

THE NEW NORMAL FOR NATURAL DISASTERS

Tom O'Rourke

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EERI Distinguished Lecture



TOPICS

- **Tohoku Earthquake**
- **Canterbury EQ Sequence**
- **Hurricanes**
 - **New Orleans**
 - **New York City**
- **New Normal**



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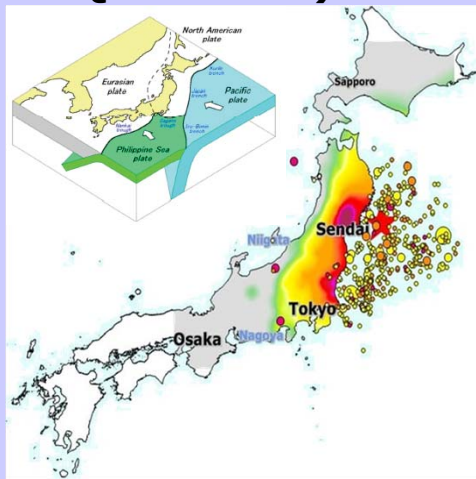


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TOHOKU EARTHQUAKE

- **9.0 Mw ($\sim 4^{\text{th}}$ Largest EQ Measured)**
- **10-25 cm Shift in Earth's Axis**
- **1000 x more power than 1995 Kobe EQ**
- **600 million x more power than Hiroshima bomb**

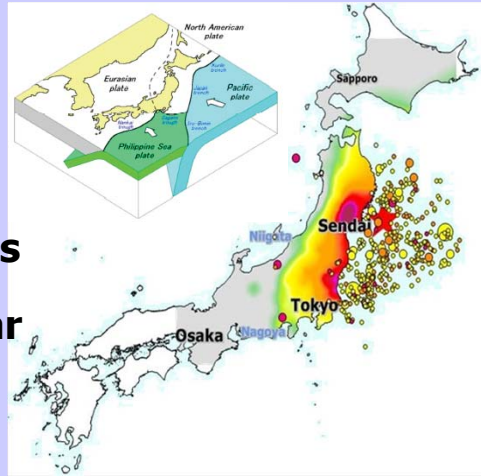


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TOHOKU EARTHQUAKE

- 15,846 Deaths
- 3,320 Missing
- 112,000 Buildings Destroyed
- \$235 B Direct Losses
- ~ \$620 B for Nuclear Decontamination & Decommissioning



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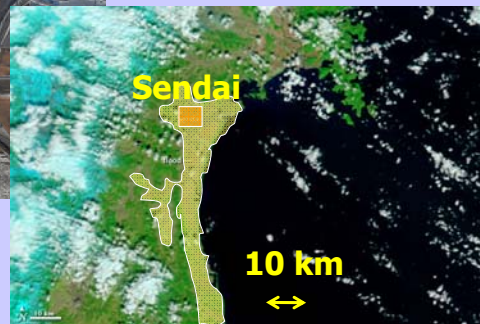


TOHOKU TSUNAMI



- Inundation = 561 km²
- Tsunami Heights = 3 to 7.3 m
- 50 km Run-up on Kitakami River

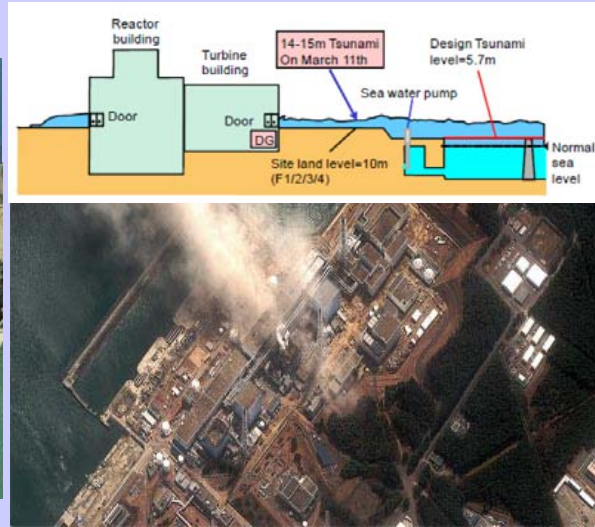
- 190 of 300 km Seawalls Heavily Damaged



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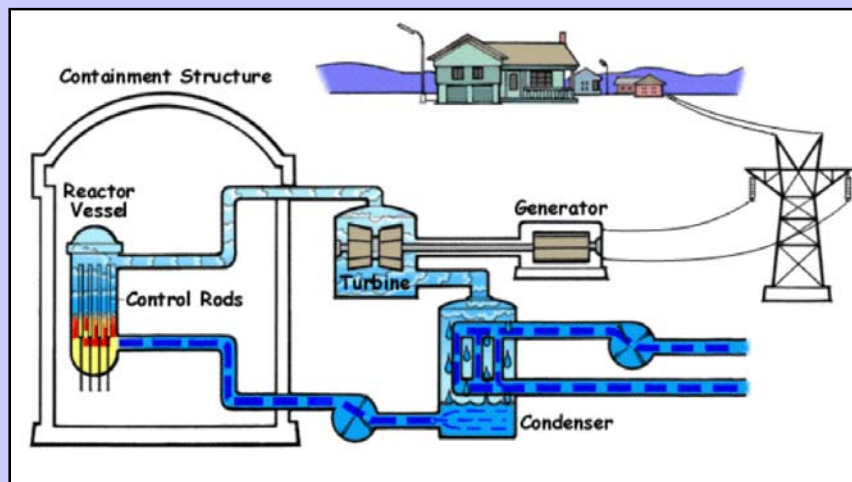
FUKUSHIMA DAIICHI NUCLEAR PLANT



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BOILING WATER REACTOR

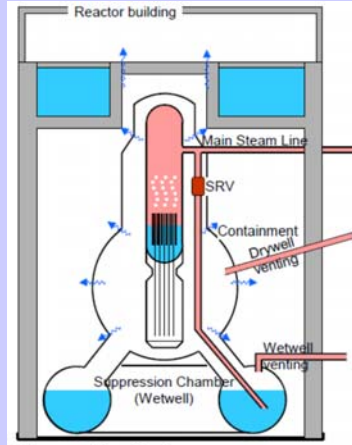
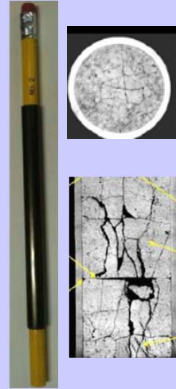
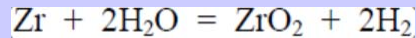
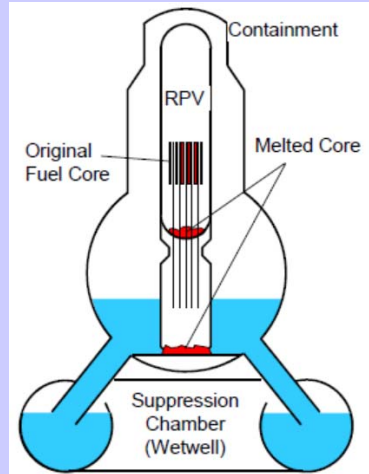


