Evaluation & Mitigation of Liquefaction Hazard for Engineering Practice
EERI Short Course April 9, 2014 Salt Lake City, Utah

Geotechnics of Tsunami Flood Losses

Tsunami Scour &

Geo-Risk Reduction

Mathew Francis, PE, M ASCE mathew.francis@urs.com
GeoEngineering & Resilience Manager, URS Corporation www.urs.com
Chair, ASCE Committee on Critical Infrastructure ciasce.asce.org

Presentation Outline

Liquefaction: A Hydraulic Hazard?

DRR Focus from a Geotechnical Engineering Perspective

1. Historical perspectives
2. Tohoku observations
3. **ASCE 7 tsunami loads & effects**
4. ASCE 24 flood scour provisions
5. Needed validations & measurements
6. **DRR through geo-risk reduction**

Ref 2014 World Disasters Report, IFRC

Geo-disasters vs Hydro-disasters

- Frequency: 10% 90%
- $ Losses: 30% 70%
- Fatalities 65% 35%

TABLE 6 Total number of people reported killed, by type of phenomenon and year (2003–2012)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Droughts/food insecurity	38	80	88	208	n.a.	6	2	2	n.a.	n.a.	424
Earthquakes/tsunamis	29,617	227,290	76,241	6,692	780	87,918	1,888	226,735	20,946	711	678,818
Extreme temperatures	74,748	556	814	5,104	1,044	1,608	1,212	57,064	806	1,758	144,714
Floods[1]	3,770	7,102	5,754	5,845	8,565	4,029	3,534	8,571	6,142	3,574	56,886
Forest/scrub fires	47	14	47	16	150	86	190	135	10	22	717
Insect infestation	n.d.r.	n.a.	n.d.r.	n.a.	n.d.r.	n.d.r.	n.a.	n.d.r.	n.d.r.	n.d.r.	n.a.
Mass movement: dry[2]	n.d.r.	44	n.d.r.	11	n.d.r.	120	36	n.d.r.	n.d.r.	16	227
Mass movement: wet[3]	707	313	646	1,638	271	504	657	3,402	314	504	8,956
Volcanic eruptions	n.a.	2	3	5	11	16	n.a.	323	3	n.a.	363
Windstorms	1,030	6,609	5,294	4,329	6,035	140,985	3,287	1,498	3,103	3,071	175,241
Subtotal climato-, hydro- and meteorological disasters	*80,340*	*14,674*	*12,643*	*17,140*	*16,065*	*147,218*	*8,882*	*70,672*	*10,375*	*8,929*	*386,938*
Subtotal geophysical disasters	*29,617*	*227,336*	*76,244*	*6,708*	*791*	*88,054*	*1,924*	*227,058*	*20,949*	*727*	*679,408*
Total natural disasters	**109,957**	**242,010**	**88,887**	**23,848**	**16,856**	**235,272**	**10,806**	**297,730**	**31,324**	**9,656**	**1,066,346**
Industrial accidents	1,444	1,797	2,281	1,857	1,667	776	933	1,061	684	787	13,287
Miscellaneous accidents	1,438	2,115	2,669	1,126	909	895	911	1,507	755	1,112	13,437
Transport accidents	7,868	6,417	6,702	7,021	5,075	5,275	5,021	4,176	5,144	4,151	56,850
Total technological disasters	**10,750**	**10,329**	**11,652**	**10,004**	**7,651**	**6,946**	**6,865**	**6,744**	**6,583**	**6,050**	**83,574**
Total	**120,707**	**252,339**	**100,539**	**33,852**	**24,507**	**242,218**	**17,671**	**304,474**	**37,907**	**15,706**	**1,149,920**

Source: EM-DAT, CRED, University of Louvain, Belgium

1. Historic Perspectives on Geo-Scour

Local Scour vs General Erosion

- 1930s-Terzaghi vs. Fillunger theories
- 1950s-River/Bridge fieldwork-Einstein
- 1960s- DOT scour programs emerge
- 1970s- HEC process development
- 1980s- FEMA tsunami scour criteria
- 1990s- Theorize tsunami liquefaction
- Post 2004 - Tsunami scour liquefaction data; FEMA P55 & P646 update
- Post 2011- ASCE 7: refine tsunami scour limits with flow, soil, site effects.

About 60% of US bridge failures are due to scour. Only 1 DOT in the USA manages scour in the structures geotechnical dept. All others manage scour in the hydraulics dept.
– Ref. Prof. Jean Louis-Briaud, Texas A&M

2. Tohoku 2011 Scour

Local scour
General erosion
Channel scour
Overtopping plunging scour

Observations:

Tohoku scour took many forms, from myriad combinations of water, soils & topography.

Conclusions: Needed ASCE 7 Mitigation Alternatives

- Elevate- structure, site
- Harden Foundations
- Countermeasures – barriers, MSE walls, paving, soil-cement

Perspective by Comparison

	2004 Sumatra Tsunami	**2011 Tohoku Tsunami**
Magnitude	M9.3	M9.1
Rupture area:	800 x 100 mi	300 x 100 mi
Rupture subsidence:	~25 ft	~25 ft
Maximum runup:	80 ft	150 ft
Infrastructure damage:	**~35B**	**~350B**
Population Affected:	~3M	~3M
Displaced:	~500k	~250k
Casualties	**~250,000**	**~25,000**

Onagawa

Otsuchi

8m tsunami wall intact parallel to flow
Large scour holes in concrete pavement.

6m Sendai Seawall

Kashima Port north

Iwaki Onahama:

Combined seismic liquefaction & tsunami scour

Ref. Tonkin, Francis & Bricker, 2013

Figure 1. Local scour, Koh Khao, Thailand. Case SS-4.

Figure 2. Overtopping scour, Taito Port, Japan. Case TO-1.

Figure 3. Channelized scour. Great Nicobar Case RS-3.

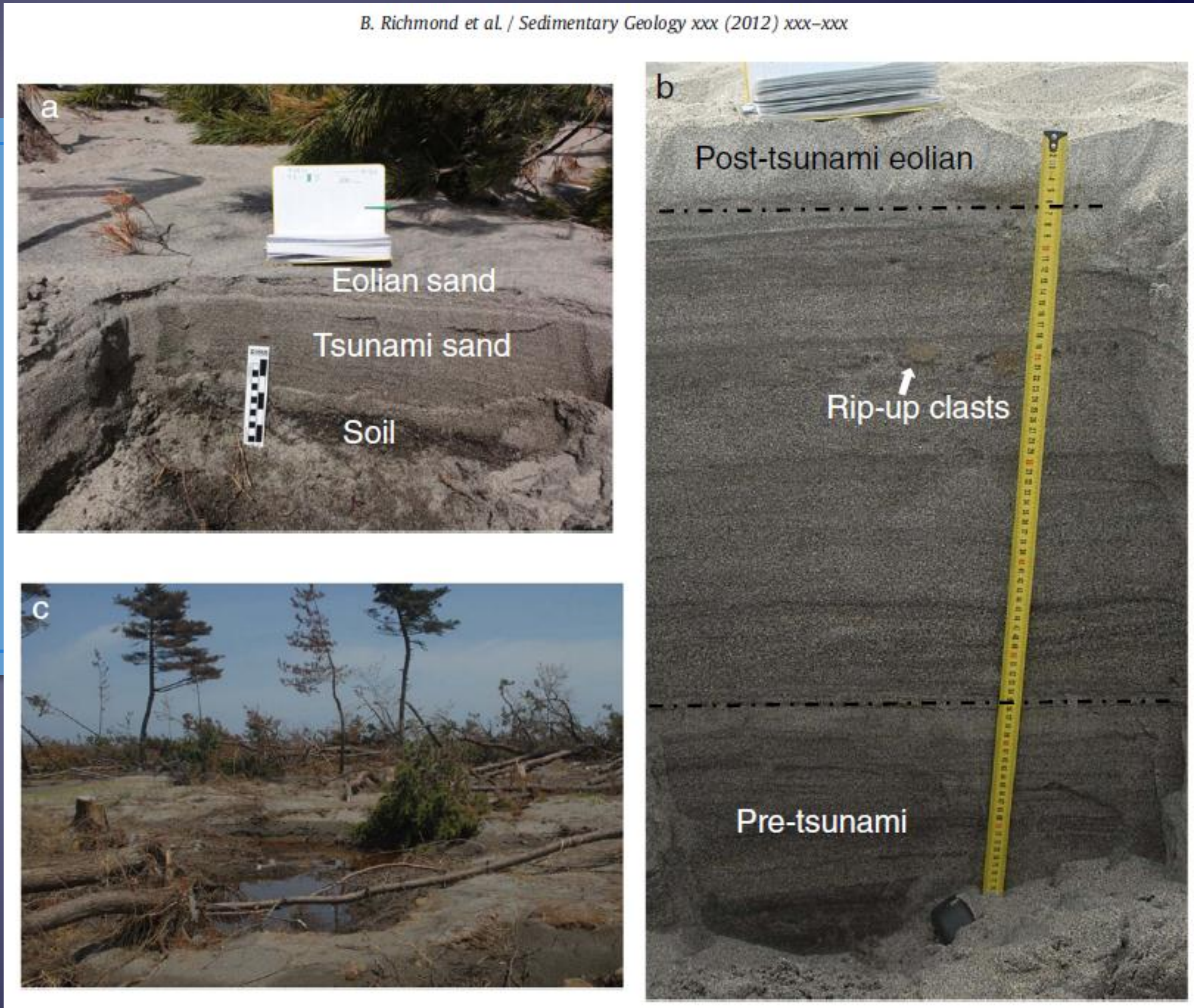
Figure 4. General scour. Yamamoto-cho, Japan. Case TN-12.

