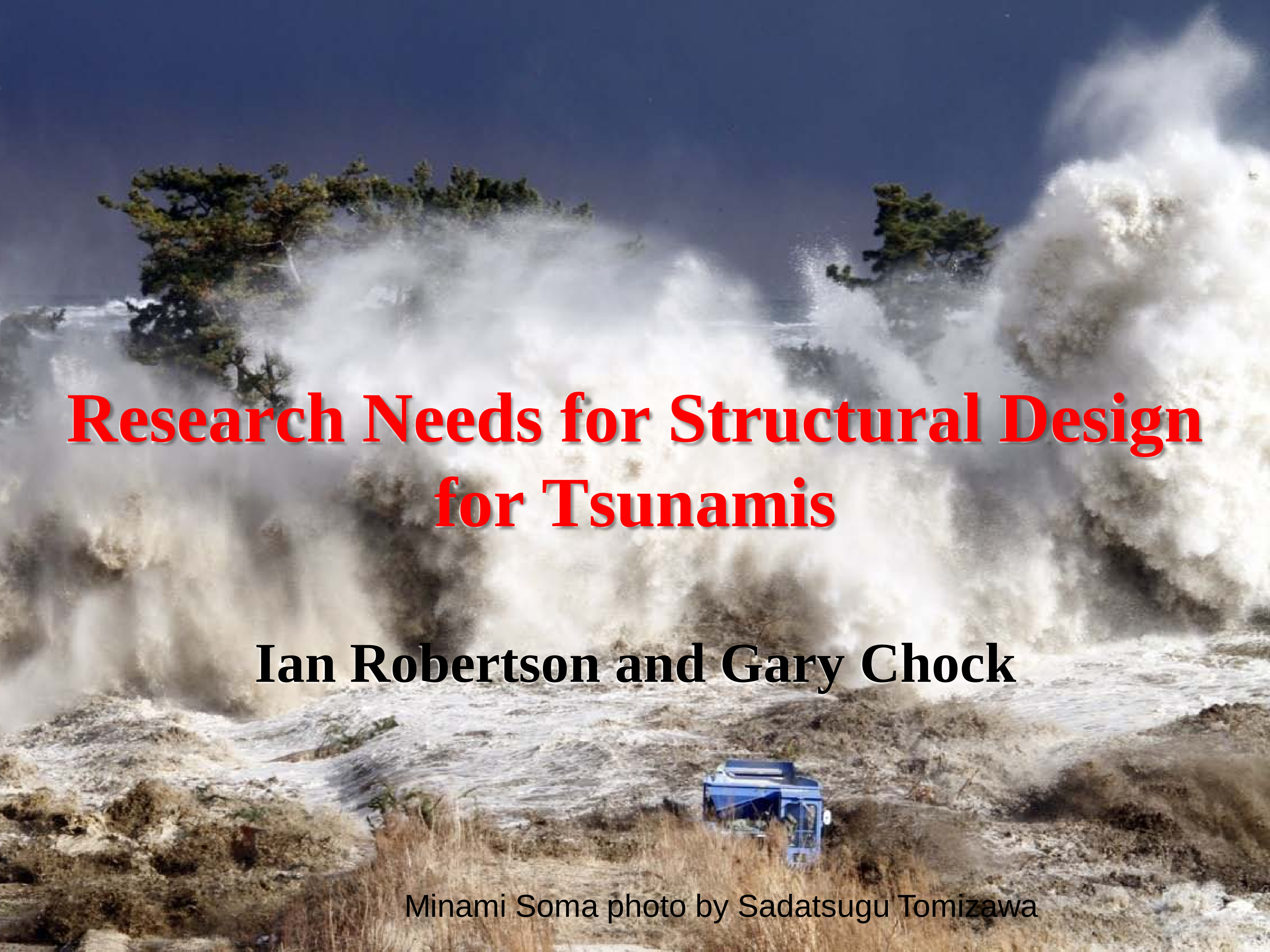
Research Needs for Structural Design for Tsunamis

Ian Robertson and Gary Chock



Minami Soma photo by Sadatsugu Tomizawa

Development of Performance Based Tsunami Engineering - PBTE

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NSF Funding: 2005-2010

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PBTE Project Outcomes

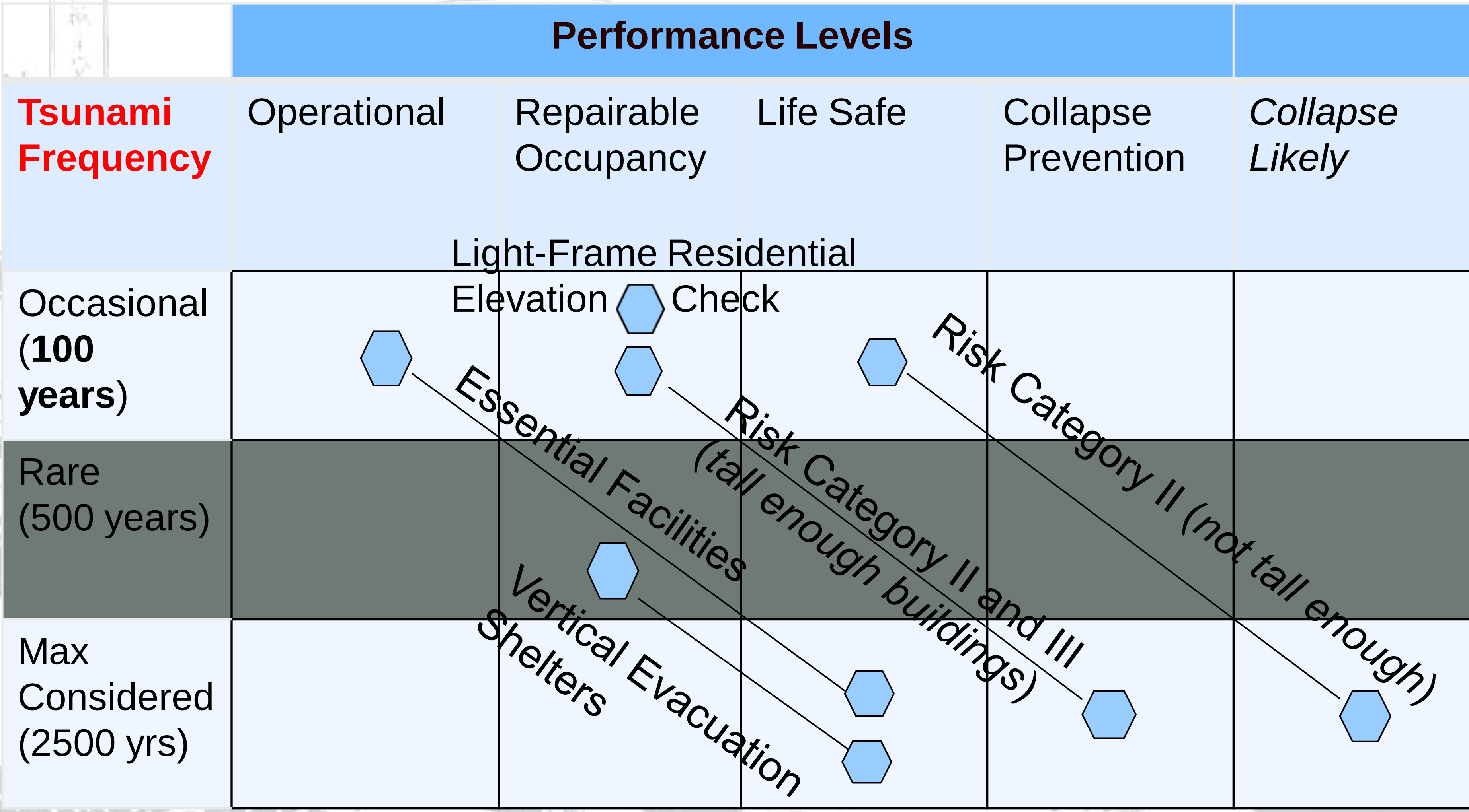
- Improvement in modeling tsunami transformation through wave breaking and inundation (Cheung)
- Improved understanding of “fluidization” or scour enhancement by increased pore pressures (Young)
- Tsunami bore loading on structural elements
  - Individual and multiple columns (shielding, etc) (Robertson)
  - Solid and perforated walls (Robertson, Riggs)
  - Uplift on floor slabs, piers and wharfs (Robertson)
- Culminating in current development of Tsunami Loads and Effects chapter for ASCE 7 (2016) (Chock)
  - ASCE 7-TLE Subcommittee formed February 2011
  - Bi-annual meetings (second in Oct. 2011 in Portland)
  - Objective - Develop TLE chapter for ASCE 7 by June 2013