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BOILING WATER REACTOR

Zirconium cladding of fuel rods decomposes to generate hydrogen

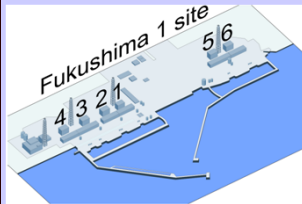


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FUKUSHIMA DAIICHI NUCLEAR PLANT



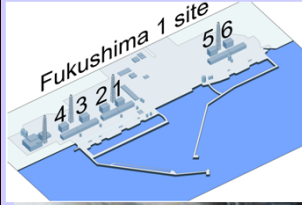
- Electric power to plant lost, including steel tower failure
- Tsunami flooded all diesel generators (DGs) except one air-cooled DG at higher elevation
- Sea water cooling system destroyed

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FUKUSHIMA DAIICHI NUCLEAR PLANT



- Partial meltdowns in Units 1, 2, & 3 in primary reactor pressure vessels (RPVs) and primary containment vessels (PCVs)
- Loss of cooling in Unit 4 spent fuel pool
- Hydrogen explosions at all 4 units



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FUKUSHIMA INDEPENDENT PANEL (Hatamura Panel)

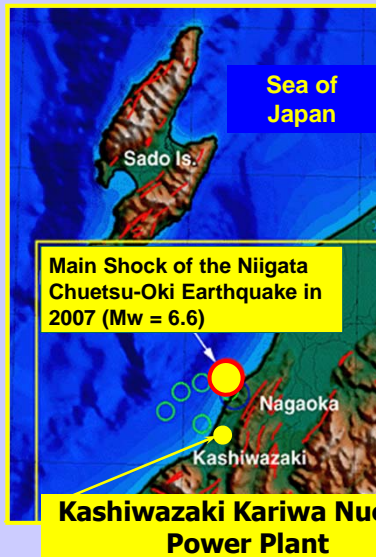
- Loss of Off-Site Emergency Center
- Failure to Delegate Authority
- Poor Coordination with Prime Minister's Office
- Errors in Use of Critical Equipment
- Inadequate Radiation Monitoring & Dissemination of Information
- Evacuation Mistakes



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2007 NIIGATAKEN CHUETSU EARTHQUAKE



TEPCO Kashiwazaki Kariwa: 7 Reactors
• Boiling Water Reactors Total Capacity - 8.2MW

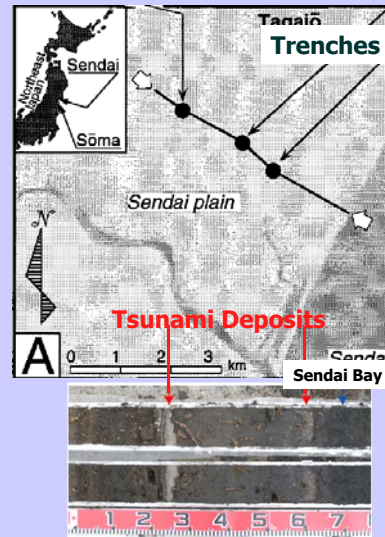


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869 SANRIKU EQ AND TSUNAMI

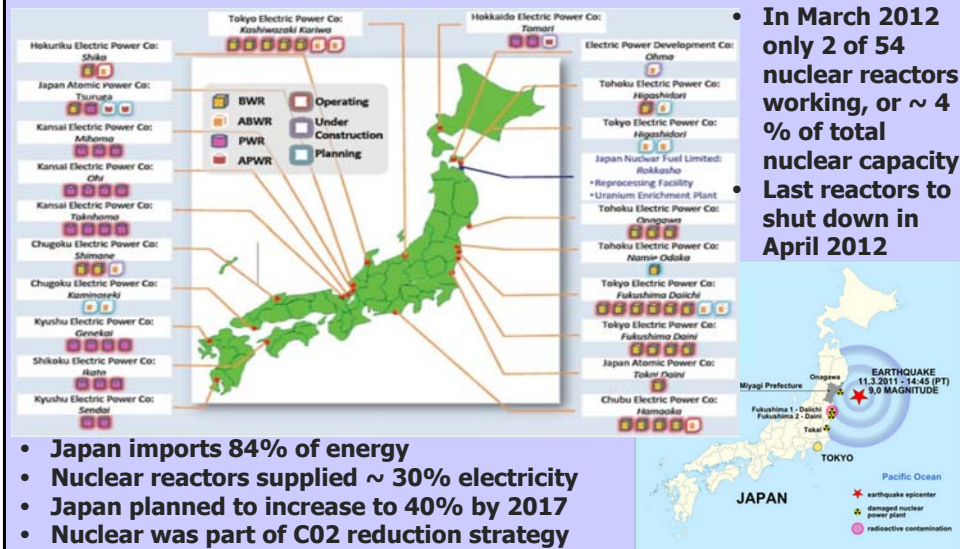
- Trenches & Soil Coring Revealed Tsunami Deposits
- Sand Layers Between Peat Layers, Carbon Dating of Organics
- Historical Documents Confirm Tsunami
- Models Show ~ 8.4 Mw EQ
- Current Studies Suggest Tsunami Run-up > Extent of Sand Deposits
- 800-1100 Yr. Recurrence



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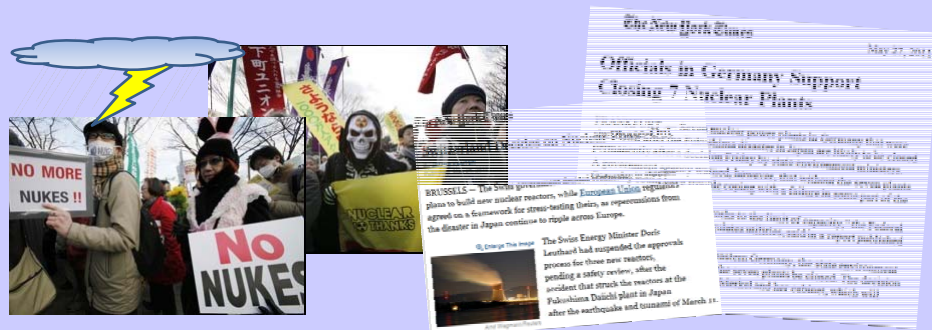