Scour modes identified for ASCE 7

• Sendai Plain, 2011

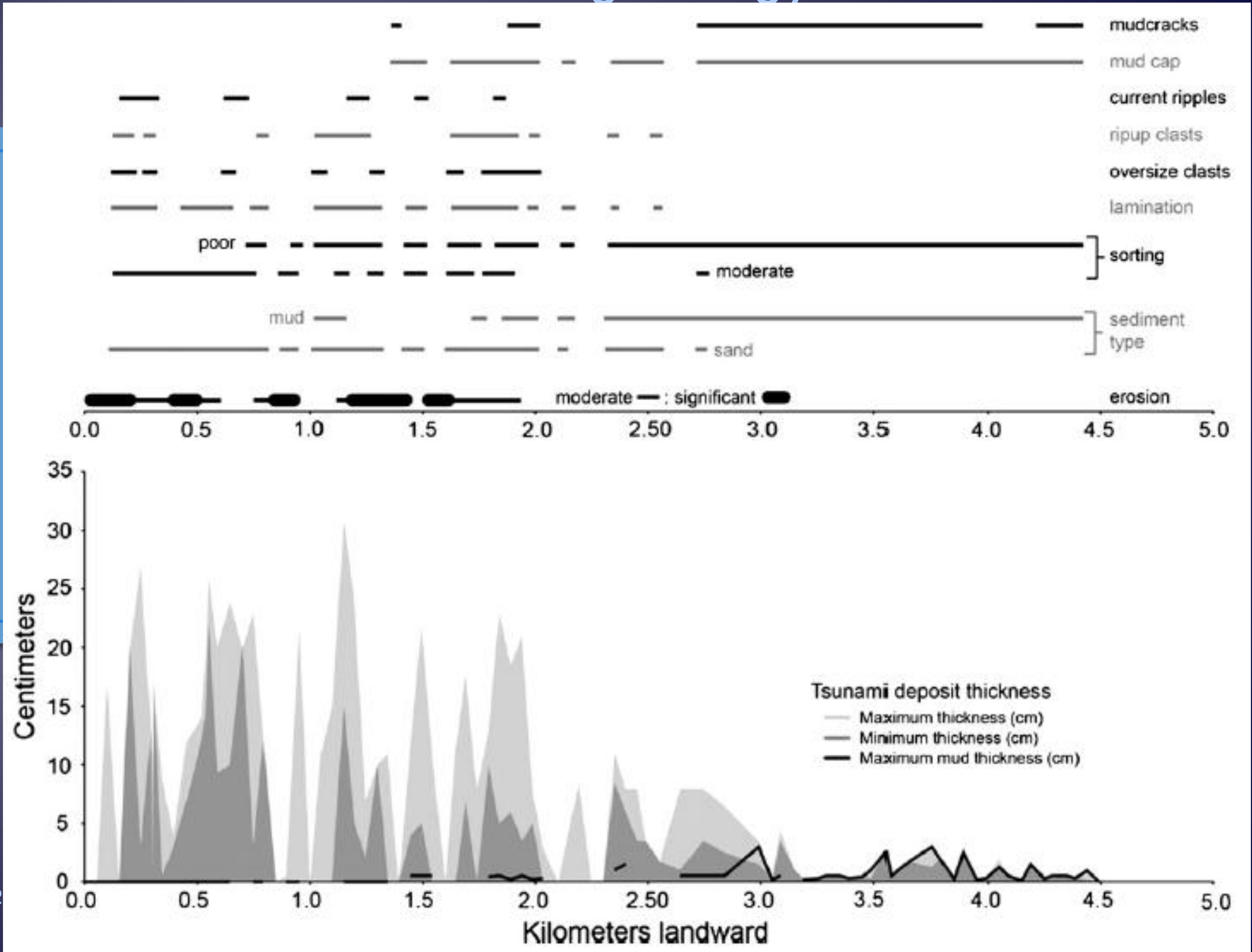
Fig. 5. Google Earth image taken 4/5/2011 showing the survey transect line, remnant artificial dune pedestals and associated shore-parallel scour depressions, probable si
partially-infilled return-flow channels on the beach face and average flow direction as determined from bent pine trees.

- Tsunami deposits- infilled scour



Ref, Richmond et al, 2012.

Modeling energy distributions



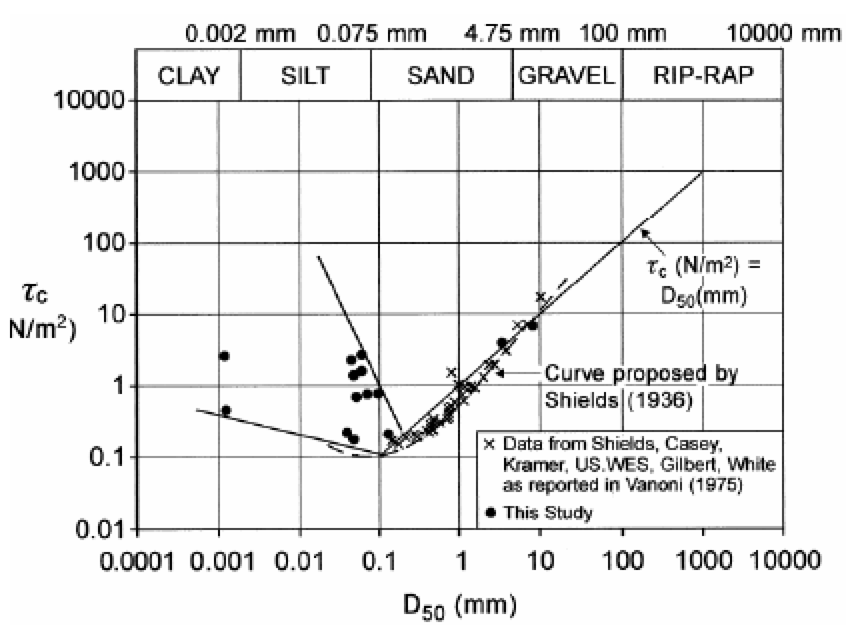


Figure 4. SRICOS scour data comparison, critical shear stress vs. soil particle size (TRB, 2003).

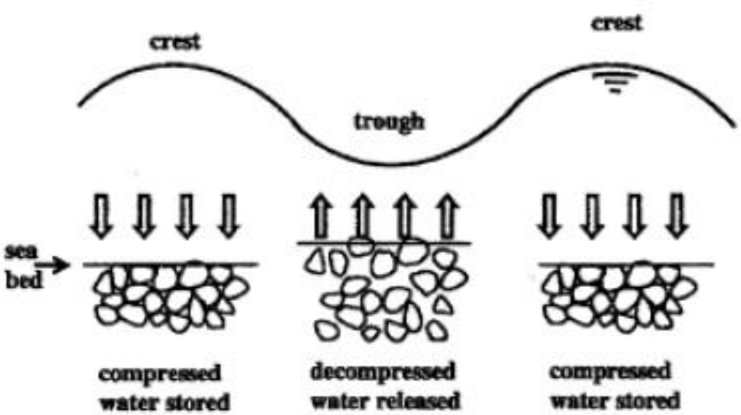


Figure 8. Liquefaction caused by wave (DeGroot, ASCE 2006).

Figure 28. *Gary Chock measures the depth of scour below a building corner (photo: Robertson/ASCE).*

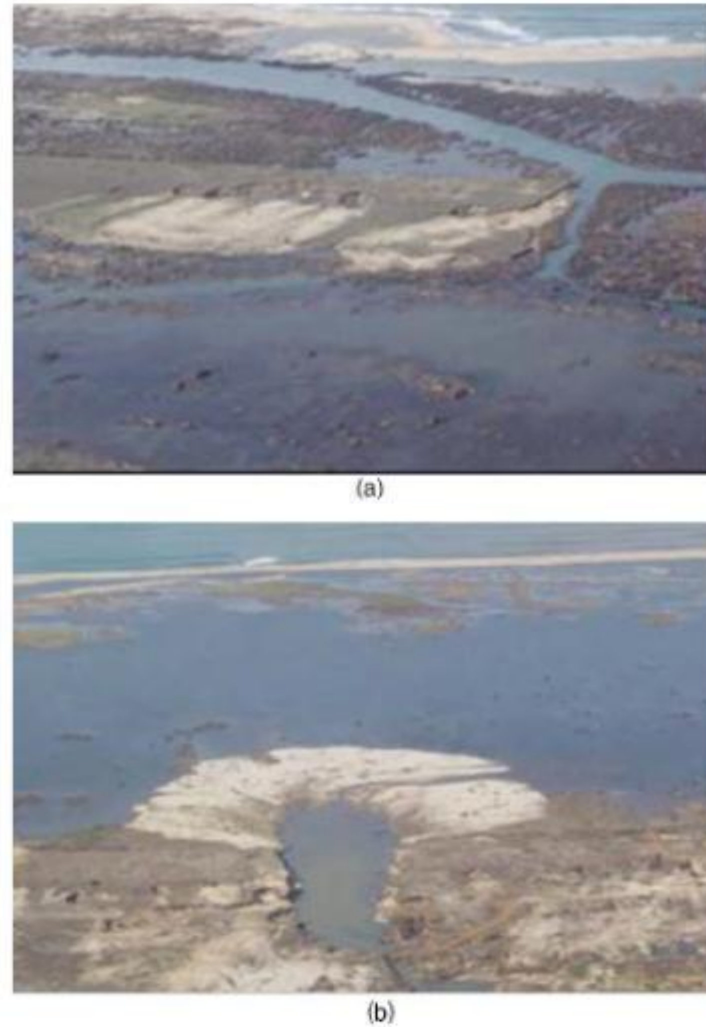


Figure 19. Liquefaction sand boils from the great tsunami, northwest coast of Sumatra (EERI, 2006, photo by W. Sengara).

Ref Francis, EERI Fellowship Report 2007 & Chock, EERI Special Report, 2011

Ref Tonkin, Francis & Bricker, 2013

Scour observations

IOT & Tohoku Events

Table 1. Scour Measurements: Estimated Flow and Observed Scour Depths in Meters

Case	Location	Flow Depth	Scour Depth	Scour Mechanism	Scour Feature
Sumatra Andaman Tsunami: Road Scour (RS) and Structure Scour (SS). Source: Francis (2008)					
RS-1	Aceh Harbor	2.4	2.5	General	Road / bridge washout
RS-2	Gle Bruk, Sumatra	2.4	2.5	Local	Abutment washout
RS-3	Great Nicobar	2.2	4.0	Channelized	Drawdown along road
RS-4	Pt. Blair, Andaman	2.2	1.0	Local	Seawall road scour
RS-5	Bang Tao, Phuket	2.15	2.0	General	Road scour
RS-6	Fishery Pier, Phangaa	2.15	1.5	Local	Abutment sinkhole
RS-7	Kuraburi, Phangaa	1.8	1.0	General	Road scour
RS-8	Ranong	1.8	1.0	General	Road boil
RS-9	Chennai	2.6	1.0	General	Road scour
RS-10	Kottapatnam	2.6	0.5	General	Road scour
RS-11	Amblangoda	2.2	1.5	General	Railway scour
SS-1	Lock Nga, Aceh	2.4	0.5	General	Flow though structure
SS-2	Kamala, Phuket	2.15	2.0	Local	Footing scour
SS-3	Khao Lak	2.15	2.0	Local	Footing scour
SS-4	Koh Khao	1.8	2.0	Local	Footing and utilities
SS-5	Kalapakkom	2.6	1.5	Local	Footing scour
SS-6	Cuddalore	2.6	0.5	Local	Footing scour
SS-7	Allapad, Kerala	1.2	1.0	Local	Footing scour
SS-8	Xaafuun Peninsula	2.65	0.5	Local	Footing scour
Tohoku Tsunami: Tohoku North (TN) and Tohoku South (TS). Source: Chock *et al.* (2012).					
TN-1	Hachinohe Kanehama	10.5	1.0	General	Stream bank, culvert
TN-2	Hirochono Taneichi	6.0	2.0	Local	Footing scour
TN-4	Noda Beach	14.0	3.0	Local	Drain outlet
TN-5a	Miyako City	6.0	4.0	Local	Bridge approach
TN-5b	Miyako City	6.0	2.0	Local	Viaduct pier
TN-6	Otsuchi Harbor	12.0	4.0	Plunging	Tsunami barrier
TN-7	Kamaishi-Ryoishi	17.0	3.0	Local	Wall and barrier gate
TN-8	Kamaishi City	11.0	3.0	Local	Building foundation
TN-9	Kamaishi Ozakishi	~ 15	1.0	General	Narrow valley
TN-10	Onagawa Harbor	17.0	3.0	General	Paved waterfront
TN-11	Sendai Airport	8.0	4.0	Overtopping	Seawall
TN-12	Nakahama School	9.0	2.0	General	Open plain
TS-13	Kashima Port	4.0	2.0	Local	Footings
TS-14	Nikawahama	5.0	< 1	General	Grass berm
TS-15	Hasaki Port	5.0	3.0	General	Paved pier
TS-16	Choshi Marina	5.5	1.0	General	Sump tank
TS-17	Iioka Inlet	5.0	3.0	Local	Roadway by channel

