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Investing in Infrastructure: The Effects of Our Decaying Infrastructure on Our National Security and Culture

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Department of Civil Engineering
University of Minnesota

November 18, 2008

Disclaimer:

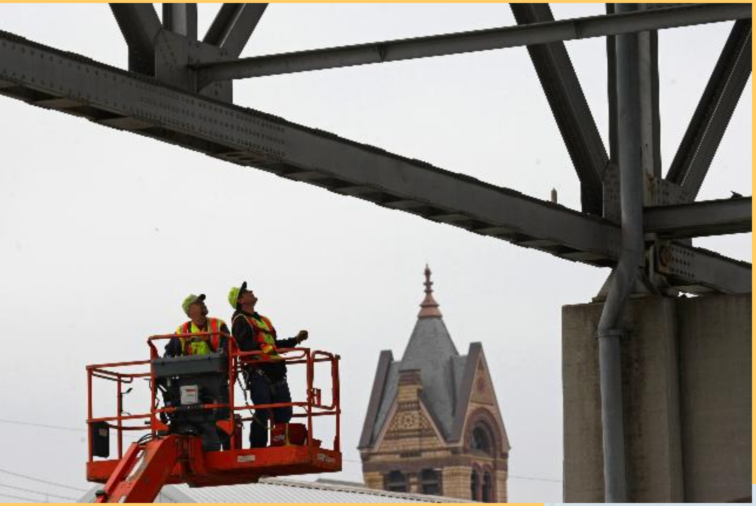
What follows is the perspective of an educator who Is also a concerned, proud and ultimately optimistic citizen of a great country.

That said:

"Human history becomes more and more A race between education and catastrophe."

H.G. Wells

Highway 43 Bridge, Winona, MN



Detour length is 65 miles.

Closed to all traffic June 3
Reopens for cars June 14
Reopens for trucks July 21
Sidewalk reopens October 2

Outline

What the Nation's infrastructure represents.

What it was, what it is, what will it be?

**What do we do about the existing infrastructure,
and what do we do about replacing it?**

**We need to take care of a very sick and old patient
whose parts were not taken care of.**

We also need to replace the patient.

**There are solutions; they involve the
commitment of lots of money for construction/repair,
education, research, etc., and most importantly, will.**

Brief summary of results of I-35W Bridge collapse

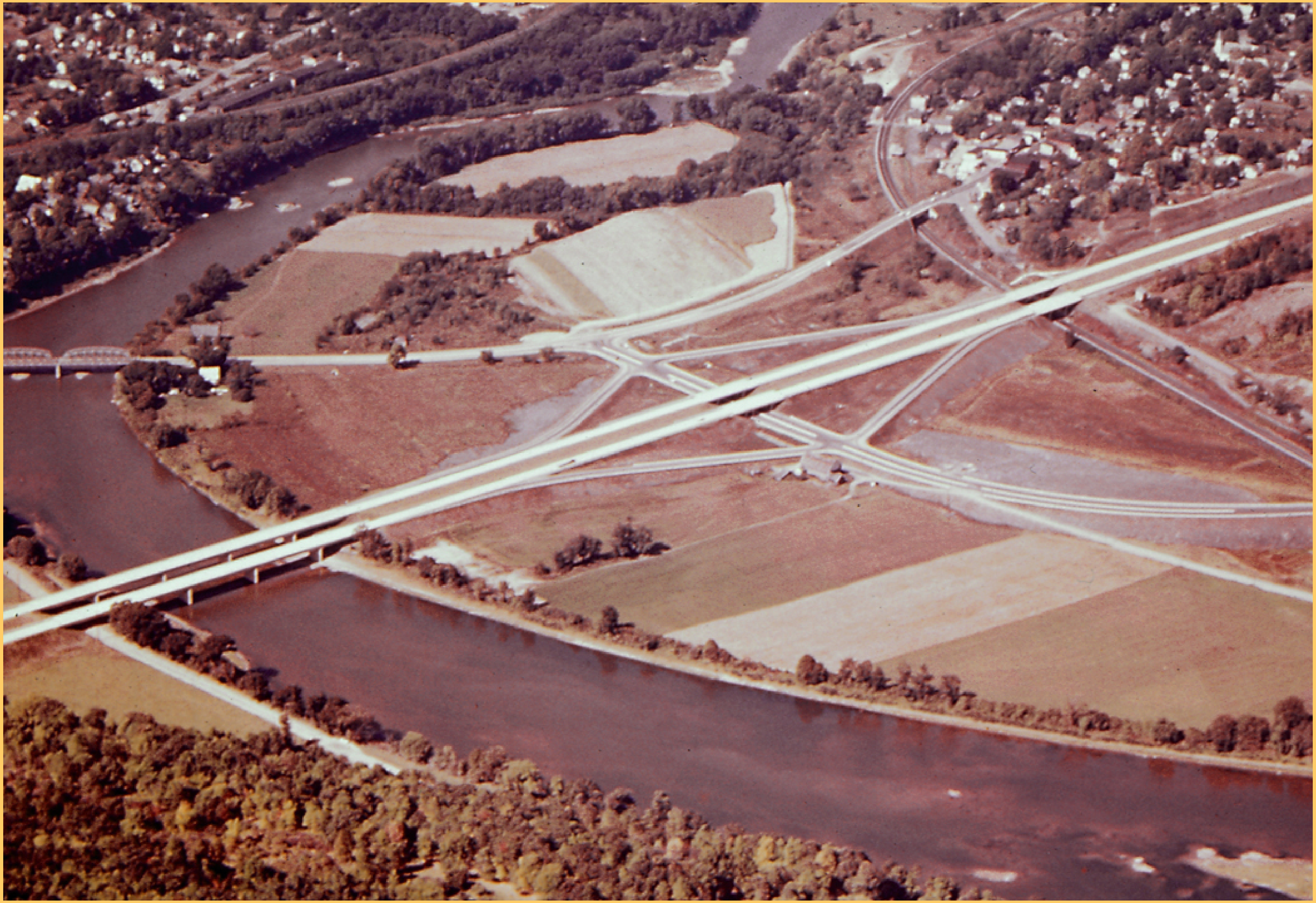
National Security; Roman Acqueduct in Pont du Gard, France

The Romans understood the roles of roads, water distribution, etc., in maintaining their empire.

National pride; Petronas Towers, Kuala Lumpur, Malaysia

Personal pride; San Gimignano, Italy

Our infrastructure was a statement of our vision, wealth, capabilities and pride.



Interstate system; I-81 Great Bend, PA (1960)

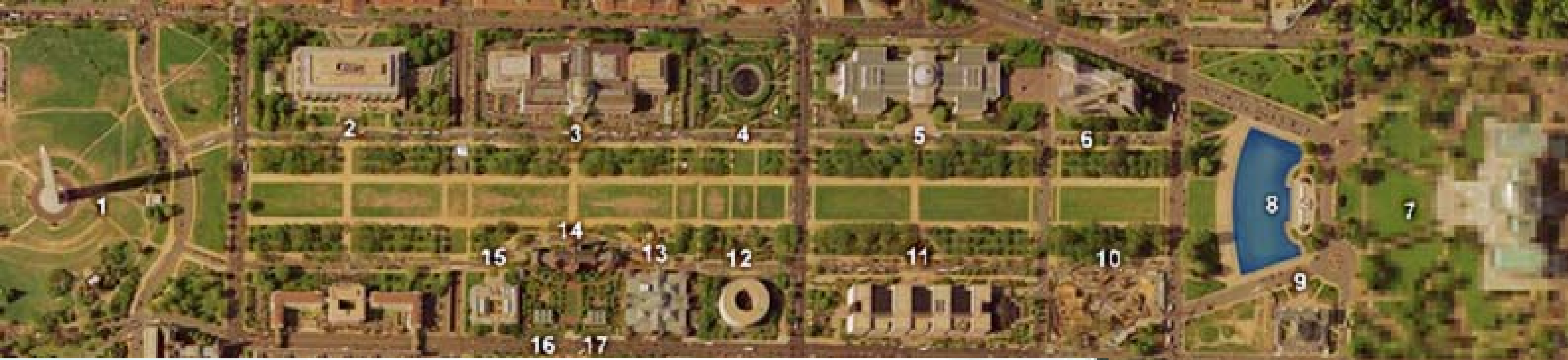
We had the most impressive infrastructure, especially given our size:

Example; Interstate Highways System

Carries 20% of traffic but only covers 1% of US land
Credited with saving ~190,000 lives and preventing ~12 million injuries

Estimated to have saved $6 for every $1 spent on its construction

Created good jobs, technical expertise, the economy, …



Infrastructure includes cultural projects!


and Education: Morrill Grant Land College Act of 1862

Investment in Infrastructure

- **1950s and 1960s ~4% of GDP**
- **1982 to 2007**

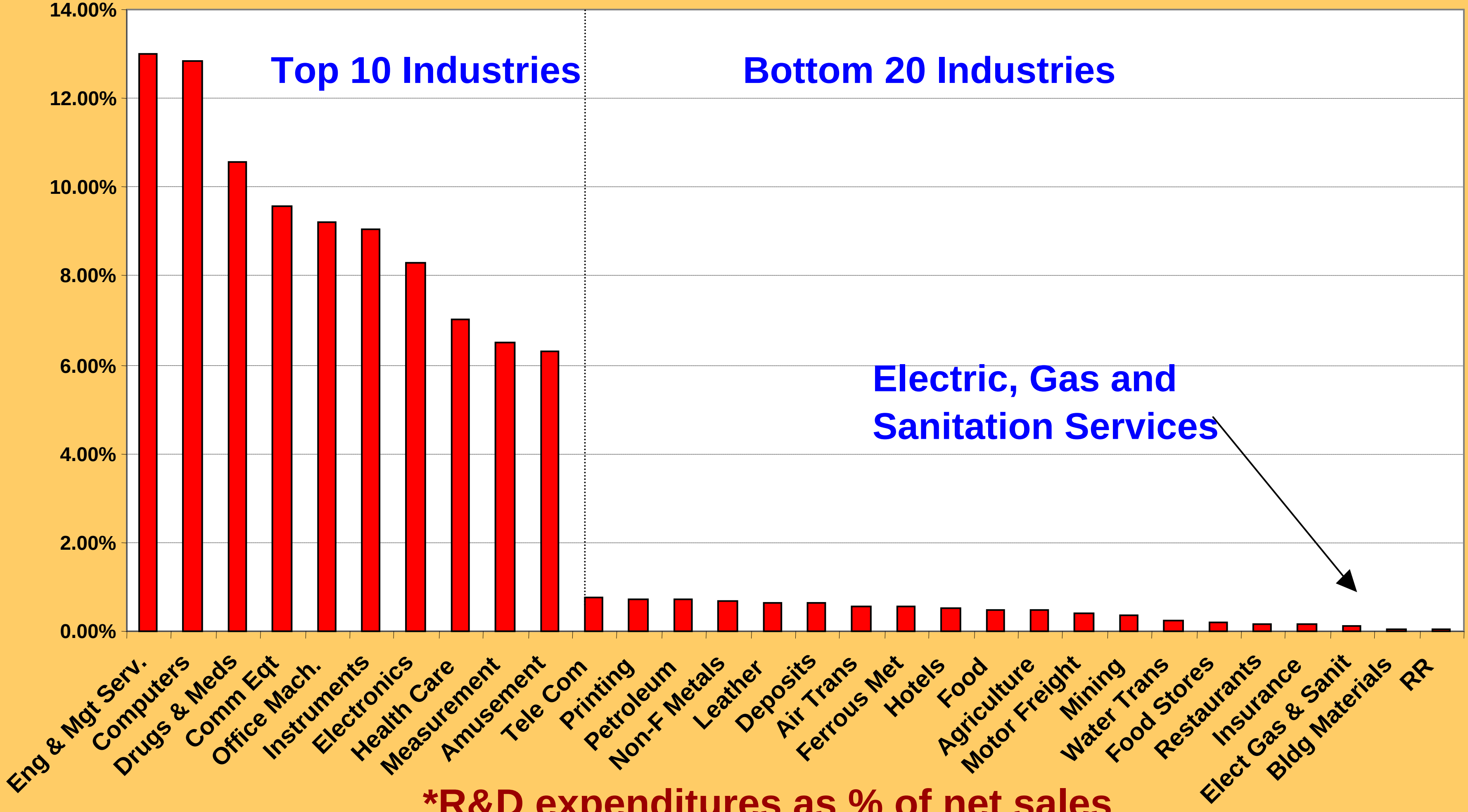
  - U.S. population – 226 to 300 million

  - U.S. GDP - $3 to $13 trillion

  - current infrastructure investment < 2% of GDP

China today ~ 9% of GDP

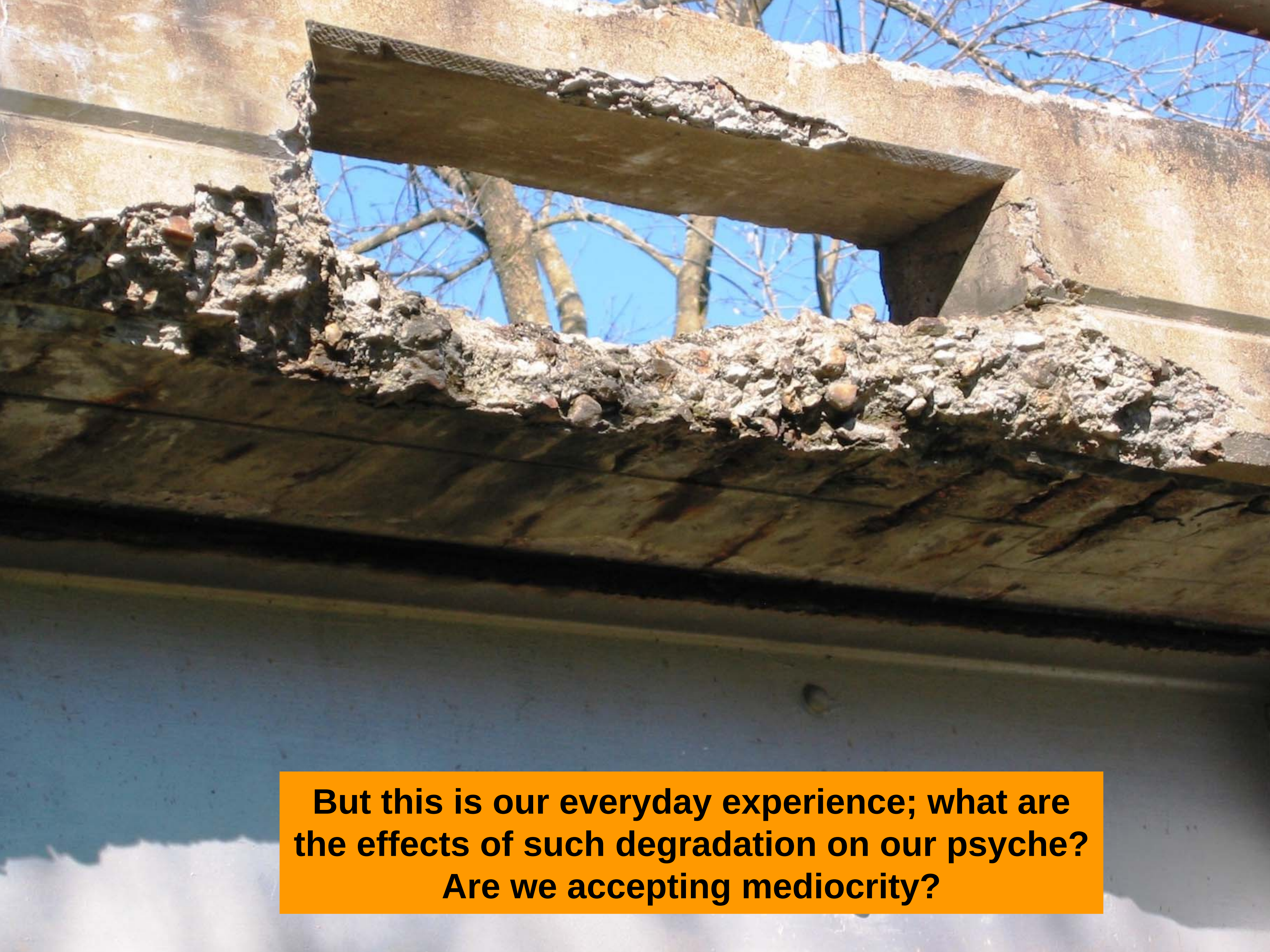
Context: R&D Expenditures*



*R&D expenditures as % of net sales

Courtesy of Dr. Massoud Amin

Most of us see this kind of road and view only when vacationing


But this is our everyday experience; what are the effects of such degradation on our psyche? Are we accepting mediocrity?

