The Role of Material Deterioration on the Resilience of Built Infrastructure

O. Burkan Isgor, Ph.D., P.E.

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Questions

• Is the resilience of a community after an earthquake or tsunami related to the state of infrastructure?

• Is material deterioration related to state of infrastructure?

• Will the response of a structure during an earthquake or tsunami be different if the structure is new vs. deteriorated?

• Will the reconstruction effort after an earthquake or tsunami be different if the structure is new vs. deteriorated?
Background
Every bridge in the US

Source: Federal Highway Administration

WASHINGTONPOST.COM/WONKBLOG
Bridges in PNW

Oregon Bridge Statistics
- Total Bridges: 7,656
- Total Deficient Bridges: 1,754
- Structurally Deficient Bridges: 431
- Functionally Obsolete Bridges: 1,323

Washington Bridge Statistics
- Total Bridges: 7,902
- Total Deficient Bridges: 2,666
- Structurally Deficient Bridges: 372
- Functionally Obsolete Bridges: 1,694

Oregon Bridges Compared to U.S.
- Percent Structurally Deficient: 5.6%
- U.S. Structurally Deficient: 10.5%
- Percent Functionally Obsolete: 13.9%
- U.S. Functionally Obsolete: 21.4%

Washington Bridges Compared to U.S.
- Percent Structurally Deficient: 4.7%
- U.S. Structurally Deficient: 10.5%
- Percent Functionally Obsolete: 13.9%
- U.S. Functionally Obsolete: 21.4%

Source: U.S. Federal Highway Administration, 2013 National Bridge Inventory

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Bridges by age

Distribution of the total bridges by age (2010 NBI data).

Distribution of the SD bridges by age (2010 NBI data).
Dams

84,000 DAMS IN THE U.S. IN ALL 50 STATES

AVERAGE AGE OF DAMS: 52 YEARS

13,991 HIGH HAZARD DAMS ARE LOCATED ABOVE POPULATION CENTERS

ONLY 66% OF HIGH HAZARD DAMS IN THE U.S. HAVE EMERGENCY ACTION PLANS SO THEY CAN BE SAFELY EVACUATED

High hazard dams

Source: National Inventory of Dams, U.S. Army Corps of Engineers
Levees

Levees in PWN

Source: US Army Corps (2016)
Why do infrastructure deteriorate?

- Chemical deterioration
  - e.g. ASR, carbonation, sulfate attack, DEF, acid attack, leaching

- Electrochemical deterioration
  - e.g. corrosion

- Physical deterioration
  - e.g. Abrasion, erosion, freeze/thaw

Water plays a major role in most deterioration mechanisms!!!
Example: Corrosion

COST OF CORROSION IN INDUSTRY CATEGORIES
($137.9 BILLION)

- Infrastructure 16.4% ($22.6 billion)
- Utilities 34.7% ($47.9 billion)
- Government 14.6% ($20.1 billion)
- Production and Manufacturing 12.8% ($17.6 billion)
- Transportation 21.5% ($26.7 billion)

Percentage and dollar contribution to the total cost of corrosion for the five sector categories analyzed.

INFRASCTURE ($22.6 BILLION)

- HAZMAT Storage 31% ($7 billion)
- Highway Bridges 37% ($8.3 billion)
- Waterways and Ports 1% ($0.3 billion)
- Gas and Liquid Transmission Pipelines 31% ($7 billion)
Example: Corrosion

There are about 583,000 bridges in the United States.
- 200,000 are constructed of steel
- 235,000 are conventional reinforced concrete
- 108,000 are constructed using prestressed concrete
- 40,000 are made with other construction materials

Approximately 15% are structurally deficient because of corroded steel and steel reinforcements.

How Does Bridge Corrosion Affect the U.S. Economy?

Estimated Total Annual Cost for Bridges is $8.3 billion

- $2 billion
- $3.8 billion
- $0.5 billion

The estimated annual overall cost of corrosion to the U.S. Economy is $276 Billion.
The cost for highway bridges equal 3% of that total cost.*
Remember the questions…

• Is the resilience of a community after an earthquake or tsunami related to the state of infrastructure?

• Is material deterioration related to state of infrastructure?

• Will the response of a structure during an earthquake or tsunami be different if the structure is new vs. deteriorated?

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Challenges
The disconnect between disciplines

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Study of deteriorated structures

Decommissioned structures

Accelerated ageing
Lack of “unified/coupled” predictive tools
Incompatibility between substrate and retrofit
OSU Materials Research Group

- **Erdem Coleri**: Pavements; asphalt and bituminous materials, service life prediction (SLP)

- **Jason Ideker**: Concrete durability, early-age properties of concrete (e.g. shrinkage, cracking, etc.), concrete pavements, ASR, SLP

- **Burkan Isgor**: Concrete durability, corrosion, electrochemistry, CP, NDT, modeling, coatings, concrete pavements, SLP

- **David Trejo**: Concrete durability, corrosion, constructability, structural engineering, concrete pavements, NDT, SLP

- **Jason Weiss**: Concrete durability, concrete pavements, cracking, early age properties of concrete, electrical properties, NDT, SLP
Example project
Power transmission towers

- Eugene Water and Electric Board (EWEB)
  - Seismic behavior of “ageing” prestressed concrete transmission poles
  - ~600 in service

- Unknowns
  - Condition of materials
  - Seismic capacity
  - Soil-structure interaction during a seismic event
Materials characterization

- External damage assessment
- Mechanical properties
- Corrosion assessment
- Microstructural analysis
  - Petrographic analysis / SEM
Test protocol for soil/structure interaction

- Assessment of soil conditions
- Assessment of tower substructure
- Development of structural testing apparatus for simulating soil/structure interaction
Structural testing

Strong Axis

Weak Axis

Geometric Properties:

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<th>Property</th>
<th>Gross</th>
<th>Torsion</th>
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<tr>
<td>A (in²)</td>
<td>168.7</td>
<td>165.4</td>
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<tr>
<td>Iy (in⁴)</td>
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<tr>
<td>Sj (in³)</td>
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<tr>
<td>k1</td>
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Crack Spacing:
2 x 4 = 0.1 da db

Loading DLMV = 4(0.04f'c dV)
0.0 - 0.0 - 0.0 - 0.0 - 0.0

Concrete

Rebar

P-Steel

All dimensions in inches
Clear cover to reinforcement = 1.29 in
Thank you...