Case	Location	Flow Depth	Scour Depth	Scour Mechanism	Scour Feature
TS-18	Ichinomiya Inlet	3.0	2.0	Local	Bridge abutment
TS-19	Taito Fishing Port	3.0	1.0	Channelized	Drawdown at seawall
TS-20	Hebara Bridge	2.5	1.0	General	Beach
Tohoku Overtopping Examples (TO). Source: Bricker *et al.* (2012).					
TO-1	Taito Fishing Port	0.3	0.4	Overtopping	Seawall
TO-2	Iikoa Town	1.0	1.5	Overtopping	Floodwall
TO-3	Iwaki City	2.0	> 1.5	Overtopping	Seawall
TO-4	Onahama Port	2.0	2.0	Local	Footing

Ref Tonkin, Francis & Bricker, 2013

Scour patterns

Combined IOT & Tohoku event data

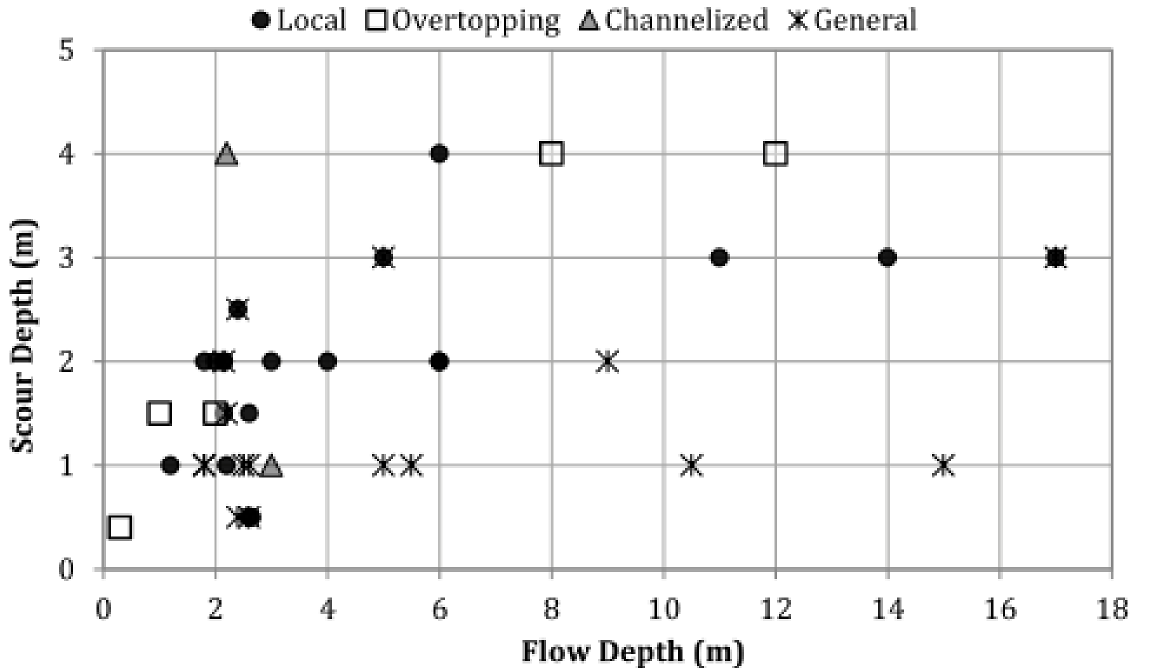


Figure 5. Correlation between observed scour depth and estimated flow depth.

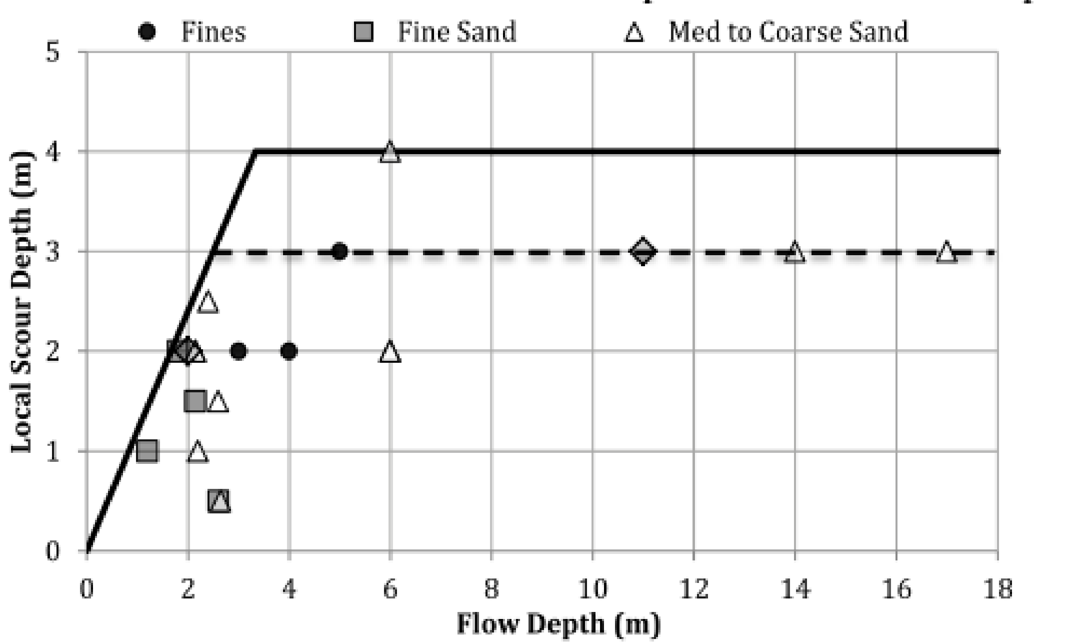
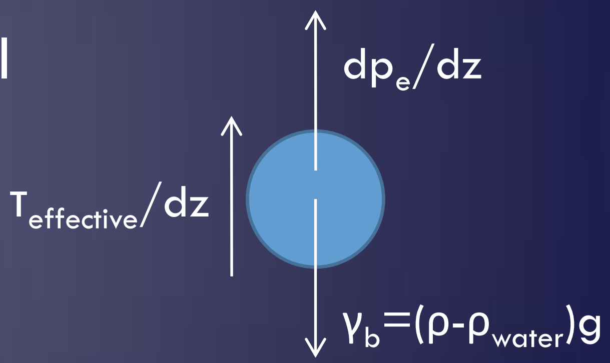


Figure 6. Observed local scour depth and estimated flow depth for different sediment types, with bounding plausible design envelopes shown.

Enhanced scour due to liquefaction induced by rapid drawdown

Tonkin & Yeh (2003) applying Terzaghi (1925):

- Soil supported by both excess pore pressure gradient and intergranular shear
- The fraction of the submerged weight of a soil particle supported by the pore pressure gradient is $\Lambda = \frac{dp_e/dz}{\gamma_b}$
- Experiments show that above a critical value (Λ_T) when $\Lambda > 0.5$, $\tau_{effective}$ is reduced enough to result in less frictional resistance to scour
- Drawdown-induced liquefaction enhances scour



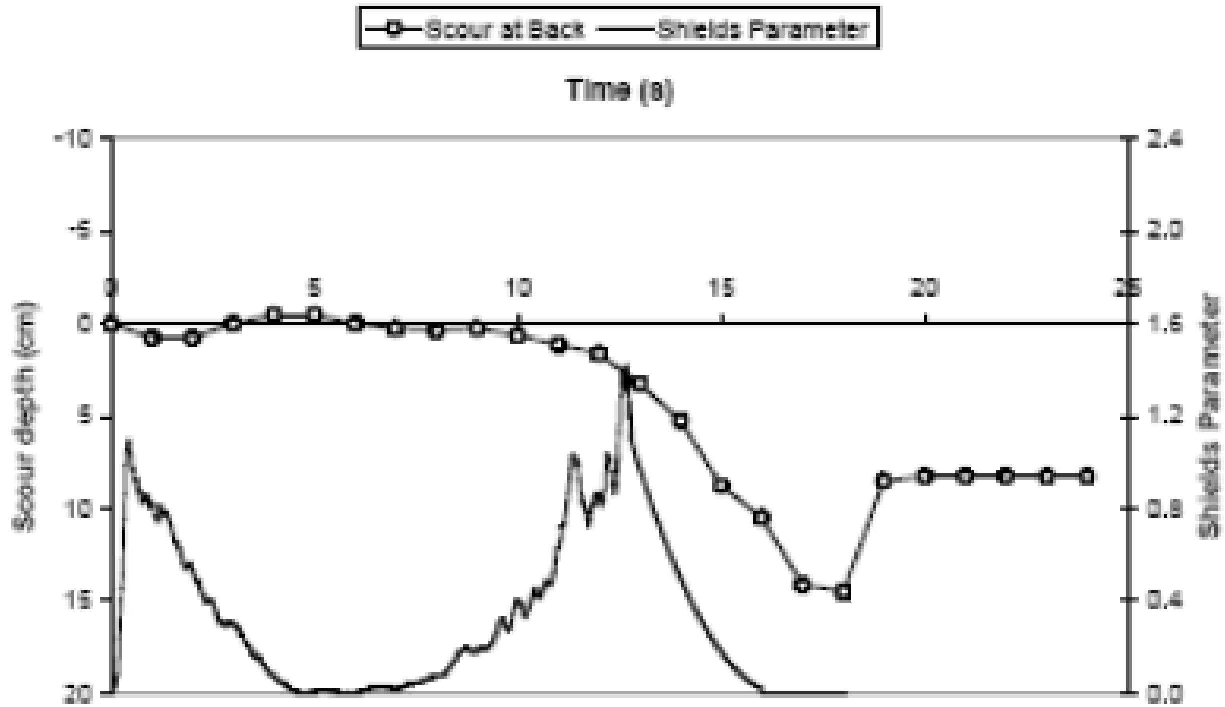


Figure 12. Measured scour depth and estimated Shields parameter for a cylinder initially at the shoreline during long period wave modeling. Water depth=2.45m, offshore incident solitary-wave height H=33cm. H/h=0.09 (Yeh et al. 2003).

