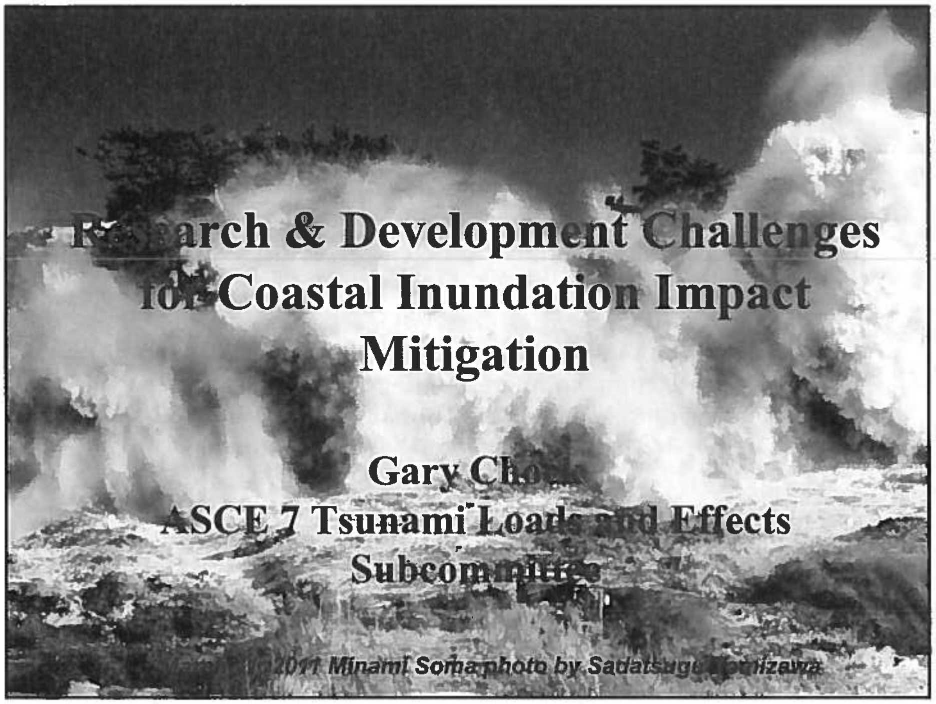
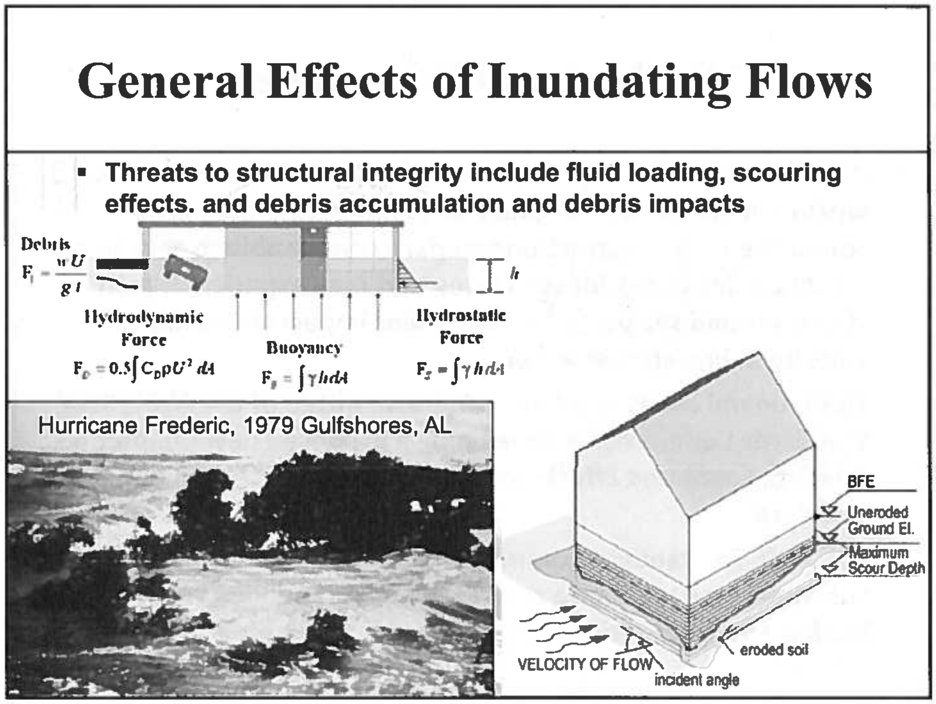