Proposed Scope of the ASCE Tsunami Design Provisions
2016 edition of the ASCE 7 Standard, Minimum Design Loads for Buildings and Other Structures

ASCE 7 Chapter 6 - Tsunami Loads and Effects

6.1 General
6.2 Definitions
6.3 Symbols and Notation
6.4 Tsunami Design Criteria
6.5 Tsunami Depth and Velocity
6.6 Design Cases
6.7 Hydrostatic Loads
6.8 Hydrodynamic Loads
6.9 Waterborne Debris Loads
6.10 Foundation Design
6.11 Structural mitigation for reduced loading on buildings
6.12 Non-building critical facility structures
6.13 Nonstructural Systems (Stairs, Life Safety MEP)
6.14 Site-Specific Analysis and Design Procedure Requirements
6.15 Special Occupancy Structures

Tsunami Performance Design Objectives (Concept)

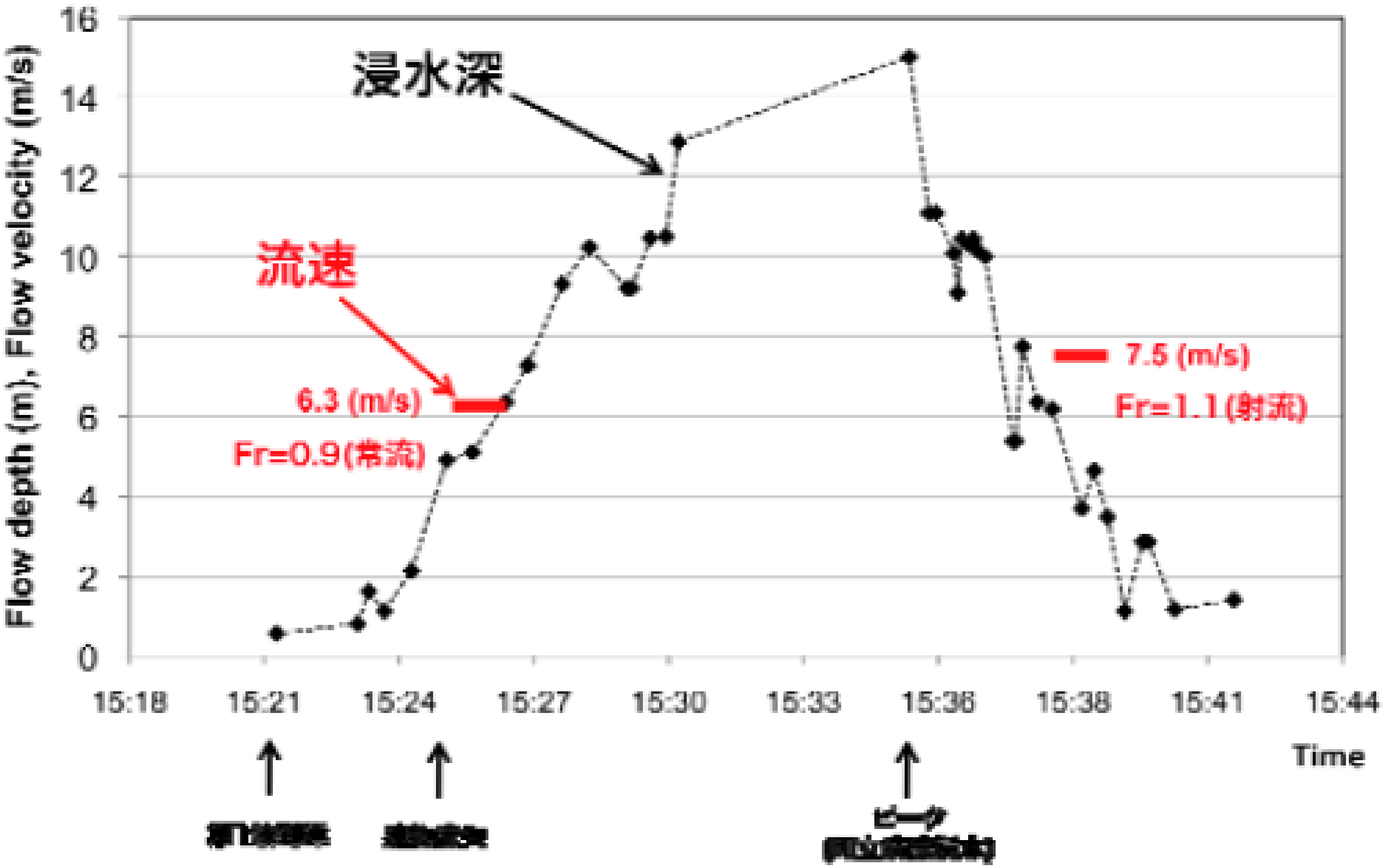


ASCE Tsunami Loads and Effects (TLE) Committee

Tsunami Research Needs

- Tsunami Characteristics
  - Probabilistic Tsunami Hazard Analysis
  - Inundation models that accurately capture wave breaking, bottom friction effects, and structural impediments (buildings, etc.)
  - Time histories of h, v, hv and hv^2 at selected locations
  - Include both incoming and outgoing flow