Limits on enhanced scour depth due to rapid-drawdown-induced liquefaction

- Diffusion of excess pore pressure within a saturated soil per Terzaghi (1956)

$$\frac{\partial p_e}{\partial t} = c_v \frac{\partial^2 p_e}{\partial z^2}$$

- Diffusion time scale is d_s^2/c_v, so drawdown time ΔT must be shorter than this: $\Delta T < d_s^2/c_v$
- Change in head ΔP must be at least as large as the change in excess pore pressure over the scour depth: $\Delta P > \Lambda_T \gamma_b d_s$
- Combine for limits on enhanced scour depth due to pore pressure softening

$$\sqrt{c_v \Delta T} < d_s < \frac{\Delta P}{\Lambda_T \gamma_b}$$

Upper limit on enhanced scour depth due to rapid-drawdown-induced liquefaction

$$\sqrt{c_v \Delta T} < d_s < \frac{\Delta P}{\Lambda_T \gamma_b}$$

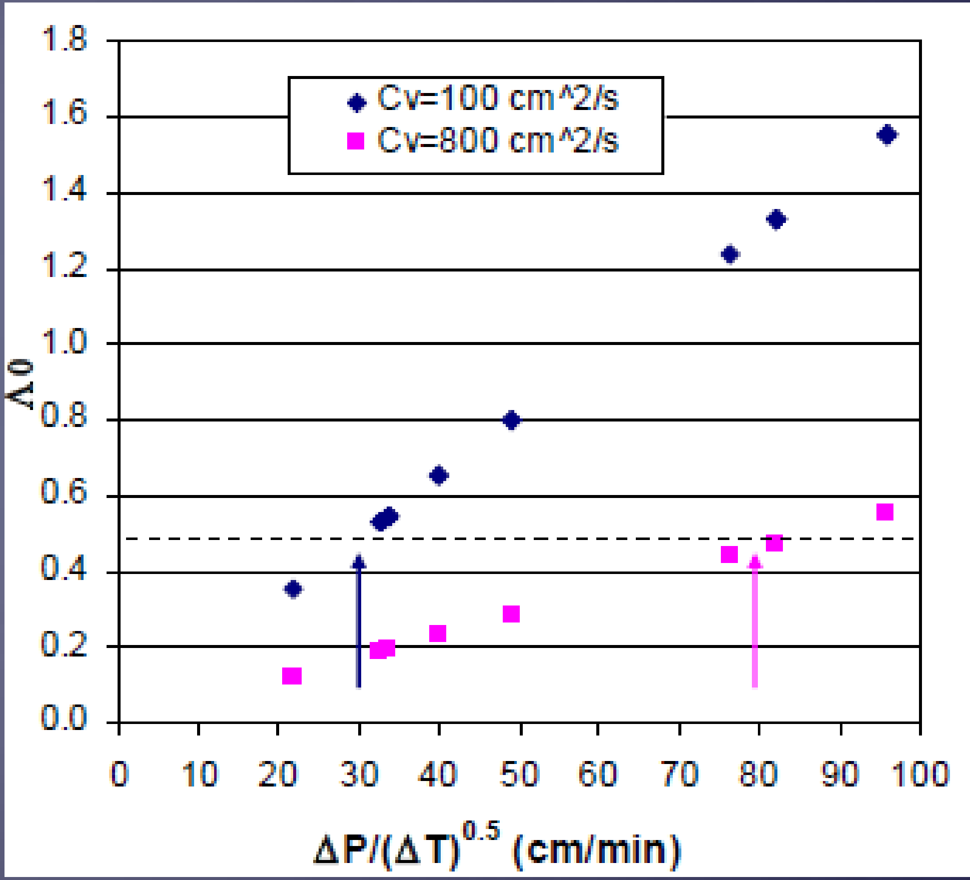
varies with soil type

constant among soil types

- Measured scour depths did not show a dependence on soil type, so the right-hand inequality appears dominant
- Estimate $\Delta P = H_{flow}$ (flood depth), $\gamma_b = 1.65$ (typical submerged soil specific weight), and $\Lambda_T = 0.5$ (from experiments)
- Results in $d_s < 1.2 H_{flow}$
- Same as measured value for local scour, so enhanced local scour due to pore pressure softening appears an important process during large tsunami events!

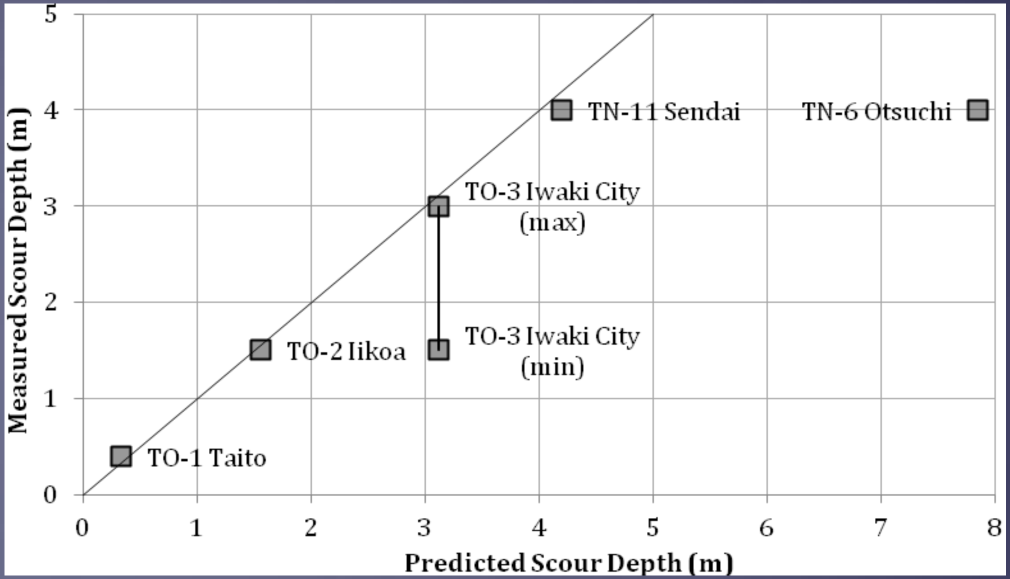
Indian Ocean Tsunami sites, hypothesized liquefaction for Lambda>0.5

1.2-2.6m tide gauge wave heights, 5-50min periods

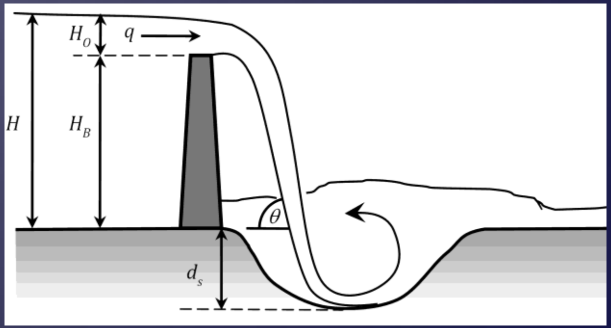


Ref Francis, 2007 EERI Fellowship Report

Measured scour depth due to overtopping scour



- Can be predicted using Fahlbusch (1994) with limit
- $$\begin{cases} d_{scour} = 2.8\sqrt{qU\sin\theta/g} \\ \max \quad d_{scour} = 4m \end{cases}$$



Ref Tonkin, Francis & Bricker, ASCE TCLEE Conf. 2013 Chengdu

Conclusions on Tsunami Scour Analysis

- Upper limit **to** **<u>local scour</u>** $\begin{cases} d_{scour} = 1.2H_{flow} \\ \max \quad d_{scour} = 3m \end{cases}$
  - Pore pressure softening important
- Upper limit to **<u>overtopping scour</u>** $\begin{cases} d_{scour} = 2.8\sqrt{qUsin\theta/g} \\ \max \quad d_{scour} = 4m \end{cases}$
- No clear dependence on soil type
  - Data quantity not sufficient?
  - High energy means macro-scale (clast) sediment transport, entrapped air pluviation, non individual grain suspension? (Ref Harry Yeh, 2013)

3. ASCE 7 Tsunami Loads & Effects

Ref. ASCE 7-16 provisional draft TOC

6.12 Foundation Design
- 6.12.1 General
- 6.12.2 Load and Effect Characterization
  - 6.12.2.1 Flow Loads
  - 6.12.2.2 Uplift and Under-Seepage Forces
  - 6.12.2.3 Loss of Strength
  - 6.12.2.4 General Site Erosion
  - 6.12.2.5 Local Scour
    - 6.12.2.5.1 Sustained Flow Scour
    - 6.12.2.5.2 Plunging Scour
  - 6.12.2.6 Horizontal Soil Loads
- 6.12.3 Foundation Performance Criteria
  - 6.12.3.1 Factor of Safety
  - 6.12.3.2 Displacements
  - 6.12.3.3 Deep Foundations
  - 6.12.3.3 Fill
- 6.12.4Foundation Countermeasures
  - 6.12.4.1 Pavements
  - 6.12.4.2 Geotextiles and Reinforced Earth Systems
  - 6.12.4.3 Facing Systems
  - 6.12.4.4 Ground Improvement
- 6.12.5 Foundation System Analysis for Risk Category IV

6.13 Structural Countermeasures for Tsunami Loading
- 6.13.1 Open Structures
- 6.13.2 Altering or Retrofitting Existing Structures
- 6.13.3 Tsunami Mitigation Barriers
  - 6.13.3.1 Methodology
  - 6.13.3.2 Site Layout

The basic Tonkin equation (2003 Tonkin & Yeh):

$$\Lambda(d_s) = \frac{\Delta P}{\gamma_b\, d_s}\left(1 - 4\mathrm{i}^2\mathrm{erfc}\left[\frac{d_s}{2\sqrt{c_v \Delta T}}\right]\right)$$

Ref. Susan Tonkin, Moffat Nichol

Note: The maximum scour d_s limits at 1.2H as ΔT goes to zero

As the flow height gets larger, the time scale gets longer, and scour depth moves further below the 1.2H theoretical limit, supporting observations of depth limitations.

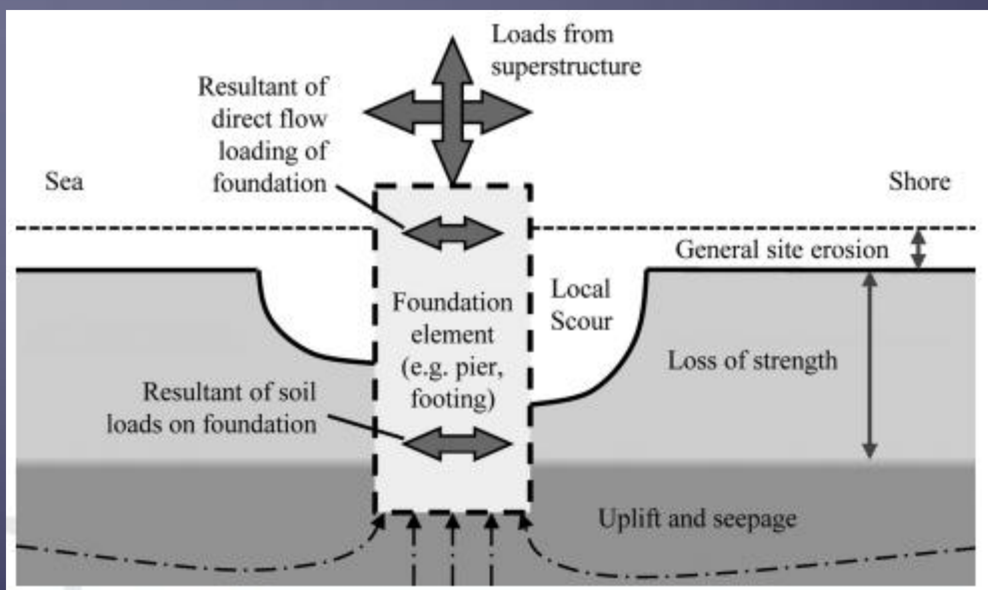


Figure C6.12-1. Schematic of tsunami loading condition for a foundation element.

