CHANGE AGENTS FOR RESILIENT INFRASTRUCTURE

Tom O’Rourke
Cornell University
TOPICS

• Global Hazards
• WTC Disaster & Hurricane Katrina
• Hurricane Sandy
• L Line Tunnel
• Global Hazards
RESILIENT INFRASTRUCTURE

DISASTER DU JOUR

3
- 2004 Sumatra-Andaman EQ & Tsunami
- 2005 Hurricane Katrina

6
- 2010 Maule Earthquake
- 2010 Haiti Earthquake (~120,000 dead)
- 2010-11 Canterbury Earthquake Sequence

4
- 2011 Tohoku Earthquake & Tsunami
- 2012 Hurricane Sandy
- 2013 Typhoon Haiyan

228,000 dead
16,000 dead
~120,000 dead
DISASTER DU JOUR 2017

- Hurricane Harvey
- Hurricane Irma
- Chiapas Earthquake
- Hurricane Maria
- Mexico City Morelos Earthquake
- Sonoma Santa Rosa Fires
HURRICANES HARVEY, IRMA, AND MARIA

- HURRICANE HARVEY $125 B
- HURRICANE IRMA $50 B
- HURRICANE MARIA $90 B

Before

After
TOPIC

• WTC Disaster/Hurricane Katrina
E V O L U T I O N  O F  P O L I C Y

S E P T E M B E R  1 1

- Protection of Critical Infrastructure

H u r r i c a n e  K a t r i n a:

- Resilient Communities

R E S I L I E N T  I N F R A S T R U C T U R E
RESILIENT INFRASTRUCTURE

2005 HURRICANES

- 28 Storms
- 15 Hurricanes
- > $180 Billion

Rita
Katrina
Wilma
Emily

PEER
CORNELL UNIVERSITY
TOPIC

• Hurricane Sandy
HURRICANE SANDY (2012)

- 159 Killed in US
- $68 Billion Property and Business Losses (Sandy Task Force)
- 8.5 Million Homes & Businesses Without Power
- NYC Evacuation & Shutdown of MTA & Public Transport
- Wall Street Shut 2 Days
- Record Flooding (Surge)
- Direct Hit
STORM SURGE AT BATTERY

NEW YORK HARBOR AT THE BATTERY

Latest observed value: 7.13 ft at 9:06 AM EDT 30-Oct-2012. Flood Stage is 6.7 ft

13.9 ft Peak

Hurricane Sandy

- 2.0 ft
~ 11.9 ft
(4.23 m)
(3.62 m)
Surge
HURRICANE SANDY INUNDATION

RESILIENT INFRASTRUCTURE
HURRICANE SANDY INUNDATION

Flooded Tunnels
- 7 Subway Tunnels
- Brooklyn Battery
- Midtown Tunnel
- PATH Tunnels
- Holland Tunnel
- Amtrak East River
- Amtrak North River
HURRICANE SANDY INUNDATION

NYC Steam System
- 105 mi. (170 km)
- 10 – 30 in. (250 – 750 mm) dia.
- 400 psi (2.8 MPa) transmission
- 140 – 180 psi (1 -1.25 MPa) distribution
- 415 – 475° F (~ 230° C)

"There is no reason to believe this is anything other than a failure of our infrastructure." - Mayor Bloomberg

Electric Power
138 kV Substation

Steam Distribution

2007 Steam Line Explosion

RESILIENT INFRASTRUCTURE
LESSONS FROM HURRICANE SANDY

• Long Tail Recovery
• Protect Against Tunnel Flooding
  • Doors, dikes, and diversions
• Back-up Power for Water Supply on Buildings
• Remove Diesel Generators from Basements and Secure Fuel Tanks and Fuel Lines
TECHNOLOGY FROM HURRICANE SANDY

• UAV Equipment and Structure from Motion Photogrammetry
• BIM for Flood Zones
  • 3-D Community Models
  • Topography & Bathymetry
• Deployable Flood Protection
  • HESCO Bastions
  • Tiger Dams
NEW YORK CITY RESILIENCE PLAN

- Authorized by Mayor Bloomberg
- Hurricane Sandy Effects
- Science of Coastal Flooding
- Engineering Options
- Community Plan by Neighborhoods
TOPIC

• L Line Tunnel
The L Train Tunnel is 1.5 miles (2.4 km) long and over 100 years old stretching from 1st Ave Station in Manhattan to Bedford Ave Station in Brooklyn...
In 2012, Hurricane Sandy filled the tunnel with salt water, from the Avenue D Fan Plant to the North 7th Street Fan Plant...
L Train Tunnel Profile and Sections

Manhattan

Tunnel Length 7,953 ft
Tube Length 7,110 ft

Av B SS and New CBH61
Av D Fan Plant

Av D Fan Plant

3,445 ft

N7th Fan Plant

1 Av Station

Pump Rm

Exist CBH61

Bedford Av Station

Brooklyn
L Train Tunnel Profile and Sections

Tunnel Length 7,953 ft
Tube Length 7,110 ft

Av B SS and New CBH61
Av D Fan Plant
N7th Fan Plant

1 Av Station
Pump Rm
Exist CBH61
Bedford Av Station

15 – 15.5 FT
~ 4.65 M
WHAT IS THE BENCHWALL?