Onagawa Flow Depth Time-History

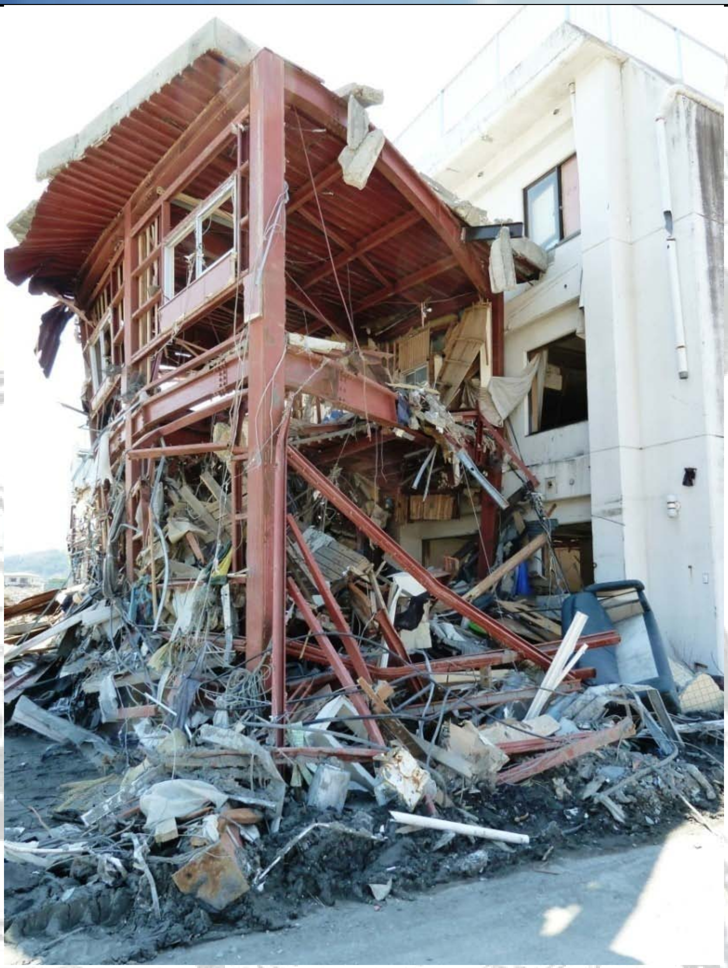


From Koshimura of Tohoku University

Structural Response Research Needs

- Loading on Structures
  - Hydrodynamic loading resulting from tsunami time-history, both incoming and outgoing flow
  - Development of time-history flow in wave flumes to replace soliton waves and dam break experiments
  - Effect of sediment and debris on hydrodynamic loading
- Structural Response
  - Develop loading time-history based on flow time-history
  - Effect of “breakaway” non-structural elements
  - Effect of debris damming – degree of blockage
  - Effect of debris impact – probability of impact severity
  - Non-linear structural response

Building Performance - Debris Loading



Three-Story SMRF collapsed and pushed into concrete building

Three-Story SMRF with 5 meters of debris load accumulation wrapping

Structural Survey Research Needs

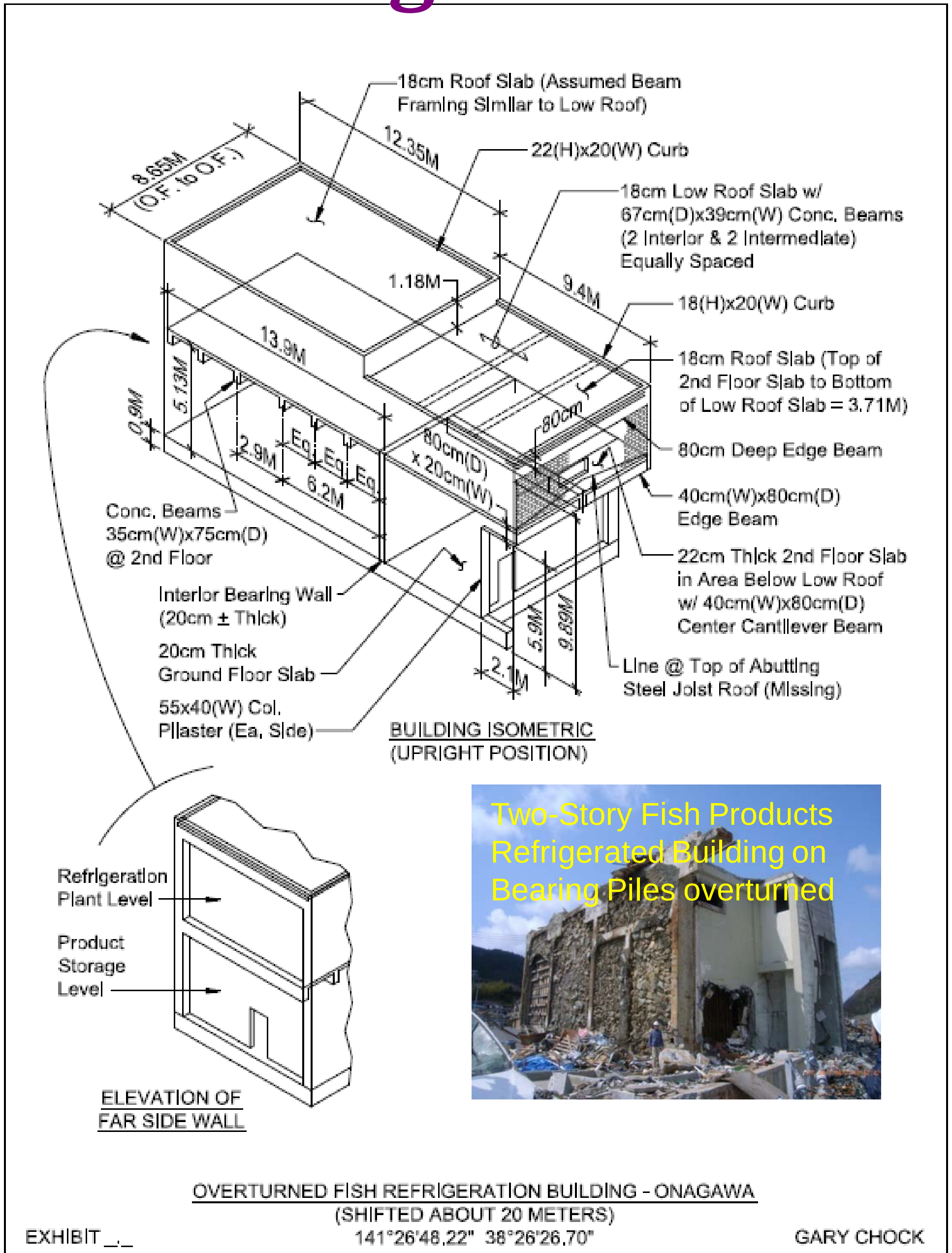
- Tsunami Survey
  - Detailed recording of structural performance
  - Sampling of material properties
  - Reverse-analysis of structural response to verify tsunami loading
  - Damage transects to aid in development of fragility curves