Ref. ASCE 7-16 provisional draft

- Conceptual comparison: Seismic vs Tsunami Liquefaction

Ref. ASCE 7-16 provisional draft

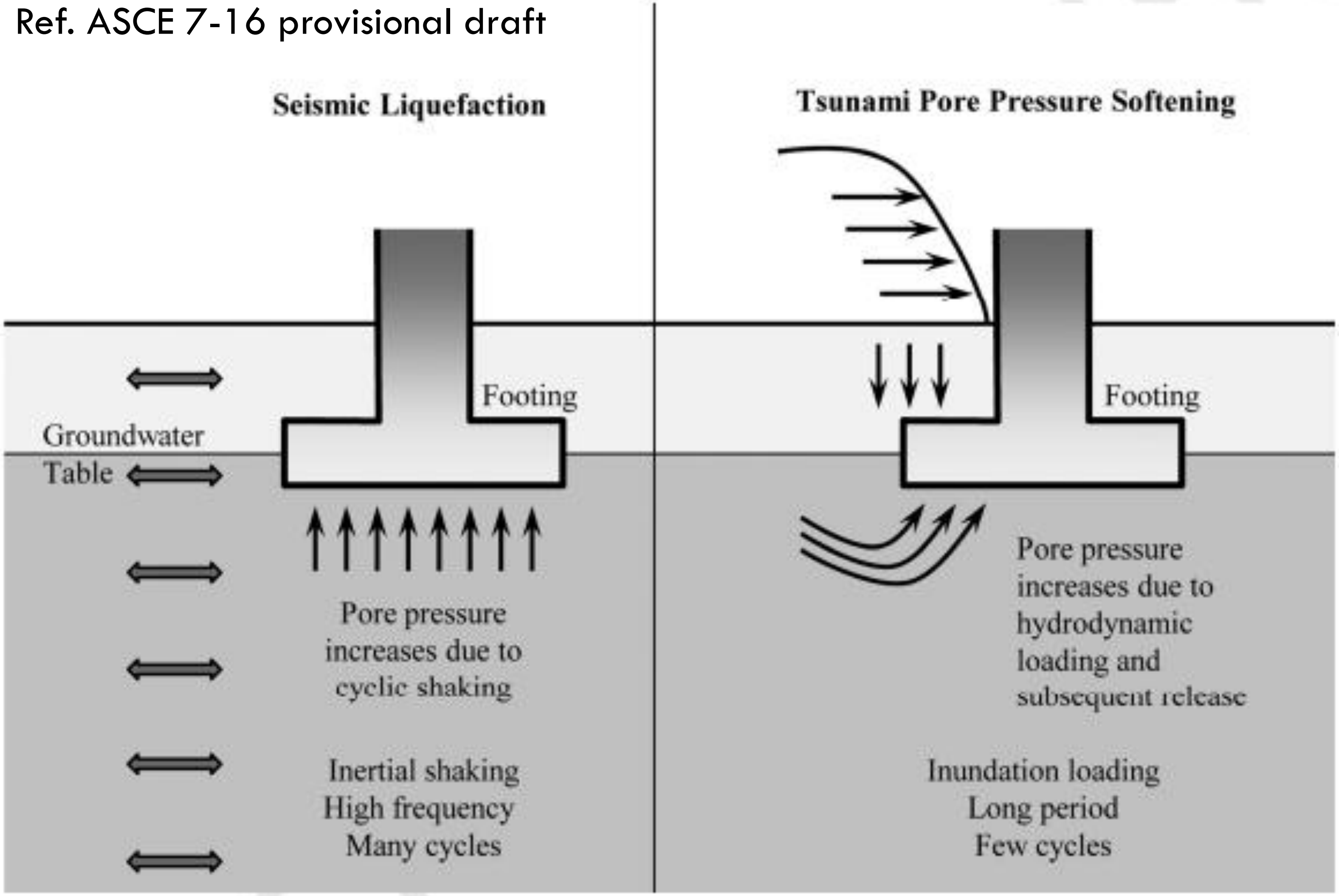


Figure C6.12-2. Schematic diagram showing differences between seismic liquefaction and tsunami-induced pore pressure softening.

ASCE 7 tsunami foundation design procedure

Ref. ASCE 7-16 provisional draft

- Foundations & barriers must consider soil & site changes from design event at end of shaking impacts
- Use design load combinations
- FS 1.3- uplift/seepage force (USACE EM1110-2-2100)
- Strength loss for scour D=1.2H
- General erosion- must include amplification/channelizing, except rock or non-erodable at v>9m/s

ASCE 7 tsunami local scour procedure

Table 6.12-1 Design Local Scour Depth due to Sustained Flow and Pore Pressure Softenin

Flow Depth *h*	Scour Depth *D**
< 10 ft (3.05 m)	1.2h
≥10 ft (3.05 m)	12 ft (3.66 m)

* Not applicable to scour of sites with intact rock strata

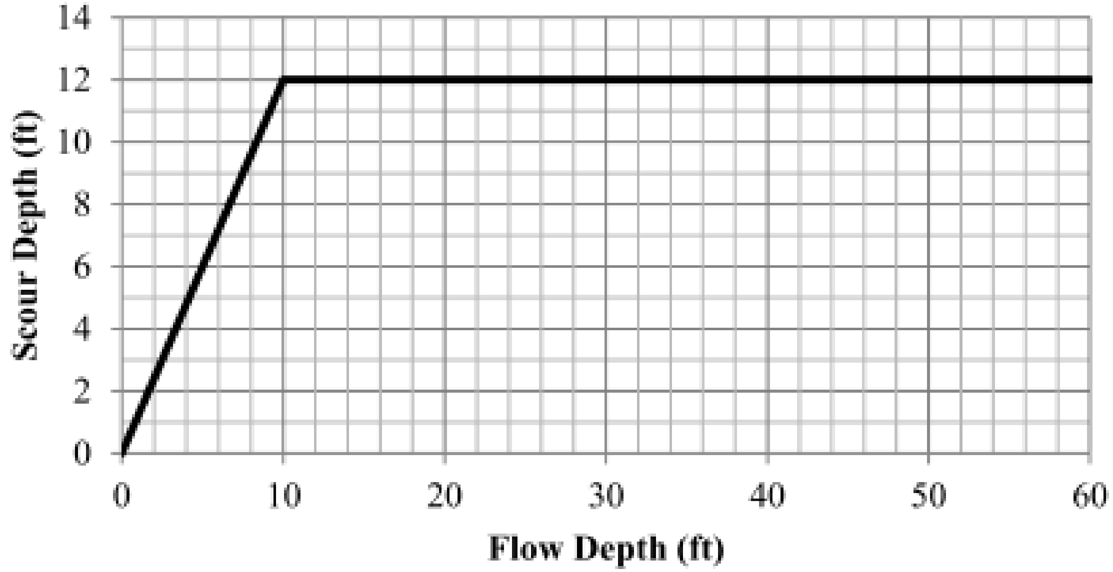


Figure 6.12-1 Local Scour Depth due to Sustained Flow and Pore Pressure Softening

Ref. ASCE 7-16 provisional draft

- Adjust downward linearly for Froude No. Fr<0.5

ASCE 7 tsunami plunging scour procedure

$$D_s = c_{2V}\sqrt{\frac{qU\sin\psi}{g}} \quad \text{(Eq. 6.12.5-1)}$$

$$U = \sqrt{2g(h+d_d)} \quad \text{(Eq. 6.12.5-4)}$$

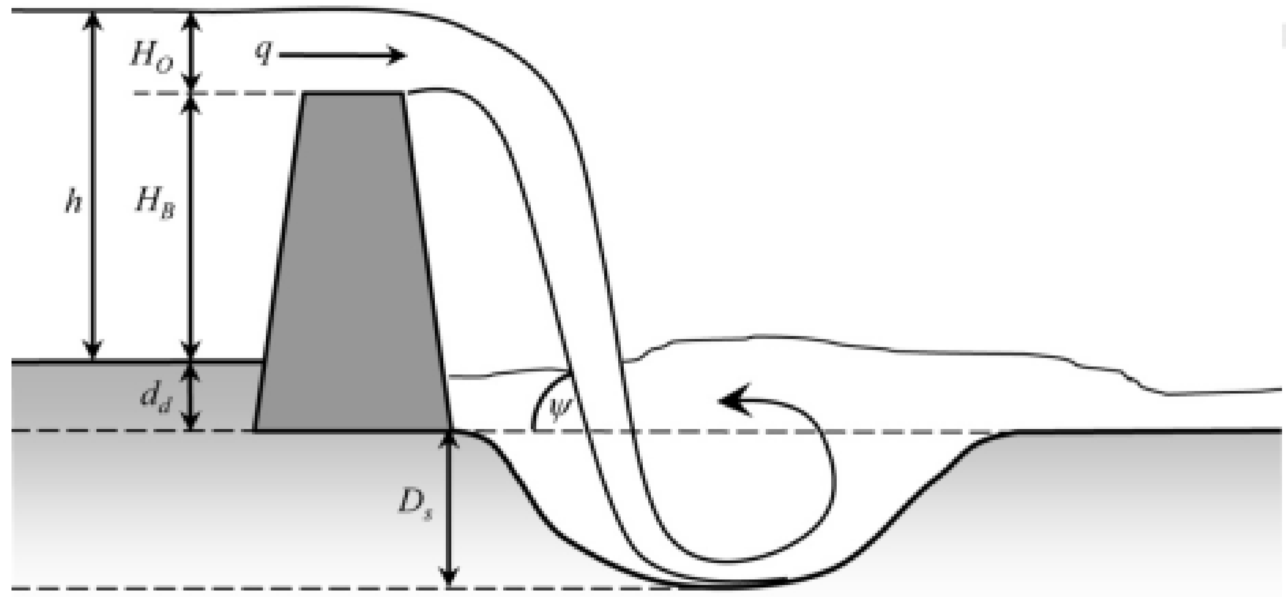


Figure 6.12-2 Plunging Scour Parameters

Ref. ASCE 7-16 provisional draft

- Dynamic modeling is permitted to supersede simplified procedure

ASCE 7 tsunami foundation performance criteria

Ref. ASCE 7-16 provisional draft

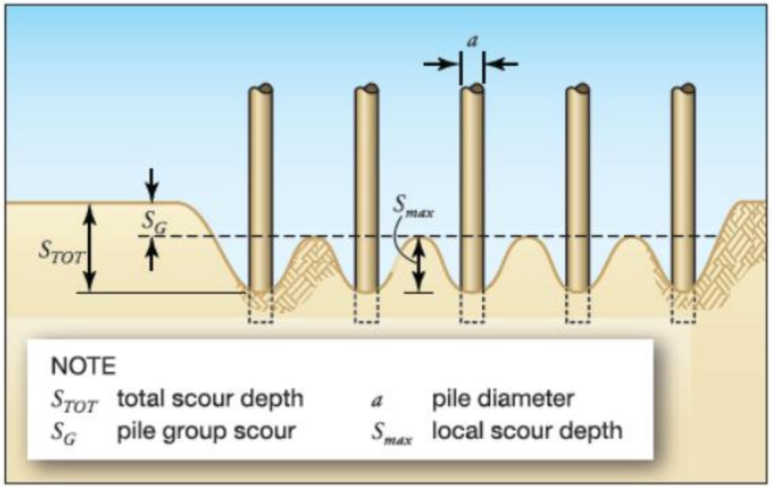
1. **FS:** 1.3 for bearing capacity, lateral/overturning, internal stability, slope stability
2. **Displacement:** Dv, Dh (footing & slopes) w traditional EP calculations to satisfy structural criteria.
3. **Fill:** follow ASCE 24- must be stable during inundation & resist loads. Add erosion/scour protection if needed

