Structural Fatigue in our Nation’s Transportation Infrastructure

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Outline

What the Nation’s infrastructure represents.

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

Two issues: 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.

But one example of distress; fatigue of steel structures.

There are solutions; and yes, they involve lots of money, education, research, and timely adoption of innovative materials and methods.
National Security; Roman Acqueduct in Pont du Gard, France
National pride; San Gimignano, Italy
We used to show our vision, power, wealth 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 jobs, expertise, the economy, ...
Most of us see this when vacationing
But this is our everyday experience; what are the effects of such degradation on our psyche?
Sinkhole swallows up SUV in New York street

Shocked driver escapes serious injury; vehicle rested on gas main

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 injuries but was taken to a hospital for treatment of shock, said Fire Department spokesman Brian Conlon.
Aging N.Y. pipes raise concerns of more blasts
Steam pipes rarely inspected; air tests ease health worries in Manhattan

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.

83 years old, and part of a system put into service in 1882!!!
Critical Infrastructure Protection: New approaches for evolving threats

Working Premise #1

This is ugly!

Courtesy of Dr. Massoud Amin
Critical Infrastructure Protection: New approaches for evolving threats

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
Critical Infrastructure Protection: New approaches for evolving threats

**Challenge**

Can we have this?

Without this?

**Courtesy of Dr. Massoud Amin**
**Civil engineers** are the doctors of infrastructure,-- and we have a patient that's sick and getting sicker.”

*ASCE Executive Director James E. Davis*
<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>GRADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>D</td>
</tr>
<tr>
<td>Aviation</td>
<td>D</td>
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<tr>
<td>Flood Control and Dams</td>
<td>B-</td>
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<tr>
<td>Drinking Water</td>
<td>B</td>
</tr>
<tr>
<td>Water Supply</td>
<td>F</td>
</tr>
<tr>
<td>Wastewater</td>
<td>B+</td>
</tr>
<tr>
<td>Solid Waste</td>
<td>C-</td>
</tr>
<tr>
<td>Schools</td>
<td>C</td>
</tr>
</tbody>
</table>
Context: R&D Expenditures*

*R&D expenditures as % of net sales

Top 10 Industries

1. Electric, Gas and Sanitation Services

Bottom 20 Industries

*Courtesy of Dr. Massoud Amin*
Other nations understand the value of Infrastructure.

Millau Viaduct
300,000,000 euros
38 months construction

Burj Dubai
Completion 2008
Skidmore, Owings and Merrill
Example of distress

Fatigue crack growth

Fast fracture
\[ N = A S^{-3} \]

or \[ \log N = \log A - 3 \log S \]

where:

- \( N \) = number of cycles to failure,
- \( A \) = constant dependent on detail category
- \( S \) = applied constant amplitude stress range.

**TABLE A1**

<table>
<thead>
<tr>
<th>AASHTO Category</th>
<th>Coefficient ( A ) (MPa(^3))</th>
<th>CAFL (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( 8.1 \times 10^{11} )</td>
<td>165</td>
</tr>
<tr>
<td>B</td>
<td>( 3.93 \times 10^{11} )</td>
<td>110</td>
</tr>
<tr>
<td>C</td>
<td>( 2.0 \times 10^{11} )</td>
<td>83</td>
</tr>
<tr>
<td>D</td>
<td>( 1.44 \times 10^{11} )</td>
<td>69</td>
</tr>
<tr>
<td>E</td>
<td>( 7.21 \times 10^{11} )</td>
<td>48</td>
</tr>
<tr>
<td>E'</td>
<td>( 3.61 \times 10^{11} )</td>
<td>31</td>
</tr>
<tr>
<td>E''</td>
<td>( 1.28 \times 10^{11} )</td>
<td>18</td>
</tr>
</tbody>
</table>

CAFL = constant-amplitude fatigue limit.
## Weld Detail Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Geometry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB</td>
<td>![GB Image]</td>
<td>Rolled steel structural plate away from all welding and structural connections. Edges as rolled or machined smooth. Any flange cut edges subsequently machined or ground smooth. Full penetration butt weld ground or machined smooth and loaded in the longitudinal direction.</td>
</tr>
<tr>
<td>CC</td>
<td>![CC Image]</td>
<td>Transverse loaded fillet weld made with automatic welding with no start-stops. Transverse loaded butt weld made with automatic welding with no start-stops. Full penetration longitudinal butt weld welded from both sides and machined or ground smooth.</td>
</tr>
<tr>
<td>CD</td>
<td>![CD Image]</td>
<td>Transverse loaded fillet welds. Full penetration transverse loaded butt weld welded from one side with backing strip. Downhand shop welds. Not submerged arc welded from both sides with edges ground or machined smooth.</td>
</tr>
<tr>
<td>CE</td>
<td>![CE Image]</td>
<td>Transverse loaded full penetration butt weld. Full penetration transverse loaded full penetration butt weld. Intermittent transverse loaded fillet welds.</td>
</tr>
<tr>
<td>CF2</td>
<td>![CF2 Image]</td>
<td>Narrow attachments. Partial penetration butt or fillet welds. Wide attachment on both sides symmetrical.</td>
</tr>
<tr>
<td>CG</td>
<td>![CG Image]</td>
<td>Wide attachment on one side. Attachments within 10mm of the edge.</td>
</tr>
<tr>
<td>CW</td>
<td>![CW Image]</td>
<td>Partial penetration butt or fillet welds.</td>
</tr>
<tr>
<td>CS</td>
<td>![CS Image]</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>![CT Image]</td>
<td></td>
</tr>
</tbody>
</table>
Examples of complex details

FIGURE A3 Fractured girder of the Hoan Bridge in Milwaukee (top) and view of critical shelf plate detail featuring intersecting welds.
Real examples of cracking in bridges

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.
Fatigue cracks can lead to catastrophies

Silver Bridge Ohio, 1967
Or they can lead to noncatastrophic damage
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.
Replacement: Leonard Zakim Bridge, Boston

$115M
Easy Up, Not-So-Easy Down

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

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 (BB2C 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. (564 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.
High-Performance A710 Grade B (NUCu 70W) Steel: 
Lake Villa, IL Bridge

Bridge Location

Morris E. Fine and Semyon Vaynman “formulated” this new steel at Northwestern University
Lake Villa Bridge, Illinois