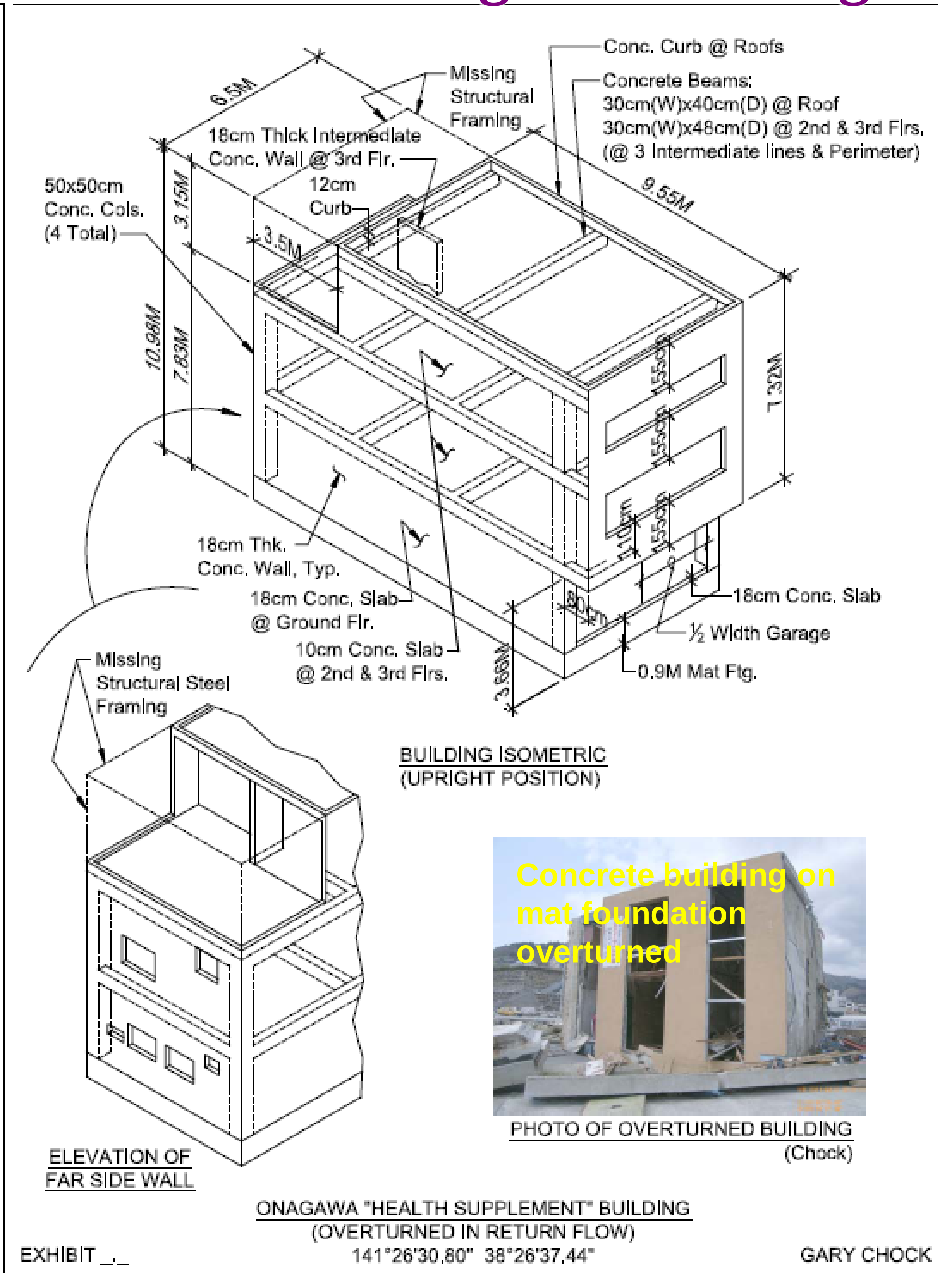
Building Performance – Total Building Overturning

Two-Story Refrigerated Concrete Warehouse (9000 kN deadweight) on Bearing Piles floated at 7 m inundation depth during inflow and then overturned about 20 meters from original position after floating over 2 m wall

Three-Story Concrete Retail Building (2050 kN deadweight) on mat foundation overturned during return flow when submerged in 8 m/s flow; would have toppled at only 3 m/s