Research & Development Challenges for Coastal Inundation Impact Mitigation

Gary Chock
ASCE 7 Tsunami Loads and Effects Subcommittee

2011 Minami Soma photo by Sadatsugu Tomizawa



General Effects of Inundating Flows

- Threats to structural integrity include fluid loading, scouring effects. and debris accumulation and debris impacts

Hurricane Frederic, 1979 Gulfshores, AL

The Principal Gaps in Tsunami Mitigation

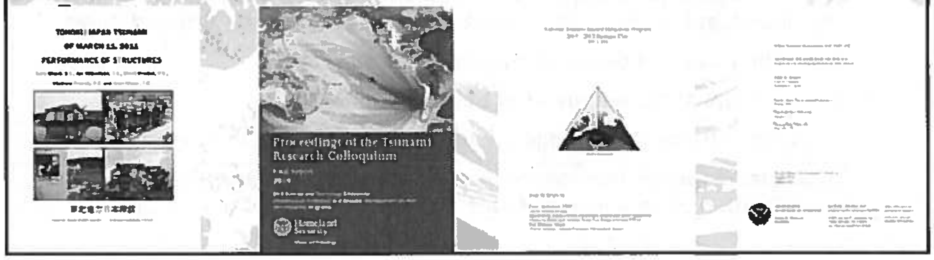
- Tsunami-resilience of a community does not result from evacuation maps and “Tsunami-Ready” warning and evacuation capability alone; those elements are necessary for evacuation to reduce fatalities, but not sufficient for actual resilience.
- Most Japanese communities were considered much more “Tsunami-Ready” than comparable US communities. Yet, a year later very few would consider the Tohoku communities to be resilient in the aftermath of the March 11, 2011 tsunami.
- Heretofore, lack of accepted tsunami structural design standards and associated design mapping has led to neglect of design mitigation. Concepts without the means of implementing hazard mitigation are non-starting. FEMA P646 is one recent exception applicable to a small class of buildings.

Background information

- A national standard for engineering design for tsunami effects written in mandatory language does not exist. There is no comprehensive construction standard comparable to seismic or wind building codes for structures that may experience both strong ground shaking and subsequent impacts from high velocity debris-strewn water.
- The Tsunami Loads and Effects Subcommittee of the ASCE/SEI 7 Standards Committee is developing a proposed new Chapter 6 - Tsunami Loads and Effects for the 2016 edition of the ASCE 7 Standard.
- The ASCE 24 Standard Committee and ASCE 7 Flood Subcommittee were also consulted on R&D needed to implement flood-resilient design.

References for this Presentation

- ASCE 7 Flood Loads Subcommittee and ASCE 24 Flood Resistant Design & Construction Committee
- ASCE 7 Tsunami Loads and Effects Subcommittee
- Tohoku Japan Tsunami of March 11, 2011 – Performance of Structures, ASCE/SEI report in publication (2012)
- Tsunami Research Colloqium 2010
- NTHMP Strategic Plan (2009-2013)
- National Tsunami Research Plan (2007) State of the Science Review



TOHOKU JAPAN TSUNAMI OF MARCH 11, 2011 PERFORMANCE OF STRUCTURES

Proceedings of the Tsunami Research Colloquium

Informational Background for R&D:
Proposed Scope of the ASCE Tsunami Design Provisions
2016 edition of the ASCE 7 Standard, Minimum Design Loads for Buildings and Other Structures

