Disasters and Linear Infrastructure Management

by

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Overview

• Motivation for research
• Overview of some major disasters
• Disaster impacts on transportation infrastructure
• Resiliency in transportation
• Future work
Motivation: Criticality of Infrastructure

• The Patriot Act defines critical infrastructure as

  "systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters"

  - (P.L. 107-56, Sec. 1016(e), 2001)

• The transportation system is one of the nation’s sixteen defined critical infrastructure sectors.
Motivation: Threat of Natural Disasters

Fig 1: Natural Disasters reported worldwide between 1900 and 2010

Source: EM-DAT: the International Disaster Database- www.emdat.be-Universite Catholique de Louvain, Brussels-Belgium
Motivation: Impact on National Economy

The table below shows the most destructive U.S. natural disasters in the last 30 years.

<table>
<thead>
<tr>
<th>Date</th>
<th>Disaster</th>
<th>Damage (billion US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/29/2005</td>
<td>Hurricane Katrina</td>
<td>125</td>
</tr>
<tr>
<td>10/28/2012</td>
<td>Hurricane Sandy</td>
<td>50</td>
</tr>
<tr>
<td>1/17/1994</td>
<td>Northridge Earthquake</td>
<td>30</td>
</tr>
<tr>
<td>9/12/2008</td>
<td>Hurricane Ike</td>
<td>30</td>
</tr>
<tr>
<td>8/24/1992</td>
<td>Hurricane Andrew</td>
<td>26.5</td>
</tr>
<tr>
<td>9/15/2004</td>
<td>Hurricane Ivan</td>
<td>18</td>
</tr>
<tr>
<td>9/23/2005</td>
<td>Hurricane Rita</td>
<td>16</td>
</tr>
<tr>
<td>8/13/2004</td>
<td>Hurricane Charley</td>
<td>16</td>
</tr>
<tr>
<td>10/24/2005</td>
<td>Hurricane Wilma</td>
<td>14.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>350.8</strong></td>
</tr>
</tbody>
</table>

Table 1: Top nine natural disasters in the United States sorted by economic damage costs (1984-2013)

Source: "EM-DAT: The OFDA/CRED International Disaster Database www.em-dat.net - Université Catholique de Louvain - Brussels - Belgium"
Hurricane Katrina (August 29\textsuperscript{th}, 2005)

- Category 3 hurricane
- Wind strength of up to 125mph
- Minimum pressure of 920mb
- Storm surge of up to 30ft
- 1833 fatalities
- Extensive damage was due to storm surge and levee breaches and resulting flooding
- $125 billion (normalized 2007 dollars) in damages
Bridges:

- 45 bridges sustained damage in:
  - Alabama
  - Mississippi
  - Louisiana

- Vital damaged bridges were:
  - I-10 Twin Span Bridge
  - Pontchartrain Causeway
  - St. Louis Bay Bridge
  - Biloxi Bridge
## Infrastructure Impacts: Bridges

<table>
<thead>
<tr>
<th>Cause of Damage</th>
<th>Type of Damage</th>
<th>Nature of Repair/Renewal</th>
<th>Cost of Repair/ Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting &amp; pounding of water, leading to breakages in connection between pilings and piers</td>
<td>Superstructure damage consisted of unseated decks and damaged guardrails with little damage to substructure</td>
<td>Elevated bridges (6 meters higher than former bridge) to reduce probability of storm surge damage</td>
<td>Estimated $1 billion in overall repair/replacement cost, including emergency repairs and rebuilding</td>
</tr>
<tr>
<td>Loose barges and boats</td>
<td></td>
<td>Twin Span Bridge equipped with monitoring system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vertical constraint devices and air vents proposed to be effective in limiting damage</td>
<td></td>
</tr>
</tbody>
</table>
### Infrastructure Impacts: Roads & Rail

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Causes/Type of Damage</th>
<th>Nature of Repair/Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>Significant debris</td>
<td>Utilities, sidewalks, American with Disabilities Act compliant ramps, driveway aprons, curbs and road paving</td>
</tr>
<tr>
<td></td>
<td>Submerged roads</td>
<td>Estimated $200 million for debris removal</td>
</tr>
<tr>
<td></td>
<td>Sections of roads torn apart e.g.: La 23 in South Louisiana</td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>Broken anchor bolts &amp; damaged angle clips Debris carried by storm</td>
<td>Switch from anchor bolts to through rods on connections to precast I-girders on new construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrosion protection by coating re-bars and using high performance concrete</td>
</tr>
</tbody>
</table>
Hurricane Sandy (October 29th, 2012)

- Category 1 hurricane, weakened to a post-tropical cyclone
- Southeast, mid-Atlantic, New England, Appalachia & Mid-West
- Maximum winds of 115mph
- Minimum pressure of 940mb
- 147 fatalities
- Storm surge of 14 feet
- Damage in U.S estimated over $50 billion