Building Performance – Total Building Overturning

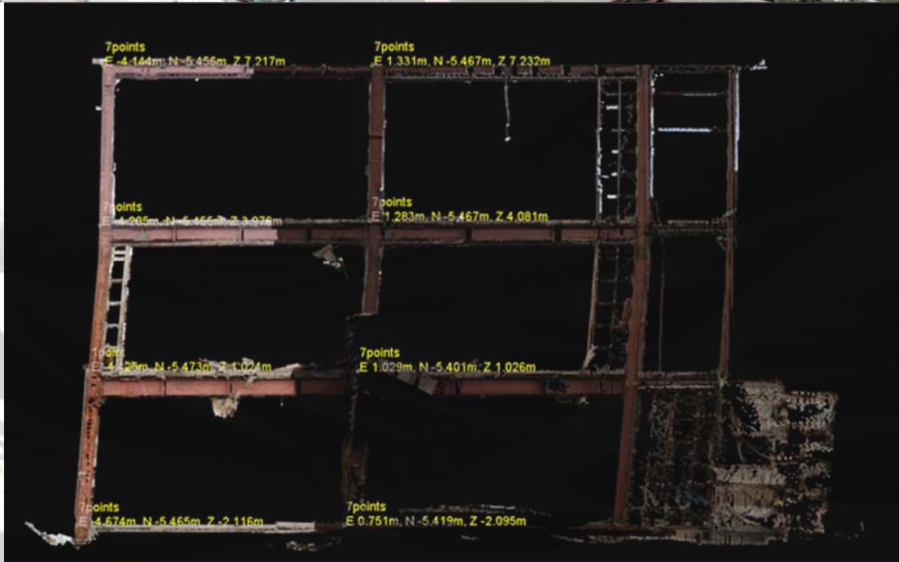




Onagawa Built Environment Captured with LiDAR

Onagawa Three-Story Steel Building Frame Survival by Load Reduction

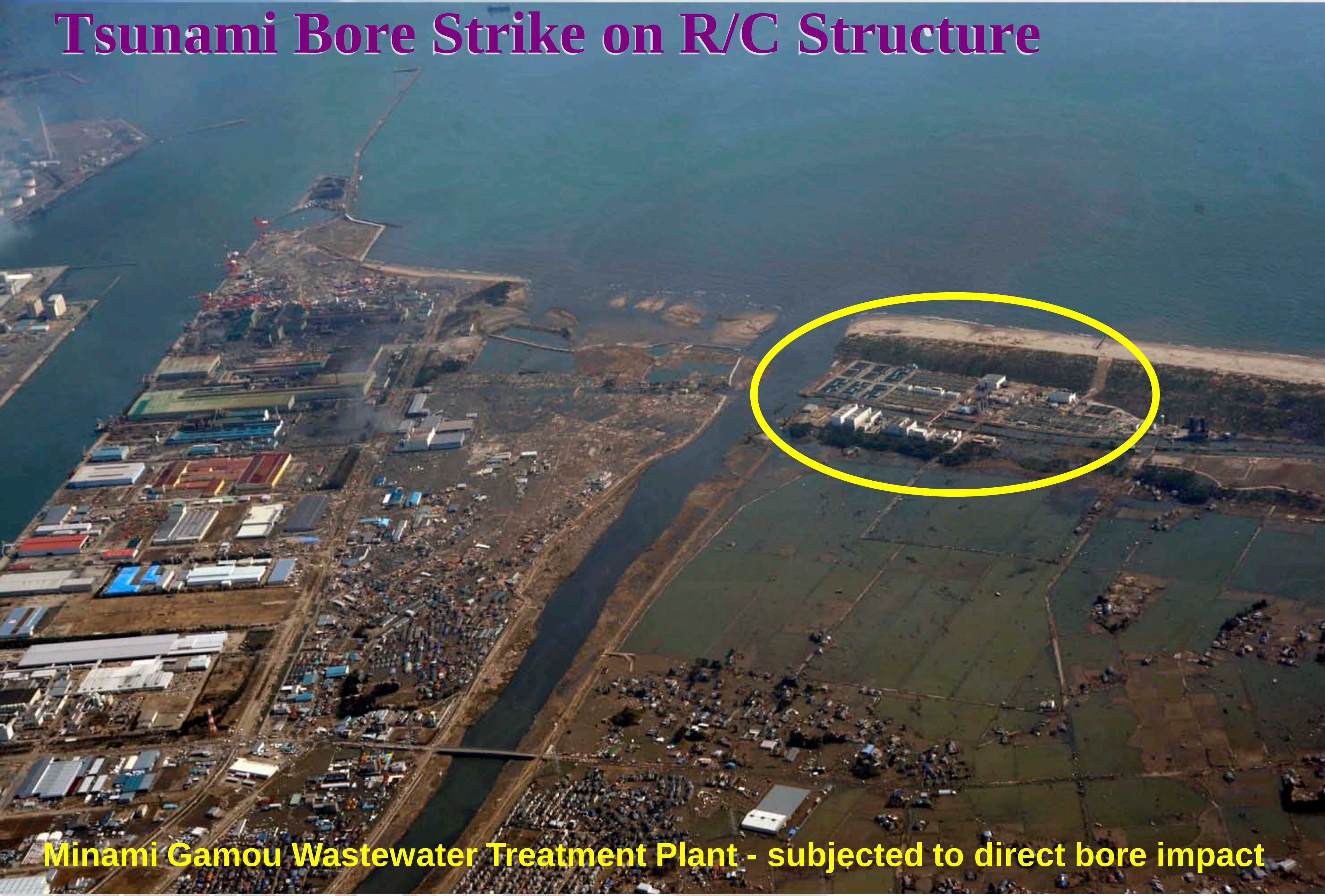
- This three-story steel moment-resisting frame exposed to 8 m/s outflow estimated from video analysis.
- At about 67% blockage of the original enclosure (33% open), the return flow is sufficient to yield the top and bottom of the second story columns with 30-cm drift of third floor (First story column is stronger section.)
- Subsequently sustained flow induced further displacement until loss of all cladding finally reduced the building's projected area. Otherwise collapse of cladded building would have occurred.
- LiDAR scan shows final 50-cm third floor drift.



Sendai Example

[Minami Gamou STP]

Tsunami Bore Strike on R/C Structure



Sendai Example

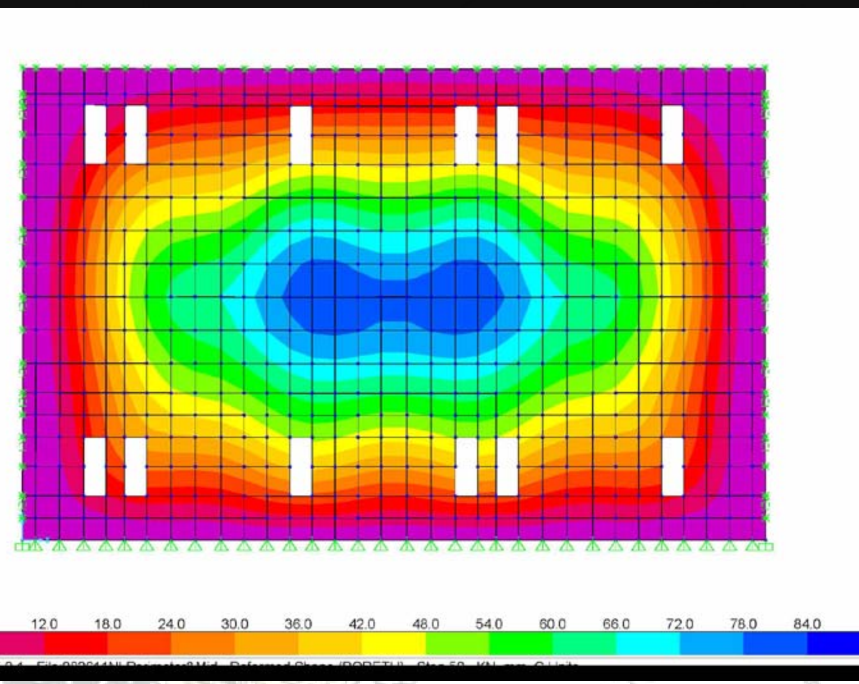
Tsunami Bore Strike on R/C Structure

Minami Gamou STP

Minami Gamou Wastewater Treatment Plant - subjected to direct bore impact

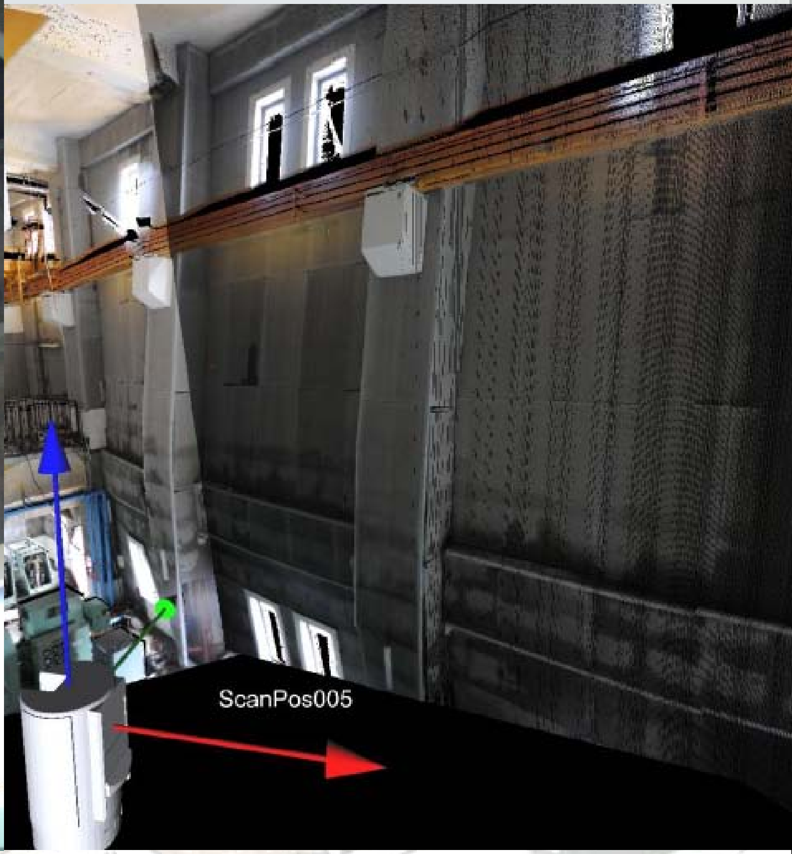
[Minami Gamou STP]()