JAPAN'S NUCLEAR POWER PLANTS



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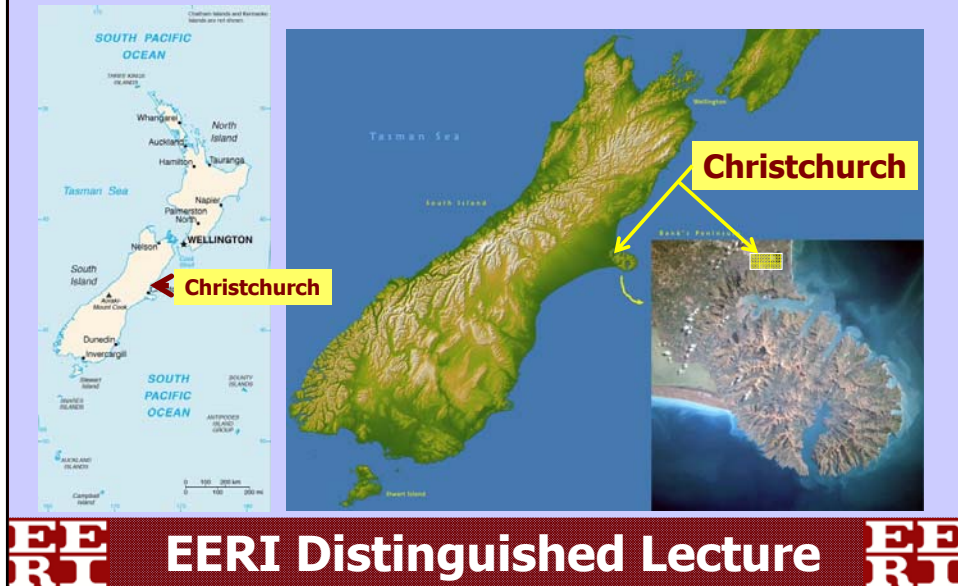
WORLDWIDE EFFECTS: NUCLEAR POWER



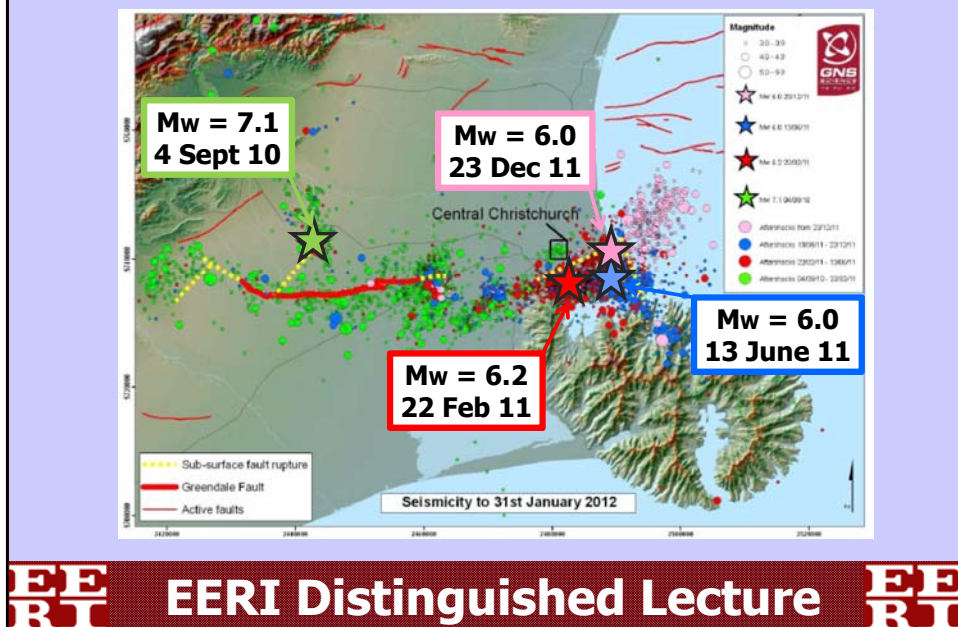
- Germany to Close Out Nuclear Power (22.4% Electricity, 2010)
- Switzerland to Terminate Nuclear (40% Electricity, 2008)
- Italy Referendum (2011): > 94% Voters Oppose Plans to Resume Nuclear Power (abandoned 1980s)

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NEW ZEALAND

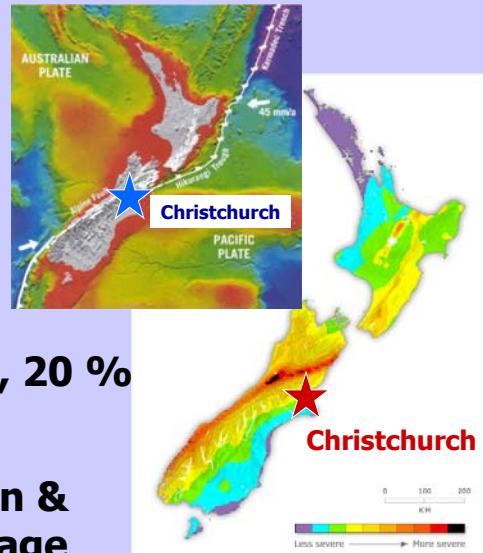


CANTERBURY EARTHQUAKE SEQUENCE



CANTERBURY EARTHQUAKE SEQUENCE

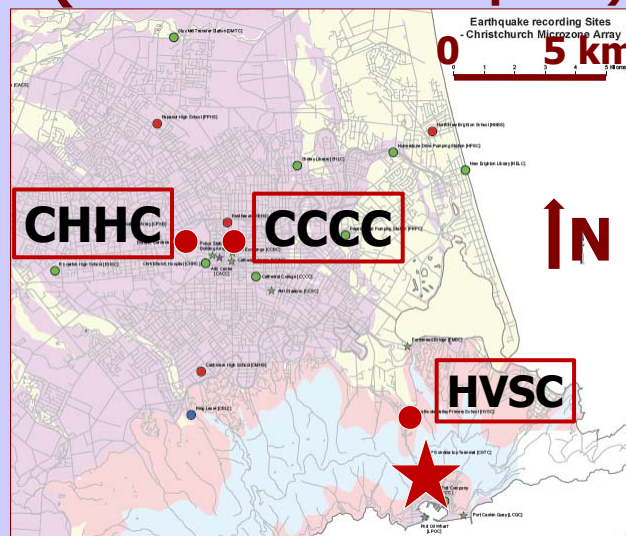
- ~ 190 Deaths
- CBD Destroyed
 - ~ 1000 CBD Bldgs. Demolished
 - 20,000 Residences Damaged
- \$25 B Direct Losses, 20 % GDP
- Massive Liquefaction & Infrastructure Damage