Rockefeller Road Bridge, Cleveland, Ohio

msnbc
A Fuller Spectrum of News

Sinkhole swallows up SUV in New York street

Shocked driver escapes serious injury; vehicle rested on gas main

WNBC-TV

The SUV rests in the Brooklyn street sinkhole.

Water main break;
SUV sitting on gas main.

AP Associated Press

Updated: 11:32 a.m. CT March 27, 2006

NEW YORK - A city street collapsed under a sport utility vehicle early Monday, leaving the vehicle nose down into a deep sinkhole that officials said was caused by a water main break.

The driver of the SUV escaped without serious injures but was taken to a hospital for treatment of shock, said Fire Department spokesman Brian Conlon.

Violation of conservation of cars assumption

msnbc

A Fuller Spectrum of News

- U.S. News
- Crime & Punishment
- U.S. Life
- U.S. Security
- Education
- Environment
- Race & Ethnicity
- Charity News
- Only on MSNBC.com
- Peculiar Postings
- Video
- U.S. News
- Politics
- World News
- Business
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- Entertainment
- Health
- Tech / Science
- Travel
- Weather
- Blogs Etc.
- Local News
- Newsweek
- Multimedia

Aging N.Y. pipes raise concerns of more blasts

Steam pipes rarely inspected; air tests ease health worries in Manhattan

Timothy A. Clary / AFP - Getty Images

A destroyed tow truck sits in a hole Thursday at the site of an underground steam pipe explosion in New York. The Wednesday explosion tore a crater in Lexington Avenue near Grand Central Terminal, sending residents running for cover amid a towering geyser of steam.

NBC video

Launch

N.Y. worries

July 19: The explosion of a weathered steam pipe has more than just New Yorkers pondering the repercussions of an aging infrastructure. NBC's Ron Allen reports.

Nightly News

AP

Updat

o: NYC steam explosion

83 years old steam pipe, and part of a system put into service in 1882!!!

Courtesy of Dennis Martenson

Let us not forget about external threats

Working Premise #1

This is ugly!

Courtesy of Dr. Massoud Amin

Working Premise #2 *…But this is uglier!*

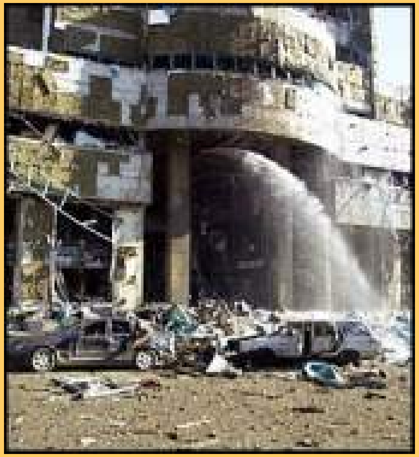
Oklahoma City, 1995

Saudi Arabia, 1996

Tanzania, 1998

Mozdok, 2003

Baghdad, 2003



Istanbul, 2003

Courtesy of Dr. Massoud Amin

New approaches for evolving threats

Challenge

Can we have this?

Without this?

Courtesy of Dr. Massoud Amin

ASCE Report Card

PROGRESS REPORT

America's Infrastructure

DATE 2003

Roads	D+	↓
Bridges	C	↔
Transit	C-	↓
Aviation	D	↔
Schools	D-	↔
Drinking Water	D	↓
Wastewater	D	↓
Dams	D	↓
Solid Waste	C+	↔
Hazardous Waste	D+	↔
Navigable Waterways	D+	↓
Energy	D+	↓
America's Infrastructure GPA	D+	
Total Investment Needs (estimated five-year need)	$1.6 Trillion	

"**Civil engineers** are the doctors of infrastructure,-- and we have a patient that's sick and getting sicker."
ASCE Executive Director James E. Davis

↑ = Improving
↔ = No Progress
↓ = Declining

A = Exceptional
B = Good
C = Mediocre
D = Poor
F = Inadequate Trends

Future – Investment Needs (5-year needs)

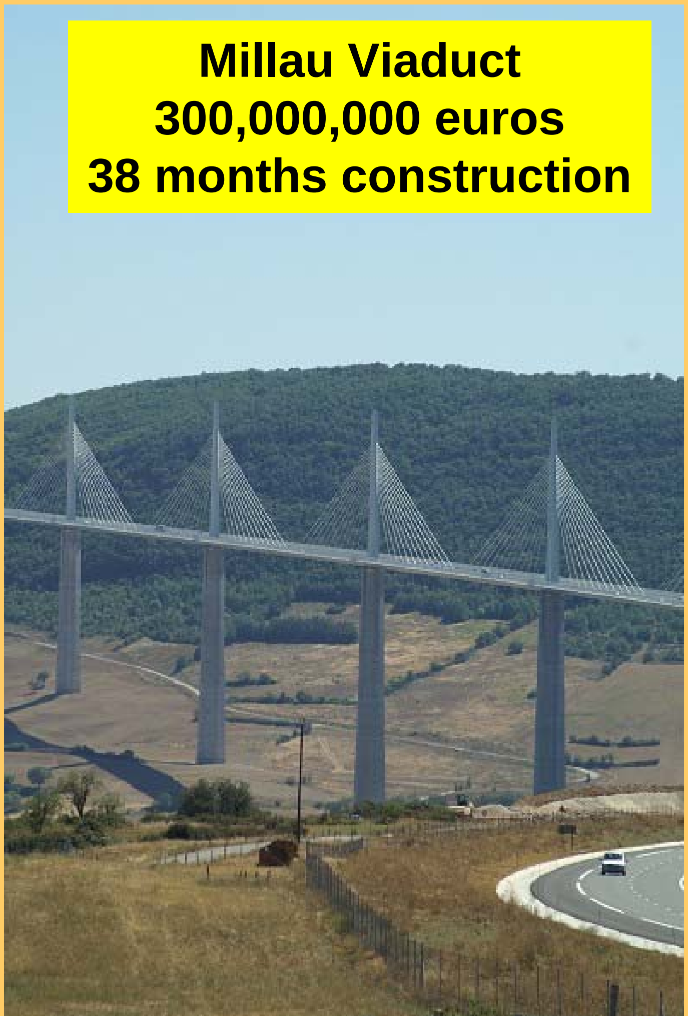
- Report Card on America's Infrastructure[1]
  - Aviation – $67 Billion
  - Bridges – $ 628 Billion (includes Roads)
  - Dams – $ 5 Billion
  - Drinking Water – $ 115 Billion (includes Wastewater)
  - Energy (National Power Grid) – $ 50 Billion
  - Hazardous Waste – $ 41.6 Billion
  - Navigable Waterways – $ 50 Billion

[1] **American Society of Civil Engineers (ASCE) - 2005**

- Public Parks & Recreation – $ 3.3 Billion
- Rail - $ 61 Billion
- Roads - $ 628 Billion (includes Bridges)
- Schools – $ 268 Billion
- Security – new category and estimate not possible
- Solid Waste – no reliable estimate
- Transit – $219.5 Billion
- Wastewater – $ 115 Billion (includes Drinking Water)

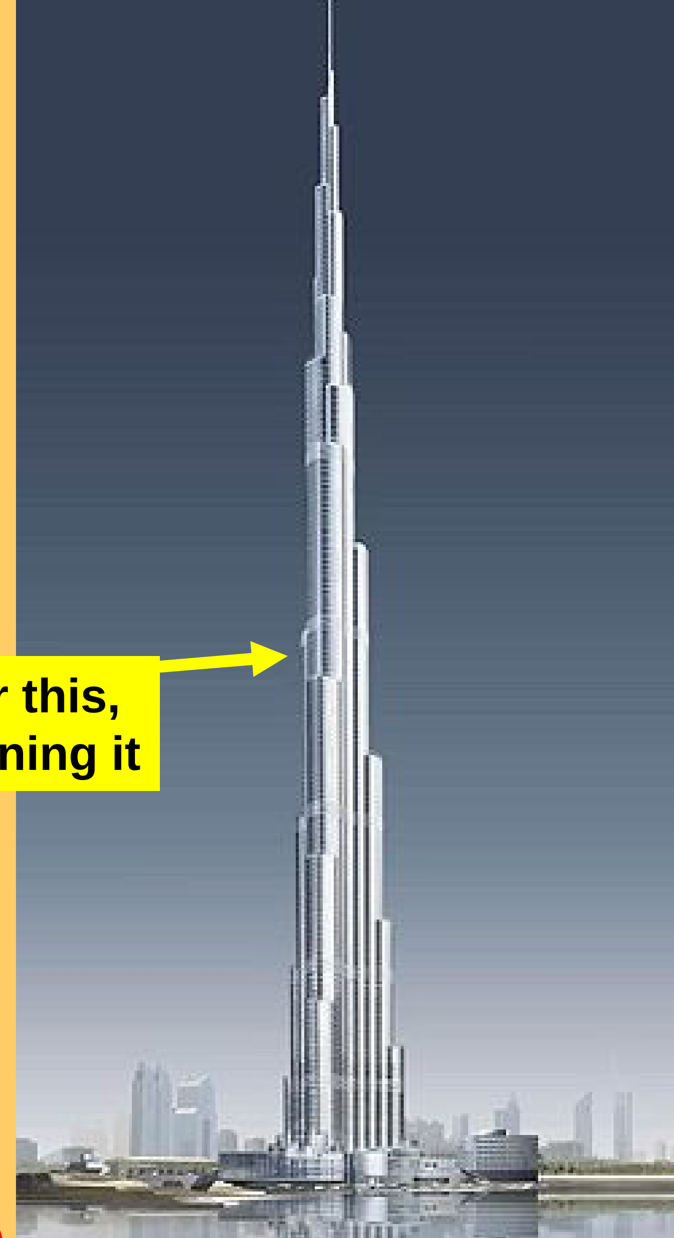
We must act soon, because the world is flat, and our Earth neighbors are doing so!

Other nations understand the value of infrastructure.



Millau Viaduct
300,000,000 euros
38 months construction

We payed for this, and are designing it



Burj Dubai
Completion 2008
Skidmore, Owings and Merrill

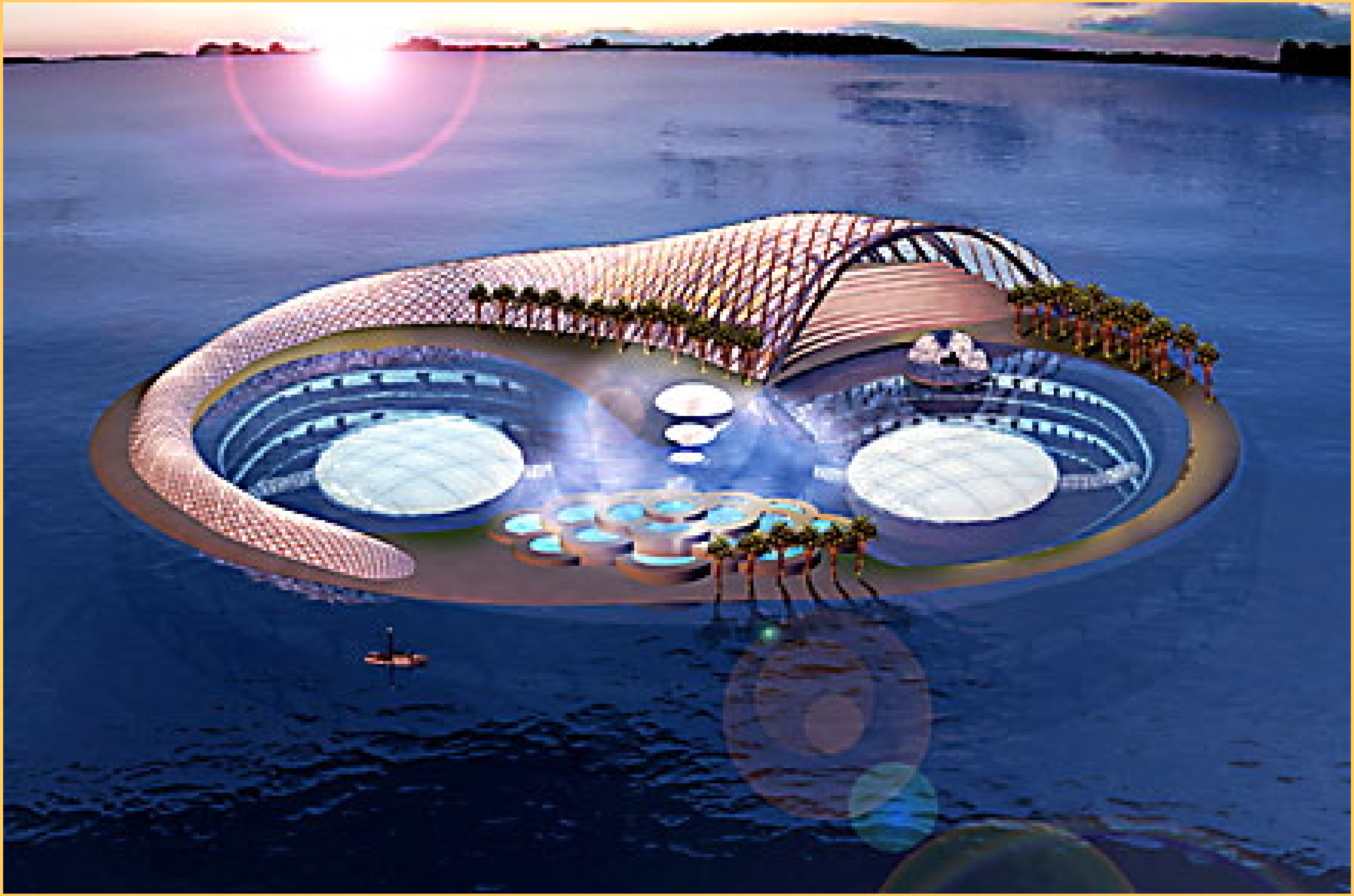
Beijing-Shanghai High-Speed Line, China

~$32 B

Double Whammy:

Congestion caused by Evacuees of Hurrican Rita

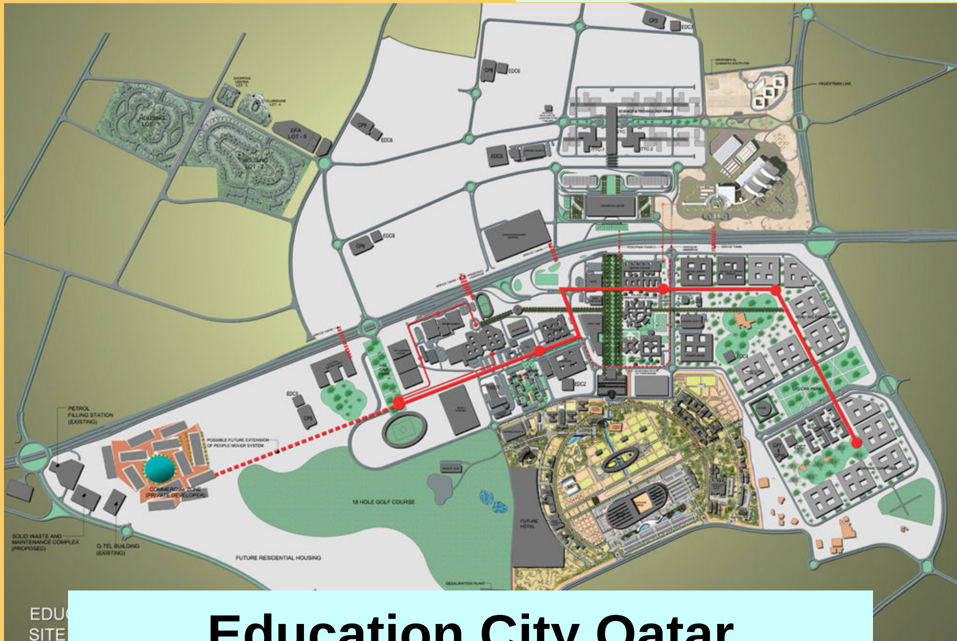
Burj Al Arab Hotel



Hydropolis; first underwater resort hotel, Dubai

Ski Dubai

It’s not just about buildings



Education City Qatar

Carnegie Mellon, Cornell, Texas A&M, Northwestern

King Abdullah University of Science and Technology

KAUST

FACULTY & STAFF

Related Information

- Press Release

Professor Brian Moran

Division Chair, Earth and Environmental Sciences and Engineering

Professor Brian Moran has been appointed Division Chair of Earth and Environmental Science and Engineering at KAUST. As Division Chair, Professor Moran will lead efforts to provide opportunities and facilities for researchers to address important scientific issues pertaining to resources and the environment.