- 6.1 General Requirements
- 6.2 Definitions
- 6.3 Symbols and Notation
- 6.4 General Tsunami Design Criteria
- 6.5 Procedures for Tsunami Hazard Assessment
- 6.6 Procedures for Tsunami Inundation Analysis
- 6.7 Design Parameters for Tsunami Flow over Land
- 6.8 Design Procedure for Tsunami Inundation
- 6.9 Hydrostatic Loads
- 6.10 Hydrodynamic Loads
- 6.11 Impact Loads
- 6.12 Foundation Design
- 6.13 Structural countermeasures for reduced loading on buildings
- 6.14 Special Occupancy Structures
- 6.15 Designated Nonstructural Systems (Stairs, Life Safety MEP)
- 6.16 Non-building critical facility structures
- Commentary and References

Primary R & D Needs for Floods and Tsunami

Outline of research needs on coastal inundation impacts that would assist practical implementation of mitigation through codes and standards.

- **Probabilistic Design Maps for appropriate performance targets**
- **Tools to evaluate hydrographs of h, v *and* hv^2. Developing governing load time-history based on the site's flow/velocity depth time-history;**
- **Inundation flow models that accurately capture the characteristics of debris floods and the effects of bottom friction**
- **Flow through urban environments with structures and buildings of various fragilities that may become "erodable" (i.e., destroyed or stripped down)**
- **Debris impacts and debris accumulation**
- **Scour effects at the perimeter of building foundations**
- **Combined structural loadings on building and non-building structures**
- **Structural response metrics for performance-based tsunami design with consideration of co-seismic effects/damage**

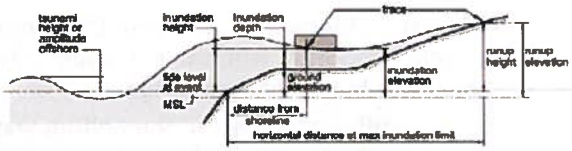
Probabilistic Maps for Use in Engineering Design Standards

- **Coastal Flood and Tsunami: There is a need for inundation design maps incorporating flow depth *and* velocities and maximum specific momentum flux hv^2 , based on probabilistic hazard analysis.**
  - This would result in mapping necessary for structural loading, moving beyond zoning and evacuation maps
- **There is a specific need for coastal storm flood (depth and current) maps with longer return periods consistent with wind design standards.**
  - Updates and refinements to the NFIP statutory 100-year flood maps alone do not adequately account for high impact storm surge scenarios, and do not support performance-based design and achieving long-term mitigation of losses.

PTHA Probabilistic Tsunami Hazard Analysis

- ASCE to include a national map of 2,500-year tsunami offshore wave height (in 30 m water depth) to use as the initial condition for local inundation maps, where the specified offshore wave height is attributed to the disaggregated governing seismic sources.

Required design tools for communities adopting tsunami design provisions include probabilistic inundation maps for the hazard level of the desired performance objective.