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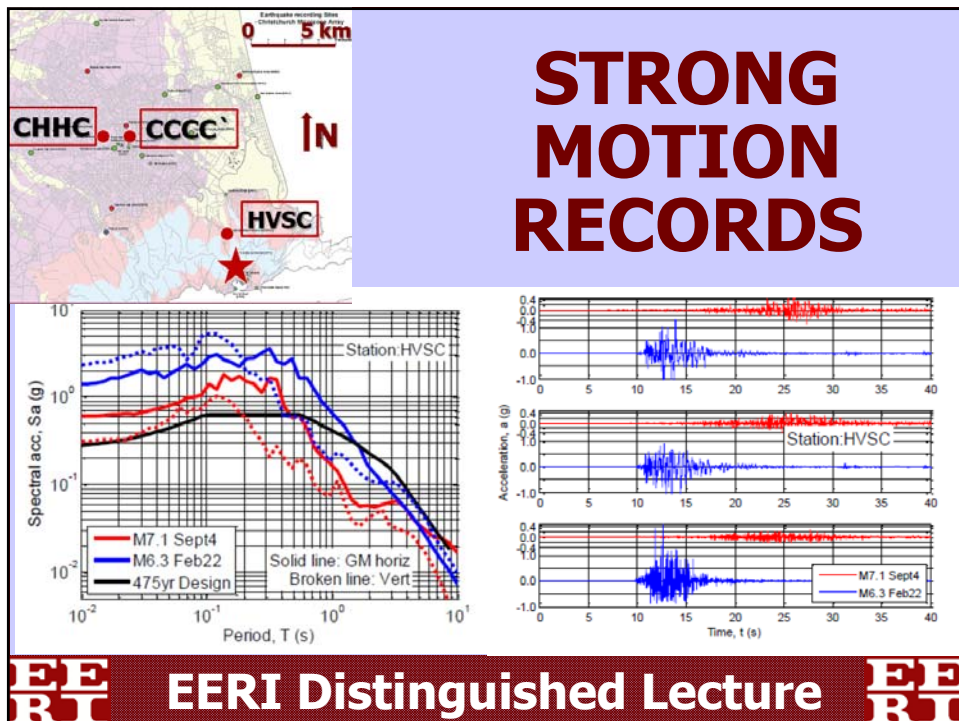
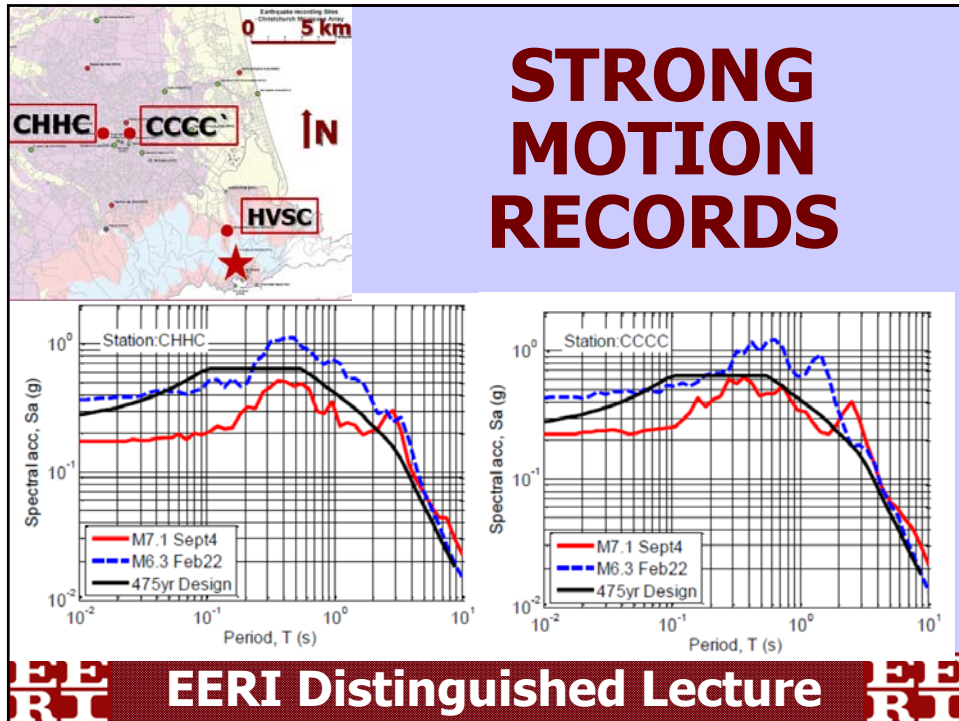


STRONG MOTION RECORDS (Christchurch Earthquake)