Prior to joining KAUST, Professor Moran served as chair of the department of Civil and Environmental Engineering at Northwestern University, and previously, as chair of the department of Mechanical Engineering. In Civil and Environmental Engineering, he chaired an advisory board in developing a program in Architectural Engineering and Design. In Mechanical Engineering, he established a research thrust in neural engineering in conjunction with Biomedical Engineering and the Rehabilitation Institute of Chicago where he led the department through program review and accreditation.

A native of Ireland, Professor Moran is a Fellow of the American Society of Mechanical Engineers. He was elected a member of the board of directors of the Society of Engineering Science and presently serves as secretary of the society. He co-chaired the Seventh World Congress on Computational Mechanics in Los Angeles in 2006.

He was twice elected by students to the Northwestern Faculty Honor Roll for Teaching and he received the W.M. Keck Foundation Award for Engineering Teaching Excellence. He has published more than 100 technical articles and he is co-author of Nonlinear Finite Elements for Continua and Structures. He and his co-authors received a best paper award from SPIE, NDE Symposium in 2005. His research interests are in multi-scale computational science and engineering, fracture mechanics and plasticity, and the use of novel techniques, such as extended finite element and level set methods for the evolution of bacterial biofilms.

Professor Moran earned his bachelors of engineering in Civil Engineering and later his masters of engineering in Mechanical Engineering from the National University of Ireland, Galway. He earned a masters of science in Applied Mathematics and doctorate in Solid Mechanics from Brown University. He received the National University of Ireland Bursary in Civil Engineering for study abroad. Professor Moran spent a year as an IBM Research Fellow at Caltech before joining Northwestern in 1988.

The job ahead of us
We need to concurrently maintain and rebuild

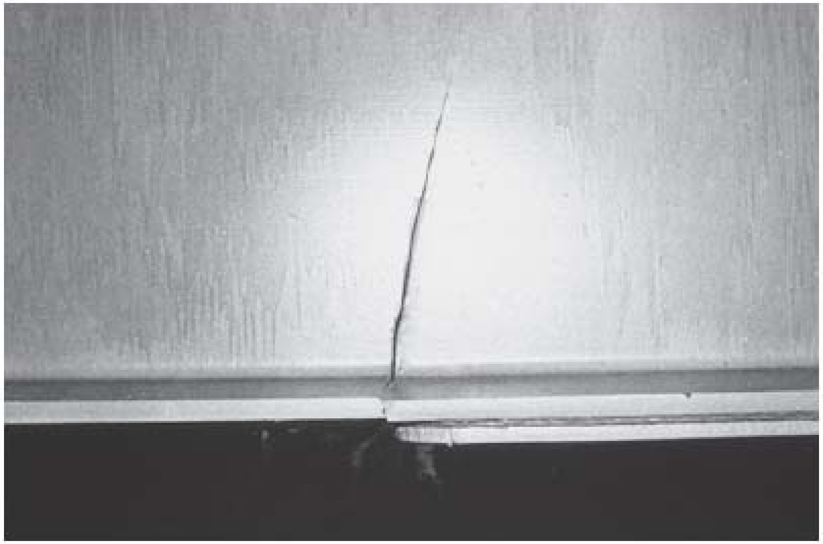


FIGURE 2 Development of fatigue crack at cover plate ends on the multibeam Yellow Mill Pond Bridge in Connecticut in 1976. (*Courtesy:* John W. Fisher.)

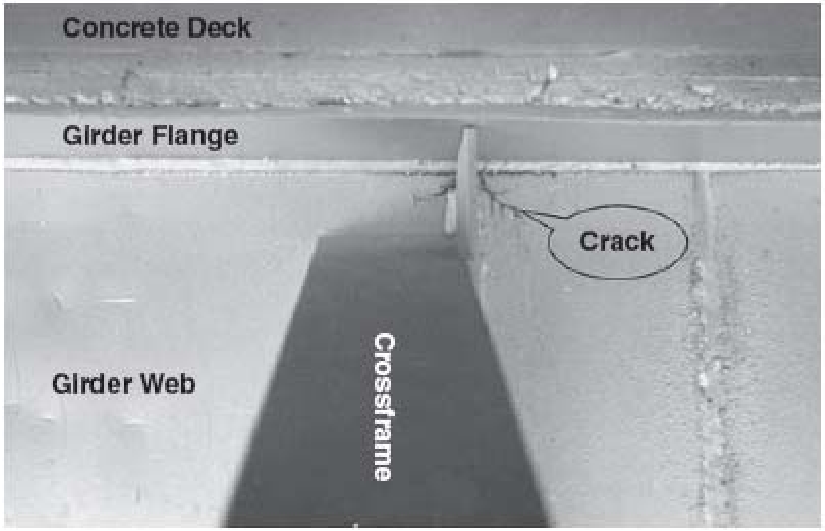


FIGURE 3 Typical web-gap fatigue cracking.

NCHRP
SYNTHESIS 354

Cracking can lead to noncatastrophic Damage.

FIGURE 16 View of cracked girder in two-girder span of Lafayette Street Bridge in St. Paul, Minnesota, as an example of a bridge that is sufficiently redundant to avoid collapse despite a fracture of the tension flange and the web of one girder.

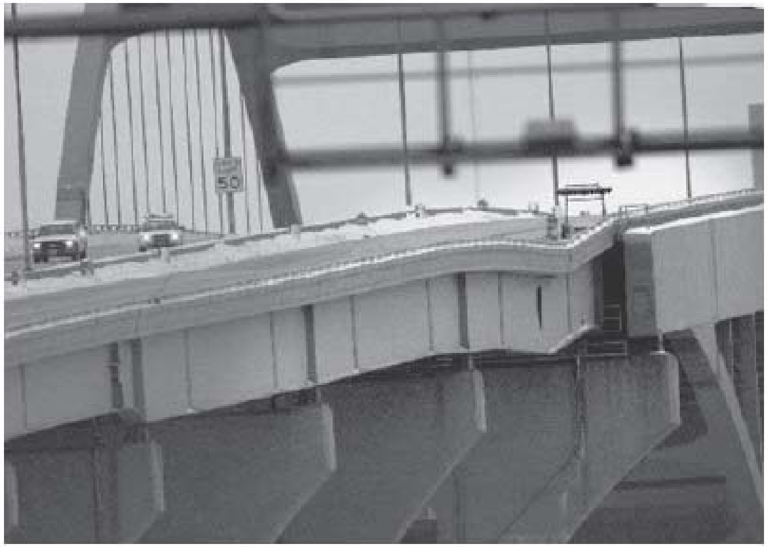


FIGURE 9 Example of bridge deck acting as catenary with hinge at fracture location in end span of the approach spans of the Hoan Bridge in Wisconsin—two of the three girders had full-depth fractures in December 2000.

NCHRP

SYNTHESIS 354

Effective retrofitting procedures are available; they cost money.

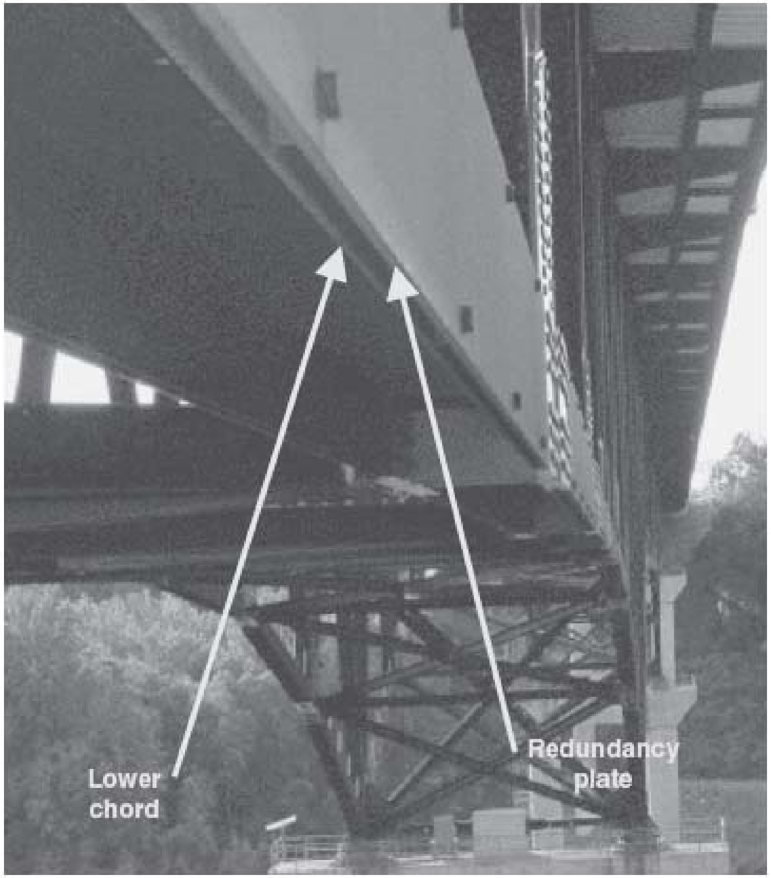


FIGURE 13 Redundancy plate bolted to lower chord of SR-33 bridge near Easton, Pennsylvania. (*Courtesy:* HNTB.)

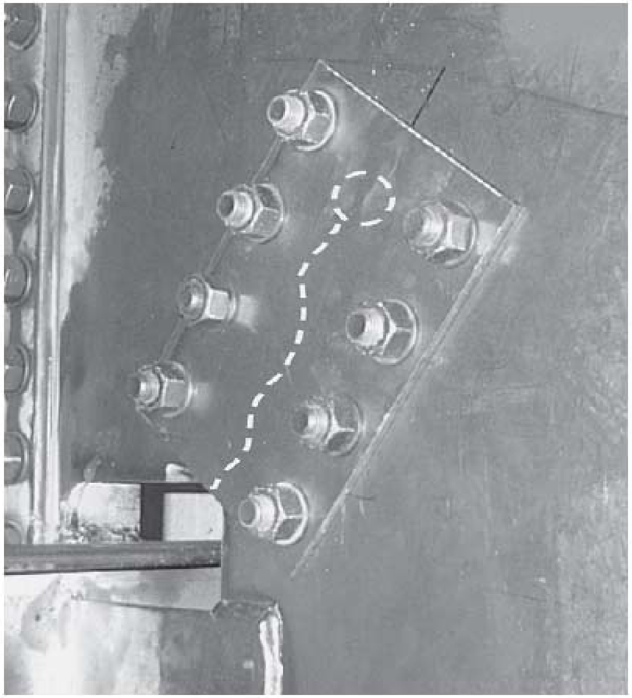


FIGURE A10 Bolted doubler plate repair. Dotted line represents crack line beneath doubler plate and circle is the hole drilled at crack tip to intercept further growth.

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News From the Field
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All Images

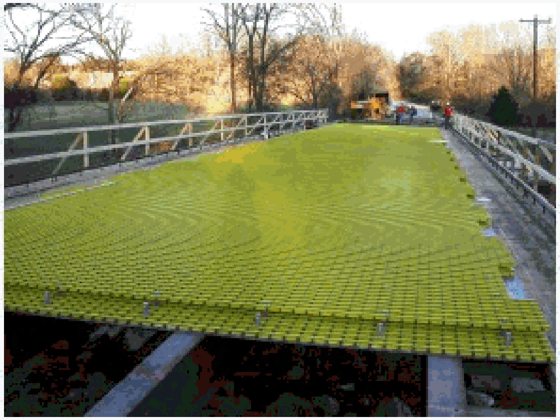
Effective repair is available

Press Release 06-040

Easy Up, Not-So-Easy Down

Builders replace bridge in only days using lightweight, corrosion-resistant composites

Back to article | Note about images

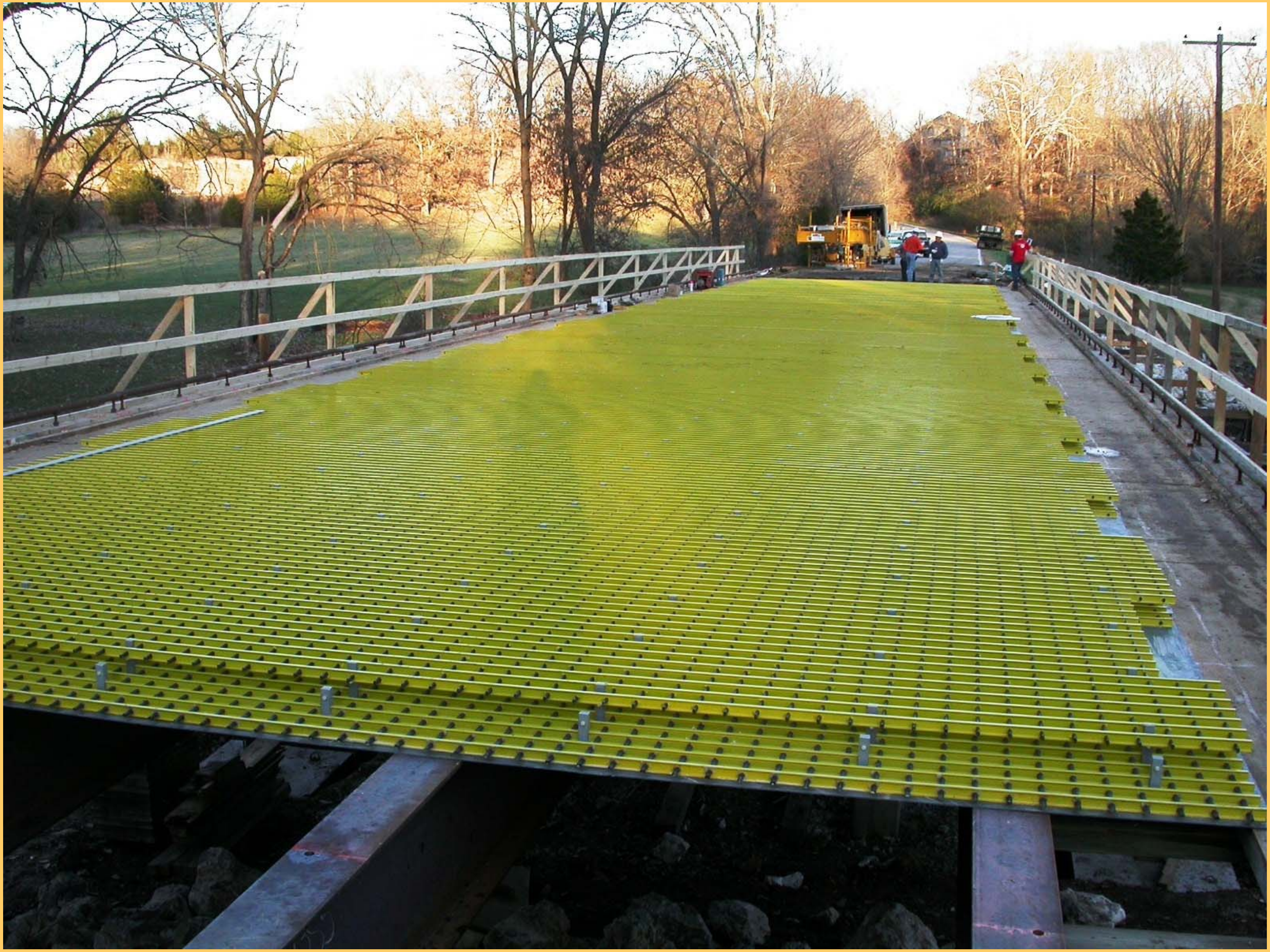


Fiberglass-polymer composites form the core of a renovated bridge deck in Springfield, Mo. University of Missouri at Rolla researchers at NSF's Buildings and Bridges with Composites Industry-University Cooperative Research Center (RB2C I/UCRC) worked with their industry partners and colleagues at the University of Wisconsin at Madison to develop the pre-fabricated, composite plates and cages.