Picture of the Statue of Liberty taken during the storm
Source: www.designbuildsource.com.au
# Hurricane Sandy: Infrastructure Impacts

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Causes/Type of Damage</th>
<th>Nature of Repair/Renewal</th>
</tr>
</thead>
</table>
| Roads/Bridges        | Two out of 28 bridges warranted emergency repairs  
Embankment washouts  
Tilted light poles  
Downed traffic signals  
Excessive debris       | Debris removal  
Traffic signal & light pole repairs/replacements |
| Subways & Tunnels    | All seven tunnels under East River flooded  
Two Long Island Rail Road Tubes flooded  
Two vehicular tunnel inundated  
One subway bridge flooded  
Three subway yards flooded  
Six bus facilities flooded | Inspecting, cleaning and repairing of electrical components |
| Wastewater           | Mixture of sewage and storm water bypassing plant flowing directly into New York’s waterways and into the flooded streets and buildings |                                                                   |
Hurricane Ike (September 5\textsuperscript{th}, 2008)

- Category 2 hurricane at landfall
- Fifth hurricane of the 2008 Atlantic hurricane Season
- Maximum winds of 145 mph
- Minimum pressure of 935 mb
- 195 fatalities
- Damages of $30 billion in the U.S
<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Causes/Type of Damage</th>
<th>Nature of Repair/Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>Generally washouts to roadbeds and shoulders</td>
<td>Emergency contracts issued to repair advance flashers and traffic detection systems</td>
</tr>
<tr>
<td></td>
<td>90% of signals in Houston were damaged or lost power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Damage to several traffic signs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5mile section of the State Highway 87 in Texas was washed away</td>
<td></td>
</tr>
<tr>
<td>Bridges</td>
<td>Decking of the State Highway 82 Causeway Bridge swing bridge was moved about 6 inches by storm surge</td>
<td>A 65-ft replacement elevated bridge built</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Causes/Type of Damage</td>
<td>Nature of Repair/Renewal</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rail</td>
<td>Debris deposited on tracks</td>
<td>Service was generally restored on affected lines within two days and after a week on less important lines</td>
</tr>
<tr>
<td></td>
<td>Decks and caps floated off trestles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tracks washed off embankments and bridges but not in areas where they secured to piles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.6 km of Union Pacific track shifted off road bed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Railroad buildings were subject to wind damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Repairs to 21 miles of track damaged by Hurricane Gustav in New Orleans were washed away</td>
<td></td>
</tr>
<tr>
<td>Canals/Ports</td>
<td>Erosion damage to Galveston Seawall</td>
<td>$25 million allocation for the rehabilitation of the seawall by the U.S Army Corps of Engineers</td>
</tr>
<tr>
<td></td>
<td>Galveston/Bolivar Ferry operations heavily damaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt water intrusion caused extensive damage to hydraulic systems</td>
<td></td>
</tr>
</tbody>
</table>
How do we protect our infrastructure?
Resistance vs Resilience

Resilience has in recent years replaced the concept of resistance in disaster research

- Resistance emphasizes the importance of *predisaster mitigation measures* that enhance the *performance* of structures, infrastructure elements, and institutions in reducing losses

- Resilience reflects the concern for improving the capacity of physical and human systems to *respond* to and *recover* from extreme events

Source: www.karenswhimsy.com
Definitions:

“The ability of a system to reduce the chance of a shock, to absorb a shock if it occurs and to recover quickly after a shock.” - (Bruneau et al. 2003)

“The ability to accommodate change gracefully without any catastrophic failure”
- (Foster, 1997)

Transportation resiliency can be defined as “the ability for the system to maintain its demonstrated level of service or to restore itself to that level of service in specified timeframe” (Heaslip et al., 2009).

More specifically, a resilient system is one that shows:
- Reduced probability of failure
- Reduced consequences from failures (damage, fatalities, negative economic & social consequences)
- Reduced time to recovery
A system’s resilience may be measured by:

- The functionality of the system after a disruption
- The time it takes to return to pre-disruption levels

Fig 2: Resilience triangle showing 50% loss in infrastructure functionality

Future Work

• Define a set of metrics that can be used to assess resilience in state DOTs
• Incorporate these metrics into a framework that can be used in the transportation planning process
References

• DesRoches, R. and Glenn, R. “Hurricane Katrina’s Impact on Louisiana’s Transportation Infrastructure”. School of Civil and Environmental Engineering, Georgia Institute of Technology.
• “DOT Activities in support of Federal Response to Hurricane Katrina”. The Disaster Center’s Tropical Storm-hurricane Katrina Page, September 5th, 2005.
• Miller, R. “Hurricane Katrina: Communications & Infrastructure Impacts”. National Defense University
• Information compiled from the National Oceanic and Atmospheric Administration’s (NOAA’s) Tropical Prediction Center (www.nhc.noaa.gov), FEMA news releases, and press reports.
Questions?

Source: www.ebenezerlutheranchurch.wordpress.com