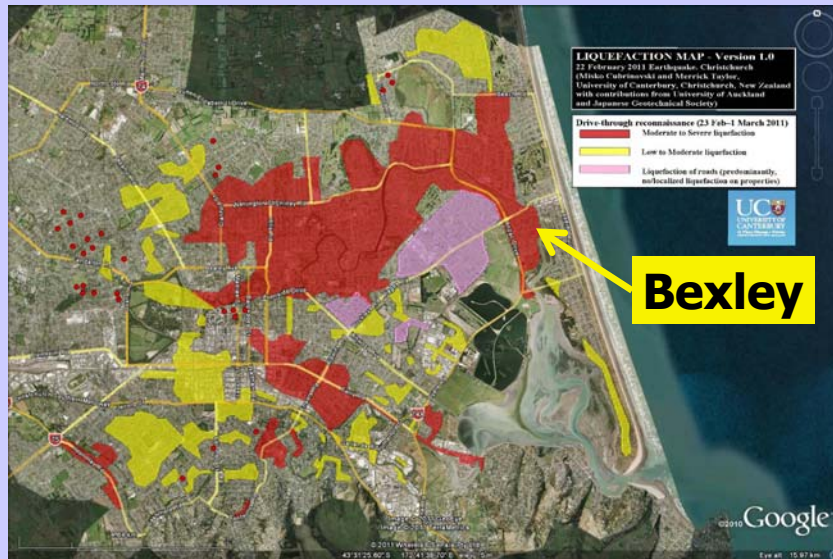


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CHRISTCHURCH LIQUEFACTION



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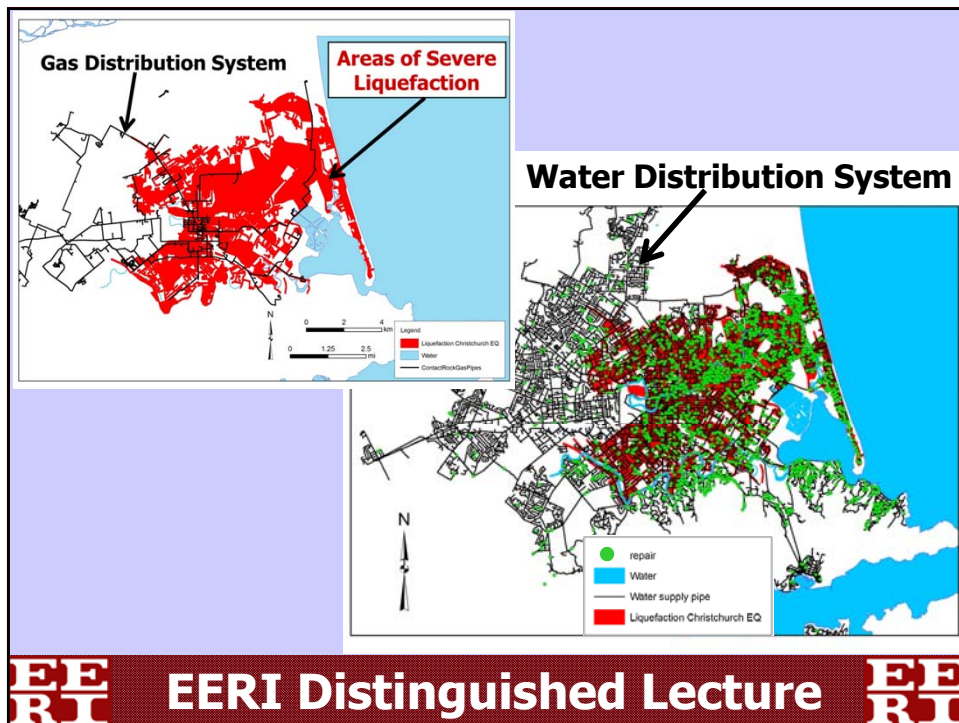
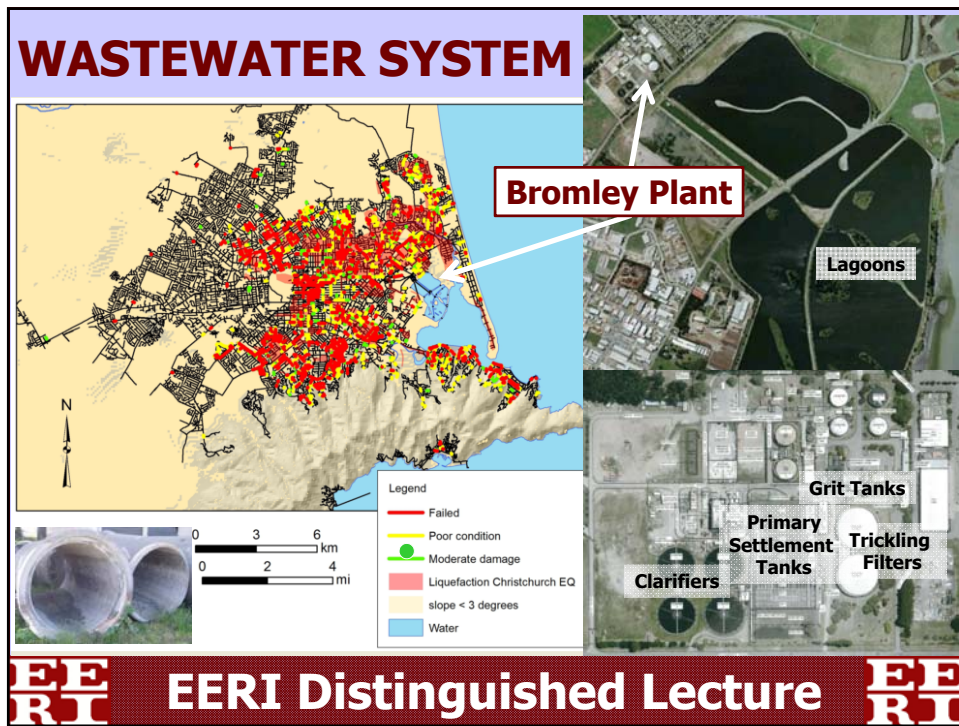
CHRISTCHURCH LIQUEFACTION



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NEW ZEALAND INSURANCE

- **Prior to EQs, Residential Building Insurance Provided by EQC**
- **After EQs, No Reinsurance**
- **Four-fold Increase in Insurance Rates, with More Projected**
- **Termination of Local Authorities Protection Program (LAPP)**



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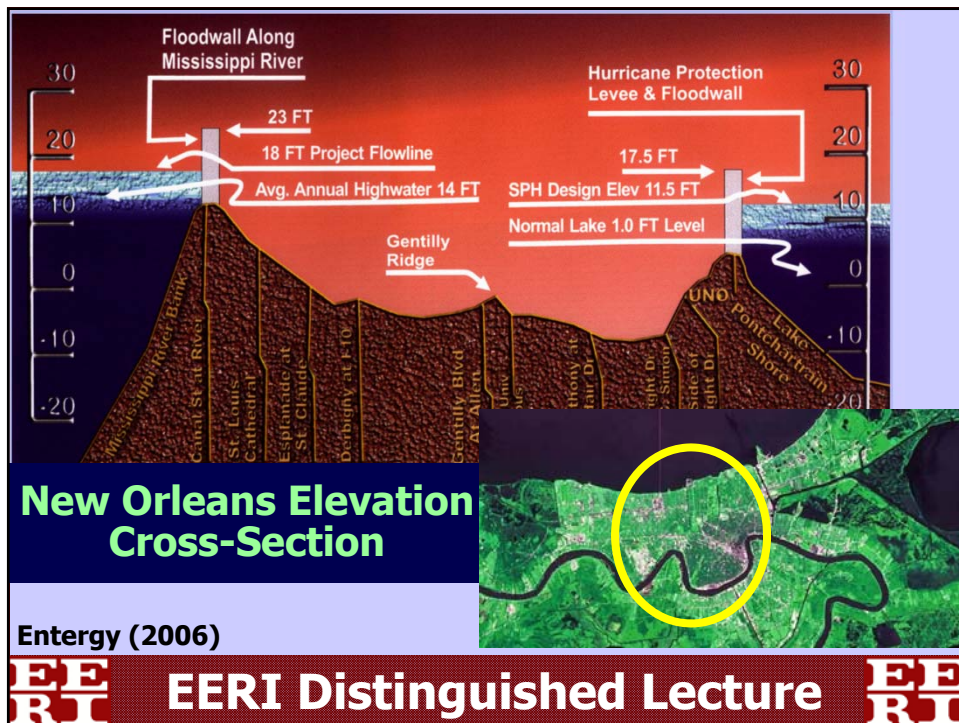
TOPICS

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- **Hurricanes**
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HURRICANE KATRINA

- Greatest U.S. Disaster
- 2000 Dead & Missing
- > \$ 100 Billion Losses
- 80% New Orleans Flooded, 53 Days to Dewater
- Impacts on Gulf Offshore Infrastructure & Energy Delivery System
- Complete Failure of Hurricane Protection System
 - Hurricane Hazard
 - Incomplete Design & Construction
 - Poor Maintenance
 - I Walls & Foundations
 - Poor Preparation
 - Inadequate Response



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EVOLUTION OF CONCEPT

September 11:

- Protection of Critical Infrastructure



Hurricane Katrina:
• Resilient Communities



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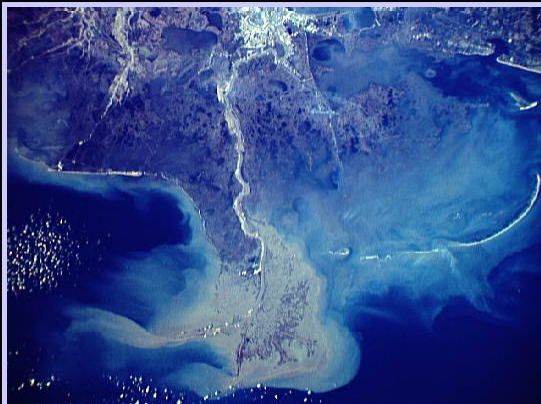
**Mississippi
River Drains
41% of US**



