississippi in Minneapolis	2012
Metro	TH 61/Mississippi at Hastings	2014

“Without warning”?

- ‘Structurally deficient’ status since 1991
- Identified as fracture critical and non-load-path-redundant
- Extensive studies carried out on fatigue and redundancy
- Identified for replacement as a ‘budget buster’

“Without warning”?

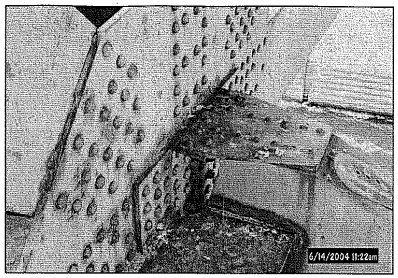
- ‘Structurally deficient’ status since 1991
- Identified as fracture critical and non-load-path-redundant
- Extensive studies carried out on fatigue and redundancy
- Identified for replacement as a ‘budget buster’
- No improvement to ‘deficient’ rating over 16 years despite work and studies on structure

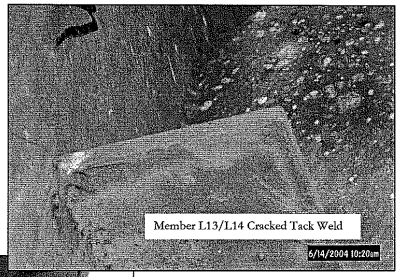
Investigations

Inspection reports - 2004

Panel Point #13 (East Truss):
Water from deck drains fall directly into river. [99/2002] Bottom chord gusset plate has section loss, flaking & pack rust. [1999] Truss bottom chord member L13/L14 has cracked tack welds at two interior stiffeners. [2004] Bottom chord member L13/L14 cracked tack weld @ diagram tab (diagram #12). Cracked tack weld @ diagram tab member L13/U14 see photos.

Bottom Chord Connection Condition

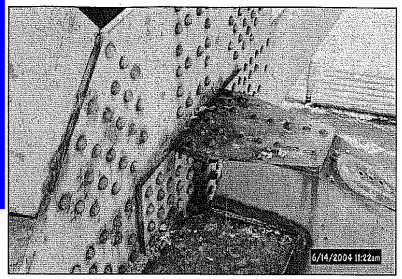




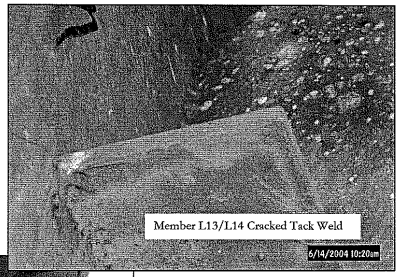
2004 Bridge Inspection
Bridge #9340 -23-

Inspection reports - 2004

Panel Point #13 (East Truss): Water from deck drains fall directly into river. [99/2002] Bottom chord gusset plate has section loss, flaking & pack rust. [1999] Truss bottom chord member L13/L14 has cracked tack welds at two interior stiffeners. [2004] Bottom chord member L13/L14 cracked tack weld @ diagram tab (diagram #1?). Cracked tack weld @ diagram tab member L13/U14 see photos.



Bottom Chord Connection Condition



Member L13/L14 Cracked Tack Weld

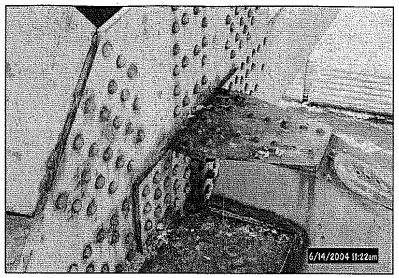
Member L13/U14 Cracked Tack Weld

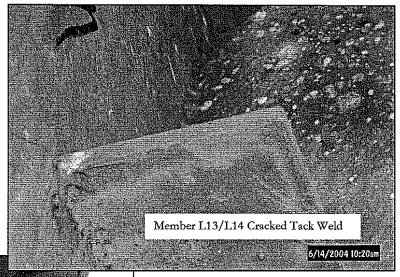
Panel Point #13 (East Truss): Water from deck drains fall directly into river. [99/2002] Bottom chord gusset plate has section loss, flaking & pack rust. [1999] Truss bottom chord member L13/L14 has cracked tack welds at two interior stiffeners. [2004] Bottom chord member L13/L14 cracked tack weld @ diagram tab (diagram #1?). Cracked tack weld @ diagram tab member L13/U14 see photos.

Inspection reports - 2005

Panel Point #13 (East Truss):
Water from deck drains fall directly into river. [99/2002] Bottom chord gusset plate has section loss, flaking & pack rust. [1999] Truss bottom chord member L13/L14 has cracked tack welds at two interior stiffeners. [2004] Bottom chord member L13/L14 cracked tack weld @ diagram tab (diagram #1?). Cracked tack weld @ diagram tab member L13/U14 see photos.

Bottom Chord Connection Condition





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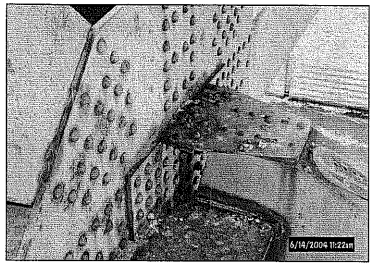
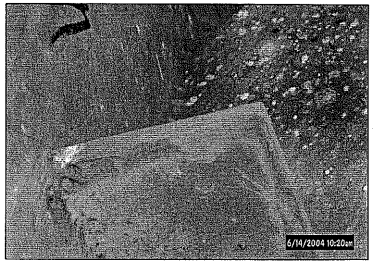
Condition @Bottom Chord Connection



Member L13/L14 Cracked Tack Weld



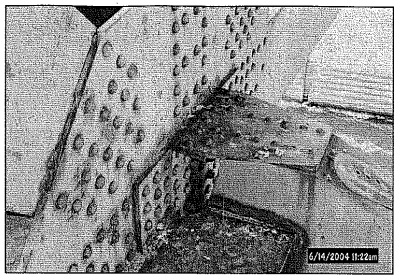
2005 Bridge Inspection
Bridge #9340 -23-

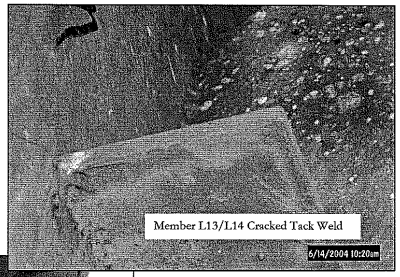
2005 Bridge Inspection
Bridge #9340 -23-

Inspection reports - 2006

Panel Point #13 (East Truss):
Water from deck drains fall directly into river. [99/2002] Bottom chord gusset plate has section loss, flaking & pack rust. [1999] Truss bottom chord member L13/L14 has cracked tack welds at two interior stiffeners. [2004] Bottom chord member L13/L14 cracked tack weld @ diagram tab (diagram #12). Cracked tack weld @ diagram tab member L13/U14 see photos.

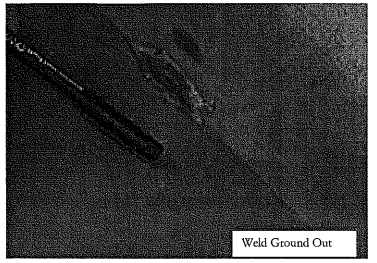
Bottom Chord Connection Condition



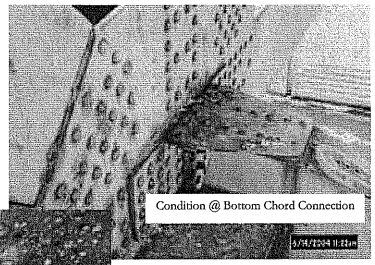


Member L13/U14 Cracked Tack Weld

Panel Point #12 (East Truss):
[1999] Truss bottom chord member L12/L13 has a cracked tack weld at an interior stiffener. [2004] Ground out pit from past inspection.

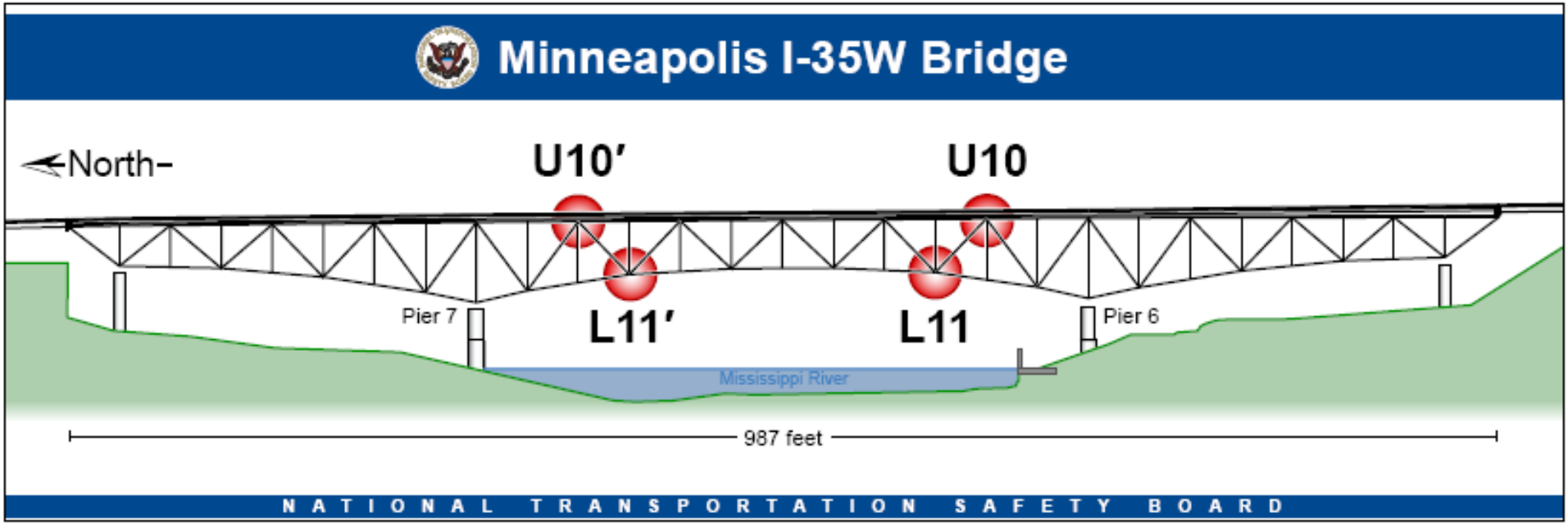


Panel Point #13 (East Truss):
Water from deck drains fall directly into river. [1999] Truss bottom chord member L13/L14 has cracked tack welds at two interior stiffeners. [99/2002] Bottom chord gusset plate has section loss, flaking & pack rust. [2004] Bottom chord member L13/L14 has cracked tack weld @ diaphragm tab. Cracked tack weld at diaphragm tab member L13/U14. See photos. [2006] Bottom chord member L13/L14 has a missing bird cover.