disaggregation for peak waveheight at 475 yr return period

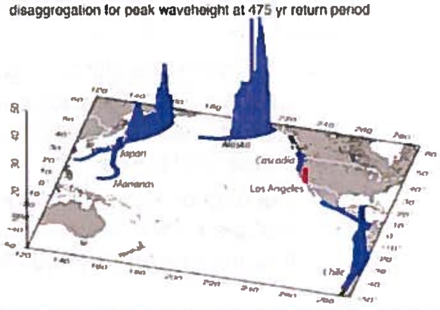
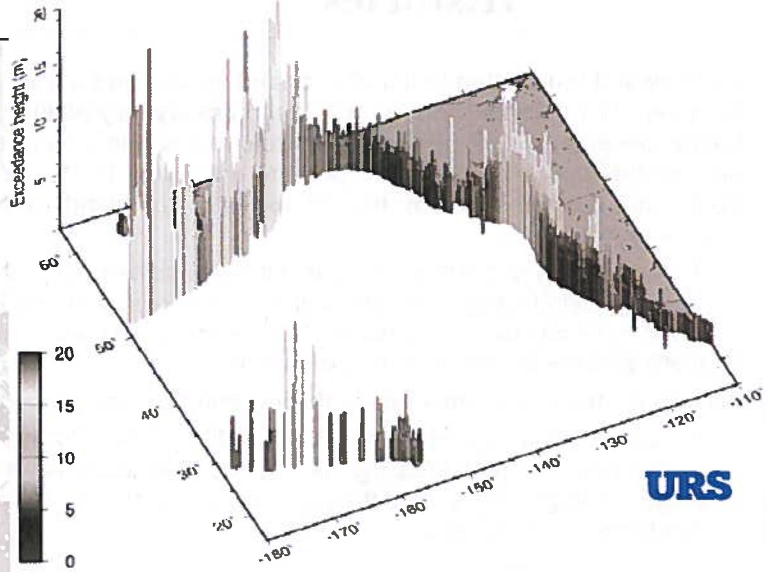


Figure 1 Source disaggregation for the tsunami hazard in the Los Angeles area for peak waveheight. The blue bars represent the relative contribution of each element towards the tsunami hazard (red bar) in the target area

Exceedance waveheights: 2500 yr

PTHA of offshore wave height



URS

Inundation Research Needs

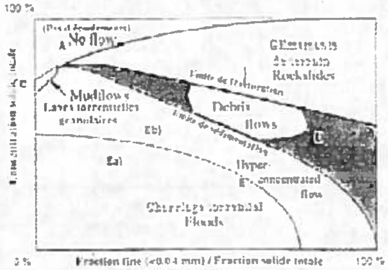
- **Coastal Floods and Tsunami: Characterize the full inundation cycle histogram with the corresponding time history of velocity, for both incoming and outgoing flow.**
- **Tsunami: Move beyond the soliton wave paradigm to actual tsunami histograms with and without superimposed wave breaking**
  - Due to the limitations in generating “true” tsunami long-period waves in existing laboratory facilities, experimental modeling of tsunami has been challenging and generally limited to soliton waves and bores.
  - Develop modeling of of time-history flow in wave flumes to replace soliton waves and dam break experiments. This tsunami flow time history should also include the drawdown condition.

Tsunami Inundation Flow Time Histories

- **Velocity and inundation limits of overland surges and bores dominated by surface friction rather than gravity (dry plains); further development of numerical models that would accurately provide the most important flow parameters during the tsunami bore overland advancement: time histories of flow depth and flow velocity.**
  - The complexity of the highly turbulent flow, combined with complex inland topography and overland roughness variation (even more complex in the coastal built environment) has hampered the development of such models.
- **Vertical profile of current velocity throughout the loading cycle**
  - Accurate measurements of the vertical profile of flow velocity in overtopping type (non-breaking) long period rising tsunami wave surge would greatly assist in the determination of realistic loading conditions on structures.

Debris-Laden Flood Research Needs

- **Coastal Flood and Tsunami: Viscous effects of sediment and debris-laden flooding, affecting flow velocity, depth profile, and hydrodynamic loading**
  - The majority of past tests and modeling have been conducted with inviscid clear water conditions which did not take into account the presence of significant bulk of floating debris or the heavy entrainment of sediment set into suspension or debris from damaged buildings and infrastructure.