**65 Kilo-tonnes/s
1927, '37. '73**



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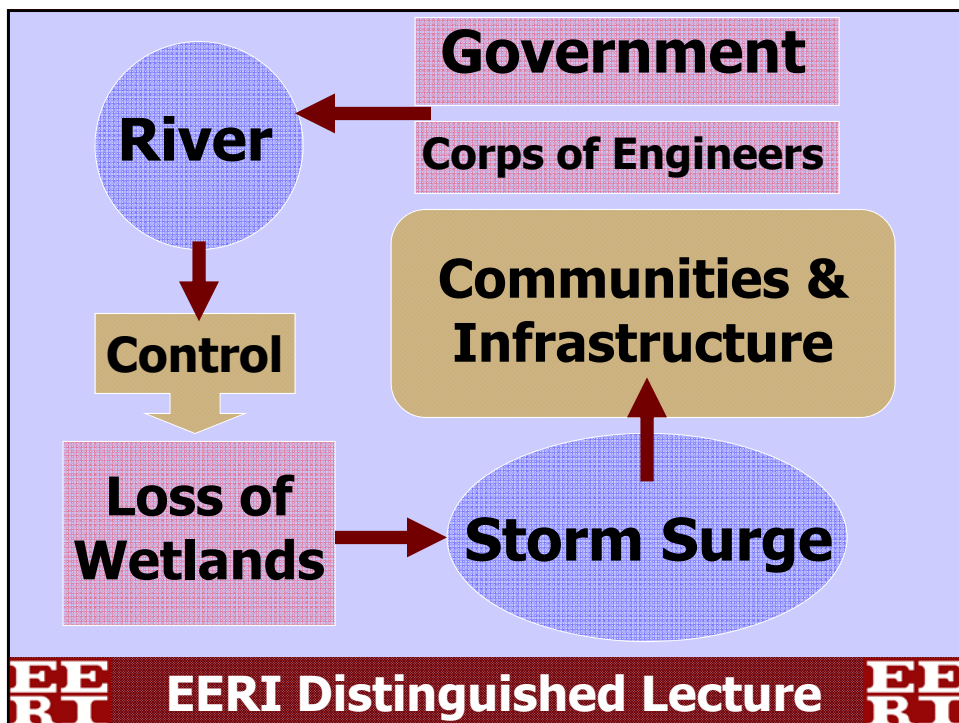
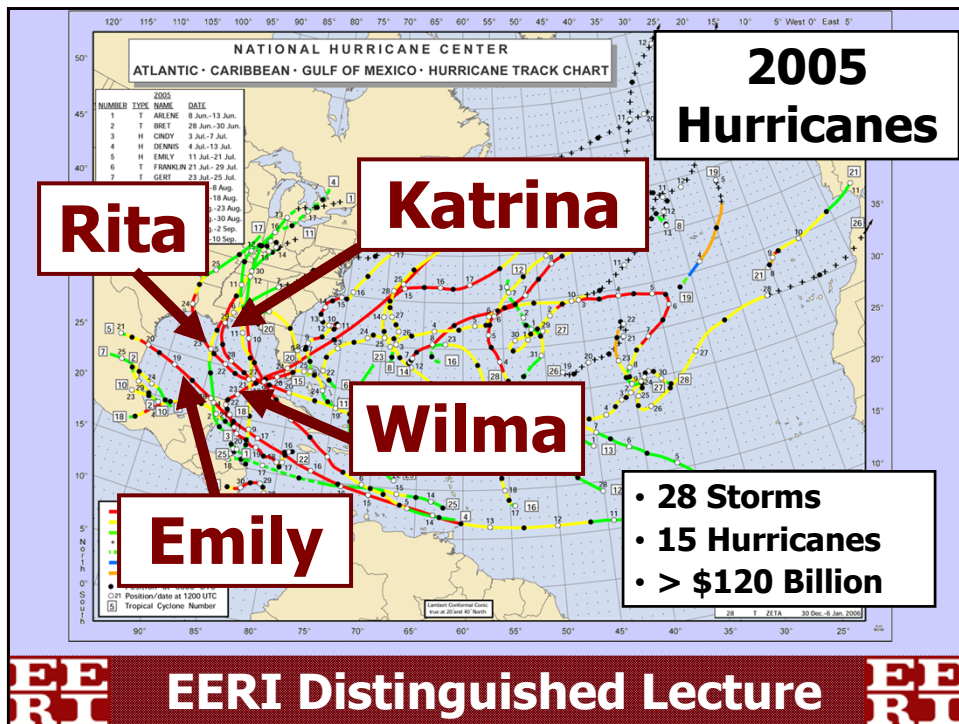
**100 km², 1-2m
Deep per Year**

**200 Million Tonnes
of Sediment/Yr.**



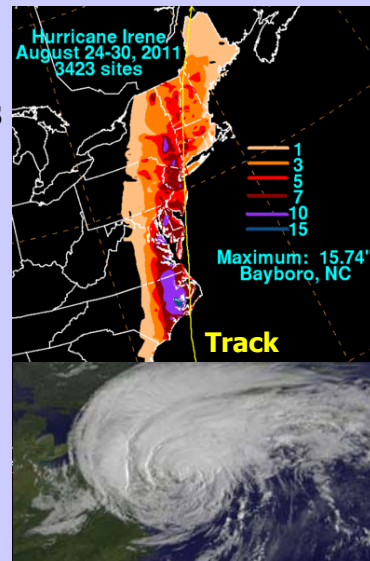
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HURRICANE IRENE

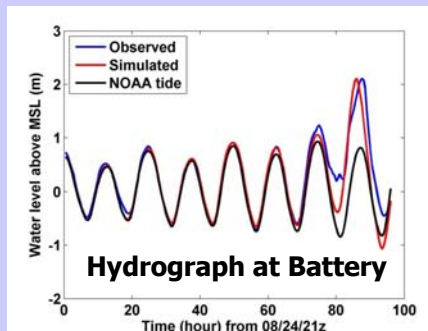
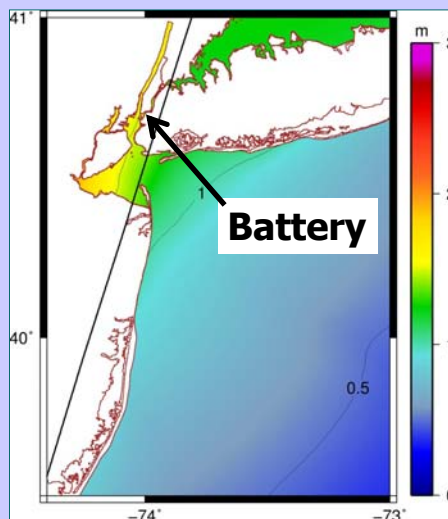
- 56 Killed
- \$10-15 Billion Direct Losses
- 7.4 Million Homes & Businesses Without Power
- NYC Evacuation & Shutdown of MTA & Public Transportation
- Record Flooding
- Near Miss



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HURRICANE IRENE SIMULATION (N. Lin, 2012)



- Physics Based Hydrodynamic Model: ADCIRC
- Excellent Agreement with Hydrograph at Battery