Credit: *Fabio Matta, UMR*

Download the high-resolution JPG version of the image. (604 KB)

Use your mouse to right-click (or Ctrl-click on a Mac) the link above and choose the option that will save the file or target to your computer.



Replacement: Leonard Zakim Bridge, Boston
$115M

And now to the bridge

The scope: education of students

(Academic investigation funded
by the National Science Foundation
and the University's Center for Transportation Studies

The cast:

Profs. T. Okazaki, A. Schultz, T. Galambos and R. Ballarini

Undergrads Tor Oksnevad and Charles De Vore

Grads Minmao Liao and Alicia Forbes

Other organizations that have studied the collapse and that have or soon will publish their findings:

Wiss, Janney, Elstner Associates, Inc. (WJE) (retained by MnDot)
National Transportation Safety Board
Federal Highway Administration (FHWA)

I-35W BRIDGE OVER THE MISSISSIPPI RIVER: COLLAPSE INVESTIGATION

BRIDGE NO. 9340
MINNEAPOLIS, MINNESOTA

FINAL REPORT
NOVEMBER 2008
WJE No. 2007.3702

Prepared for:
Minnesota Department of Transportation
Bridge Office
Oakdale, Minnesota

Prepared by:
Wiss, Janney, Elstner Associates, Inc.
330 Pfingsten Road
Northbrook, Illinois 60062

Howard J. Hill
Jonathan C. McGormley
Michael J. Koob
William J. Nugent

Our calculations and conclusions are in agreement with those that appear in the WJE report

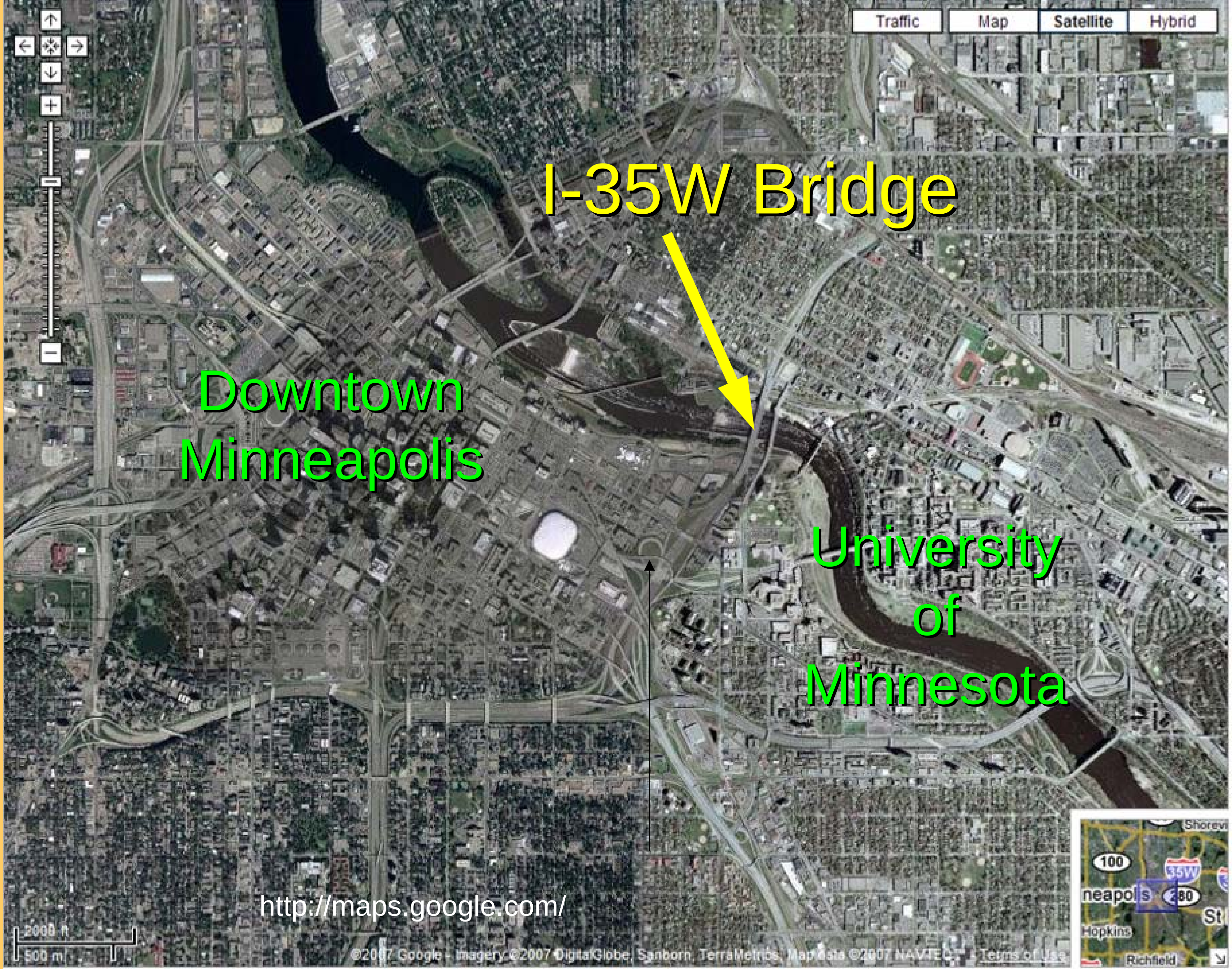
The truss members were capable (with acceptable safety factors) of carrying the loads experienced by the bridge. There is no reason to suspect they are responsible for the collapse.

With respect to the design service loads, the safety factor of the gusset plates at nodes U10 was approximately equal to 1.0, instead of the roughly 2.0 required by the requirements of the design code in 1967. For unexplained reasons, these plates were ½" instead of 1" thick.

The bridge collapsed as a result of the failure of the gusset plate(s) at a U10 node, in the vicinity of the L9-U10 compression diagonal. The calculated capacity of the gusset plates (that failed) was very close to the demands that were placed on it at the time of the bridge collapse. Had the plates been 1" thick, the capacity would have exceeded the demands.

The "final straw" was most likely the weight of the construction material placed on the bridge hours before the collapse. The calculations show this weight significantly increased the stresses on the gusset plates.

We note that temperature cycles could have significantly influenced the forces in the truss members framing into the U10 nodes, and in the stresses experienced by the gusset plates, as could have a number of heavy vehicles passing over the bridge near the time of collapse.

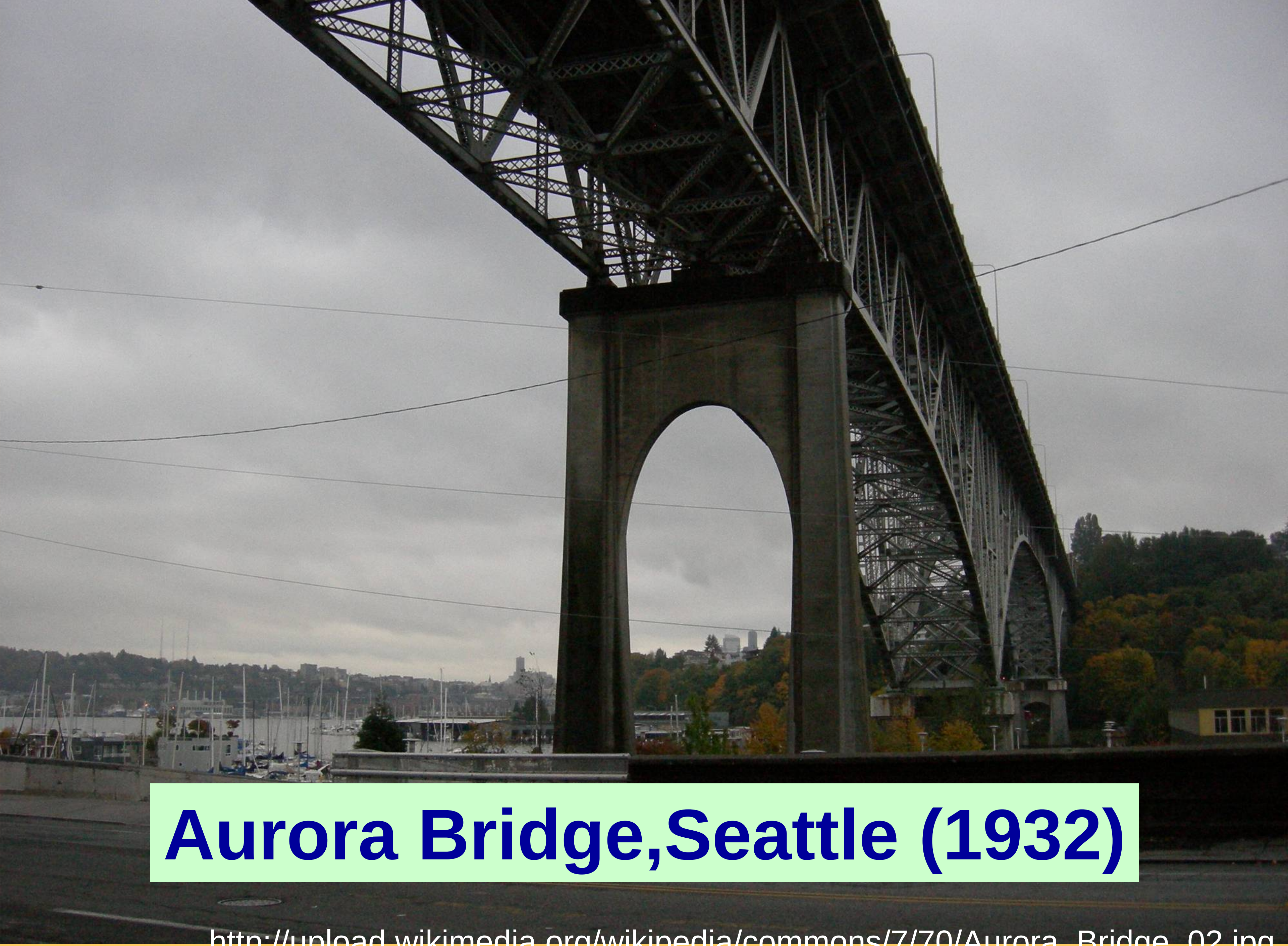


I-35W Bridge
Downtown Minneapolis
University of Minnesota
http://maps.google.com/
Traffic
Map
Satellite
Hybrid

- Opened to traffic in 1967
- 140,000 vehicles per day
- 5,700 heavy vehicles per day
- Multiple retrofits over past decade

http://en.wikipedia.org/wiki/I-35W_Mississippi_River_bridge


St. Cloud, MN (1957)