- Holds and protects cables, which decades ago were less stable and did not have state-of-the-art fireproofing materials.
- Provides access/egress walkway for workers or, in the event of an emergency, for train passengers and first responders.
CUTAWAY OF BENCHWALL

- Walkway
- Concrete Wall
- Cables
- Track
BENCHWALL CONDITIONS:
SOME PORTIONS CRUMBLING, SOME WEATHERED, OTHER PORTIONS STABLE

Example of cement benchwall in good condition.

Concrete deterioration: alkalai silica reaction
Much of the benchwall was planned to be removed by hand a laborious, time-consuming process — to avoid damage to the century-old tunnel concrete lining...
An expert review team was organized from Cornell and Columbia engineering schools to do a final review of the plan ahead of the L Train shutdown.
RECOMMENDATION SUMMARY

1. Implement a new power and control system.
2. Decouple power cable housing from benchwall.
3. Implement racking system for cables.
4. Jacket cables with low smoke, zero halogen fireproof material.
5. Abandon all old cables in benchwall.
7. Install “smart” sensor systems to monitor benchwall integrity.
8. Install elevated walkway where benchwall removed.
9. Increase flood resilience measures.
10. Enhance public safety.
Decouple power cable housing from benchwall.

Implement racking system to suspend cables on the side of the tunnel. Place negative returns on the track bed.

Jacket cables with zero halogen fireproof material successful in the airline/aero-space industry and satisfies NFPA 130 fire code.
6. **Benchwall**
   
a. Leave benchwall where structurally stable.

b. Fortify weakened structure with fiber reinforced polymer (FRP) wrap and strapping, reducing the need for continual fixes.

c. Remove unstable benchwall.
RECOMMENDATIONS

Smart Sensors

7. a. Install “smart” fiber optic sensor cables along remaining benchwall to detect shifts or cracks in benchwall.

b. Use high resolution LiDAR to monitor for benchwall deformation.
SMART TUNNEL TECHNOLOGY

Proven Technology

- Fiber Optics
- High Resolution LiDAR

- Distance range ≈ 10-30 km
- Readout resolution = 0.05 m
- Gauge length resolution = 0.2-1 m
- Strain resolution = 10-30 με
9. Increase tunnel resilience against flooding:
   a. Increase pump capacity as currently planned.
   b. Install a permanent generator to power pumps, providing redundancy to power sources from both Manhattan and Brooklyn. Explore natural gas vs. diesel fuels.
   c. Consider watertight submarine-type gates (similar to QMT and BBT).
   d. Consider sealing capability for all openings on the L-line from 1st Ave station to Bedford Ave station, depending on critical elevation.
FLOOD ZONE PROTECTION

2x Emergency Hatches
2x Manholes
5x Vent Batteries (30x Vent Bays)

2300 Openings in Category 2 flood zone

L Line Tunnel

Watertight hatch doors
Watertight manhole inserts

Mecanical closure devices
Marine doors
10. Enhance public safety:
   a. Detailed evaluation of control options for dust and airborne silica with an assessment of their impact on construction schedule.
   b. Enlisting an independent environmental firm to monitor air quality and report directly to NYC Transit.
   c. Ongoing structural condition monitoring with smart tunnel technology.
RESILIENT INFRASTRUCTURE

THIS MEANS...

- No closure of service is necessary with this new design.
- Work can be completed with weekend and nighttime closures of ONLY ONE TUBE at a time leaving the other to run trains in both directions.
- This new system design approach can be potentially applied to other projects, such as the Second Ave. Phase 2 and Amtrack Tunnels.
GATEWAY PROJECT

Hudson River Tunnel Project
Alignment Overview

- Manhattan Tunnel
- Hudson River Tunnel
- Palisades Tunnel
- Surface Alignment
- Hudson Yards RCW Preservation (NIC)
- Existing North River Tunnel
- Existing Northeast Corridor
- Existing Penn Station
- A-Yard Interlocking

- Existing Northeast Corridor
- Allied Interlocking
- Tunnel Portal
- Hoboken Shaft
- Frank R. Lautenberg Station At Secaucus
- Inset
LESSONS FOR RESILIENT INFRASTRUCTURE

- It takes a village to build infrastructure
- Change agents vs agencies that don’t change
- Innovation through integration
- Build back better
- Fusion of innovative financing, emerging technology, and community engagement
ENGINEERING FOR DISASTER RESILIENCE

- Summer 2019 Issue of The Bridge
- National Academy of Engineering Flagship Publication
- Resilient Infrastructure
- https://www.nae.edu/21020/Bridge