(also ref. FEMA 55, section 10.3)

ASCE 7 tsunami foundation performance criteria

4. **Deep foundations:** resist Fv, Fh incl. general erosion & local scour w exposed grade beam

Figure 8-16.
Scour around a group of foundation piles
SOURCE: ADAPTED FROM SUMER ET AL. 2001



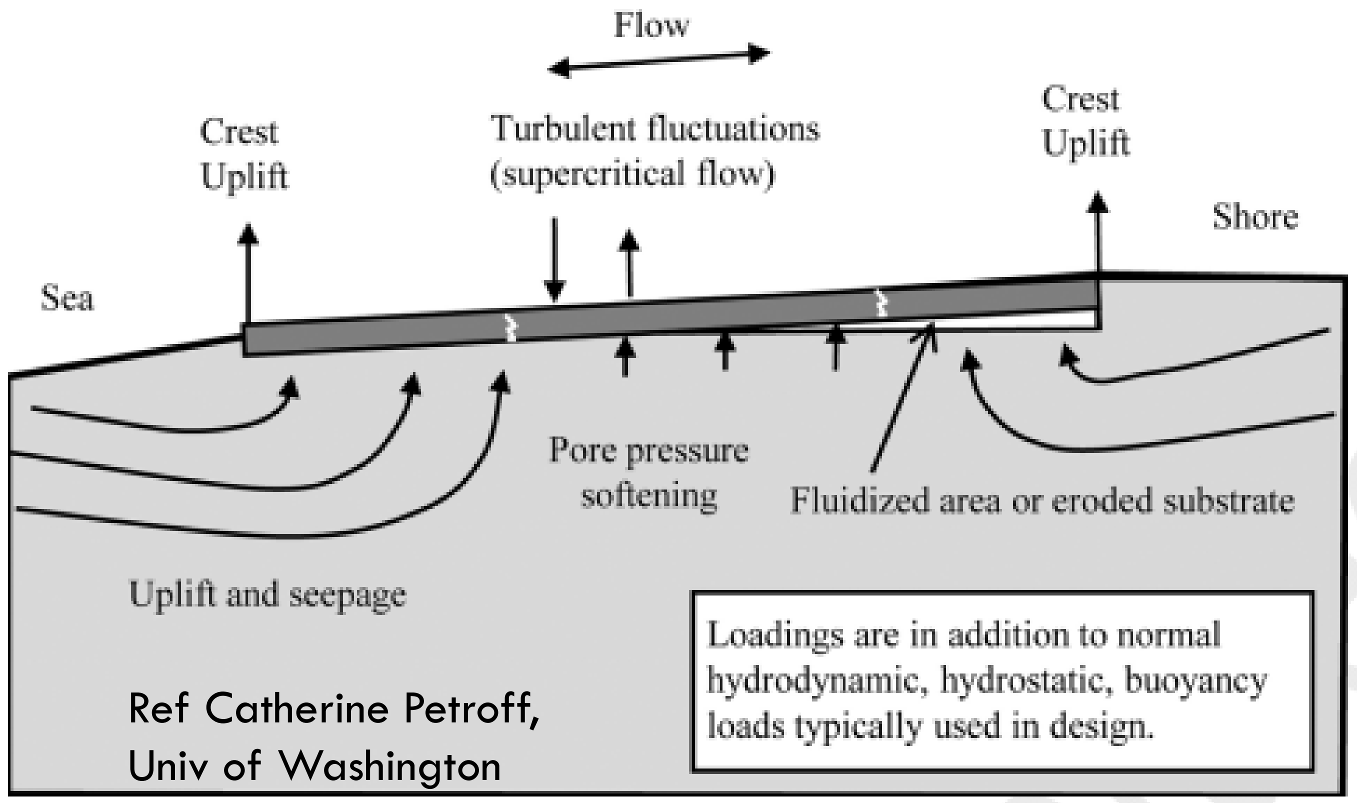
Ref. ASCE 7-16 provisional draft

(ref. FEMA 55, section 10.5)

1. Pavements (for roads & building perimeters)

1. Shear forces from sustained flow at maximum tsunami flow velocity, u_{max}, over the pavement.
2. Uplift pressures from flow acceleration at upstream and downstream pavement edges for both inflow and return flow.
3. Seepage flow gradients under the pavement if the potential exists for soil saturation during successive tsunami waves.
4. Pressure fluctuations over pavement sections and at joints.
5. Pore pressure increases from liquefaction and from the passage of several tsunami waves.
6. Erosion of substrate at upstream, downstream and flow parallel pavement edges as well as between pavement sections.

ASCE 7 tsunami foundation countermeas- ures



Ref Catherine Petroff, Univ of Washington

Figure C6.12-3. Schematic of tsunami –induced loading on pavement.

Ref. ASCE 7-16 provisional draft

2. Geotextiles & Reinforced Earth

same FS 1.3 criteria as foundations – bearing capacity, lateral/overturning, internal stability, slope stability

ASCE 7 tsunami foundation countermeas-ures

1. Geotechnical Engineering Circular No. 11 - Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes 2010 FHWA-NHI-10-024
2. AASHTO, "Standard Specification for Geotextile Specification for Highway Applications", M288-06 – filtration criteria

The following reinforced earth systems are permitted to be used and are presented in order of increasing strength and robustness.

1. Geotextile tubes constructed of high strength fabrics capable of achieving full tensile strength without constricting deformations when subject to the design tsunami loads and effects.
2. Geogrid earth and slope reinforcement systems including adequate erosion protection and a maximum lift thickness of 1 ft (0.3m) and facing protection.
3. Geocell earth and slope reinforcement erosion protection system designs including an analysis to determine anticipated erosion performance if no facing is used.

Ref. ASCE 7-16 provisional draft

ASCE 7 tsunami foundation countermeas-ures

Ref. ASCE 7-16 provisional draft

3. Facing systems

Facing systems shall be sufficiently strong and anchored to resist uplift and displacement during design load inundation. The following are facing methods for reinforced earth systems that shall be permitted to be used:

1. Vegetative facing for erosion resistance where tsunami flow velocities are less than 12.5 ft/s (3.8 m/s). Design shall be in accordance with methods and requirements in the recognized literature.
2. Geotextile filter layers including primary filter protection of countermeasures using a composite grid assuming high contact stresses and high energy wave action design criteria in AASHTO M288-06, including Soil Retention, Permeability, Clogging Resistance and Survivability.
3. Mattresses including adequate flexibility include energy dissipation characteristics, and edges shall be embedded to maintain edge stability under design inundation flows.
4. Concrete facing provided in accordance with pavement countermeasures in **Section 6.12.7.1** and containing adequate anchorage to the reinforced earth system under design inundation flows.
5. Stone armoring and riprap provided to withstand tsunami shall be designed as follows:

a) Stone diameter per HEC 23 Design Guideline 4

b) For Fr>0.5 consider high velocity turbulence

c) Peer reviewed numerical model permitted alternate.

ASCE 7 tsunami foundation countermeas-ures

4. Ground improvement

Soil cement mixing for non-erodible surface-100psi avg UCS.

5. Risk Category IV Structures

Encouraged soil-structure-fluid interaction analysis to verify performance consistent with structural design load combinations.

Key references:

1. An Introduction to The Deep Soil Mixing Methods As Used in Geotechnical Applications, FHWA-RD-99-138 March 2000.
2. USACE, Design and Construction of Levees, App G Soil-Cement for Protection, EM 1110-2-1913 (2000)
3. ASTM D1633 - 00(2007) Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinder

Ref. ASCE 7-16 provisional draft

4. ASCE 24 flooding scour provisions

-Non prescriptive analysis not routinely applied

-Flood zone vs. elevation and foundation types

Hurricane Sandy moved sand off the beach and ocean water undermined beachfront properties.

Source: Liz Roll/FEMA

Wave, storm surge and erosion damage to oceanfront house in Belle Harbor, Rockaway, NY.

Source: Figure 3-1/Hurricane Sandy MAT Report

5. Needed validations & Measurements

- field
- lab
- probabilistic
- economic

1. More scalable scour photos
2. Soil samples from events
3. Instrumentation of pore pressures during events
4. Catalog foundation type, embedment, siting and failure loss vs scour depth
5. Load energy & orientation
6. Discrete element modeling
7. Work with insurers, ie. FEMA COASTAL Equation, **fragilities**.
8. Debris flows/mud flows in flood

6. DRR through geo-risk reduction

-Quantify geo-loss drivers (elevate, harden, protect)

-SROI for prioritization

Examples: (google keywords for details)

1. PPD-8/21 NDRF – functional resilience & recovery goals
2. New ASCE resilience division (www.ciasce.asce.org)
3. NYC: SIRR, PlaNYC & open industrial siting
4. Coastal vs building protections- hard vs soft; green infrastructure & climate adaptation
5. **Oregon Resilience Plan**
6. **FEMA MAT & Hazus modeling**
7. **ATC-1: Geo-disaster focus**

Guidance on Construction in floodplains

Mitigation Assessment Team (MAT) Report - Hurricane Sandy in NY & NJ





Published November 2013

Federal Emergency Management Agency

(FEMA P-942)

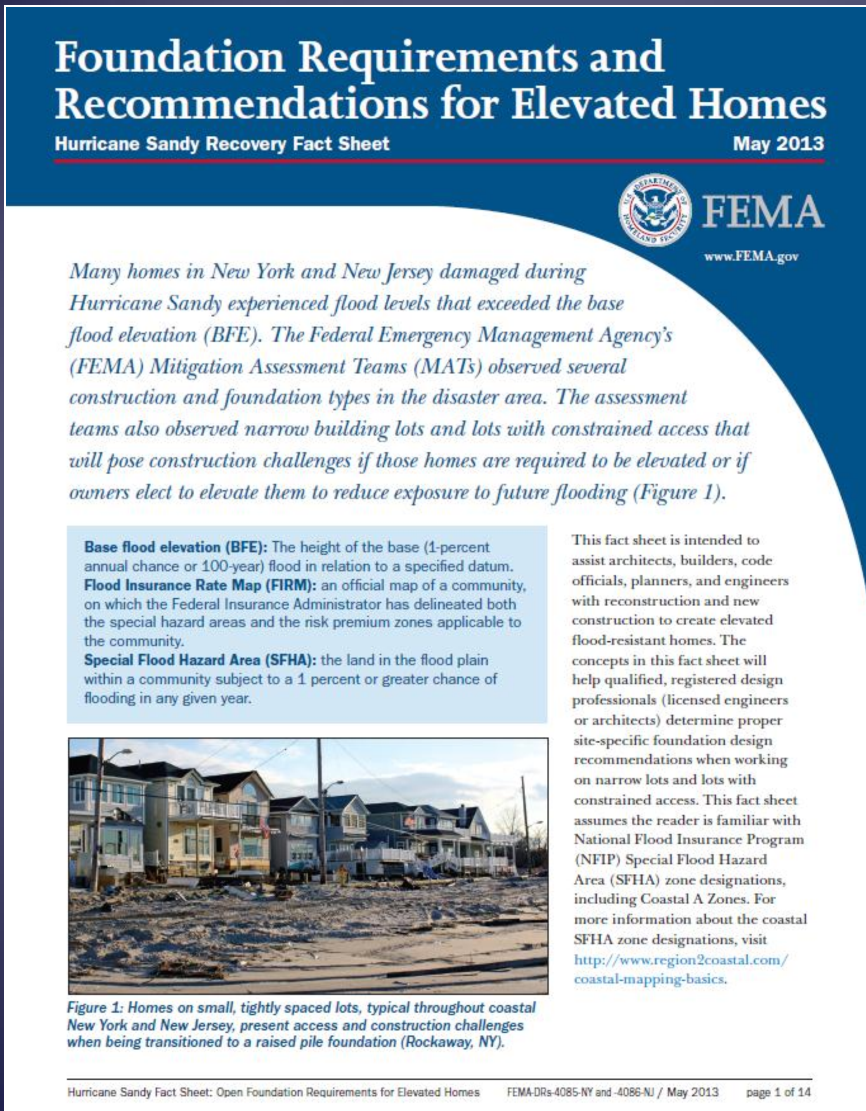
http://www.fema.gov/hurricane-sandy-building-science-activities-resources