Sendai Example
Tsunami Bore Strike on R/C Structure



Minami Gamou Wastewater Treatment Plant - subjected to direct bore impact

Sendai R/C Structure

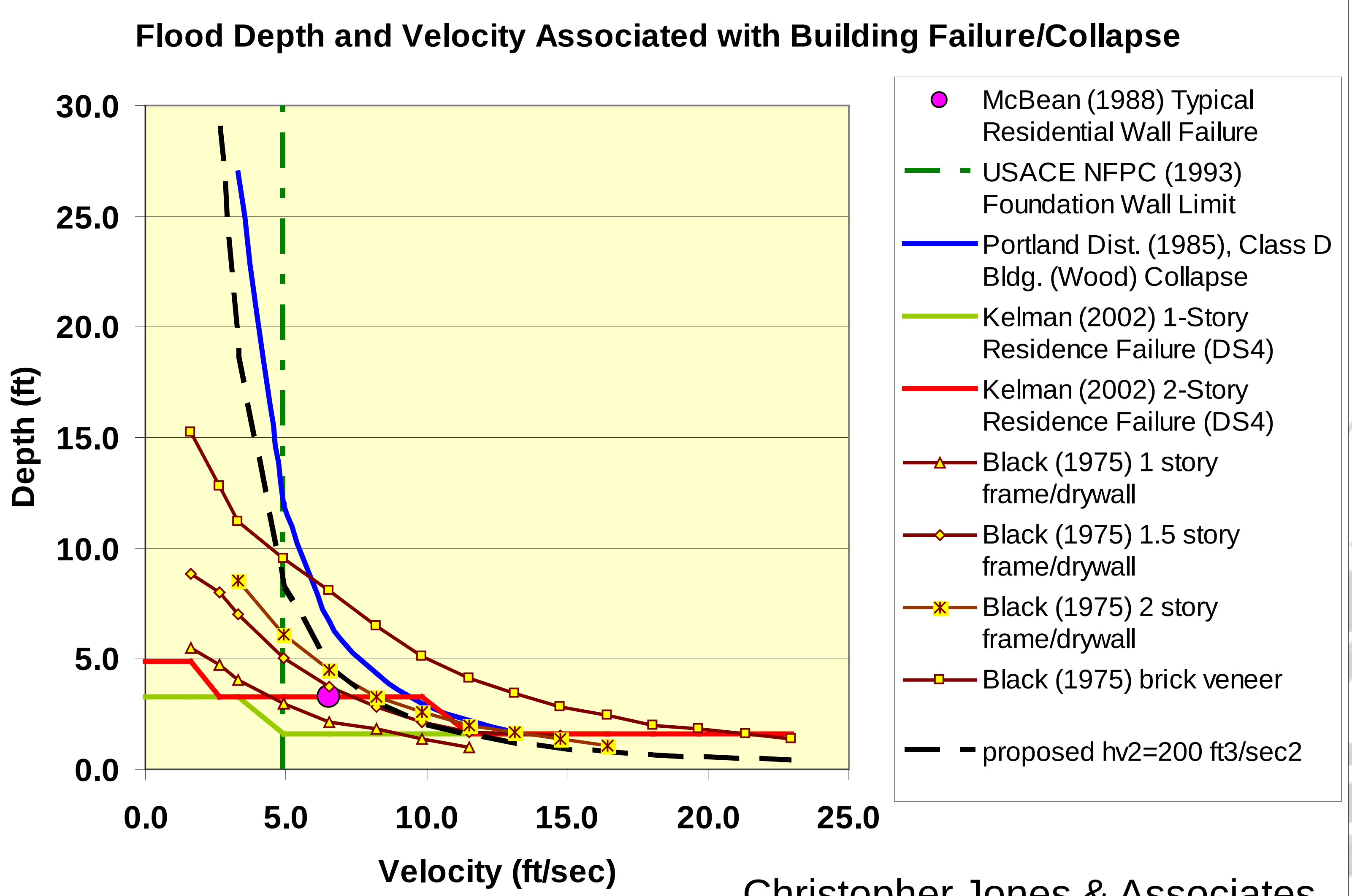


Minami Gamou Wastewater Treatment Plant

Structural Fragility

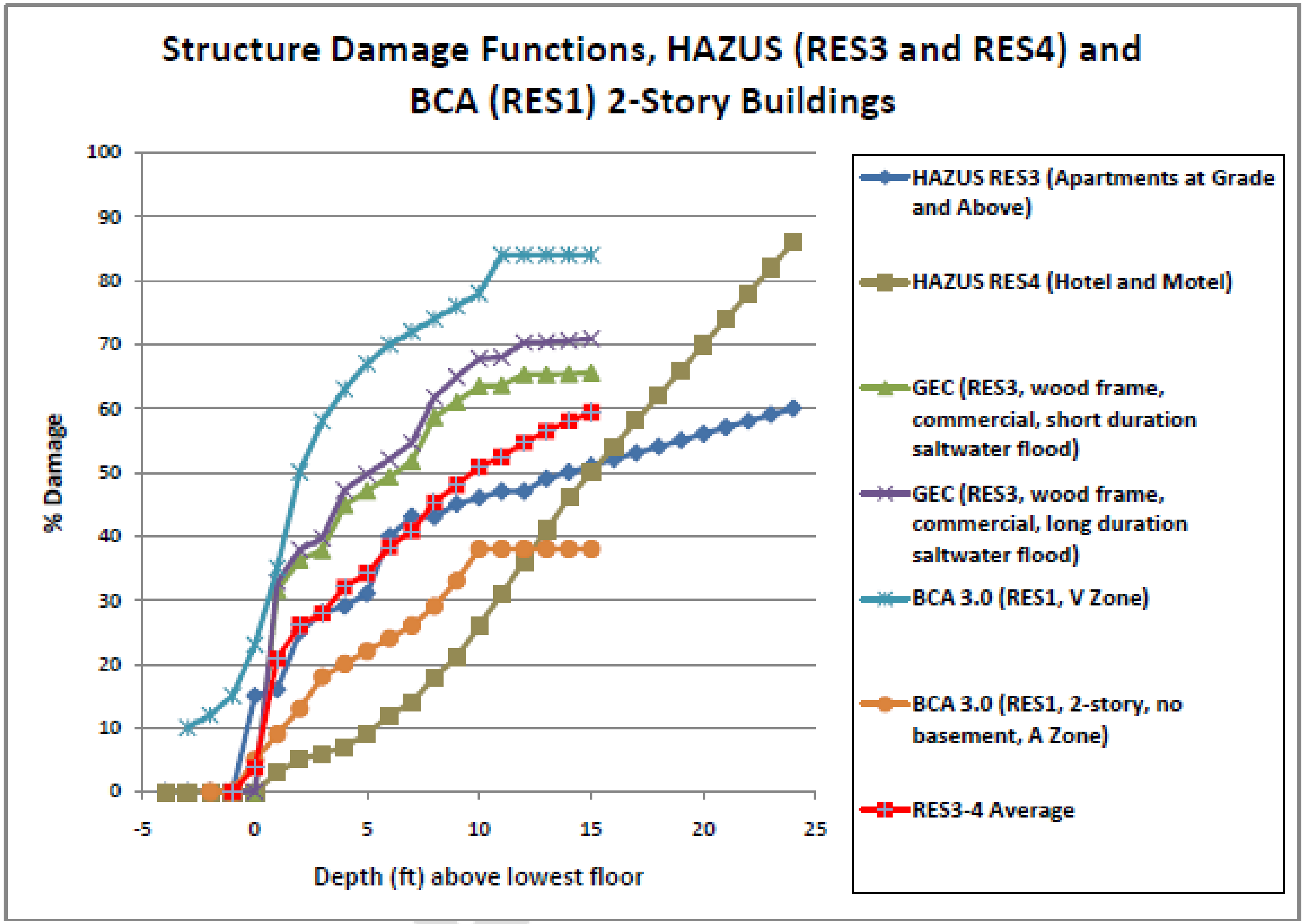
- Need to develop fragility curves for structural response to tsunami loading
- Can learn from field surveys
- Must adjust for code differences in other countries