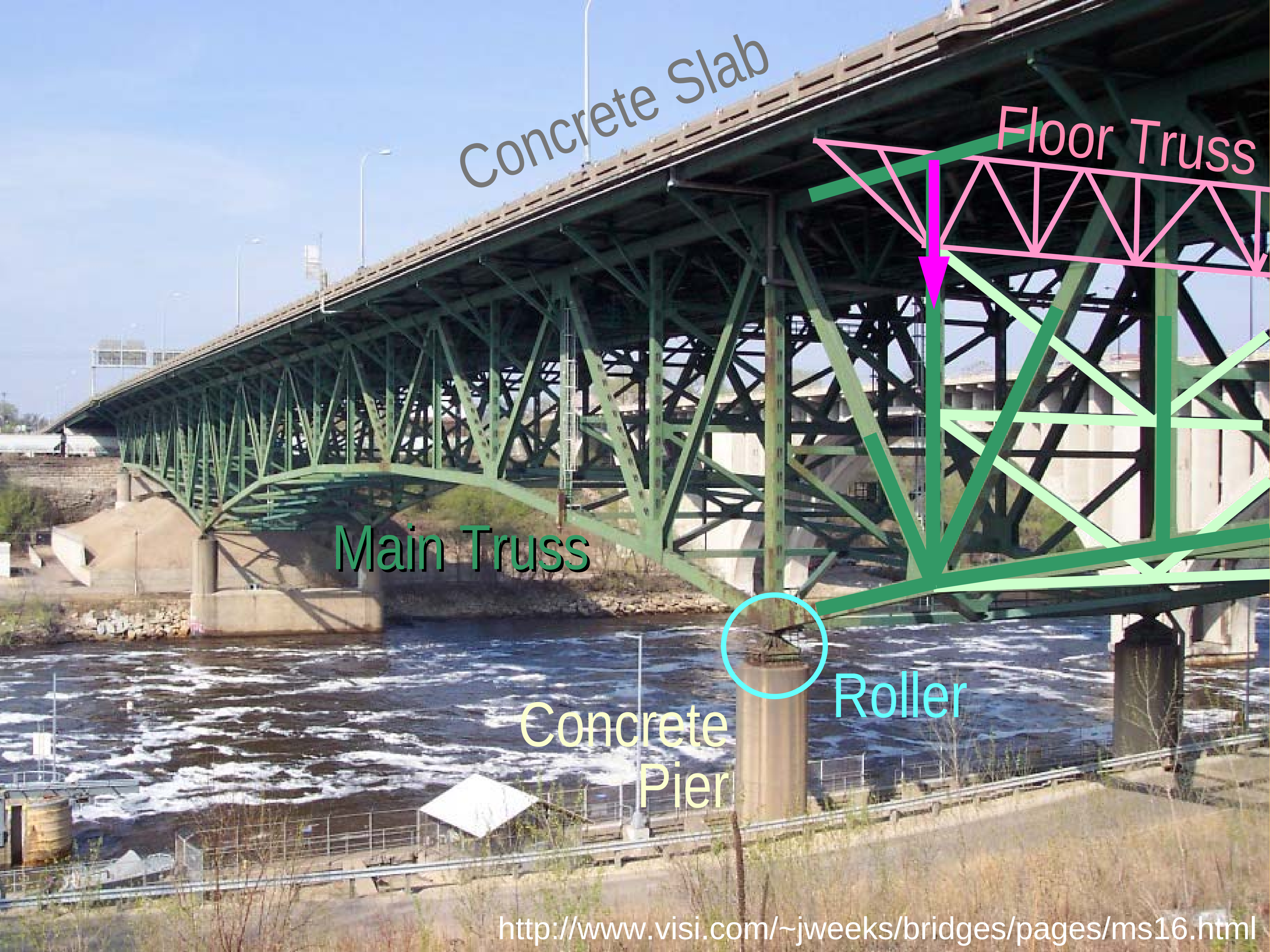


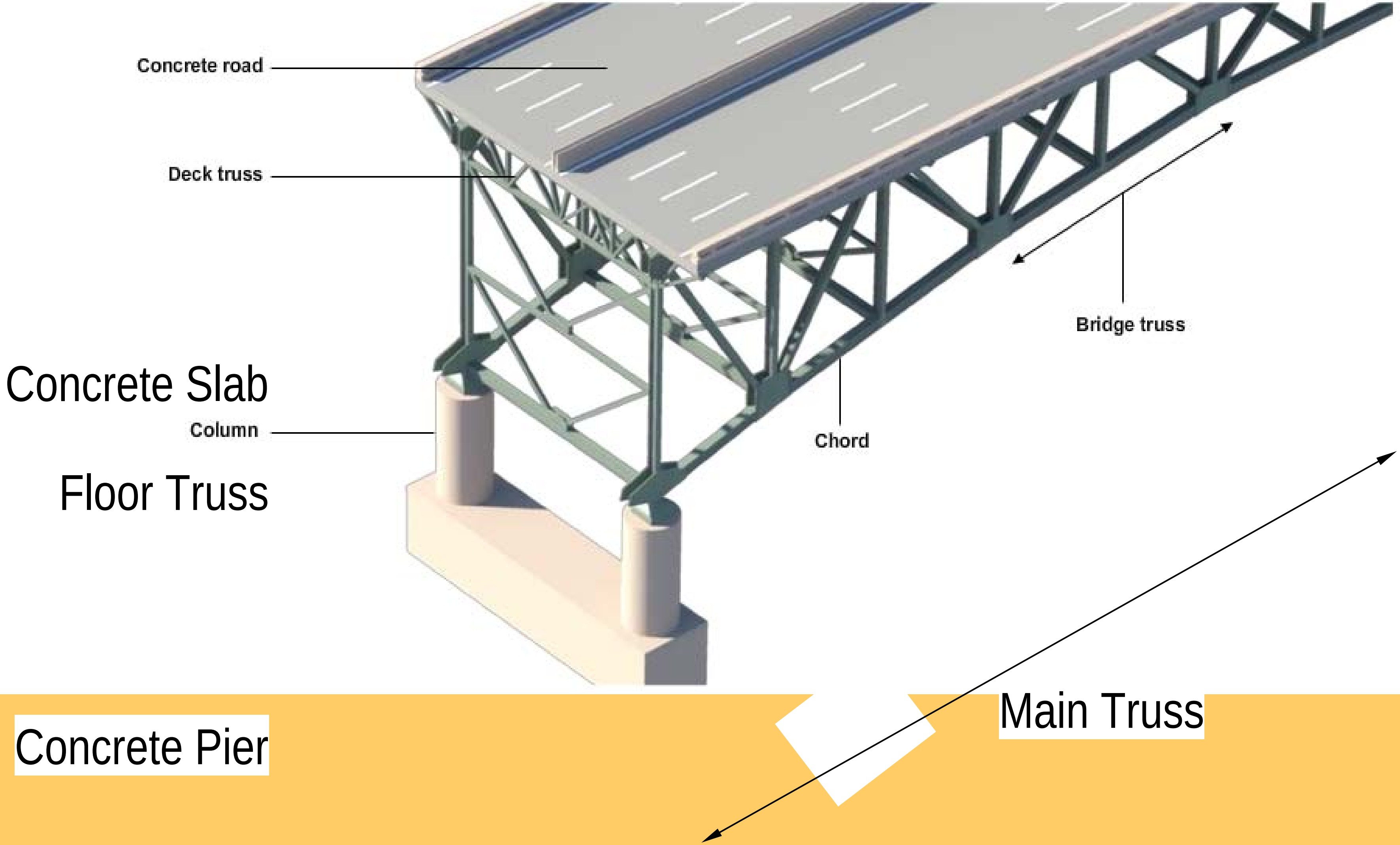
Aurora Bridge,Seattle (1932)

http://upload.wikimedia.org/wikipedia/commons/7/70/Aurora_Bridge_02.jpg

Liberty Bridge, PA (1928)

http://pghbridges.com/pittsburghE/0585-4476/liberty.GIF


Concrete Slab
Floor Truss
Main Truss
Roller
Concrete
Pier
http://www.visi.com/~jweeks/bridges/pages/ms16.html



It is instructive to keep in mind the relative weights:

The weight of the concrete deck is roughly three times the weight of (all of) the steel!

CONSTRUCTION ZONE IN THE HOURS BEFORE THE COLLAPSE

This photo, taken less than three hours before the bridge collapse, shows cars and trucks creeping through the construction zone which reduced traffic from eight lanes to two lanes in each direction.

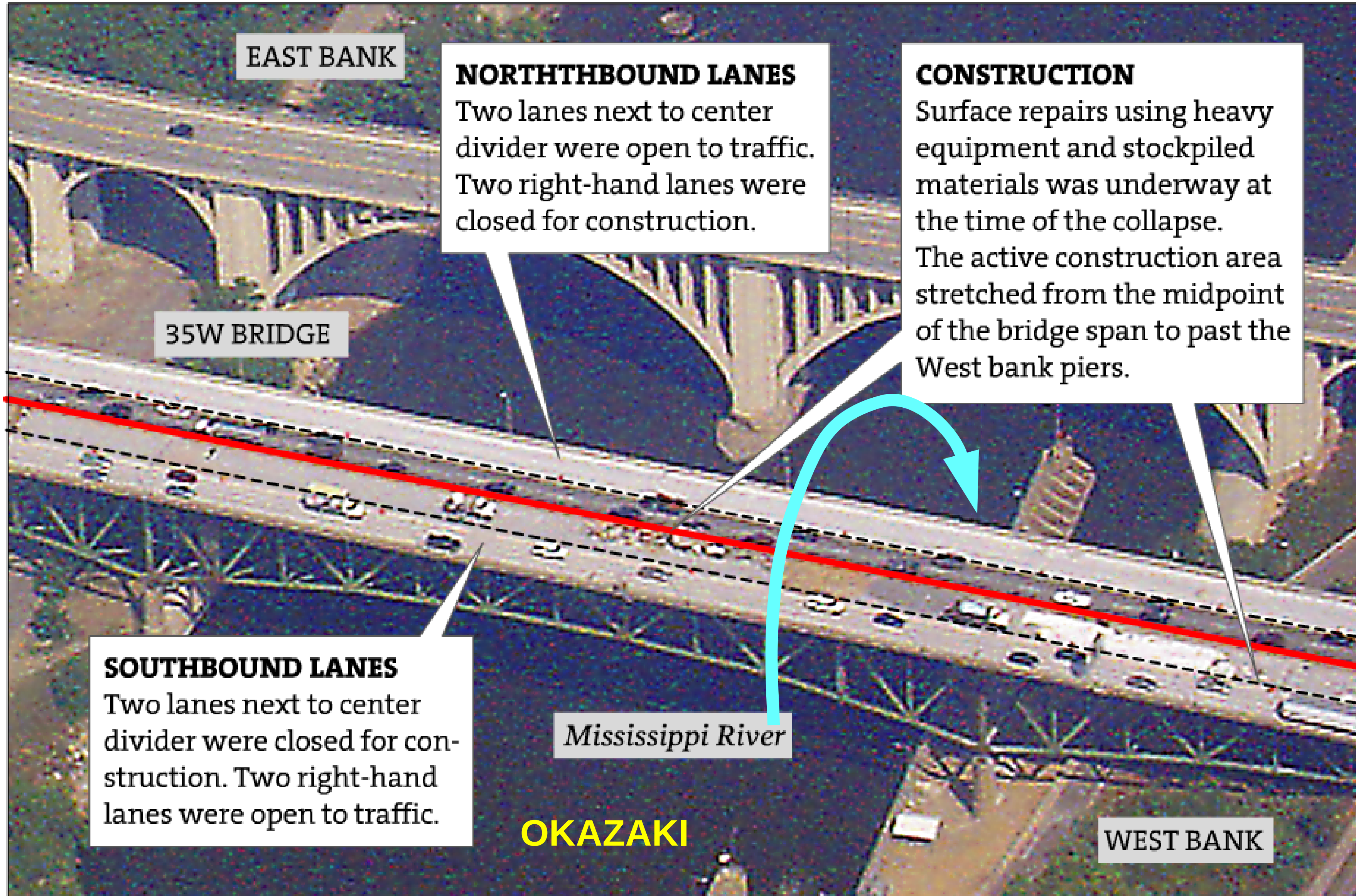
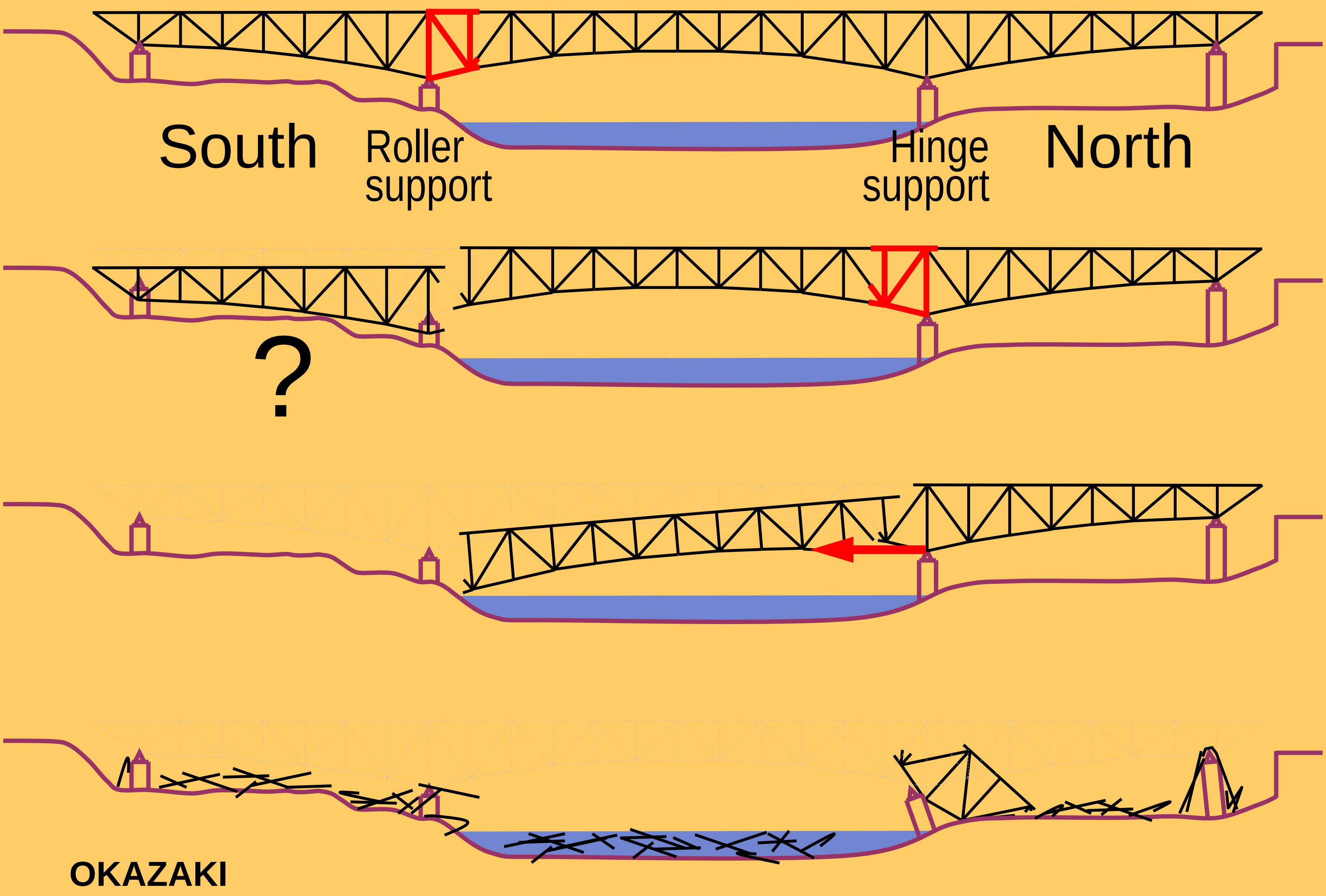
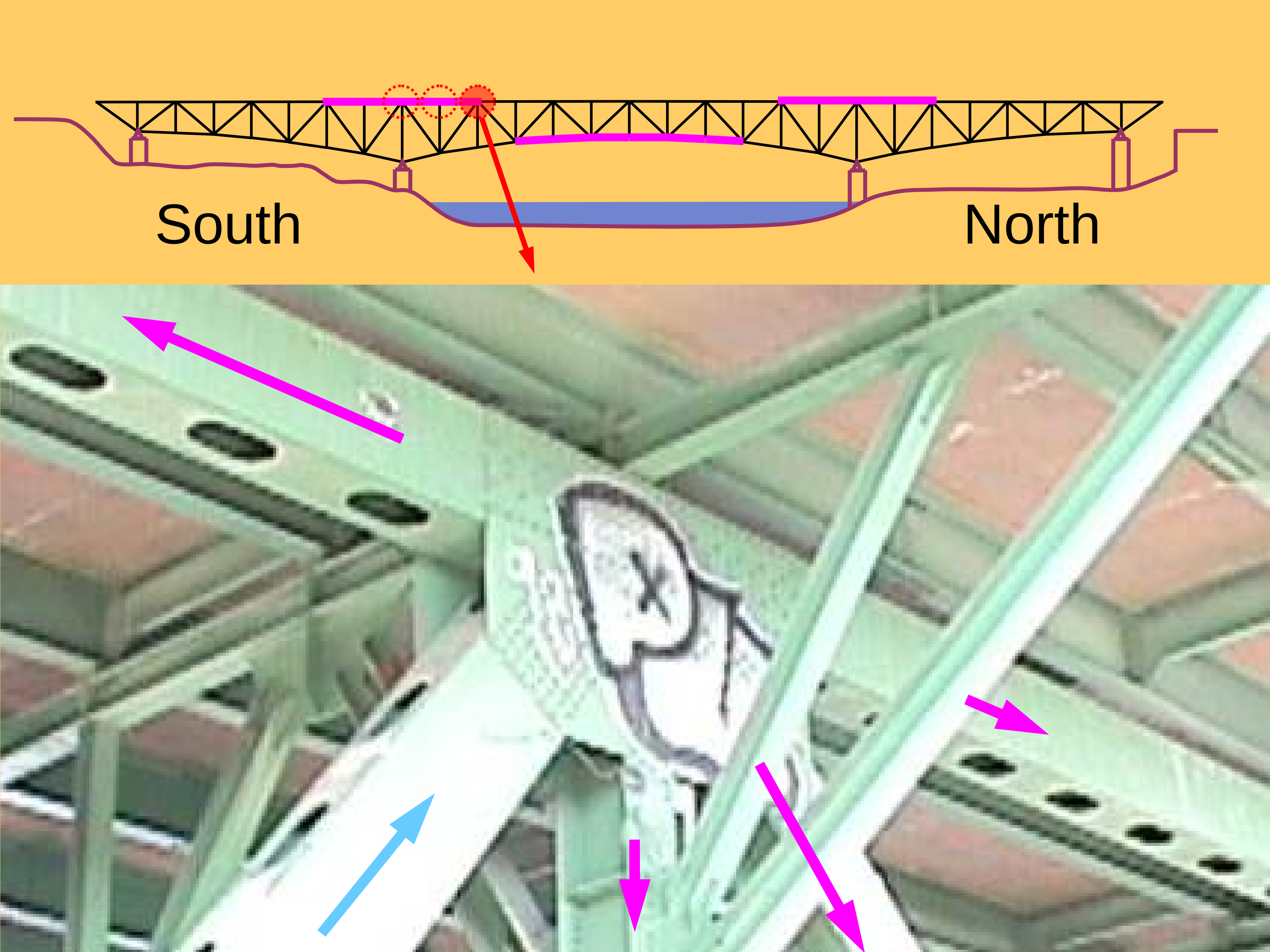
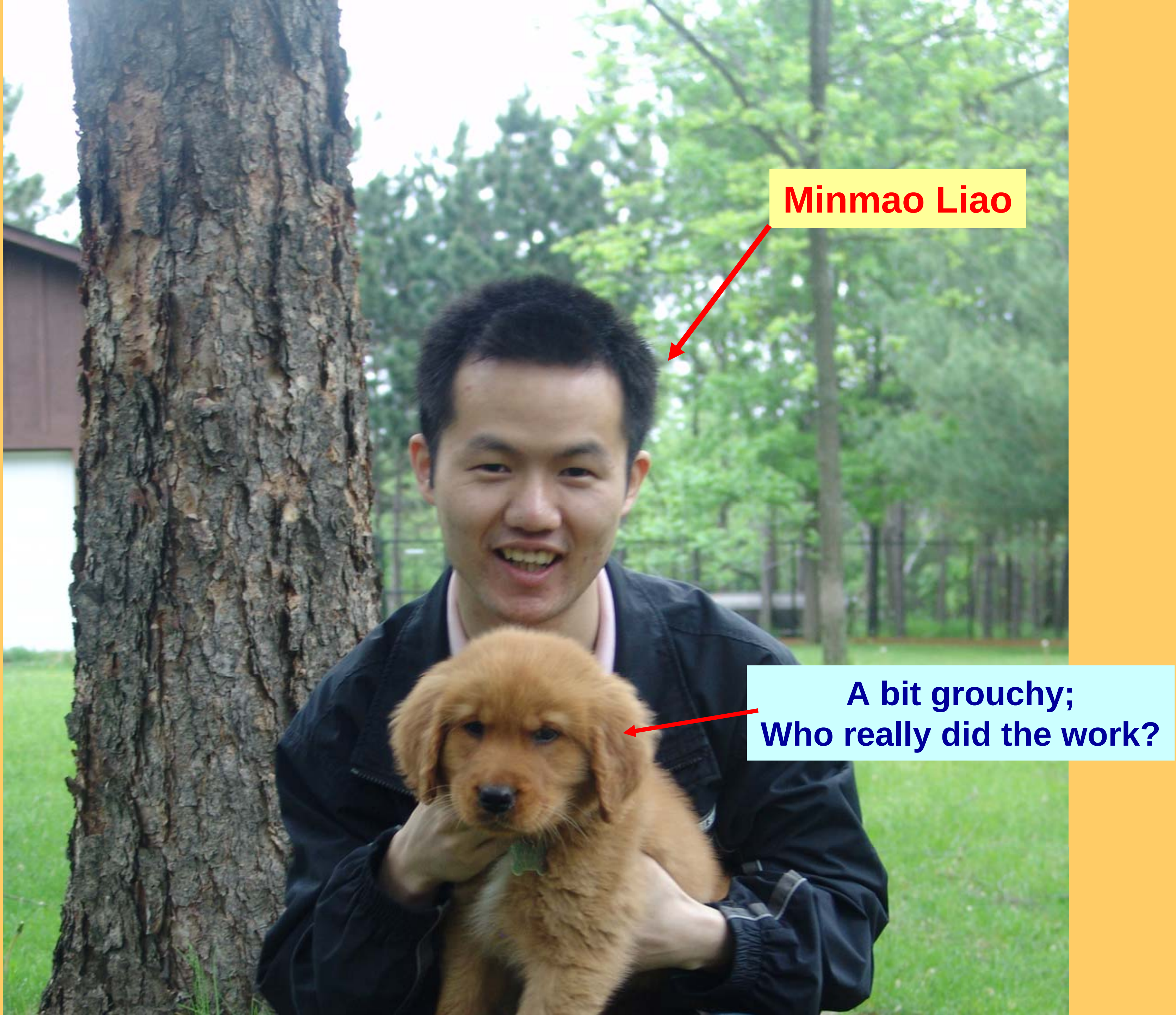
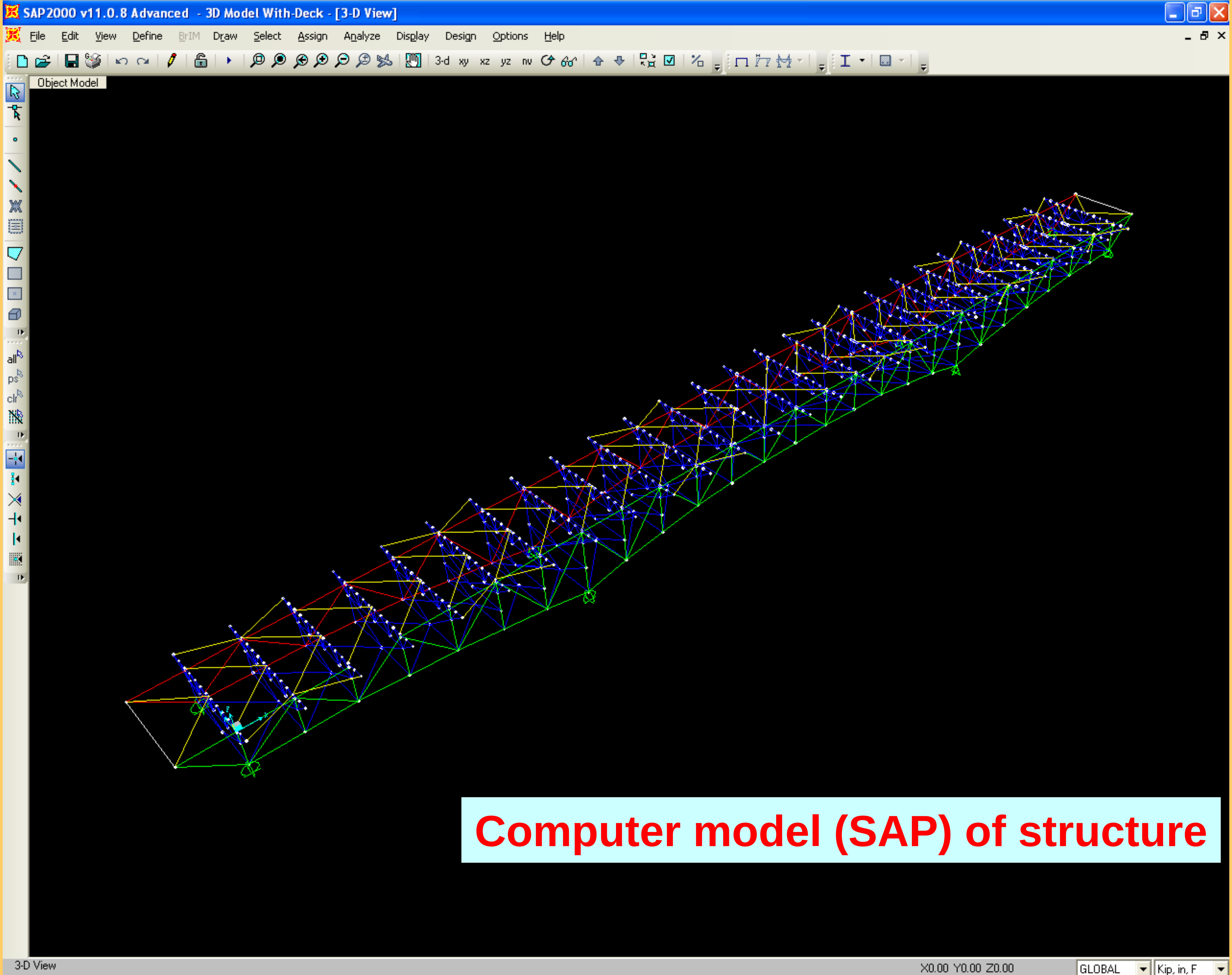