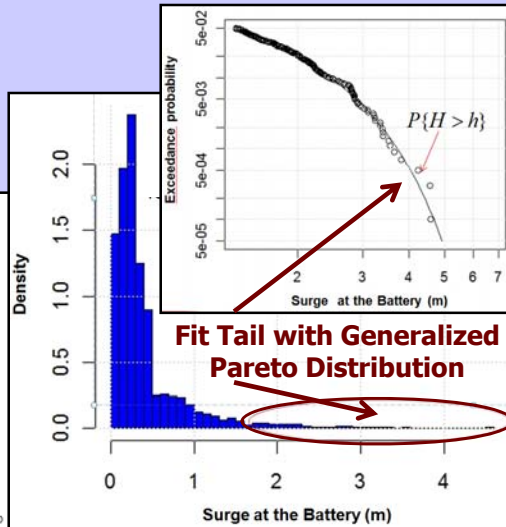
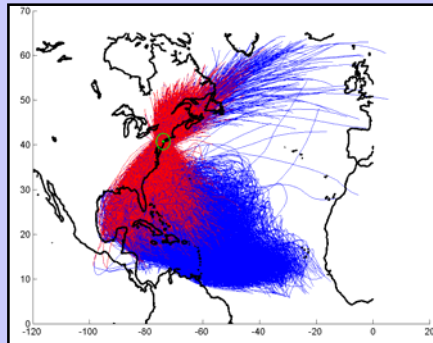


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HURRICANE SIMULATION (N. Lin, 2012)

- Simulated 5000 Storm Tracks Within 200 km of Battery



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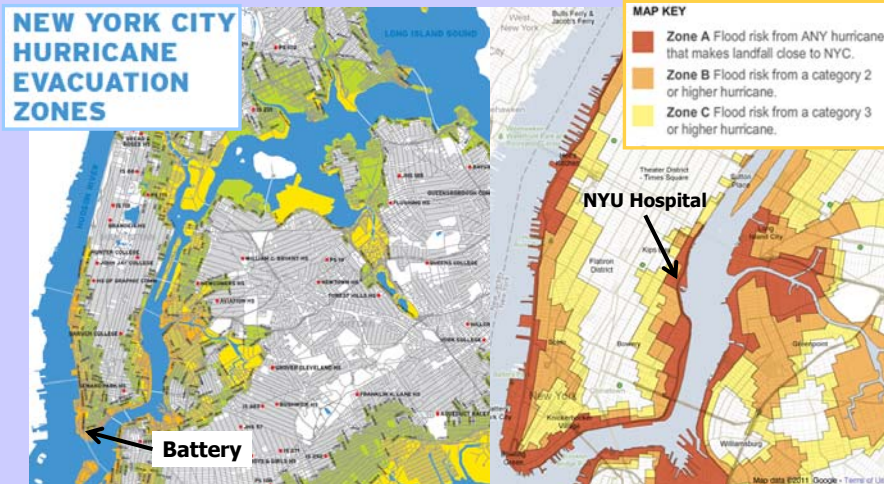
LONG ISLAND SOUND SURGE



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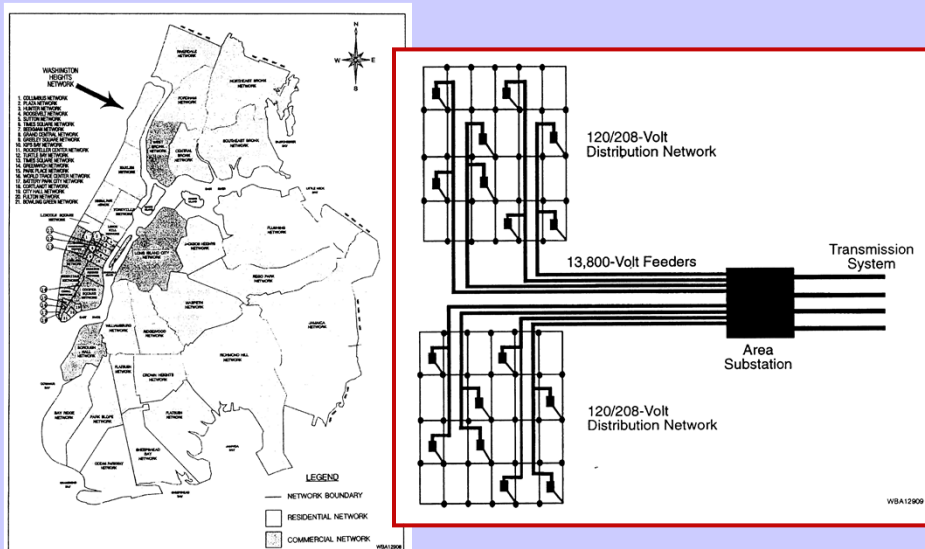
NEW YORK CITY HURRICANE FLOOD ZONES



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NEW YORK CITY ELECTRIC POWER



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- Canterbury EQ Sequence
- Hurricanes
 - New Orleans
 - New York City
- **New Normal**

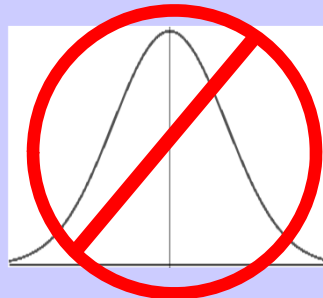


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OBSERVATIONS

- **Anything But Normal**
 - Target nuclear failure probability $\approx 1 \times 10^{-5}/\text{yr}$
 - 5 major nuclear releases in 14,000 reactor years = $3 \times 10^{-4}/\text{yr}$
 - Probability tails control
- **Problems Compounded by Institutional Constraints, Politics, Lack of Perspective, & Dysfunction**



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NEW NORMAL

- Too Big To Fail
 - Reassess Risk Related to Critical Infrastructure
 - Reassess & Identify *Critical* Infrastructure
- Local Coalitions
 - Coalitions to Protect Critical Infrastructure Too Big to Fail
- Punctuated Resilience



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SOUTHERN CALIFORNIA WATER SUPPLY



- Southern California highly dependent on imported water
 - Population: 22 Million

70% Imported Water:

- California Aqueduct
- Los Angeles Aqueducts
- Colorado River Aqueduct

30 % Ground Water



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SOUTHERN CALIFORNIA WATER SUPPLY (after Davis, 2010)

- **CA Aqueduct (CA DWR)**
 - 49 billion m³/yr
 - Faulting Rupture in >15 places
- **LA Aqueducts (LADWP)**
 - 390 million m³/yr
 - Elizabeth Tunnel
- **Colorado River Aqueduct (MWD)**
 - 900 million m³/yr
 - Multiple fault ruptures & ~ 4 m uplift