Wood Residential Building Failure



Christopher Jones & Associates

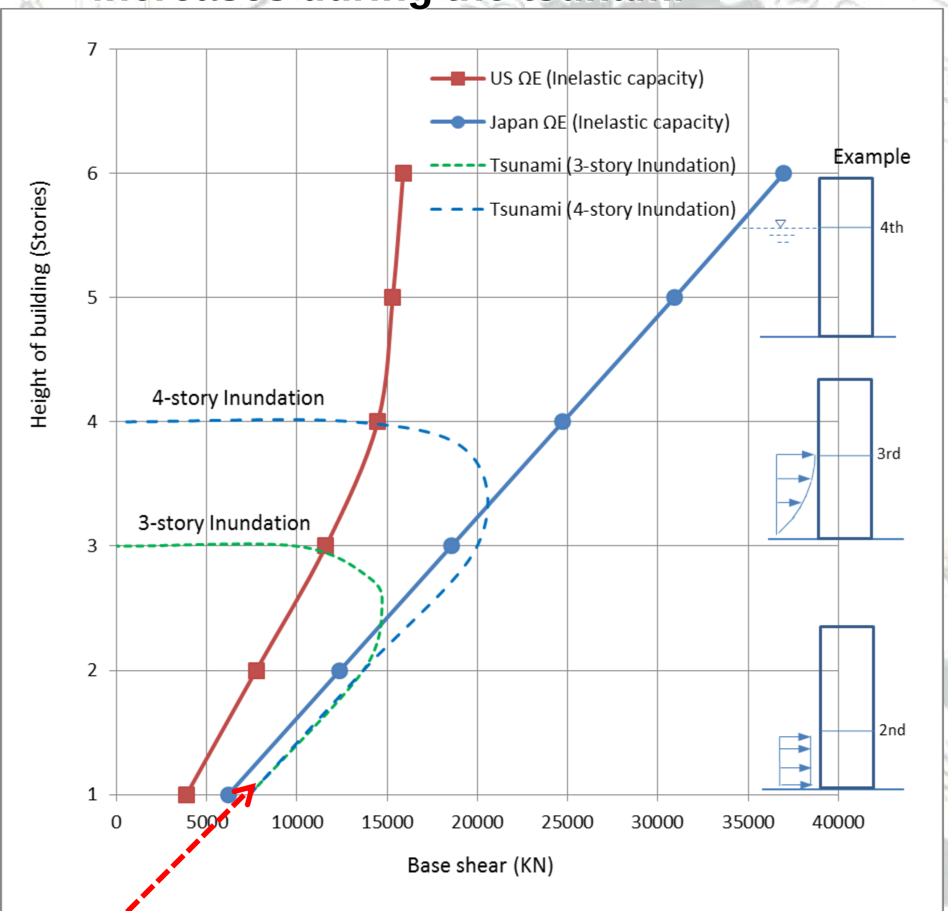
Fragility curves for coastal flooding

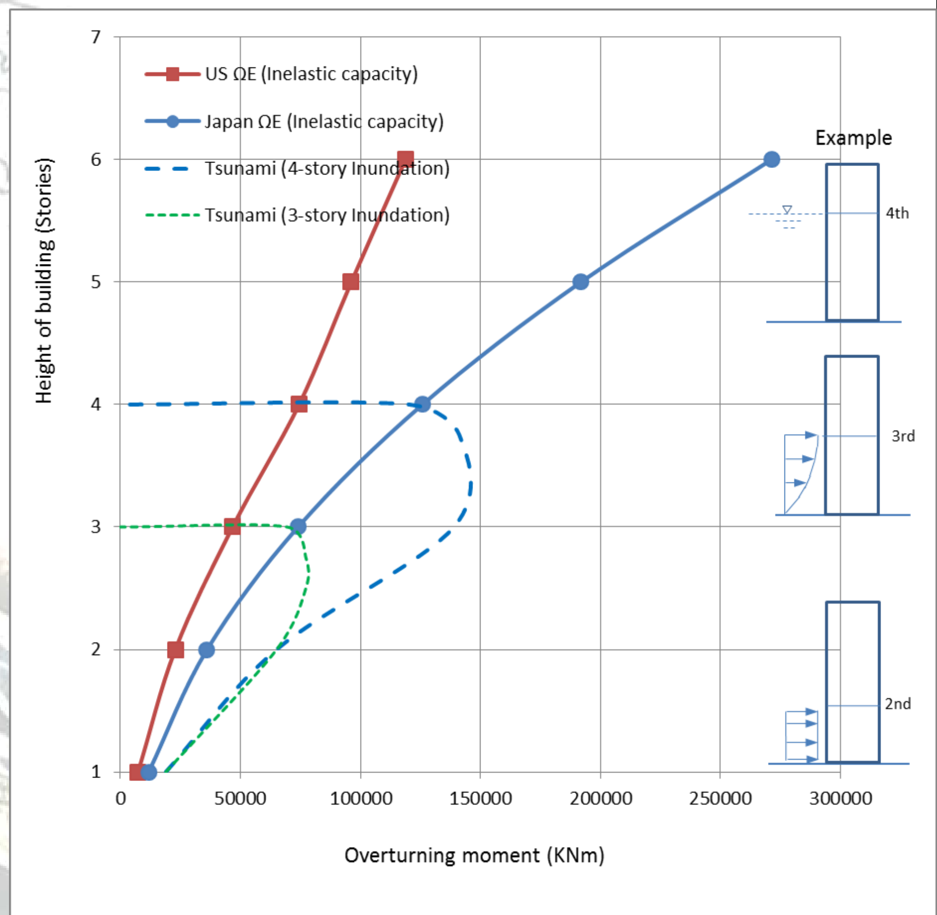


Christopher Jones & Associates

Comparing Low-Rise High Seismic (SMRF) vs. Max. Tsunami Loads

- Assume undamaged by Earthquake); evaluate max. capacity per Ω x required E
- Building is 25% open
- Each load curve represents the sequence of hydrodynamic loading as inundation increases during the tsunami