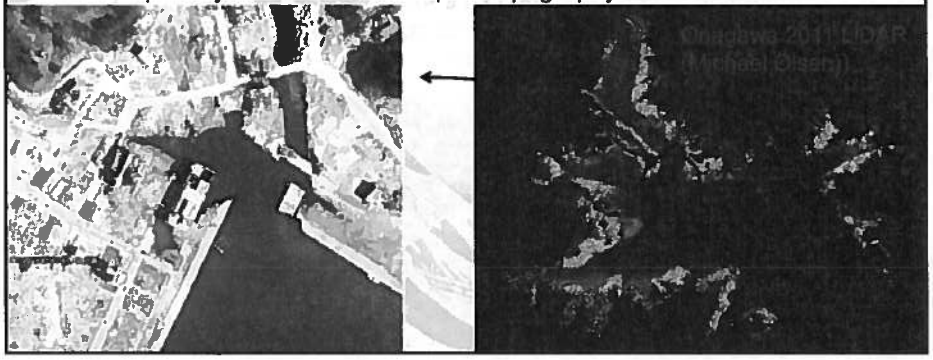
Characterization of Site Effects – Floods and Tsunami

- **Onshore friction is now characterized by an equivalent macro-roughness. Very detailed studies may incorporate modeling of buildings as indestructible objects in the flow.**
- **Structures can serve to either shield adjacent structures or focus accelerated flow onto adjacent structures. Flow through constricted urban corridors can resemble fast-moving rivers.**
  - Research is required to quantify these effects, which can change rapidly as the more fragile structures are eliminated. Inflow and drawdown conditions are quite different

Kamaishi 2011 (ASCE)

Characterization of Site Effects

- **Tsunami drawdown flow can often be faster and more significant to scour.**
    - While the backwash flow is a function of the flood time history characteristics, the spatial extent of the inland inundation, and topography of the area, there are no clear procedures of how to quantify such flows in complex topography.



Onagawa 2011 LiDAR (Michael Olsen))

Debris Impact and Accumulation – Floods and Tsunami

- **Effects of incomplete or delayed clearing of "breakaway" non-structural elements and building contents on hydrodynamic drag**
- **Effect of debris damming and degree of blockage**
- **Impacts by larger floating and tumbling debris objects embedded in the flow**
- **Modeling of mechanics of large debris transport overland**
- **Effects of low-speed debris impact – probability of impacts by severity of net momentum considering debris sources and transport**
- **Determination of appropriate added fluid mass effects on debris impact**

Yuriage, Natori 2011 (Gary Chock)

Otsuchi 2011 (Gary Chock)

Structural Damage by Debris Impacts

Hurricane Katrina, 2005 (Ian Robertson)

Hurricane Iwa, Poipu Village, Kauai, 1982 (Arthur Chiu)
(Hotel was rebuilt at this site with same structural system just in time to be destroyed again in Hurricane Iniki 1992)

Characterization of Scour – Flood and Tsunami

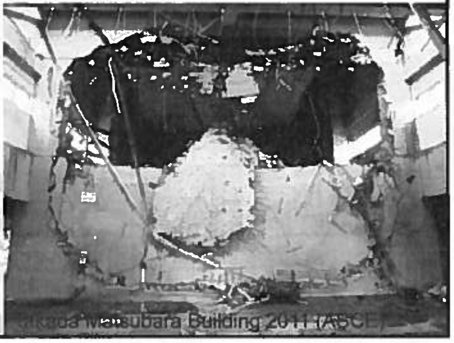
- **Scour effects at the perimeter of building foundations lacks rational methodology for design**
  - Present methods based on research on isolated (bridge-type) piers do not scale up well to building forms and footprints and have been discontinued in the Coastal Construction Manual
  - Mechanisms of bed shear stress vs. pore pressure softening during drawdown
  - Effect of soil type permeability not easily validated in the field

Onagawa 2011 (ASCE)

Structural Loading

- Research has been conducted internationally over the past few decades on the impact of hydrodynamic forces on classical coastal protection works of simple geometry (breakwaters, seawalls, etc.)
- More emphasis is needed on fluid pressure distributions and component forces on buildings, bridges, ports, and other lifeline infrastructure located inland.