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LOS ANGELES AQUEDUCTS



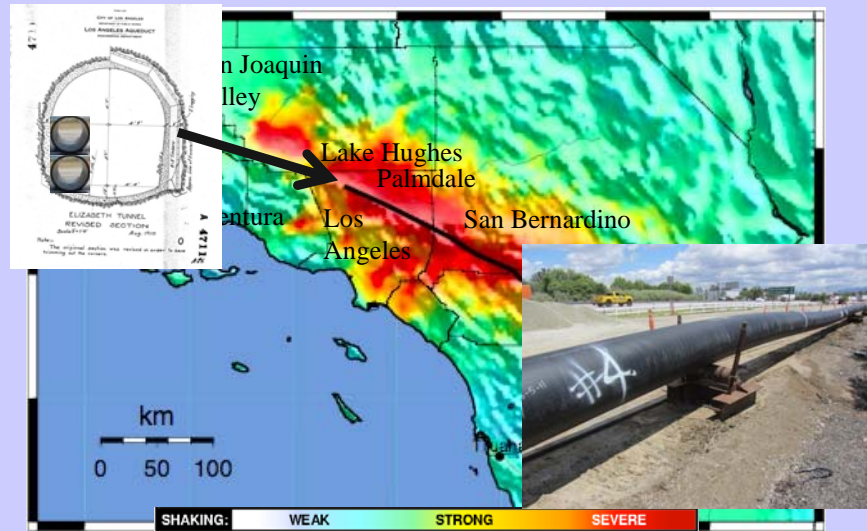
- 3.3m Horizontal Fault Displacement
- 2.9m Wide Elizabeth Tunnel
 - Cuts off tunnel



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LA WATER SUPPLY CROSSES SAN ANDREAS FAULT

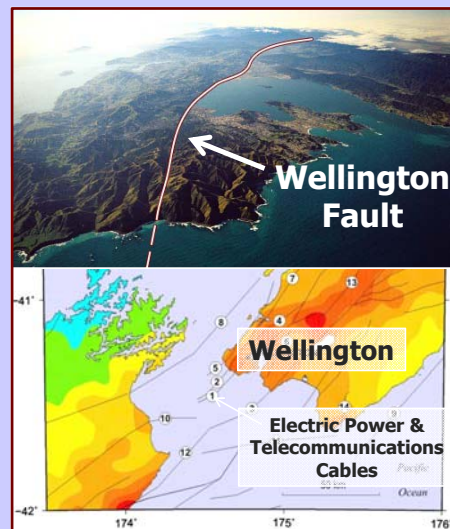


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WELLINGTON SEISMIC RISK

- **Urgent Need to Apply Christchurch Lessons**
 - Harbor Facilities
 - Water Supply
 - Fire Hazards
 - Major Highways
 - Electric Power System
 - Telecommunications
 - National Government



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CRITICAL INFRASTRUCTURE PROJECTS

- **Southern California Water Supply**
- **Sacramento River Delta Flood Protection System**
- **San Francisco Fire Protection System & Auxiliary Water Supply**
- **New York City Water Supply**
- **New Madrid Zone Transportation & Liquid Fuel Lifelines**
- **Mississippi Delta Flood Management**



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LEADERSHIP & PUBLIC OUTREACH



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ENGAGE ENGINEERS IN THE DIALOGUE

The Future of Cities 2011
Centres of innovation for urban solutions
28 February - 1 March 2011 | Chatham House, London



No Engineers of 28 Speakers

THE IDEAS ECONOMY
IDEAS THAT PRESS FORWARD

< 10 % Engineers

Intelligent Infrastructure
THE ARCHITECTURE OF PROGRESS
FEBRUARY 16 - 17, 2011
PACE UNIVERSITY, NEW YORK CITY

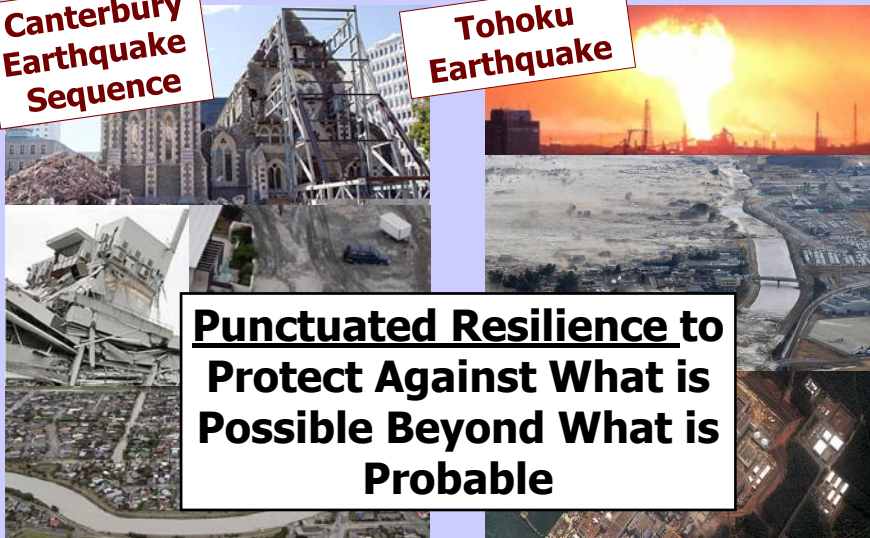
3 Engineers of 300 Participants

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NEW NORMAL FOR NATURAL DISASTERS

Canterbury Earthquake Sequence

Tohoku Earthquake



Punctuated Resilience to Protect Against What is Possible Beyond What is Probable

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Ofunato City, Japan



Daily Siren Tests:
0700 *Edelweiss*
1200 Traditional
1700 *Purple Haze*



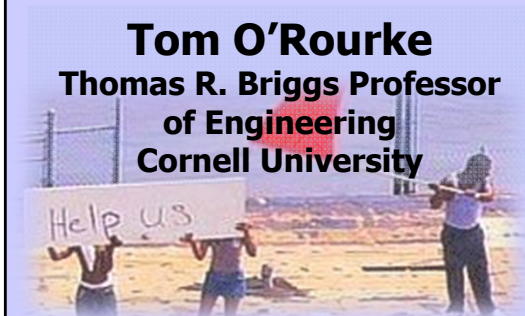
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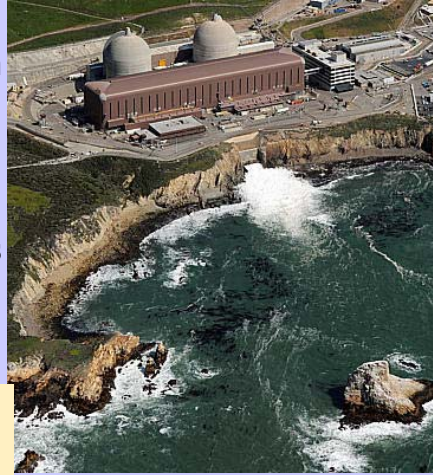


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U.S. NRC TASK FORCE RECOMMENDATIONS

- Fukushima Event Unlikely
- Defense in Depth Integration of emergency preparedness & operating procedures
- Seismic & Flood Hazards
- Station Black-out Procedures
- Hardening BWR Vents
- Spent Fuel Pool Instruments
- Tens of \$ Millions New Work
- Feb 12 NRC Approval for 2 Reactors at Vogtle Plant, GA



Diablo Canyon, CA



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