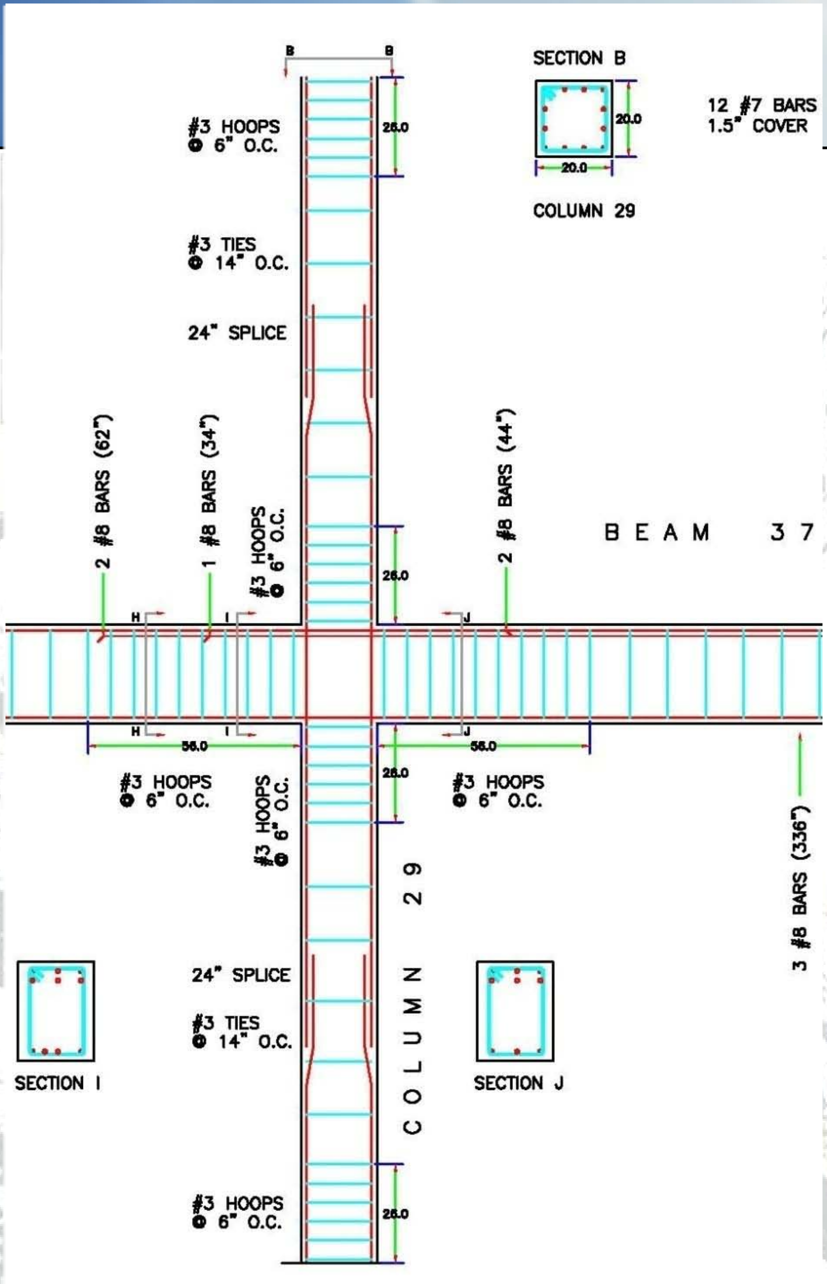


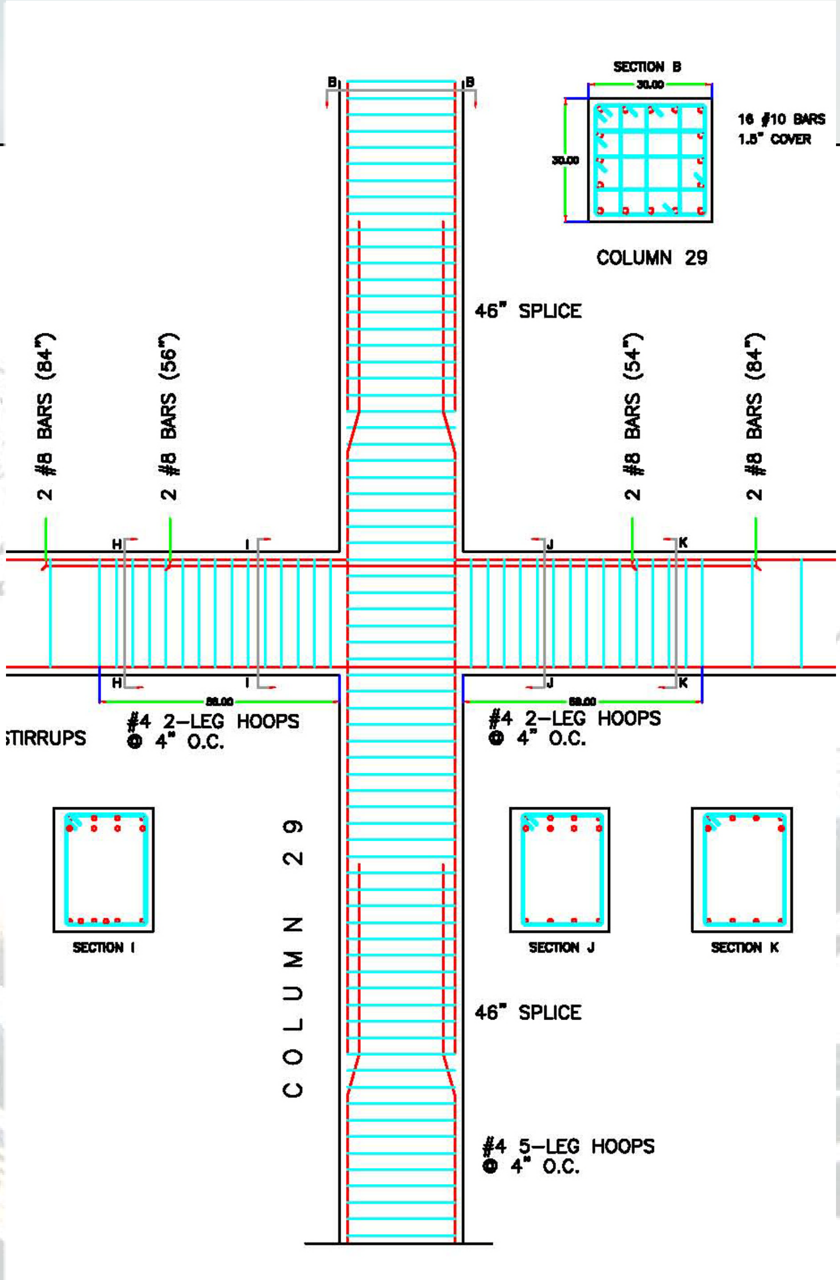


Financial Implications

- Cost of Tsunami Design
  - 16 prototypical buildings designed for seismic and wind
  - Redesign for various tsunami scenarios
  - Evaluate increased construction cost
- Prototypical Buildings
  - (3) 12 Story RC Office Buildings (MRF)
  - (3) 12 Story RC Residential Buildings (Shear Walls)
  - (3) 12 Story Steel Office Buildings (EBF)
  - (3) 4 Story PC Parking Structures (CIP, PT)
  - (3) 3 Story RC School Building (Bearing wall)
  - 4 Story Steel Shopping Mall (Concentric BF)

Intermediate and Special Detailing





Financial Implications

- Loss and repair costs
  - Casualties
  - Loss of contents
  - Structural and non-structural repair
  - Downtime

Any Questions?