Numata Bridge, Rikuzen [illegible] (ASCE)



kada Matsubara Building 2011 (ASCE)

Structural Loading

- Wave impulsive loads on elevated structures: Loads from combined waves and currents acting on foundations and superstructures.
- Loadings on non-building critical facility structures in the inundation hazard zone
  - Seawalls,
  - Industrial facilities,
  - Port facilities,
  - Tanks
  - Utility poles

Minami Gamou STP Building 2011 (Lyle Carden) Video

Establishment of performance-based response metrics for structures

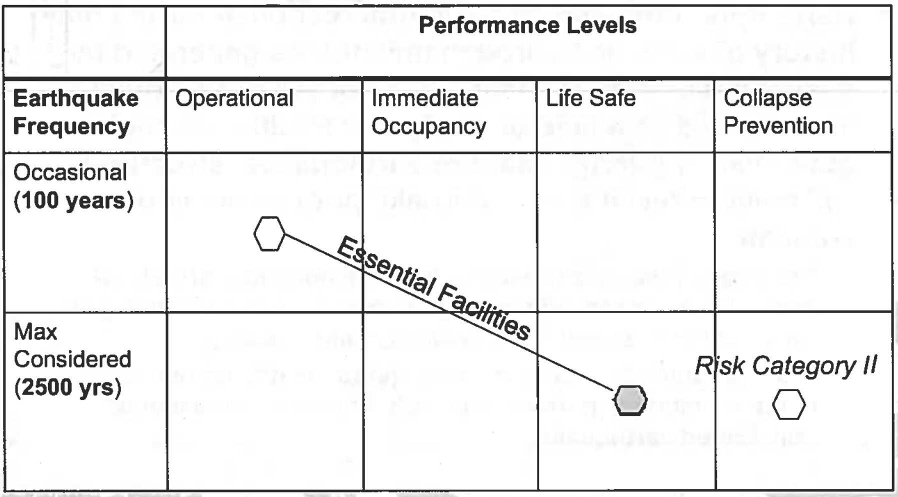
- Heretofore, post-elastic structural response for the time-history of extreme hydrodynamic forces generated by design basis-level tsunamis has not yet been explicitly investigated as a field of study. For Pacific NW regions governed by nearby offshore earthquakes, structures will need to resist the earthquake prior to onset of tsunami.
    - *Therefore, research should include the nonlinear structural response of earthquake damaged structures to repeated cycles on sustained psuedo-static hydrodynamic loading.*
    - From parametric studies could develop the design response limits for tsunami performance subsequent to a maximum considered earthquake.

Risk categories of buildings and other structures per ASCE 7

Risk Category I	Buildings and other structures that represent a low risk to humans
Risk Category II	All buildings and other structures except those listed in Risk Categories I, III, IV
Risk Category III	Buildings and other structures with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.
Risk Category IV	Buildings and other structures designated as essential facilities

Evacuation procedures for emergency response are still necessary

Seismic Performance-Based Design Objectives (Concept)