Photo by Michael Coddington • Special to the Star Tribune

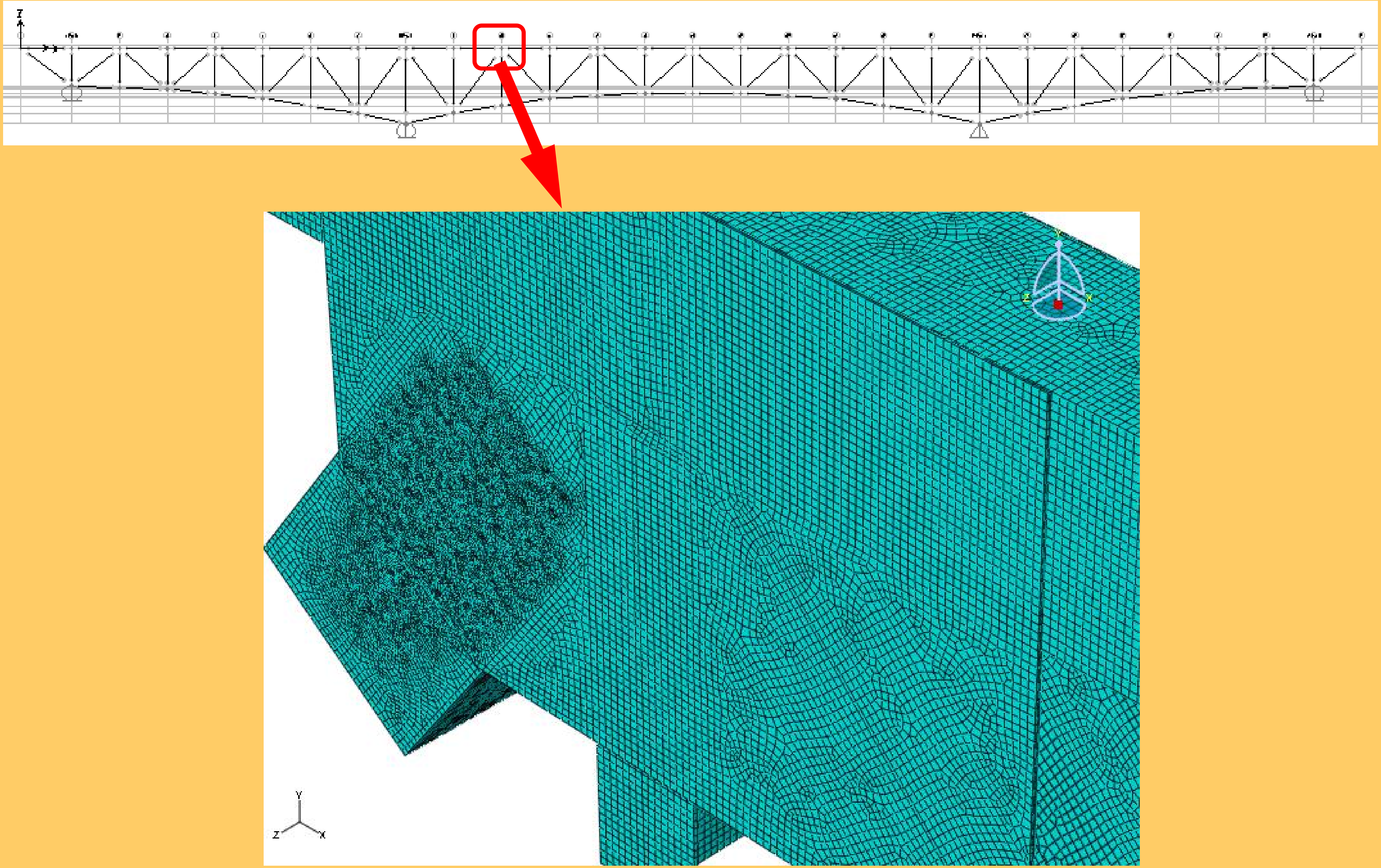

South
Roller
support
Hinge
support
North
?
OKAZAKI


South
North

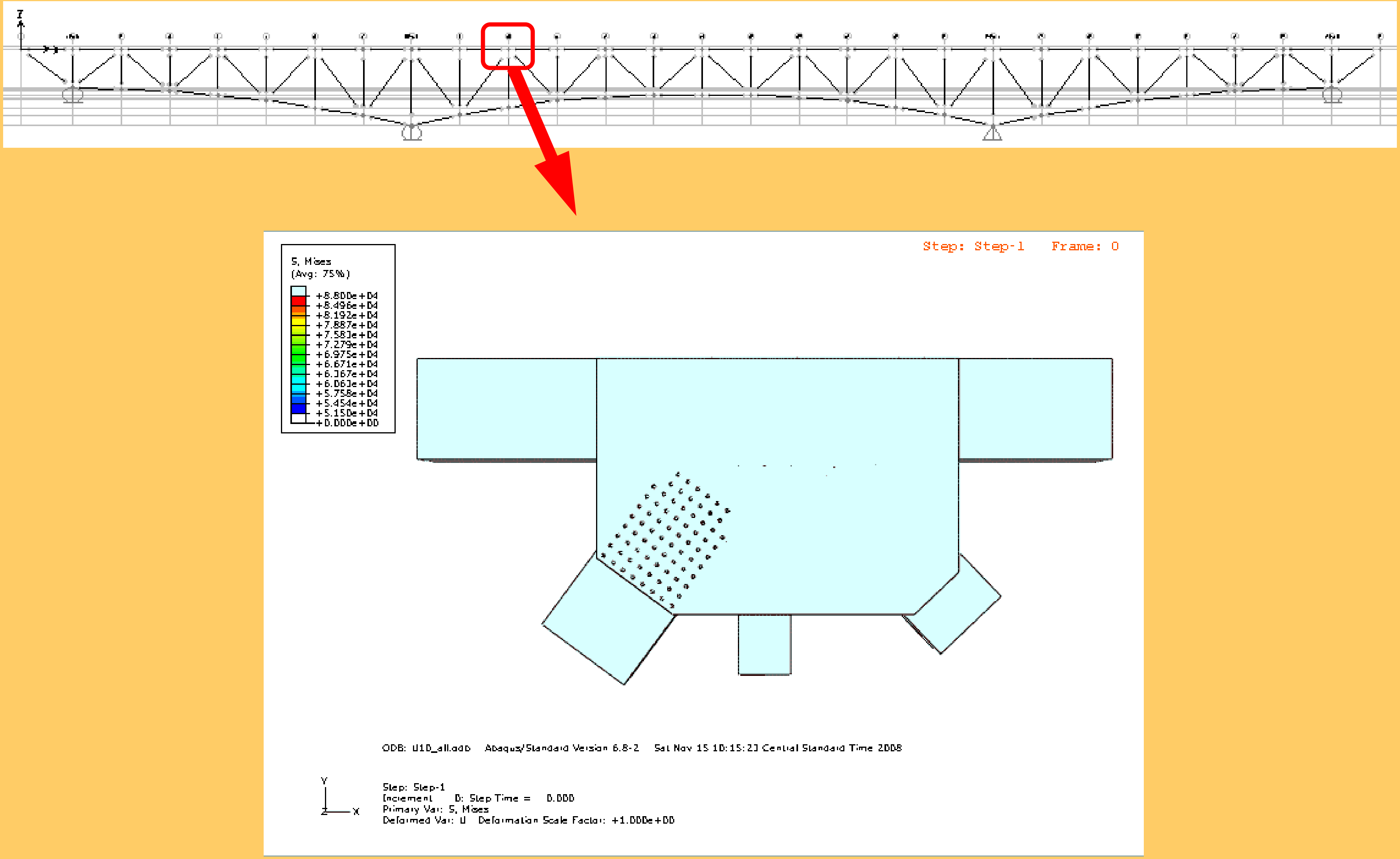

Minmao Liao
A bit grouchy;
Who really did the work?