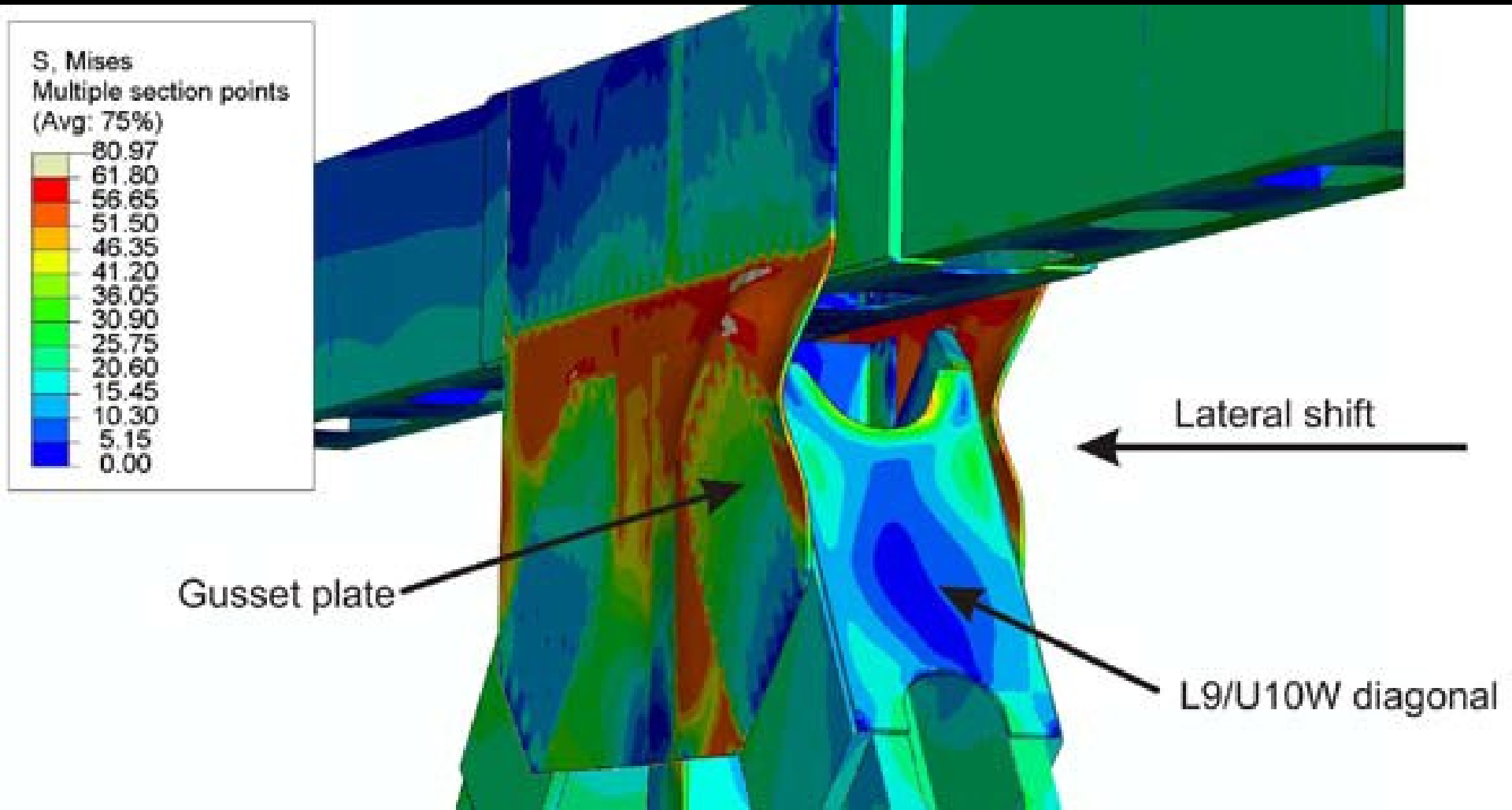


2006 Bridge Inspection
Bridge #9340 -24-

Global analysis

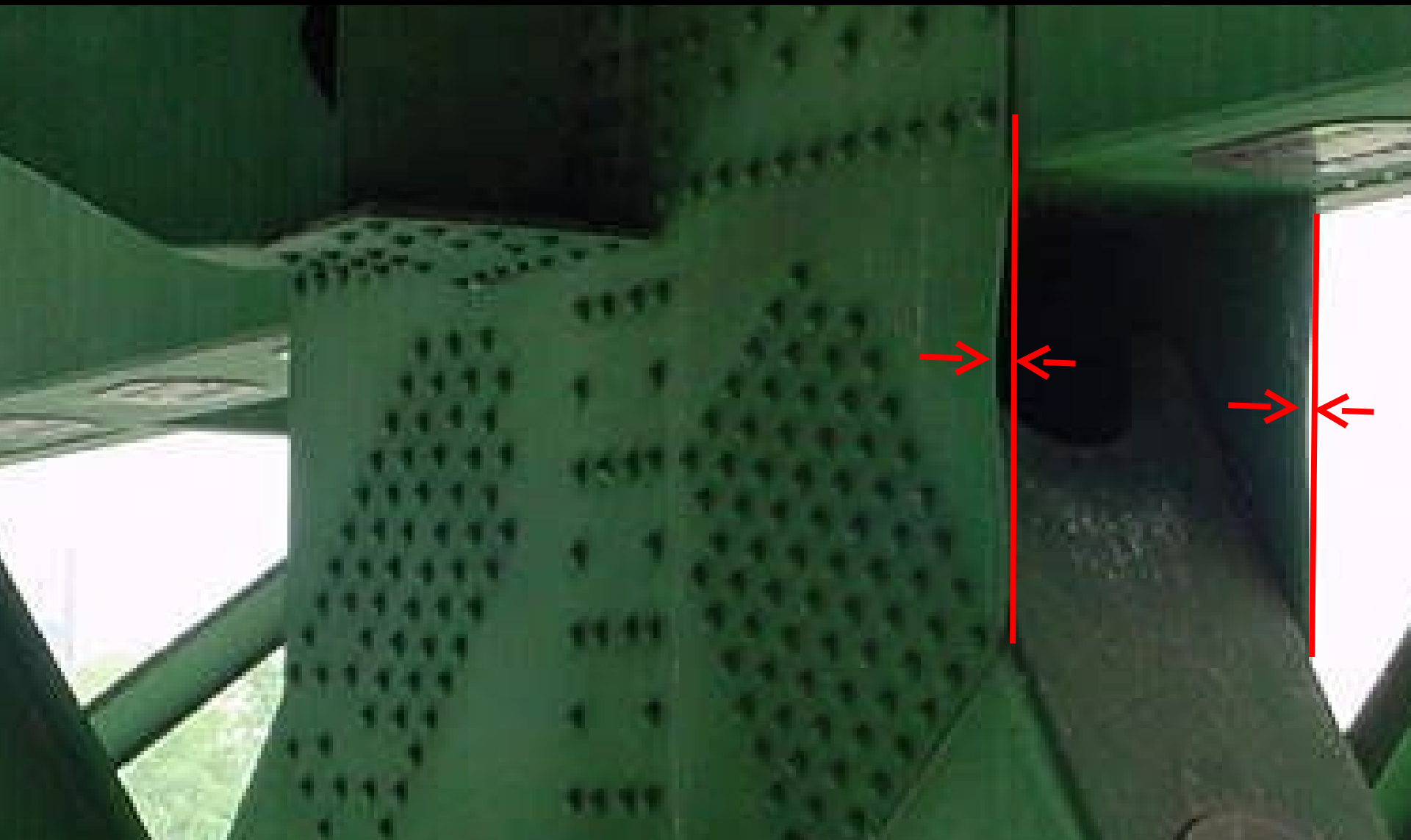


Gusset plate FE model

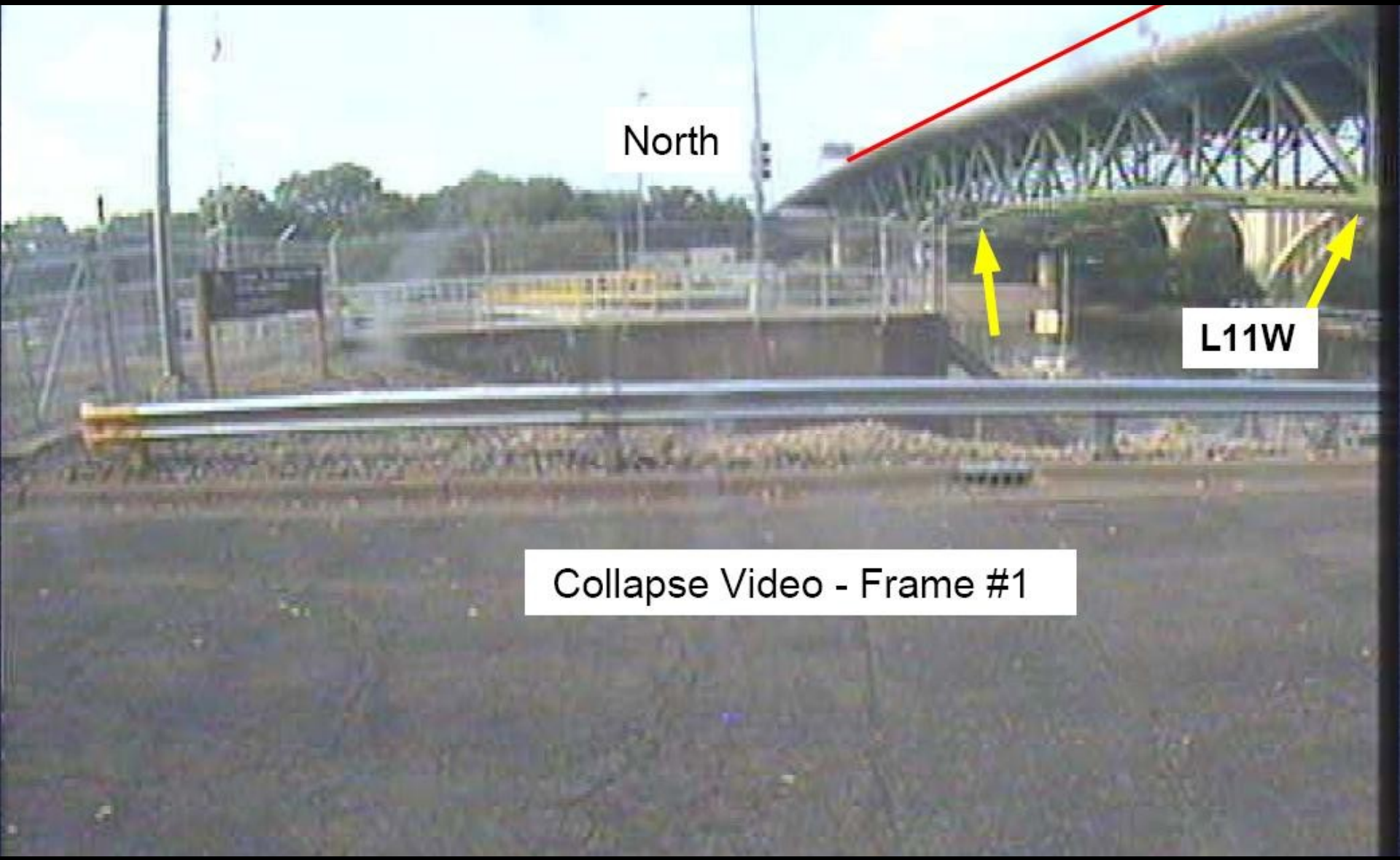


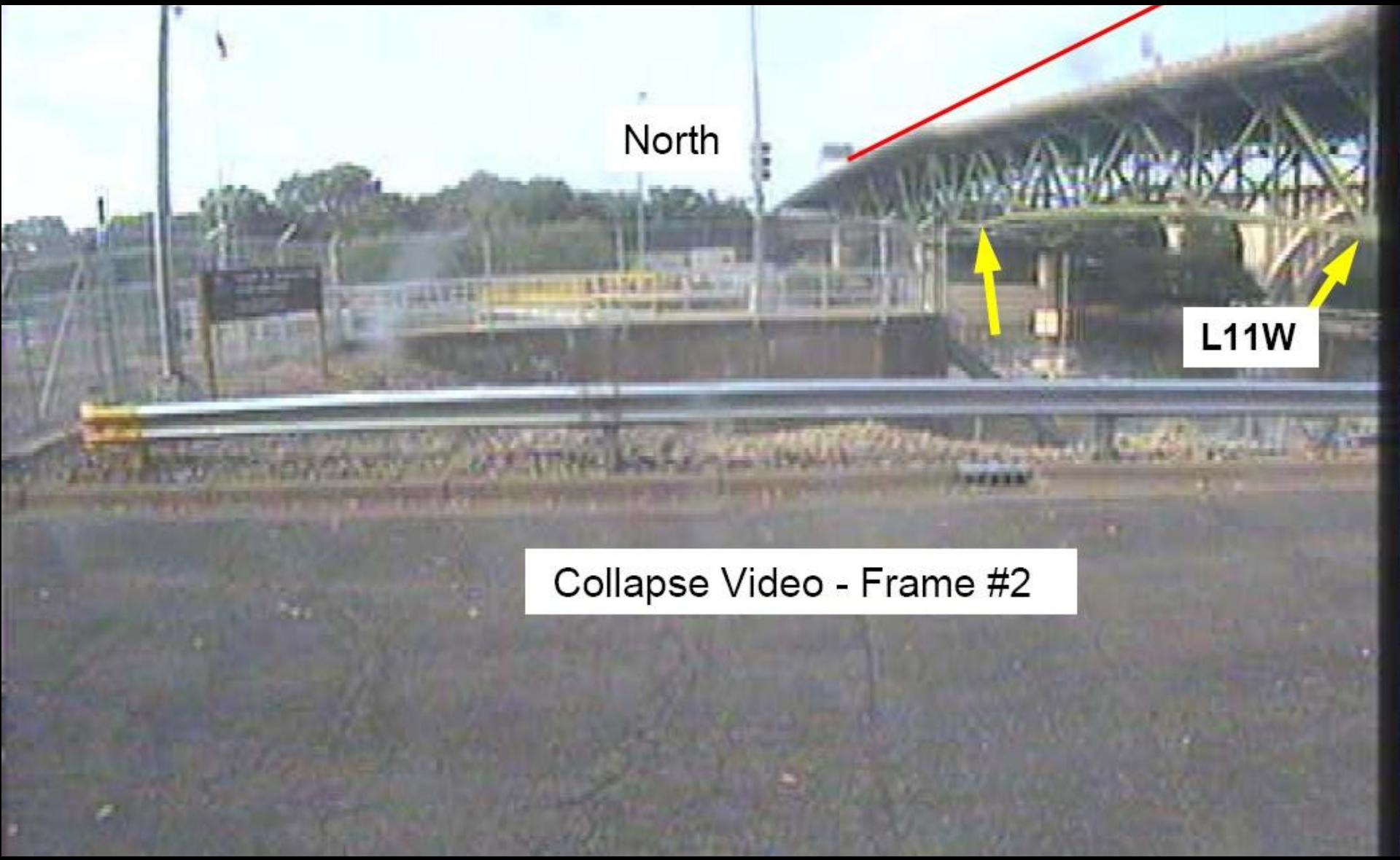
Gusset plate U10W - 2003