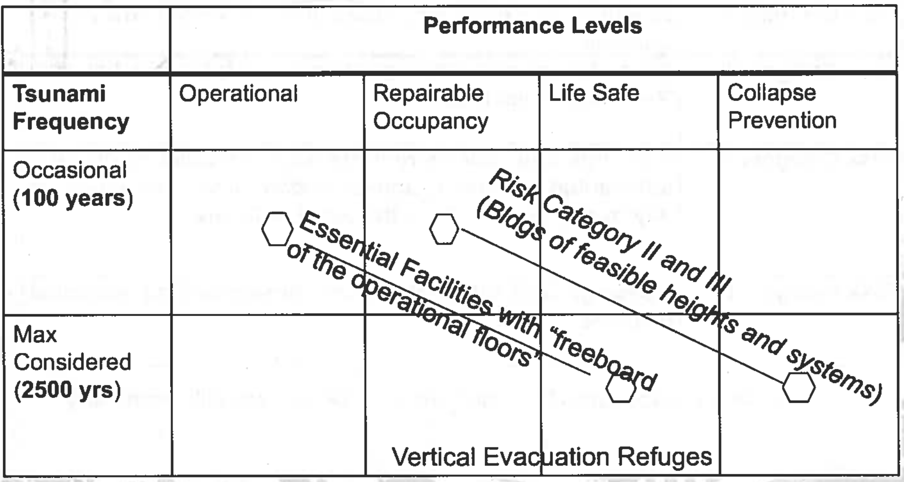


	Performance Levels			
Earthquake Frequency	Operational	Immediate Occupancy	Life Safe	Collapse Prevention
Occasional (100 years)				
Max Considered (2500 yrs)				

Essential Facilities

Risk Category II

Tsunami Performance Design Objectives (Concept)



	Performance Levels			
Tsunami Frequency	Operational	Repairable Occupancy	Life Safe	Collapse Prevention
Occasional (100 years)				
Max Considered (2500 yrs)				

Essential Facilities with "freeboard of the operational floors"

Risk Category II and III (Bldgs of feasible heights and systems)

Vertical Evacuation Refuges

ASCE Tsunami Loads and Effects (TLE) Committee

Relationship of Seismic and Tsunami Engineering

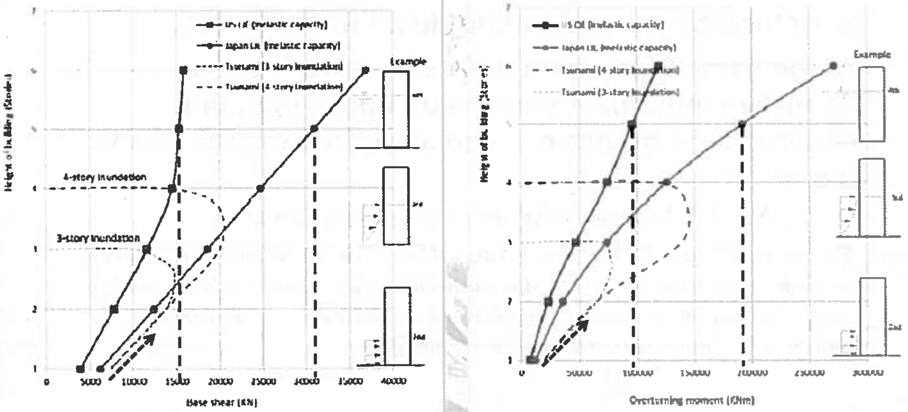
- The increments of height and seismic design level necessary along with other tsunami-specific countermeasures to provide a desired level of structural performance should be investigated.
- At the same time, code differences from other countries must be considered in post-tsunami observations before extrapolating that experience to the USA.
  - USJNR Joint Panel on Wind and Seismic Effects Strategic Plan (2011-2015) Focus Item: *Pursue collaborative research to study the effects of the Tohoku tsunami on Japanese buildings, bridges and other structures that are similar to US construction, in order to enhance and modernize tsunami design codes.*

Example of Comparing Seismic Base Shear vs. Tsunami Hydrodynamic Drag

- Seismic design alone does not result in acceptable tsunami performance due to the local effects of concentrated fluid and impact forces on elements as well as scour effects. (Necessary but not sufficient)
  - Consider low-rise concrete construction; 2-6 floors
  - Assume building undamaged by earthquake
  - Evaluate capacity using Ω x required E
    - Base shear
    - Overturning moment
  - Foundation assumed to exceed building capacity
  - Both ASCE 7-10 and Japan Code considered
  - Consider tsunami flow depth increasing to 3 or 4 floor levels.
  - Tsunami hydrodynamic drag assuming building is 25% open (75% blocked by structure, debris, etc.)