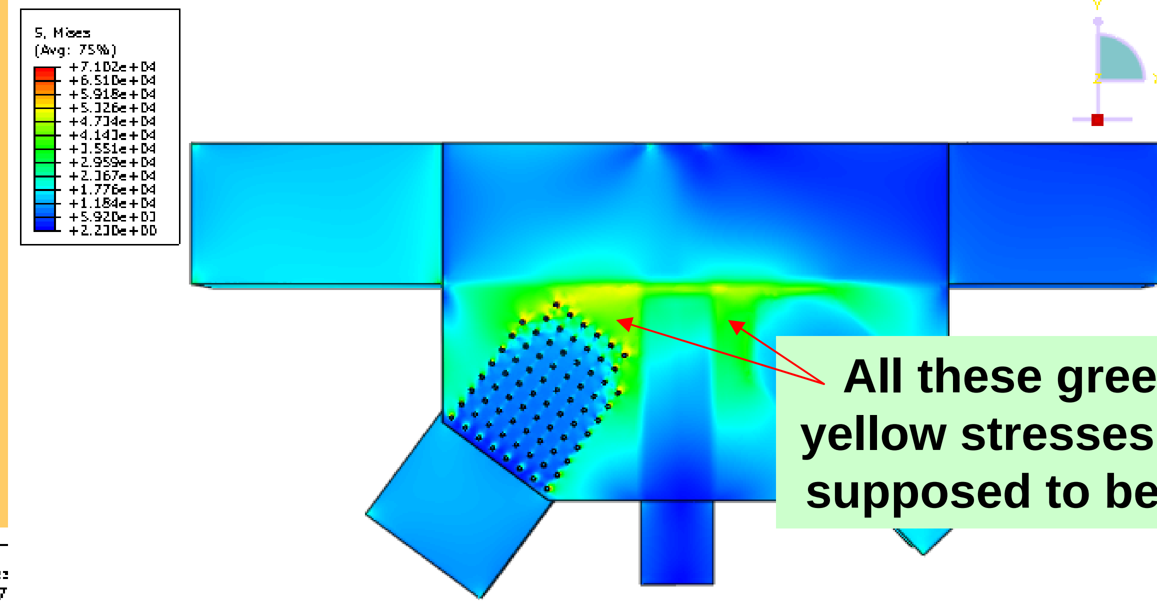
Computer model (SAP) of structure



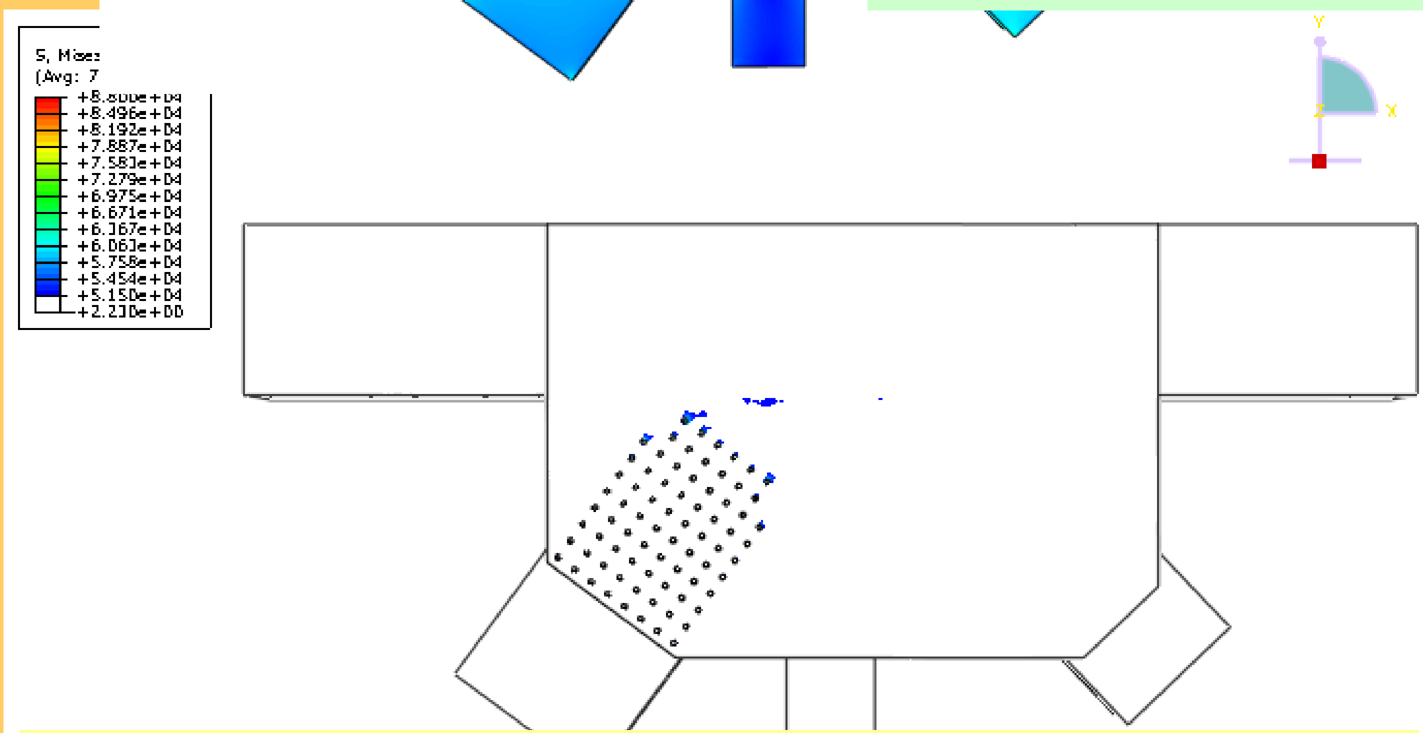
Finite Element Method Model; thanks to
The (University of) Minnesota Supercomputing Institute



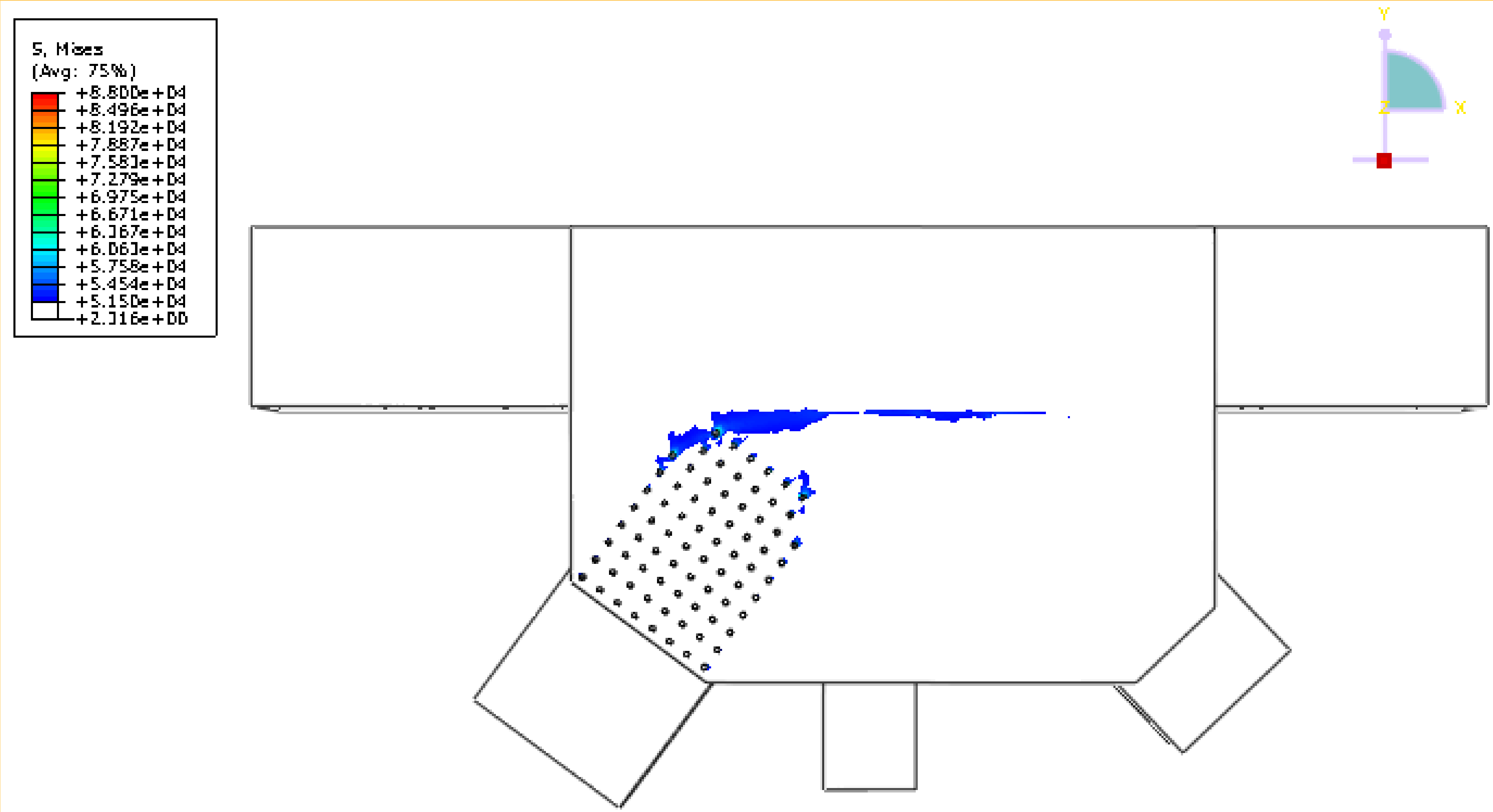
Finite Element Method Model



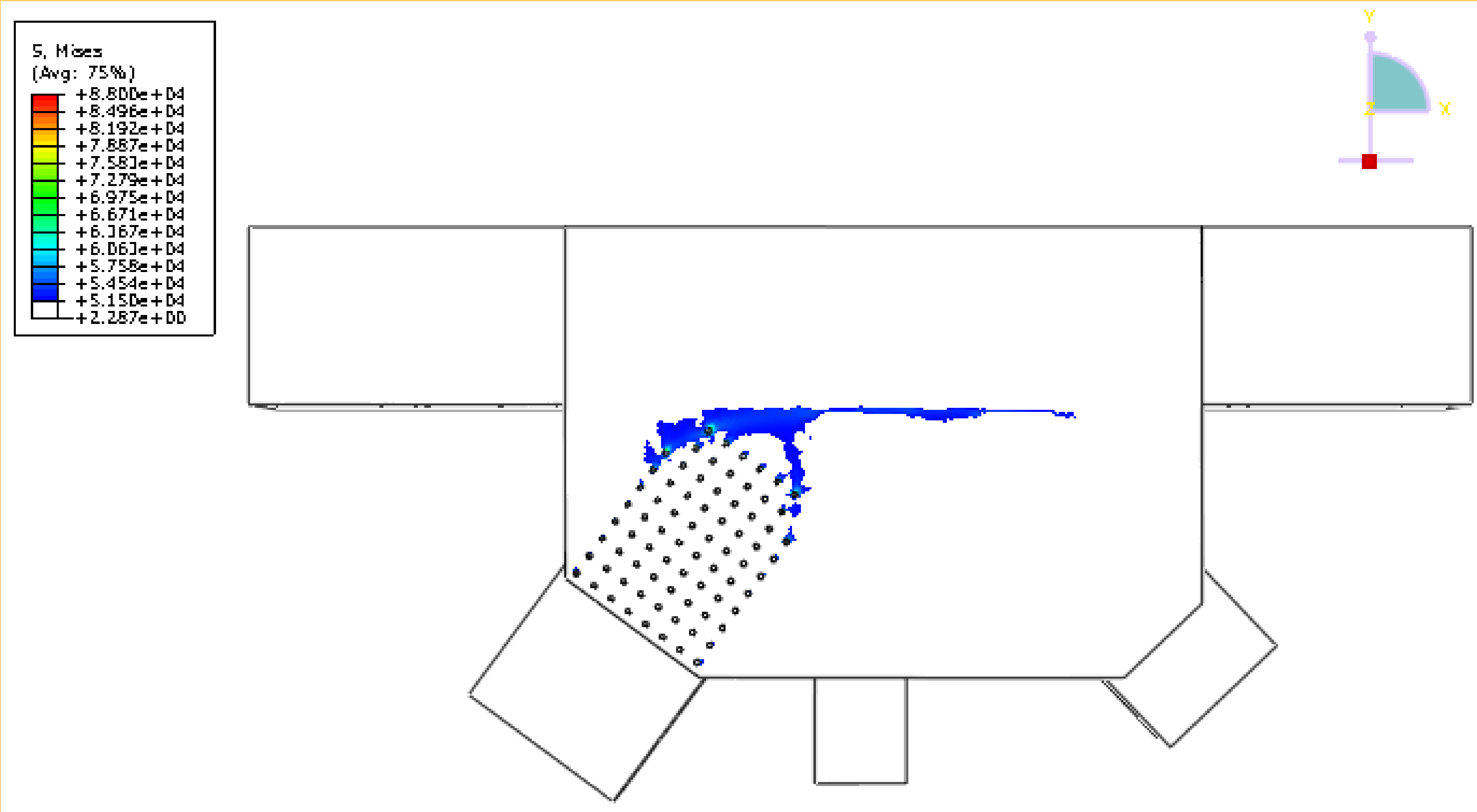
All these green and yellow stresses are not supposed to be there!!



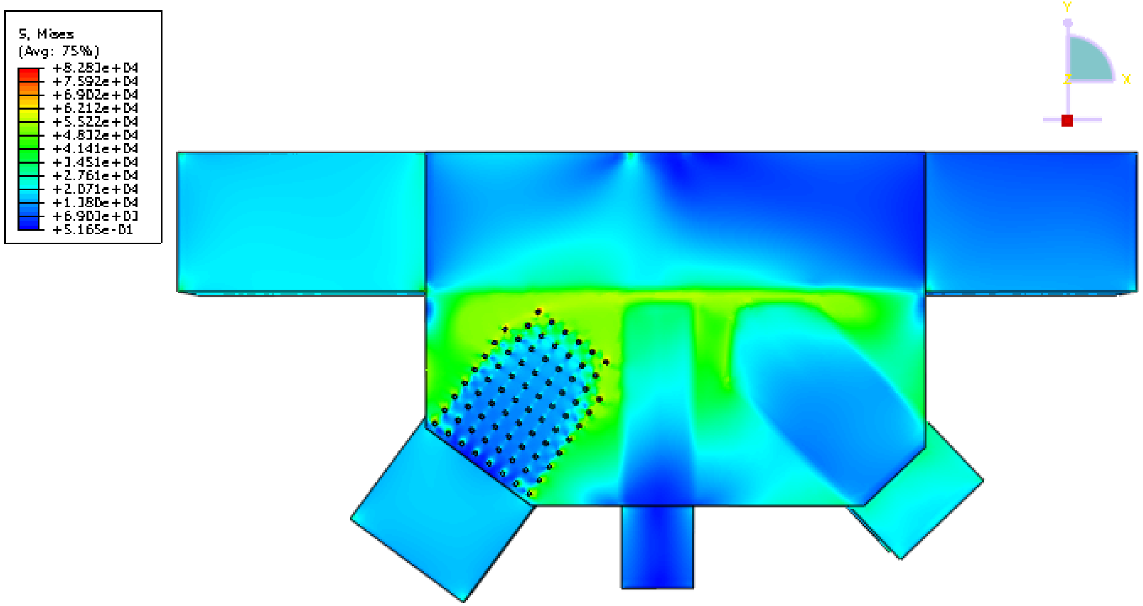
Plastic deformation of as-constructed bridge