Gusset plate U10W - 2003




North
Pre-Collapse


North
L11W
Collapse Video - Frame #1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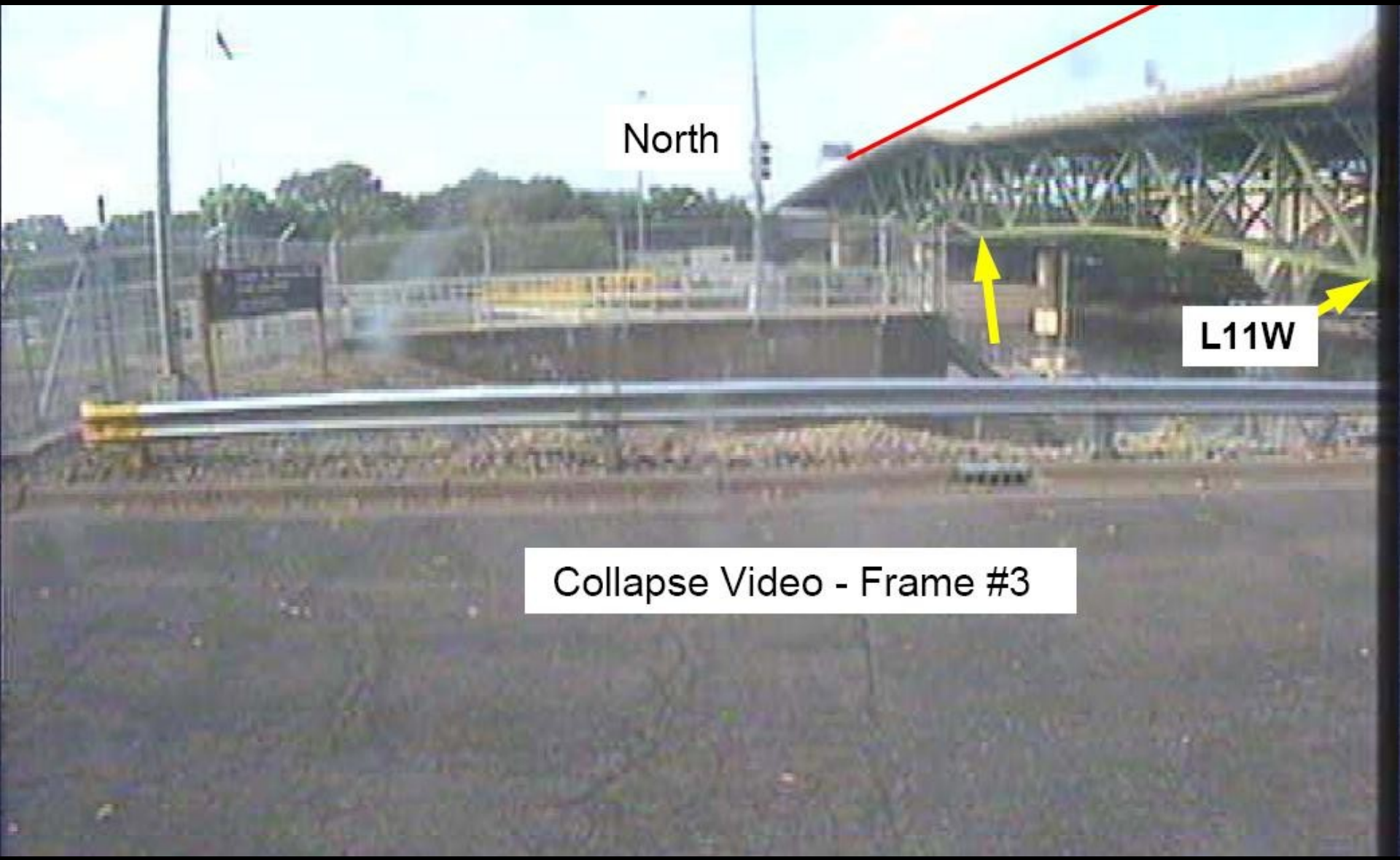
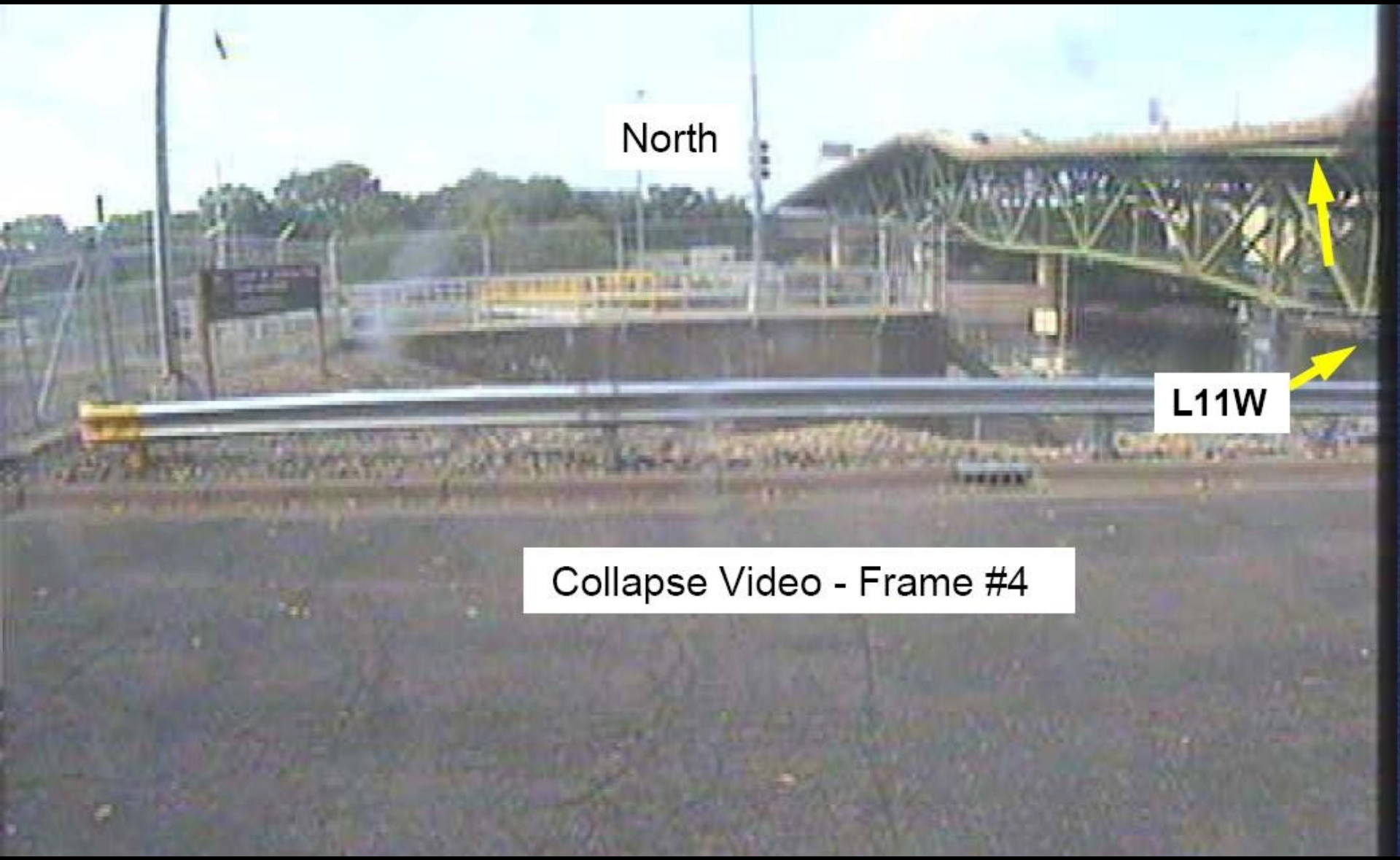
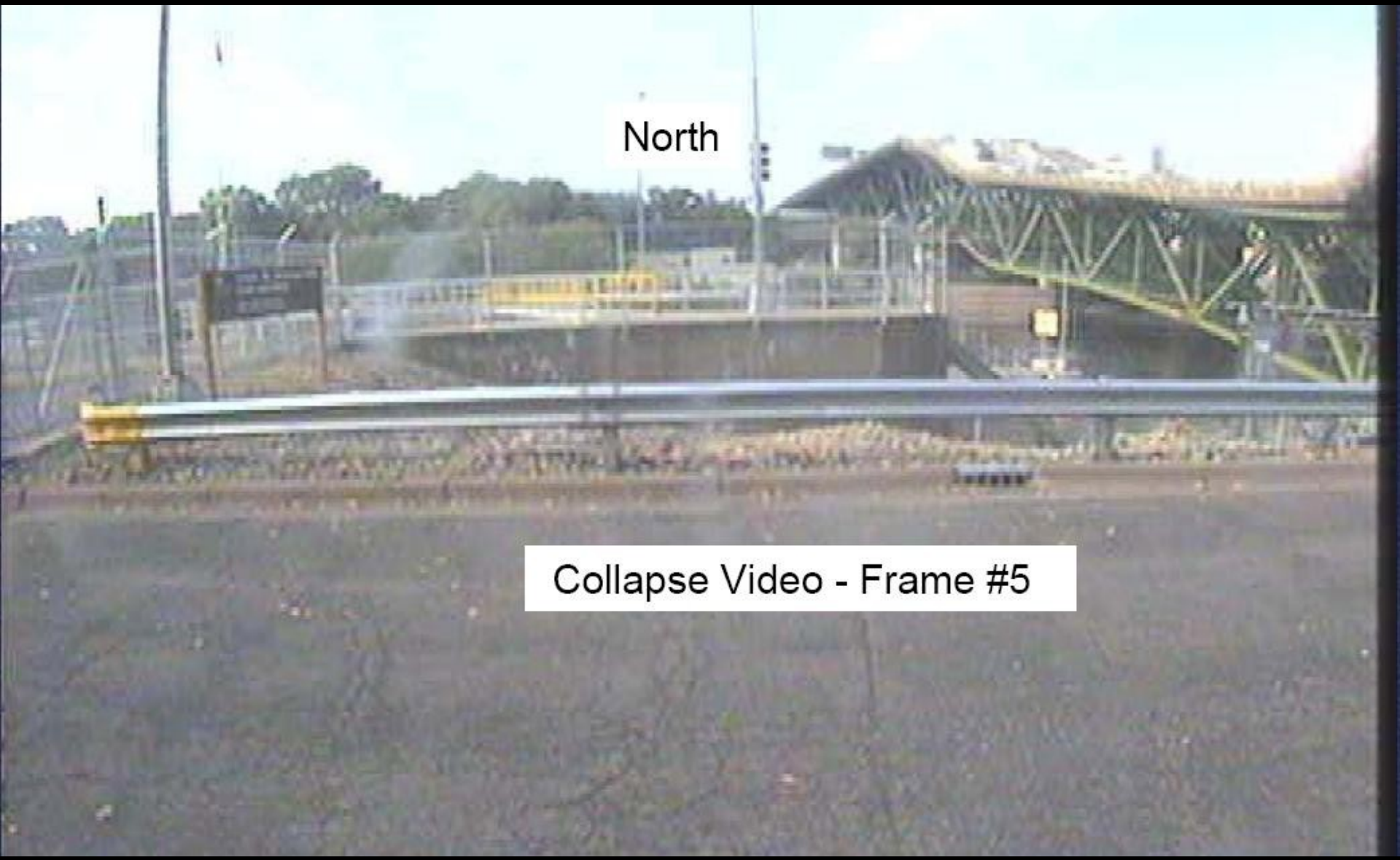
L11W
Collapse Video - Frame #2