FEMA

Building Science Branch

Ref: john.ingargiola@fema.dhs.gov

Fact Sheet



Foundation Requirements and Recommendations for Elevated Homes

Hurricane Sandy Recovery Fact Sheet **May 2013**

FEMA
www.FEMA.gov

Many homes in New York and New Jersey damaged during Hurricane Sandy experienced flood levels that exceeded the base flood elevation (BFE). The Federal Emergency Management Agency's (FEMA) Mitigation Assessment Teams (MATs) observed several construction and foundation types in the disaster area. The assessment teams also observed narrow building lots and lots with constrained access that will pose construction challenges if those homes are required to be elevated or if owners elect to elevate them to reduce exposure to future flooding (Figure 1).

Base flood elevation (BFE): The height of the base (1-percent annual chance or 100-year) flood in relation to a specified datum.
Flood Insurance Rate Map (FIRM): an official map of a community, on which the Federal Insurance Administrator has delineated both the special hazard areas and the risk premium zones applicable to the community.
Special Flood Hazard Area (SFHA): the land in the flood plain within a community subject to a 1 percent or greater chance of flooding in any given year.

Figure 1: Homes on small, tightly spaced lots, typical throughout coastal New York and New Jersey, present access and construction challenges when being transitioned to a raised pile foundation (Rockaway, NY).

This fact sheet is intended to assist architects, builders, code officials, planners, and engineers with reconstruction and new construction to create elevated flood-resistant homes. The concepts in this fact sheet will help qualified, registered design professionals (licensed engineers or architects) determine proper site-specific foundation design recommendations when working on narrow lots and lots with constrained access. This fact sheet assumes the reader is familiar with National Flood Insurance Program (NFIP) Special Flood Hazard Area (SFHA) zone designations, including Coastal A Zones. For more information about the coastal SFHA zone designations, visit http://www.region2coastal.com/coastal-mapping-basics.

Hurricane Sandy Fact Sheet: Open Foundation Requirements for Elevated Homes FEMA-DRs-4085-NY and -4086-NJ / May 2013 page 1 of 14

Foundation Requirements and Recommendations for Elevated Homes

Purpose: To provide information for reconstructing and building new elevated flood-resistant homes

Source: FEMA

Fact Sheet

Foundation Requirements and Recommendations for Elevated Homes

Key Issues

Elevating a building sited on small, confined lot can be difficult

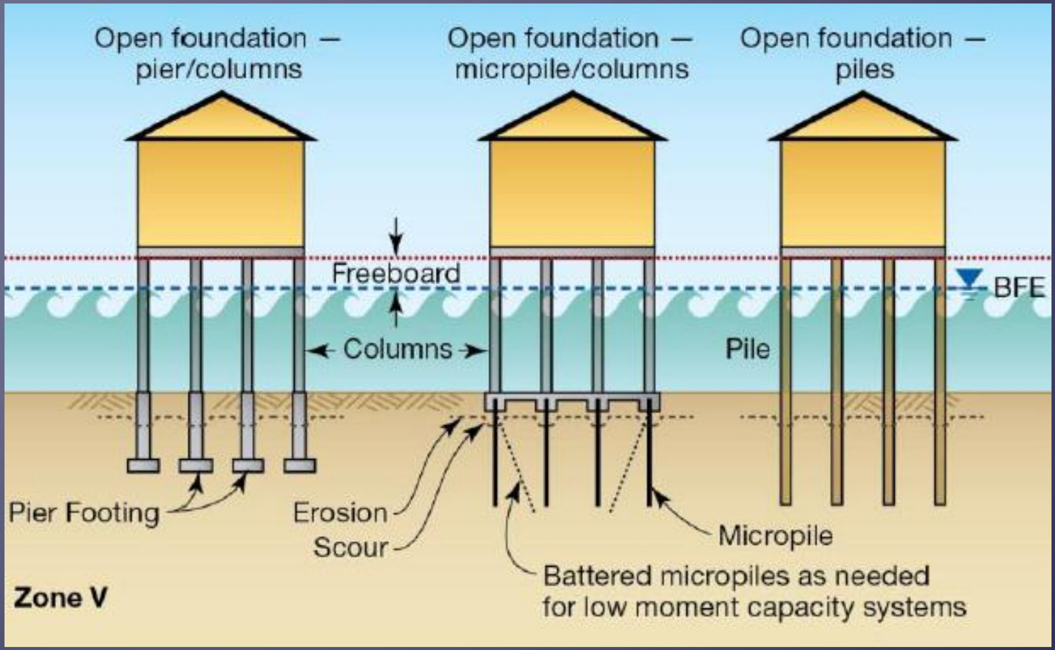
1. Eliminates possibility of moving building while timber piles are driven for new foundation
2. If elevating in place, overhead clearance is usually insufficient to drive traditional timber piles

Source: FEMA

Fact Sheet

Key Recommendations

3. Understand Substantial Improvement (SI) / Substantial Damage (SD) as they relate to NFIP requirements – with regards to flood zone



Examples of NFIP-compliant homes in Zone V

Source: FEMA

Fact Sheet

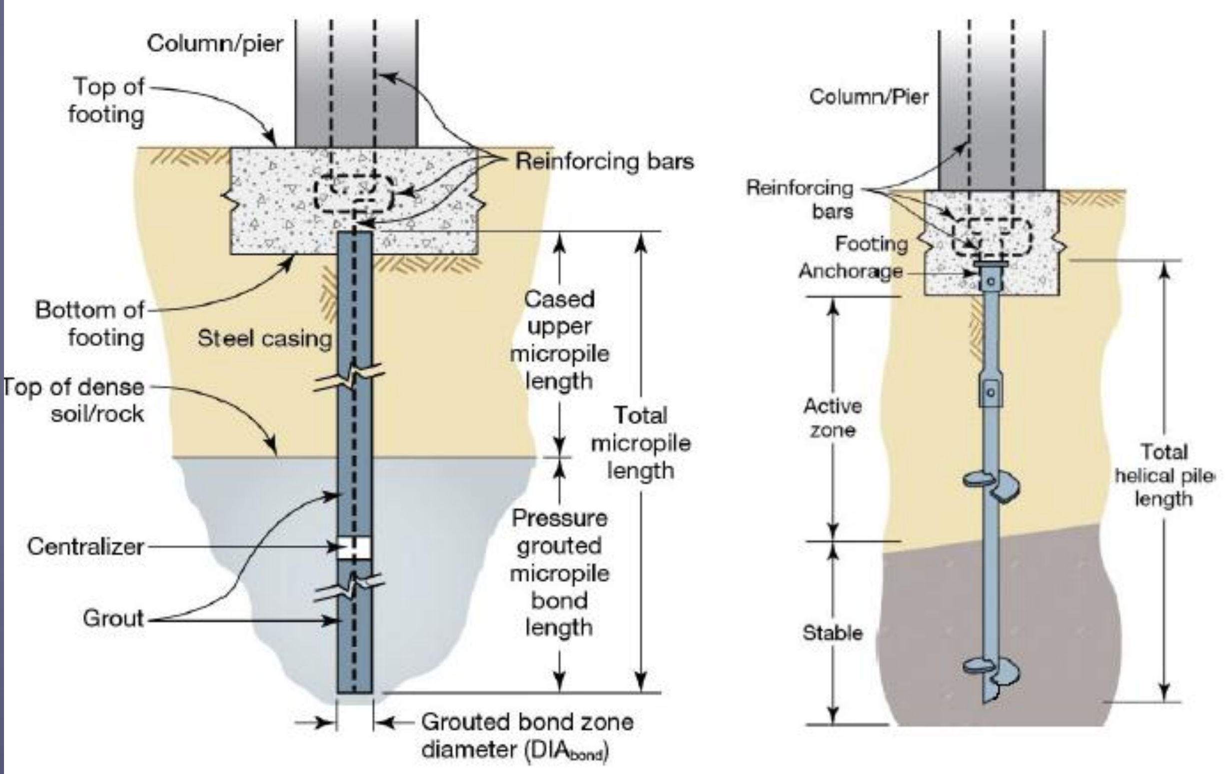
Foundation Requirements and Recommendations for Elevated Homes

Key Recommendations

4. Consider possible foundations

a) Pier
b) Pile
c) Use of micropiles

Elevated construction on open foundations



Source: FEMA

Fact Sheet

Table 1: Design Considerations for Elevating Buildings on Open Foundations in Zone V (and Coastal A Zones)

Overall Category	Data Needed	Consider
State and local requirements	State and local building code requirements Local flood ordinance requirements Zoning ordinance requirements BFE or ABFE, if applicable Natural resources conservation regulations	Open foundations are required in Zone V For new homes and homes that have sustained Substantial Damage or will be Substantially Improved, open foundations including piers, columns, and piles, and micropiles may be used Elevating to (or above) the BFE/ABFE will help protect the home in future storms and reduce flood insurance costs
Structural condition of home	Structural strength of load paths. Determine whether the home is structurally strong enough to be lifted	How connections can be improved to strengthen the home
	Structural strength of the existing footings. Determine whether the footings are adequate for the proposed modification	How the footings can be strengthened or replaced
Geotechnical condition of site	Determine whether a shallow foundation is feasible	Piers/Columns are appropriate for shallow foundations
	Determine whether a deep foundation is required	Piles, piers/columns and micropiles are appropriate for deep foundations
	Predicted flood conditions, including the effects of scour and long-term erosion	Piling and Pier/Column foundations with footings and grade beams can be designed to withstand 3-foot wave loads, but may fail if erosion and scour undermine the foundation Micropile foundations may not be able to withstand lateral loads when exposed by scour and erosion
	Elevation of the water table	Grade beams can be elevated above the water table, but the pile or pier/column must be designed to resist cantilever action, moments, and deflection at the top. Deeper embedment may be necessary

Source: FEMA

Fact Sheet

Table 2: Comparison of Relative Costs and Considerations Associated with Elevating Homes on Alternative Open Foundations in Tight, Narrow Lots