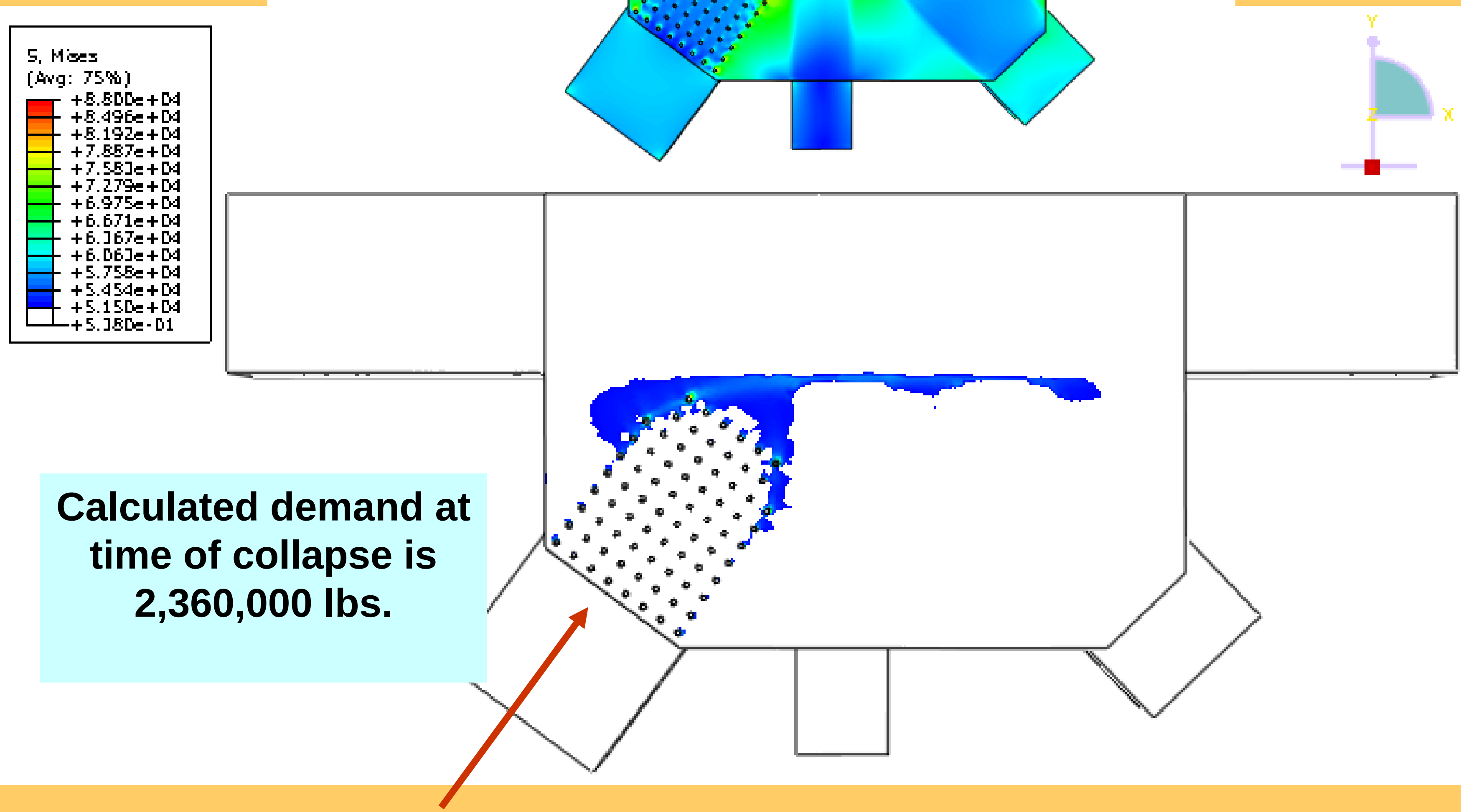


Plastic deformation resulting from increase of slab thickness from 6.5” to 8.5”

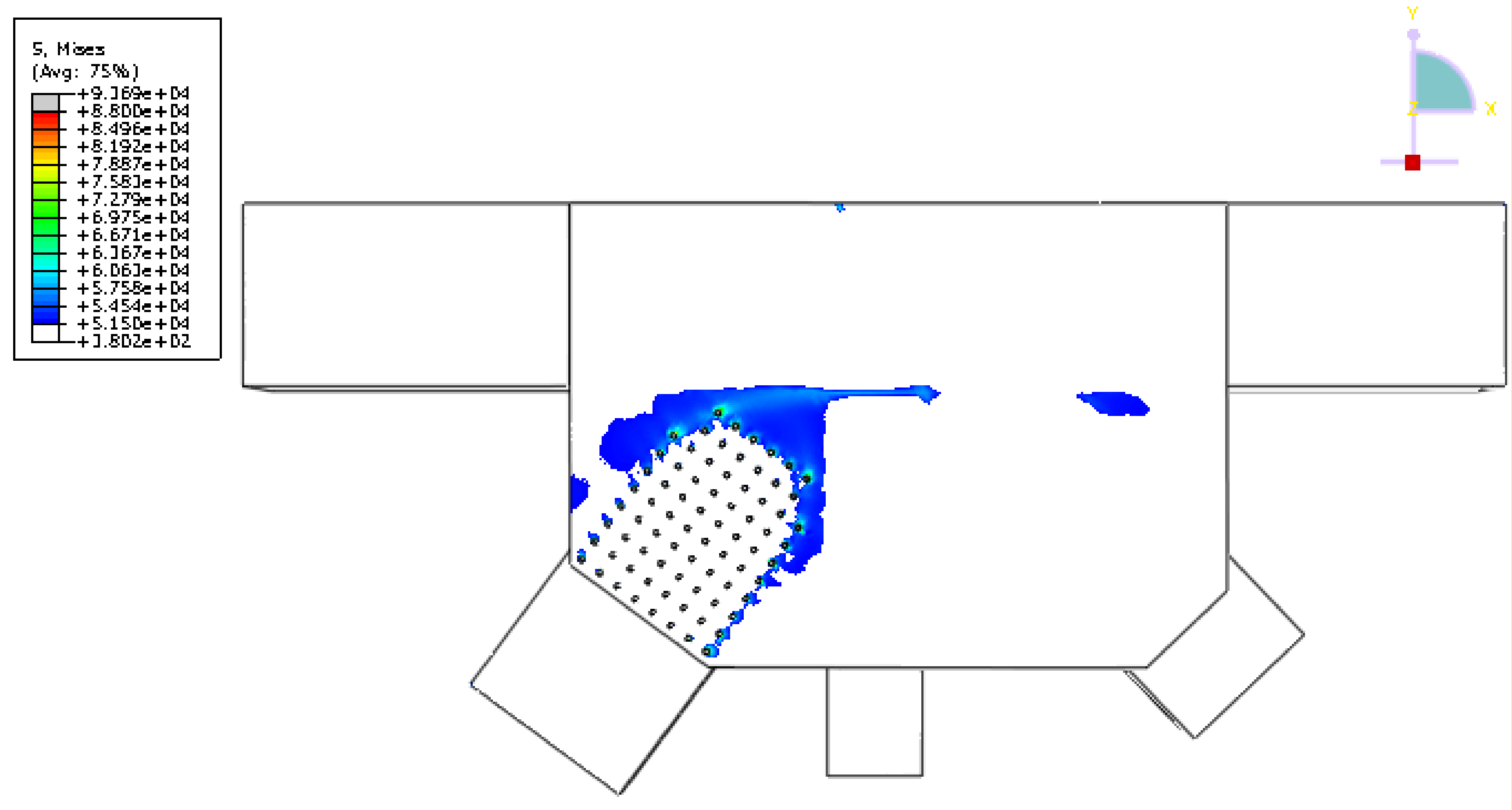


Plastic deformation resulting from averaged traffic load added to 8.5" deck

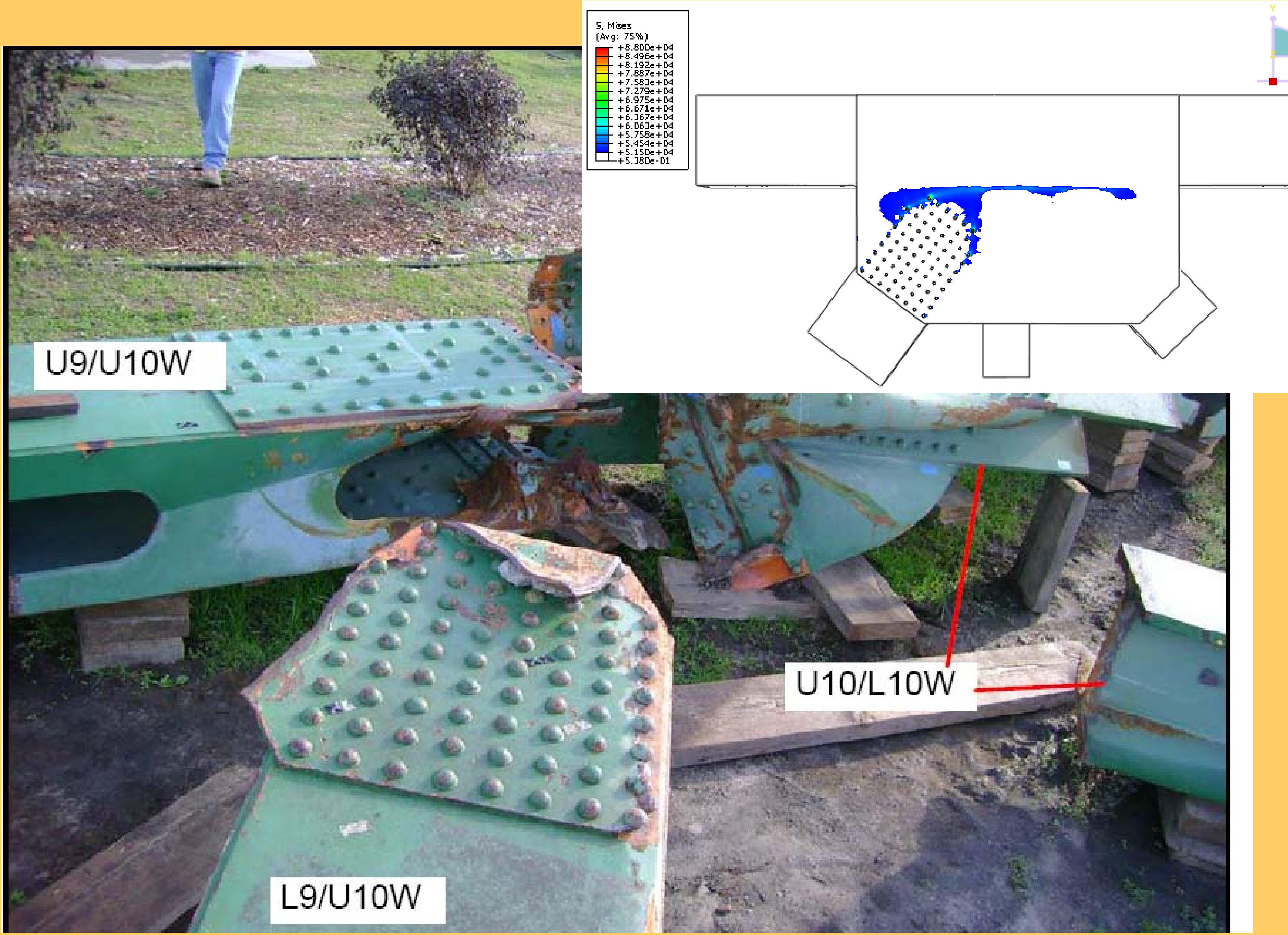




Calculated demand at time of collapse is 2,360,000 lbs.



Plastic deformation resulting from addition of 30ºF temperature differential from one side of joint to the other


S, Mises
(Avg: 75%)
+8.800e+04
+8.496e+04
+8.192e+04
+7.887e+04
+7.583e+04
+7.279e+04
+6.975e+04
+6.671e+04
+6.367e+04
+6.063e+04
+5.758e+04
+5.454e+04
+5.150e+04
+5.380e-01
U9/U10W
U10/L10W
L9/U10W

A comparison of our results with those In the WJE report

Calculated capacity of a 7/8" thick plate

Force in the L9-U10 diagonal framing into the U10 node

Ultimate capacity of gusset plate

Demand at time of collapse is 2,340,000 lbs

(virtually the same as our 2,360,000 lbs)

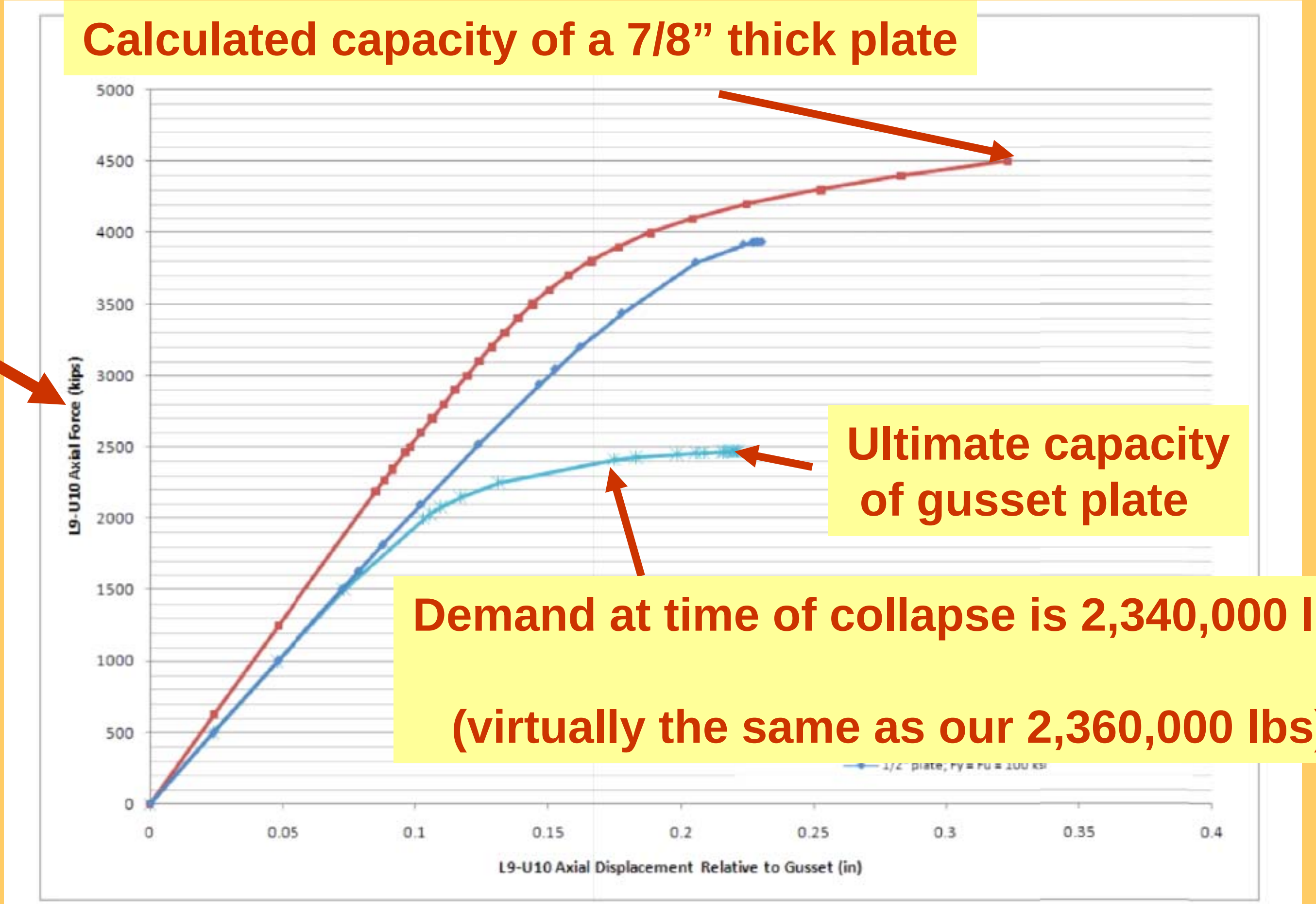


Figure 6.9 Load-displacement relationship for various configurations of U10 gusset plate.