North
L11W
Collapse Video - Frame #3


North
L11W
Collapse Video - Frame #4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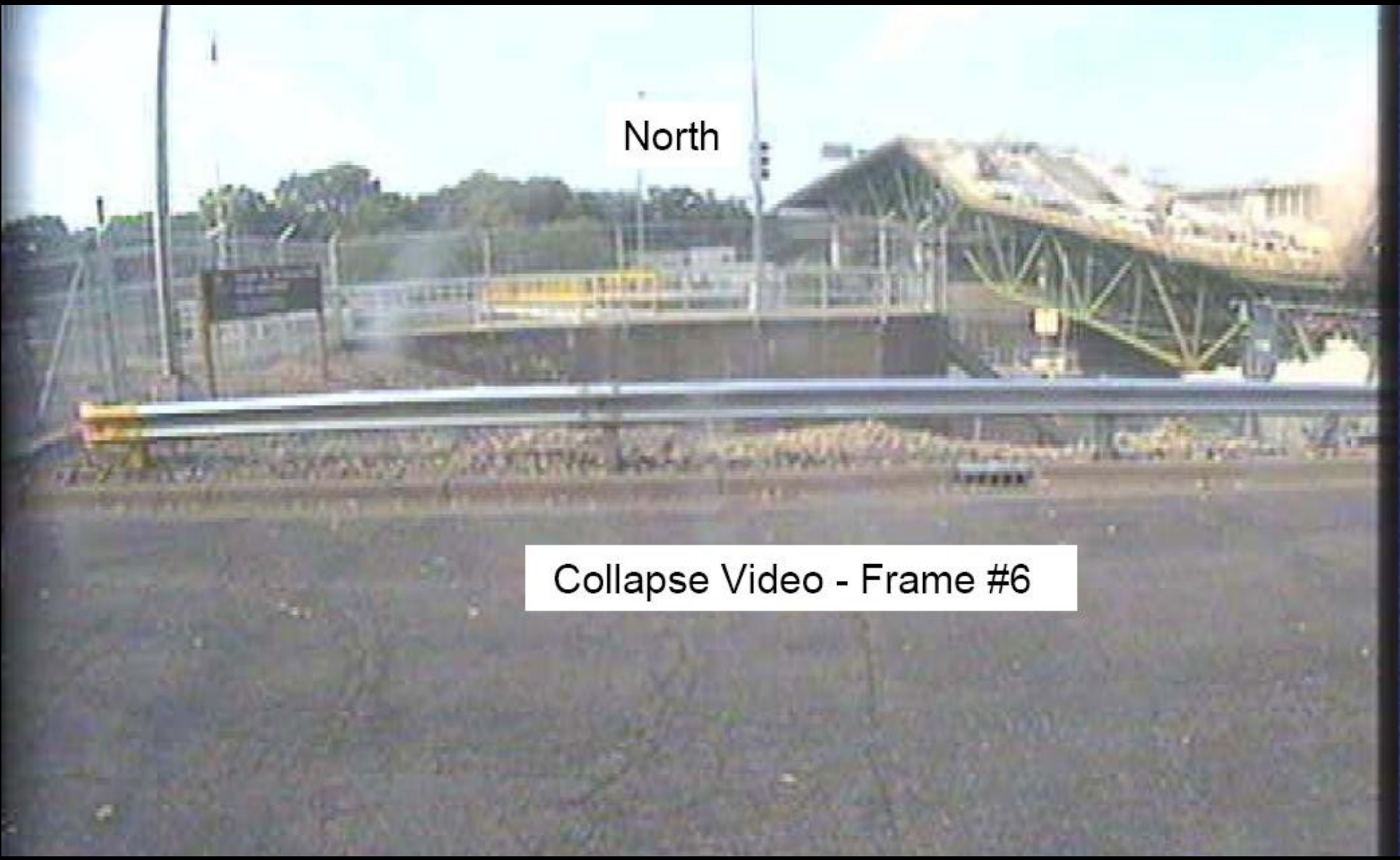
Collapse Video - Frame #5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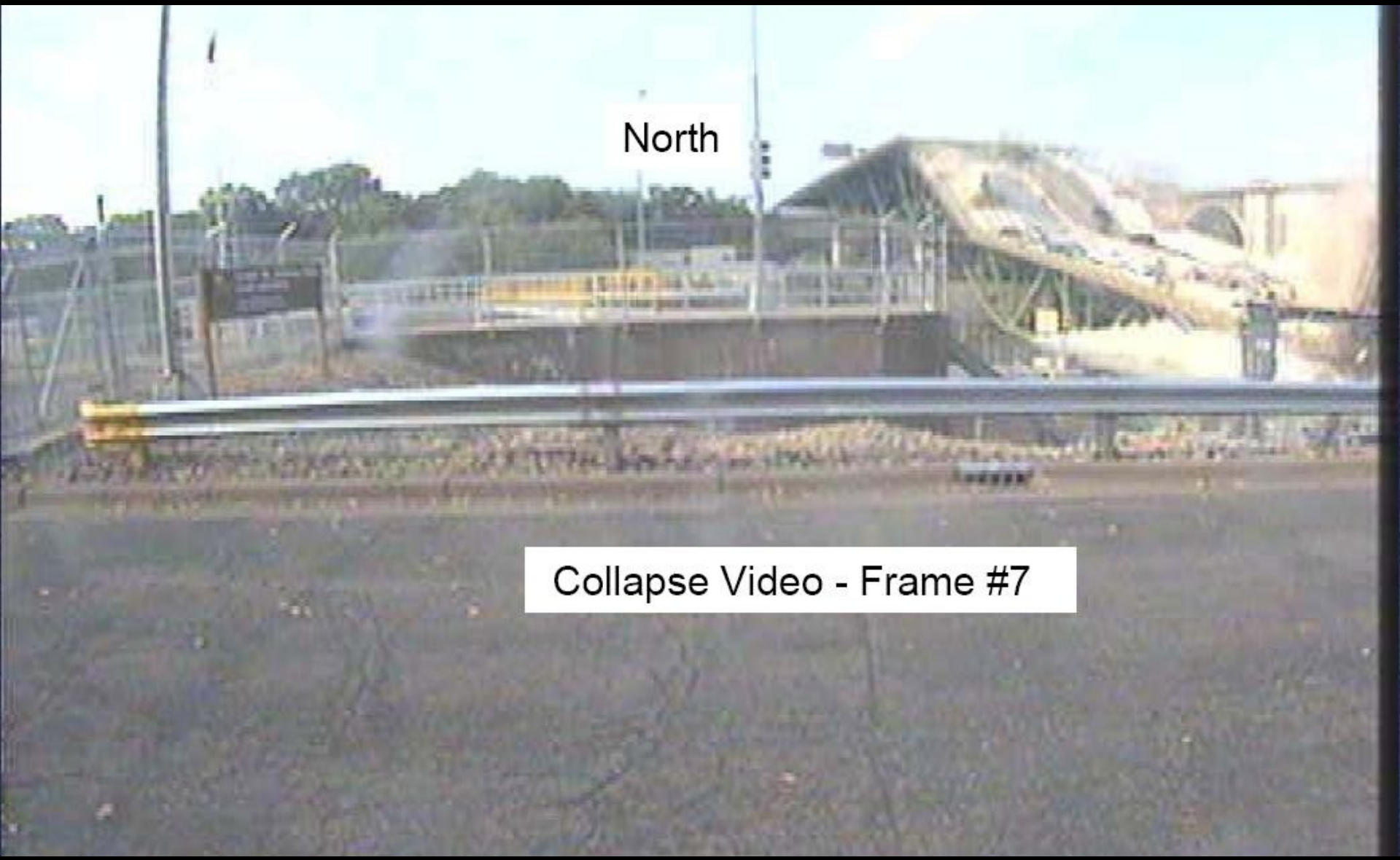
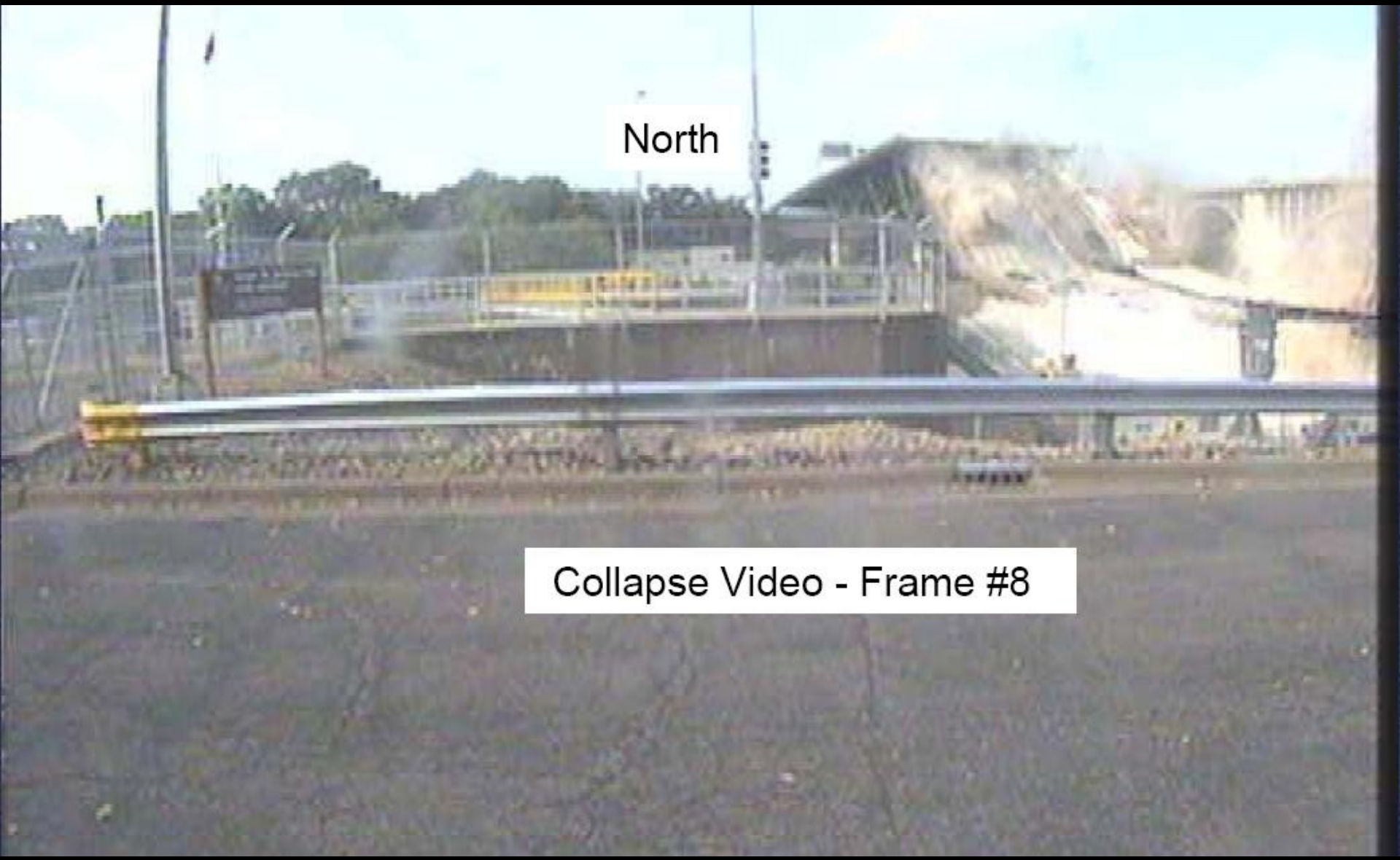
Collapse Video - Frame #6