Reinforced Concrete Special Moment Resisting Frame

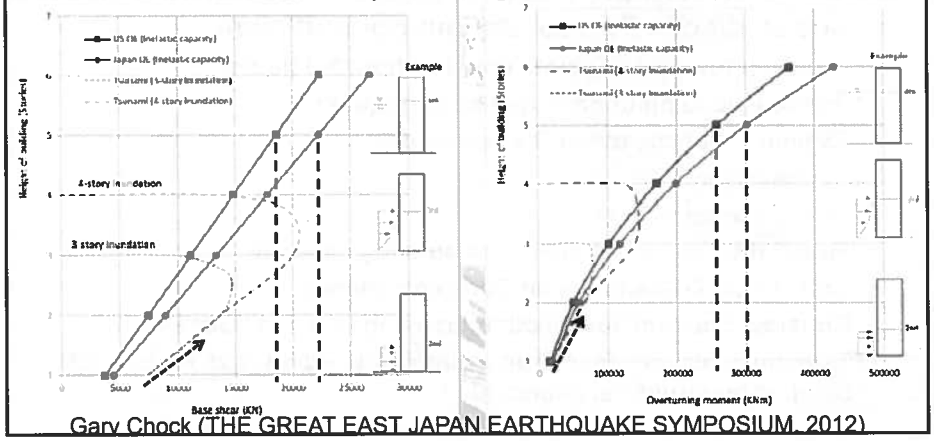
- Each dashed load curve represents the sequence of hydrodynamic loading as inundation increases during the tsunami
- Example 5-story SMRF – US building can survive 3-story but not 4-story flow – Japan building can survive 4-story flow



Gary Chock (THE GREAT EAST JAPAN EARTHQUAKE SYMPOSIUM, 2012)

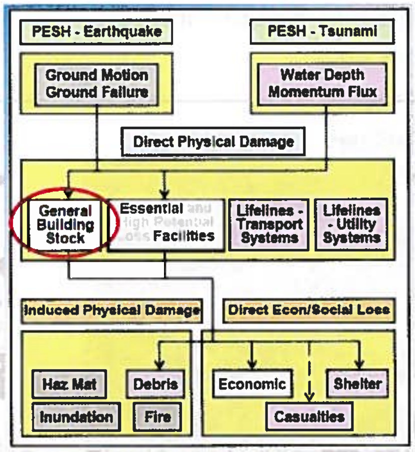
Special Reinforced Concrete Shear Walls

- Each dashed load curve represents the sequence of hydrodynamic loading as inundation increases during the tsunami
- Example 5-story SRCSW – US building can survive 3-story but not 4-story flow – Japan building can survive 4-story flow



Gary Chock (THE GREAT EAST JAPAN EARTHQUAKE SYMPOSIUM, 2012)

Community-Level Physical Damage and Losses – HAZUS Tsunami in development in addition to existing HAZUS Flood Loss Software



HAZUS Tsunami Hazard Assessment to use NOAA PMEL's MOST Inundation Forecasting model

- General Building Stock (and Essential Facilities)
- •Input Modules
  - Earthquake Ground Motion
  - Earthquake Ground Failure
  - Tsunami Flood (Water Depth)
  - Tsunami Flow (Momentum Flux)
- •Output Modules -Induced Damage and Losses
  - Debris
  - (Casualties)
  - Shelter
  - Direct Economic

Requested Priorities of R & D Needs

- Probabilistic Design Maps for appropriate performance targets
- Tools to evaluate hydrographs of h, v *and* hv^2. Developing governing load time-history based on the site's flow/velocity depth time-history;
- Inundation flow models that accurately capture the characteristics of debris floods and the effects of bottom friction
- Flow through urban environments with structures and buildings of various fragilities that may become "erodable"
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- Structural response metrics for performance-based tsunami design with consideration of co-seismic effects/damage

Any Questions?

- ASCE 7 Tsunami Loads and Effects Subcommittee
  - Gary Chock gchock@martinchock.com
- ASCE 7 Flood Load Subcommittee
  - Chris Jones chris.jones@earthlink.net