Collapse Video - Frame #7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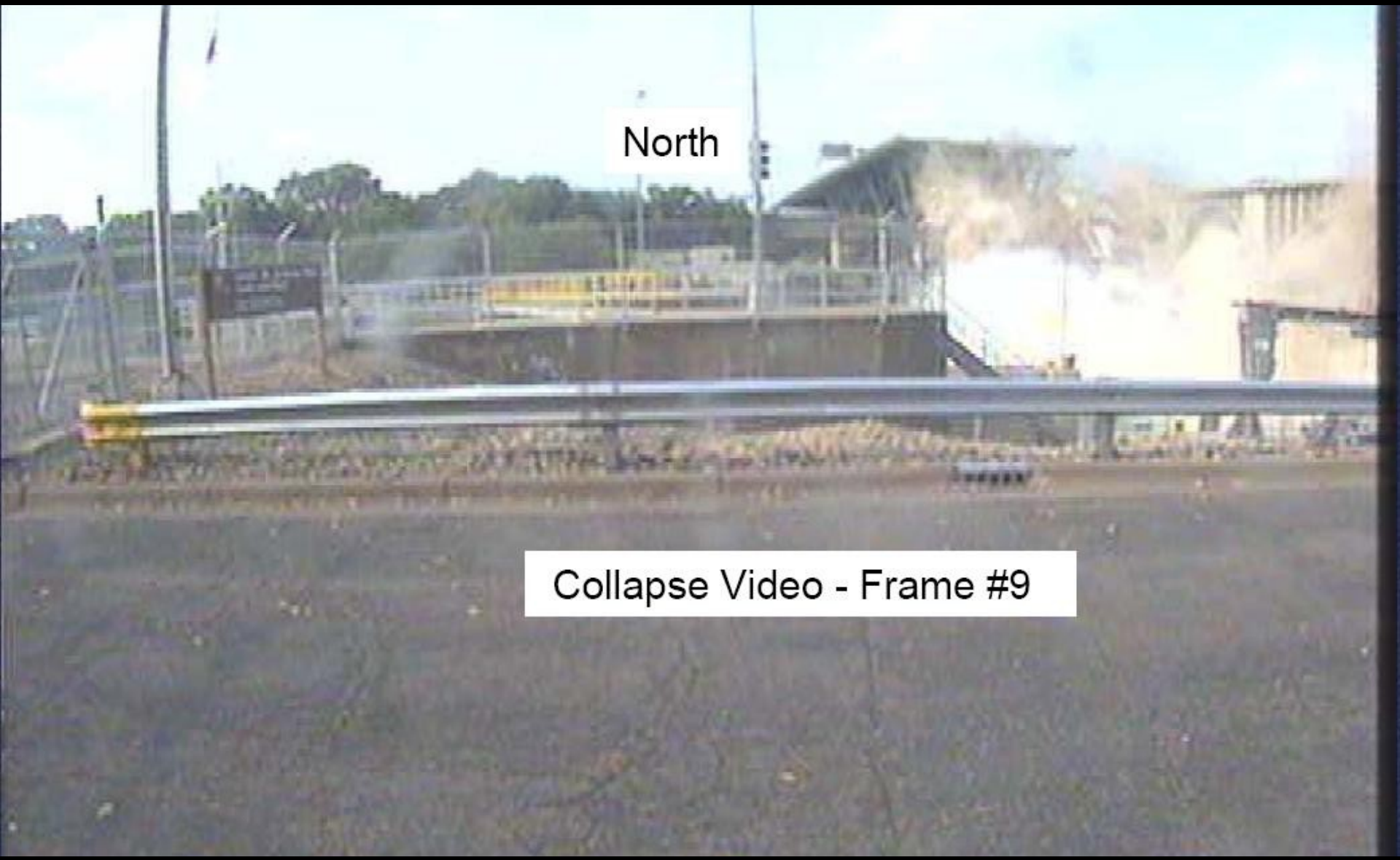
Collapse Video - Frame #8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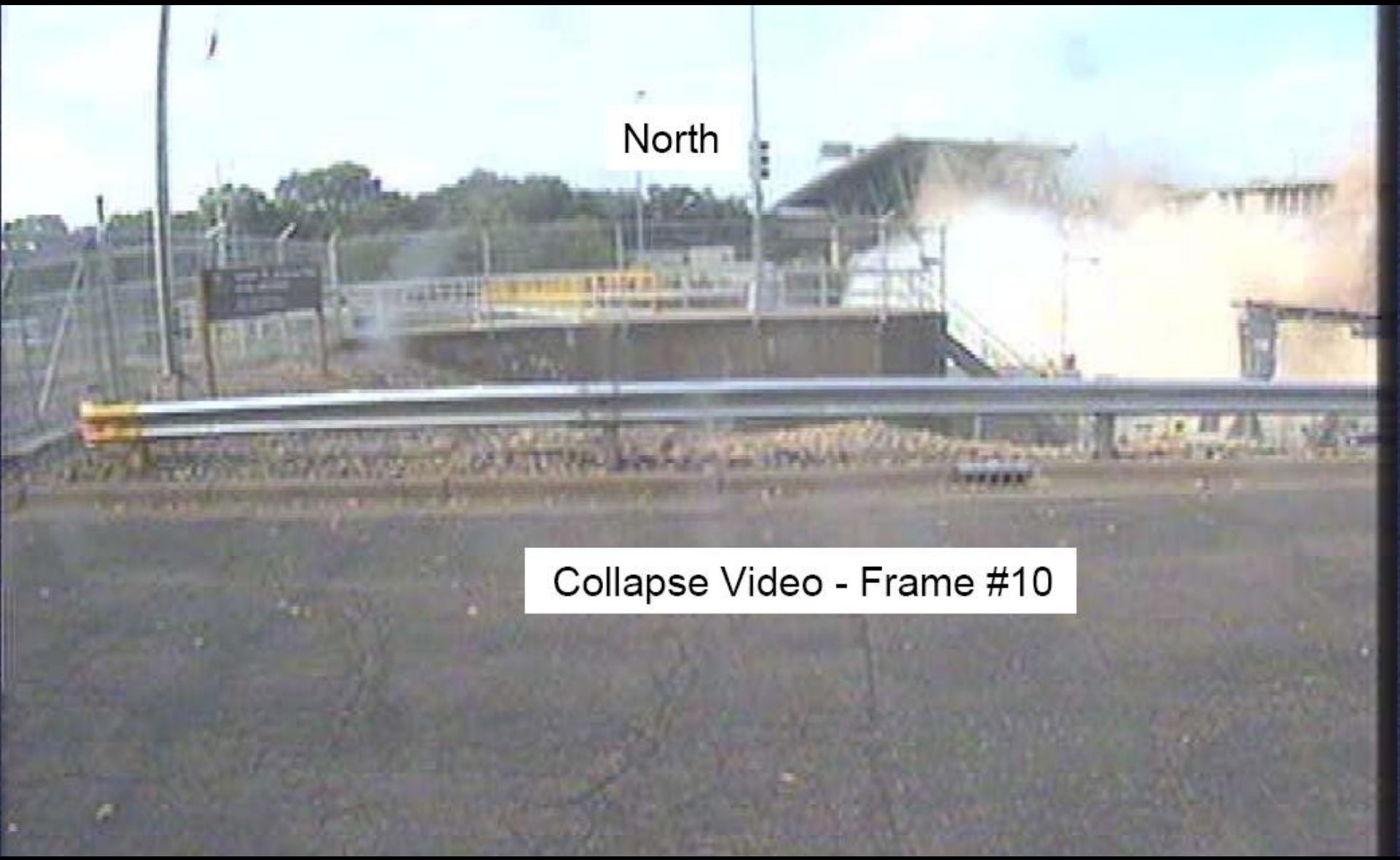
Collapse Video - Frame #9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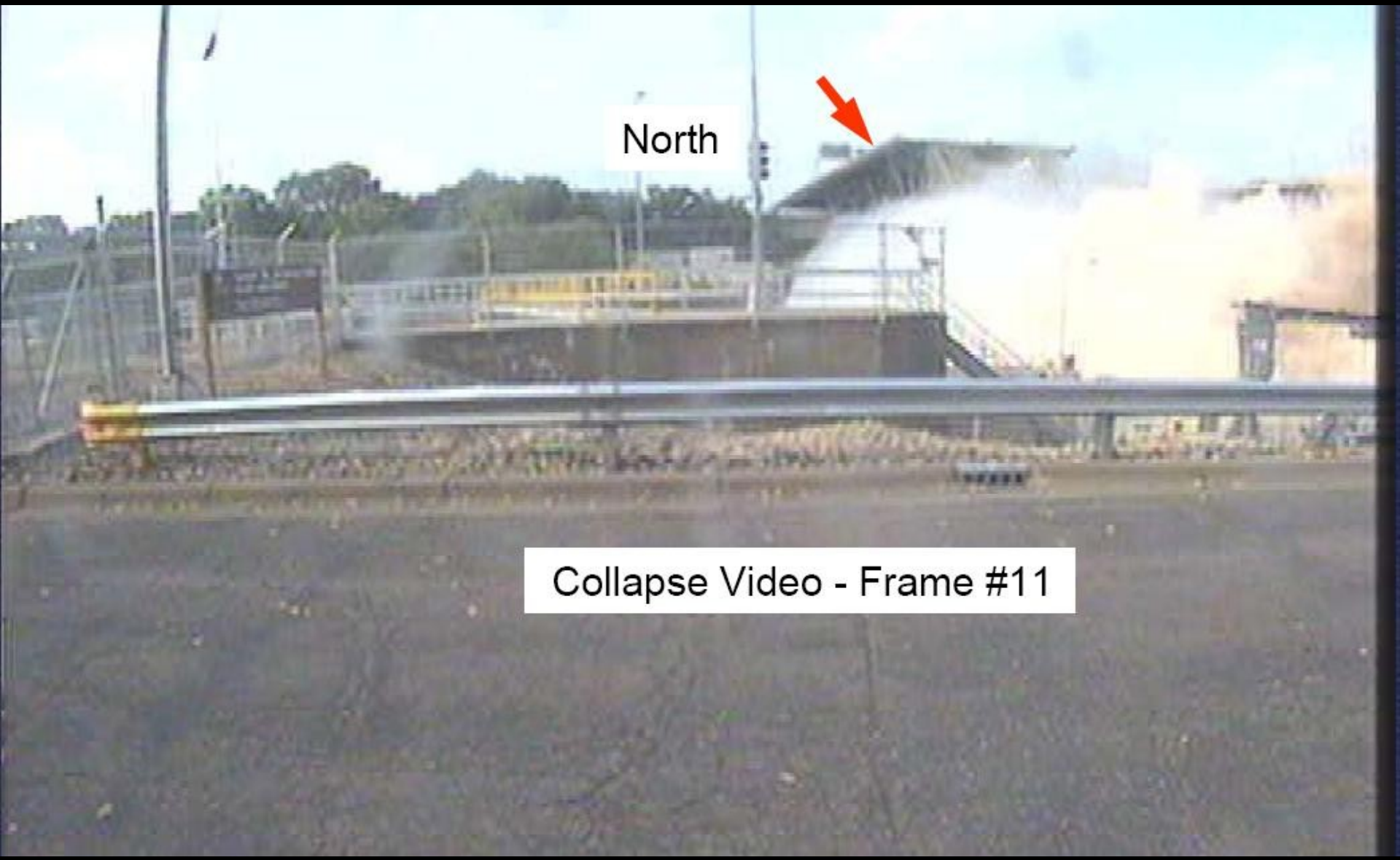
Collapse Video - Frame #10


North
Collapse Video - Frame #11

Probable cause

Accident report determined cause to be:

- inadequate load capacity of the gusset plates at the U10 nodes
- due to design error

Failure occurred under combination of:

- substantial weight increases due to bridge modifications
- concentrated construction loads

“Without warning”?

Bridge owner concerned about:

- ‘Structurally deficient’ condition rating
- Fatigue cracking

These factors did not contribute to the collapse

Assumptions on gusset plates

The bridge designer (design checker):

"...joints are typically stronger than the members they connect ... believe the detailer was a relatively new employee"

Assumptions on gusset plates

The bridge inspector:

"...that's fit up, that's original construction ... the reason we made that determination is, one, from me from undergrad, gusset plates are overdesigned. The factor safeties within those gusset plates are 2 to 3."

Assumptions on gusset plates

The standards writers:

"...the AASHTO Guide for Commonly Recognized Structural Elements does not include gusset plates as a bridge structural element requiring specific attention and subsequent condition rating during bridge inspections."

Assumptions on gusset plates

The software writers:

"...commonly used computer programs for load rating analysis do not include gusset plates ... the resulting load ratings might not accurately reflect the actual capacity of the structure."

Assumptions on gusset plates

The bridge owner:

"...because bridge owners generally consider gusset plates to be designed more conservatively than the other members of a truss ... bridge owners typically ignore gusset plates when performing load ratings"

Learning from failure

Federal Highway Administration issues technical advisory (15 Jan 2008). Gusset plate capacity to be checked on non-load-path-redundant truss bridges:

- for new/replacement bridges during initial load rating
- for future load rating calculations for changes in condition or dead load
- review previous calculations for bridges subject to significant changes in stress levels

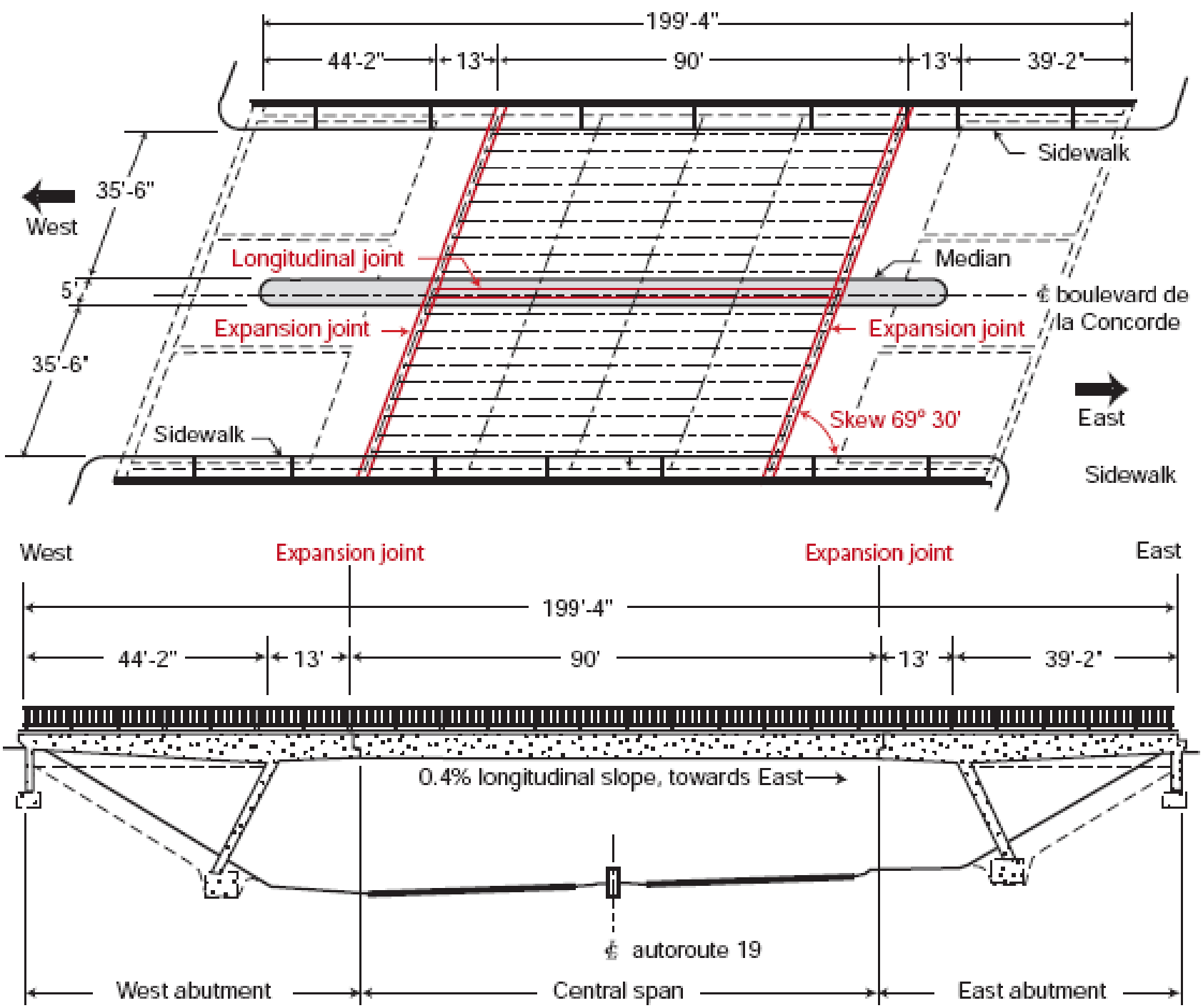
Grand River Bridge, Ohio

- Gusset plates buckled on 24 May 1996
- Construction traffic parked on bridge
- Gusset plate thickness inadequate

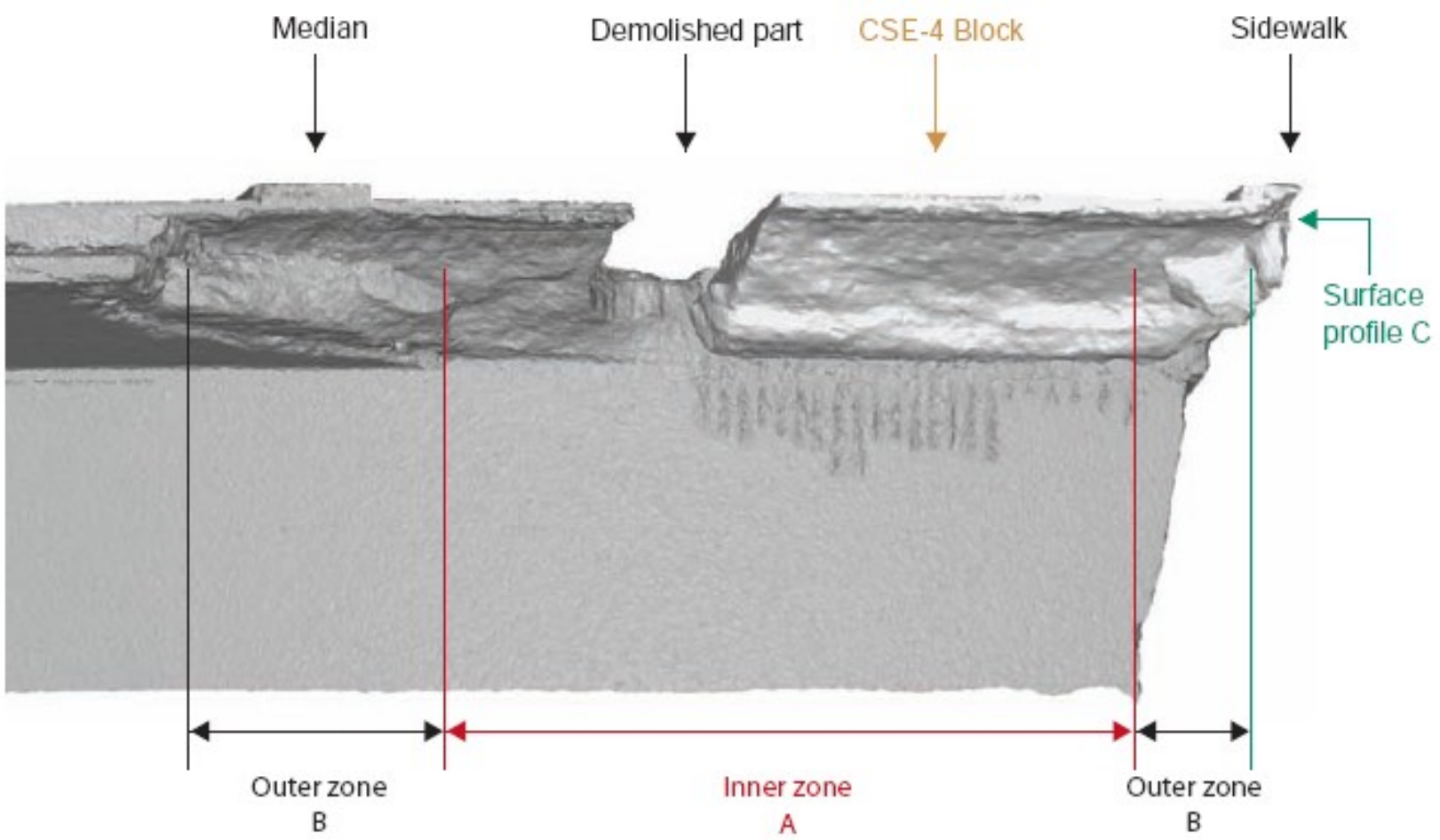
Learning from failure?

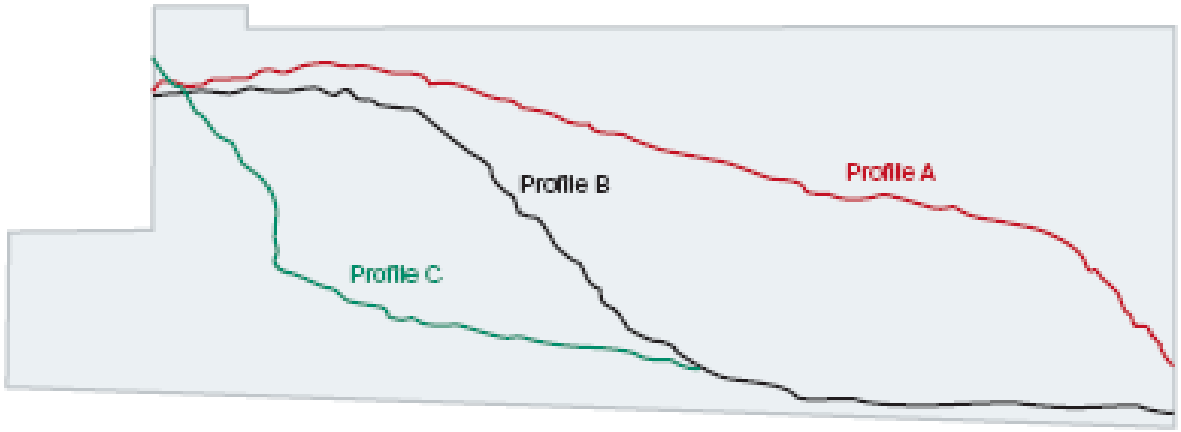
- Bridge repaired with thicker gusset plates
- Importance of inspecting gusset plates emphasised in Ohio bridge inspector training
- Article in Sept 1997 Civil Engineering magazine

Boulevard de la Concorde overpass, Montreal


199'-4"
44'-2"
13'
90'
13'
39'-2"
Sidewalk
35'-6"
West
Longitudinal joint
Median
5'
℄ boulevard de la Concorde
Expansion joint
Expansion joint
35'-6"
Skew 69° 30'
East
Sidewalk
Sidewalk
West
Expansion joint
Expansion joint
East
199'-4"
44'-2"
13'
90'
13'
39'-2"
0.4% longitudinal slope, towards East
℄ autoroute 19
West abutment
Central span
East abutment


Failure in thick slab
Half-joint intact


Median
Demolished part
CSE-4 Block
Sidewalk
Surface profile C
Outer zone B
Inner zone A
Outer zone B


Profile A
Profile B
Profile C

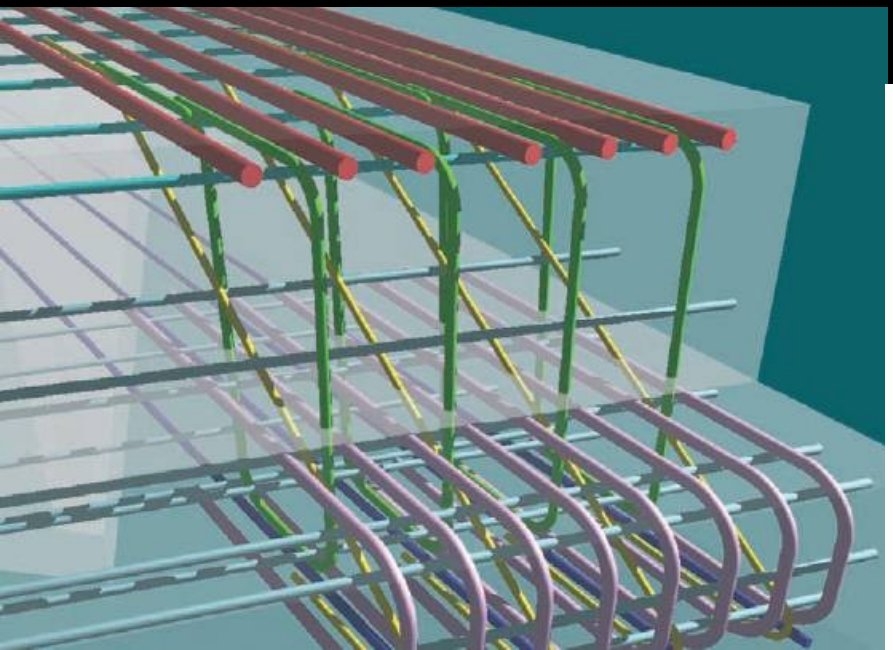

N
N
105

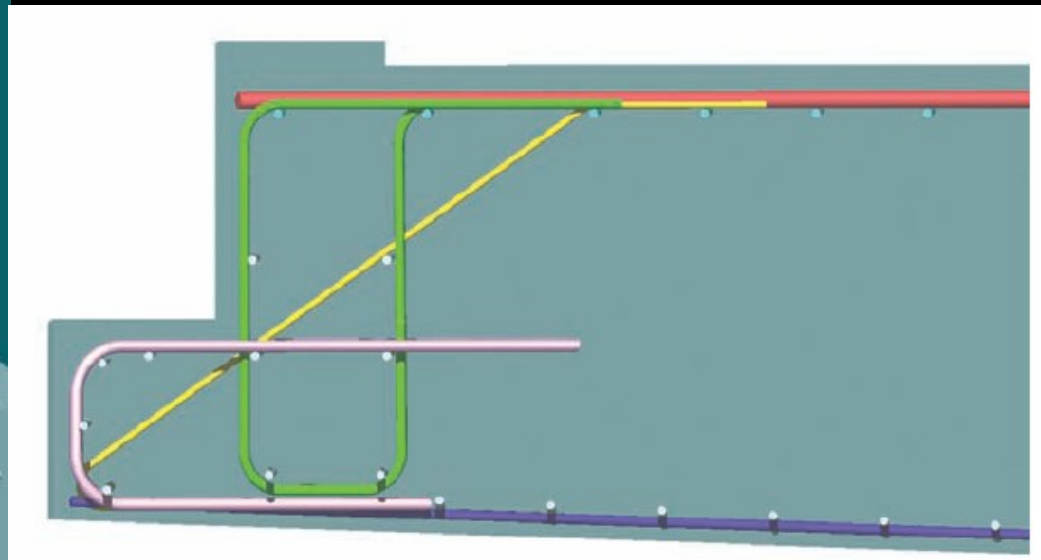

CINEI-CS
a)

Causes - poor anchoring detail

Reinforcement detailing:

- not in accordance with best practice
- inadequately anchored
- but did not contravene 1966 code

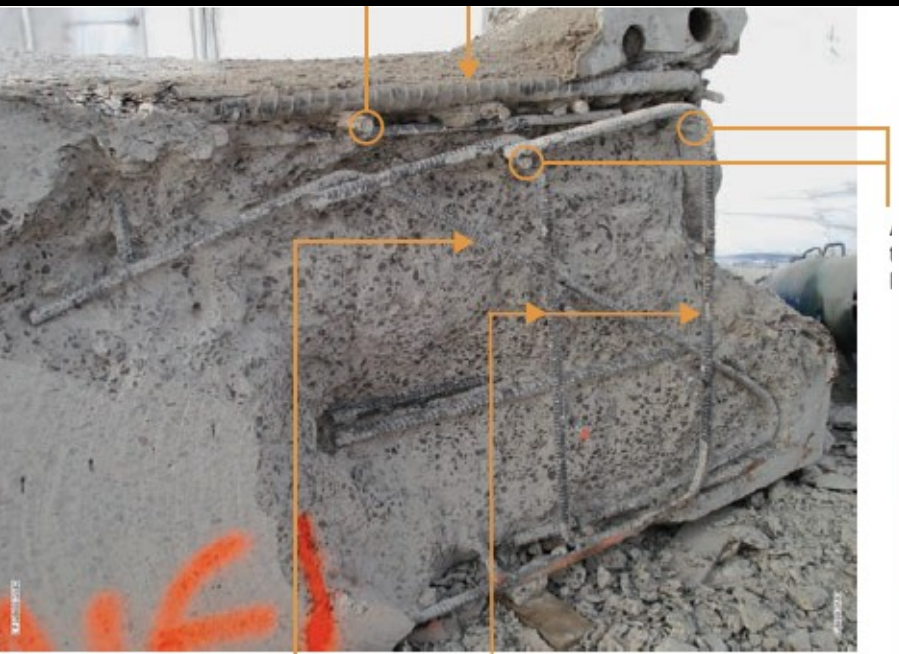


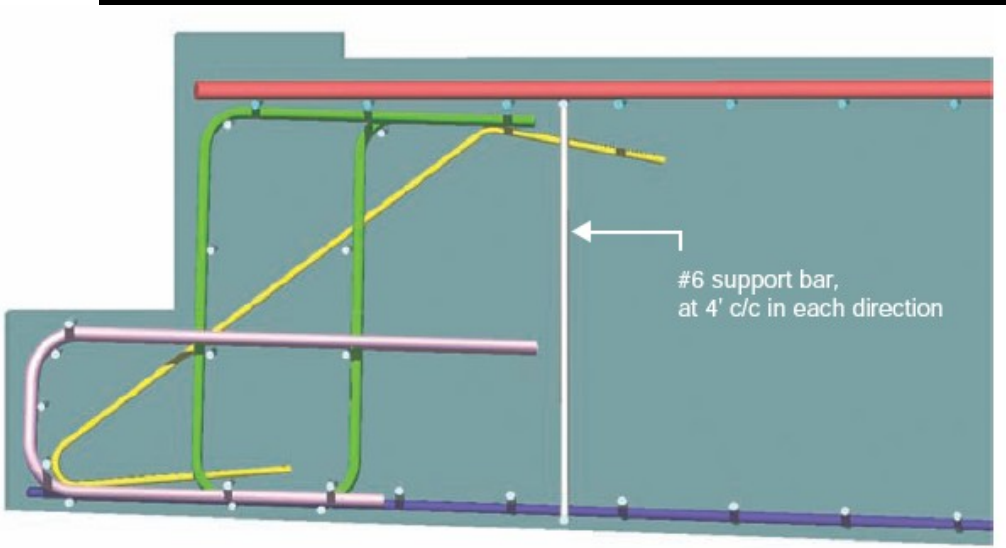


Causes - misplaced reinforcing bars

As-built reinforcement:

- hanger bars misplaced
- created unreinforced zone of weakness





Contributory physical causes

- Absence of shear reinforcement in thick slab
- Absence of proper waterproofing
- Damages induced by repair work

Inspections

"the inspection reports ... show significant deficiencies and are not compliant with the manuals"

Montreal Commission of Inquiry

Inspections

"the inspection reports ... show significant deficiencies and are not compliant with the manuals"

Montreal Commission of Inquiry

"MnDOT did not follow its own policies with respect to documenting the deteriorating condition of the bridge"

Minnesota Legislature Investigative Report

Repair work – Feb 1992

Special inspection – 15 July 2004

Inspection – day of collapse

UK infrastructure

Bridge management issues

"...numerous file-keeping flaws in the case of the de la Concorde overpass"

Montreal Commission of Inquiry

Bridge management issues

"...numerous file-keeping flaws in the case of the de la Concorde overpass"

"The absence of a complete file accessible to the ...inspectors ... was a key factor that contributed to the lack of follow-up on the progressive deterioration of the overpass"

Montreal Commission of Inquiry

Bridge management issues

"...numerous file-keeping flaws in the case of the de la Concorde overpass"

"The absence of a complete file accessible to the ...inspectors ... was a key factor that contributed to the lack of follow-up on the progressive deterioration of the overpass"

"...many opportunities were missed throughout the years to investigate in detail the condition of the structure"

Montreal Commission of Inquiry

Vulnerable structures

Montreal: Thick slabs without shear reinforcement

Minnesota: Gusset plates / non-load-path-redundant

"...the *Ministère* must better identify the structures that are at risk and award them special status in the management system"

Montreal Commission of Inquiry

Design approval

"...the *Ministère* approved the preliminary design ... without anticipating the considerable difficulties that would result ... it did not assess the inspection problems that such a structure might involve"

Design approval

"...the *Ministère* approved the preliminary design ... without anticipating the considerable difficulties that would result ... it did not assess the inspection problems that such a structure might involve"

"The Commission recommends that any mandate for structural design should specifically be validated (verification of designer's concept, drawings and calculations)"

Montreal Commission of Inquiry

Recommendation 6

Design approval

"Develop and implement ... a bridge design quality assurance / quality control programme ... 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..."

National Transportation Safety Board

Recommendation H-08-17

Technical approval

	TA prevent?
Poor anchoring detail of top bars	
Misplacement of bars	
Concrete not durable	
Absence of shear reinforcement	
Absence of proper waterproofing	
Damages induced by repair work	
Use of half-joints	

Technical approval

	TA prevent (1968)?
Poor anchoring detail of top bars	✓
Misplacement of bars	
Concrete not durable	✓
Absence of shear reinforcement	
Absence of proper waterproofing	
Damages induced by repair work	N/A
Use of half-joints	

Technical approval

	TA prevent (1968)?
Poor anchoring detail of top bars	✓
Misplacement of bars	×
Concrete not durable	✓
Absence of shear reinforcement	×
Absence of proper waterproofing	×
Damages induced by repair work	N/A
Use of half-joints	×

Technical approval

	TA prevent (1968)?	TA prevent (2009)?
Poor anchoring detail of top bars	✓	✓
Misplacement of bars	×	
Concrete not durable	✓	✓
Absence of shear reinforcement	×	
Absence of proper waterproofing	×	
Damages induced by repair work	N/A	
Use of half-joints	×	

Technical approval

	TA prevent (1968)?	TA prevent (2009)?
Poor anchoring detail of top bars	✓	✓
Misplacement of bars	×	
Concrete not durable	✓	✓
Absence of shear reinforcement	×	✓
Absence of proper waterproofing	×	✓
Damages induced by repair work	N/A	
Use of half-joints	×	✓

Technical approval

	TA prevent (1968)?	TA prevent (2009)?
Poor anchoring detail of top bars	✓	✓
Misplacement of bars	×	?
Concrete not durable	✓	✓
Absence of shear reinforcement	×	✓
Absence of proper waterproofing	×	✓
Damages induced by repair work	N/A	?
Use of half-joints	×	✓

Knowledge management

"The Commission recommends that the Government ensure that there be an effective surveillance of scientific intelligence processes and knowledge involving academics and top-level practitioners; this will ensure that persons responsible for designing and maintaining structures ... be kept constantly informed of new developments and changes in standards and practices"

Montreal Commission of Inquiry
Recommendation 3

Knowledge management

"The Minnesota Legislature should request the Federal Highway Administration to gather information on all major bridge deficiencies, as they become known, and to share the information with all state departments of transportation to assure systematic and timely incorporation of newly developed safety concerns into state bridge inspection practices"

Minnesota Legislature Investigative Report
Recommendation 4a

Reassessment

	TA prevent (1968)?	TA prevent (2009)?
Poor anchoring detail of top bars	✓	✓
Misplacement of bars	×	?
Concrete not durable	✓	✓
Absence of shear reinforcement	×	✓
Absence of proper waterproofing	×	✓
Damages induced by repair work	N/A	?
Use of half-joints	×	✓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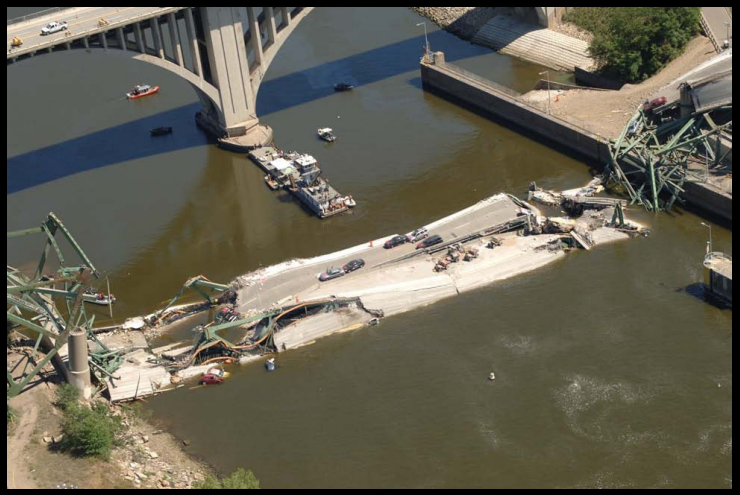
Construction issues

"...the Commission is of the opinion that the best supervision practice was the one provided for in DSA's contract for professional services, namely the full-time presence of supervisors on site"

Montreal Commission of Inquiry

Learning the lessons from bridge collapses



Minnesota
I35W Highway bridge

Montreal
de la Concorde overpass

Key issues

- Assumptions
- Quality of bridge management
- Vulnerable structures
- Load-carrying evaluation
- Knowledge management
- Design validation

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