Consideration		Column/Pier Foundation	Traditional Pile Foundation	Micropile Foundation
Requires moving home off footprint		No	Yes	No
Elevate-in-place		Yes	No	Yes
Impacts to neighboring properties		Medium to High	High	Low
Cost	Foundation	$	$$$	$$
	Foundation connection	$$	$	$$
	Elevation	$$	$$$	$$
Ease of installation		Yes	Maybe	Yes
Design basis		IBC[1]/ASCE 24/FEMA P-55[2]	IBC[1]/ASCE 24/FEMA P-55[2]	IBC[1]/ASCE 24/ FEMA P-55[2]/FHWA NHI-05-039[3]

1 IBC, International Building Code
2 *Coastal Construction Manual* (2011)
3 *Micropile Design and Construction Guidelines Manual* (2005)

Source: FEMA

MAT Support – Code Changes

2015 IRC Code Change Proposals: FEMA Proponent

- IRC, requirements for tanks
- IRC, freeboard in all zones
- IRC, Flood-resistant foundation wall requirements
- IRC, treat CAZ, if delineated, as CHHA (Zone V), except permit filled stemwalls
- IFC, fire safety and evacuation plans must consider flood hazard

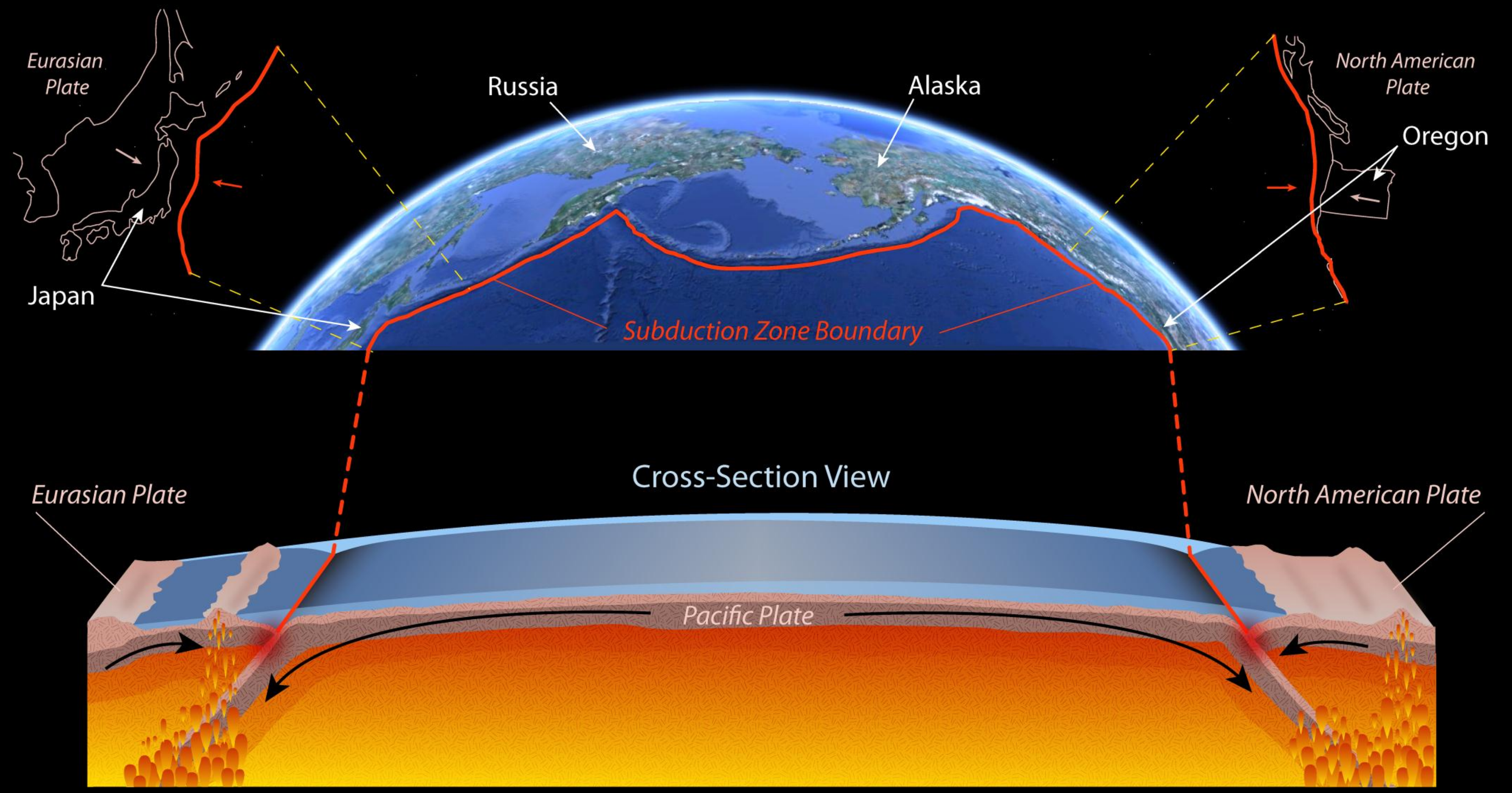
The FEMA MAT has been providing additional code support to NYC

Source: FEMA

Example of Tsunami Resilience

Source:
kentyu@seftconsulting.com

Oregon Resilience Plan
Cascadia Subduction Earthquake

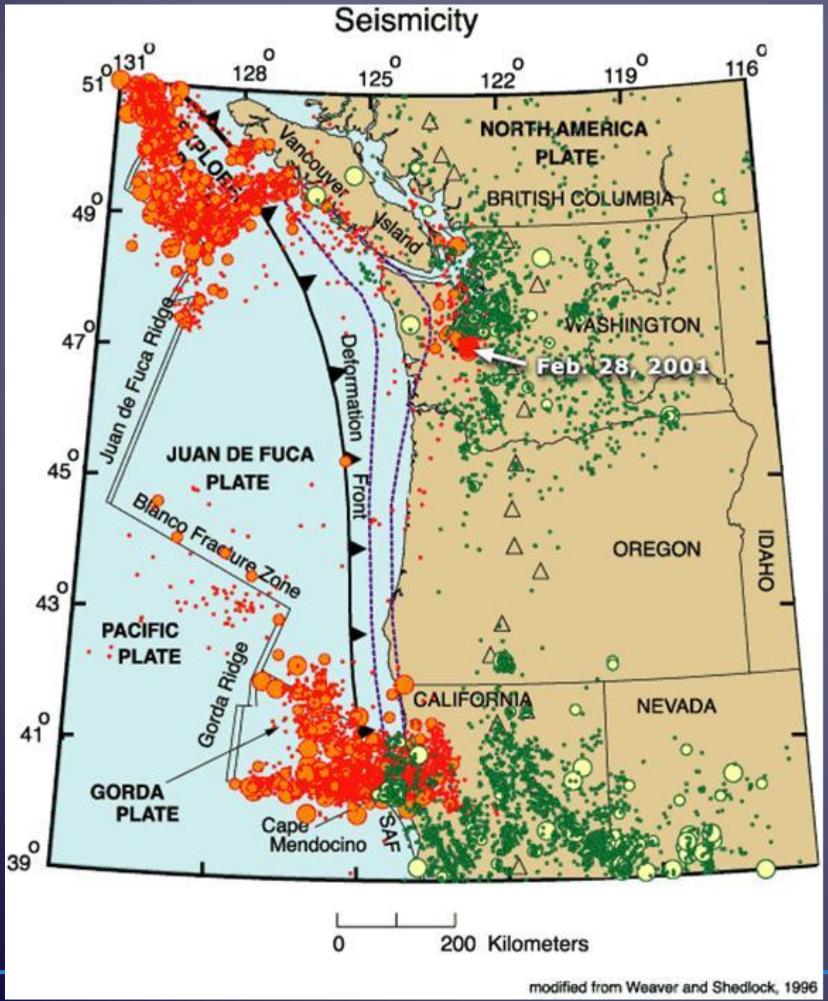


http://www.oregon.gov/omd/oem/pages/osspac/osspac.aspx#Oregon_Resilience_Plan

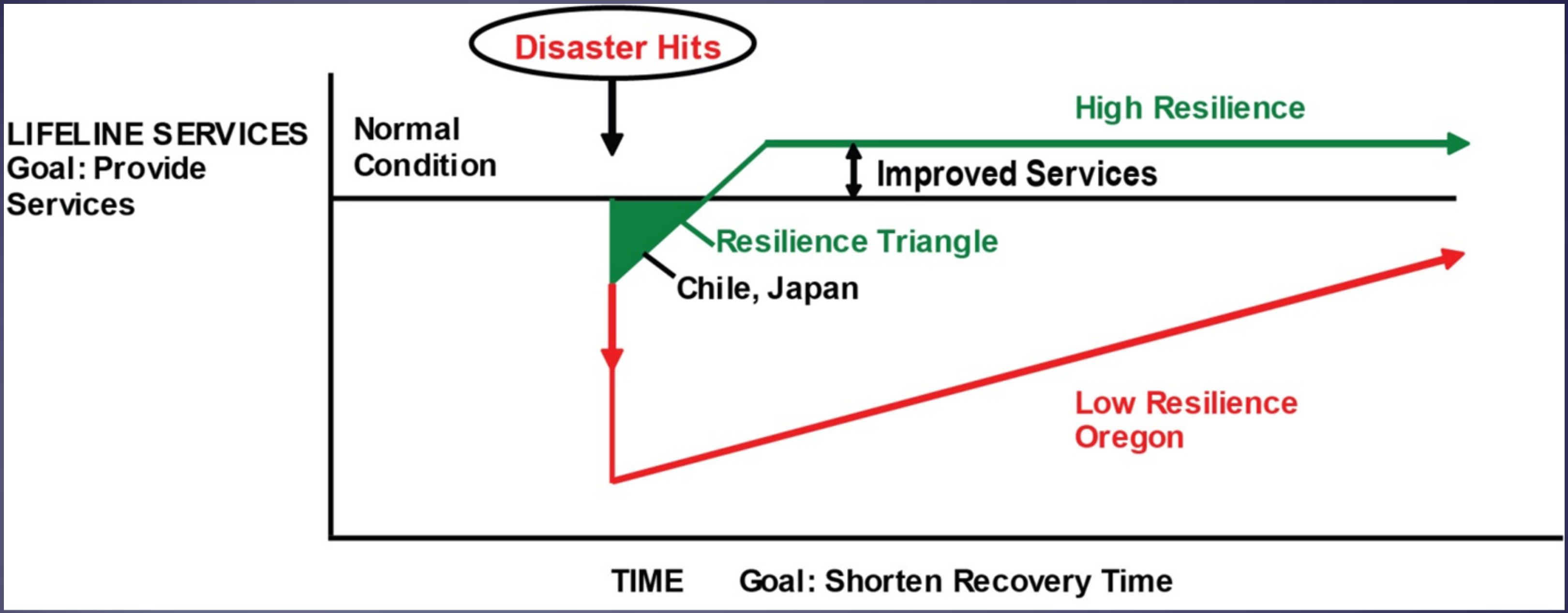
Cascadia Subduction Earthquake

- Strong Ground Shaking (M9 w/ 2 - 4 min shaking)
- Tsunami within 15 to 25 minutes

Source: kentyu@seftconsulting.com



Definition of Resilience

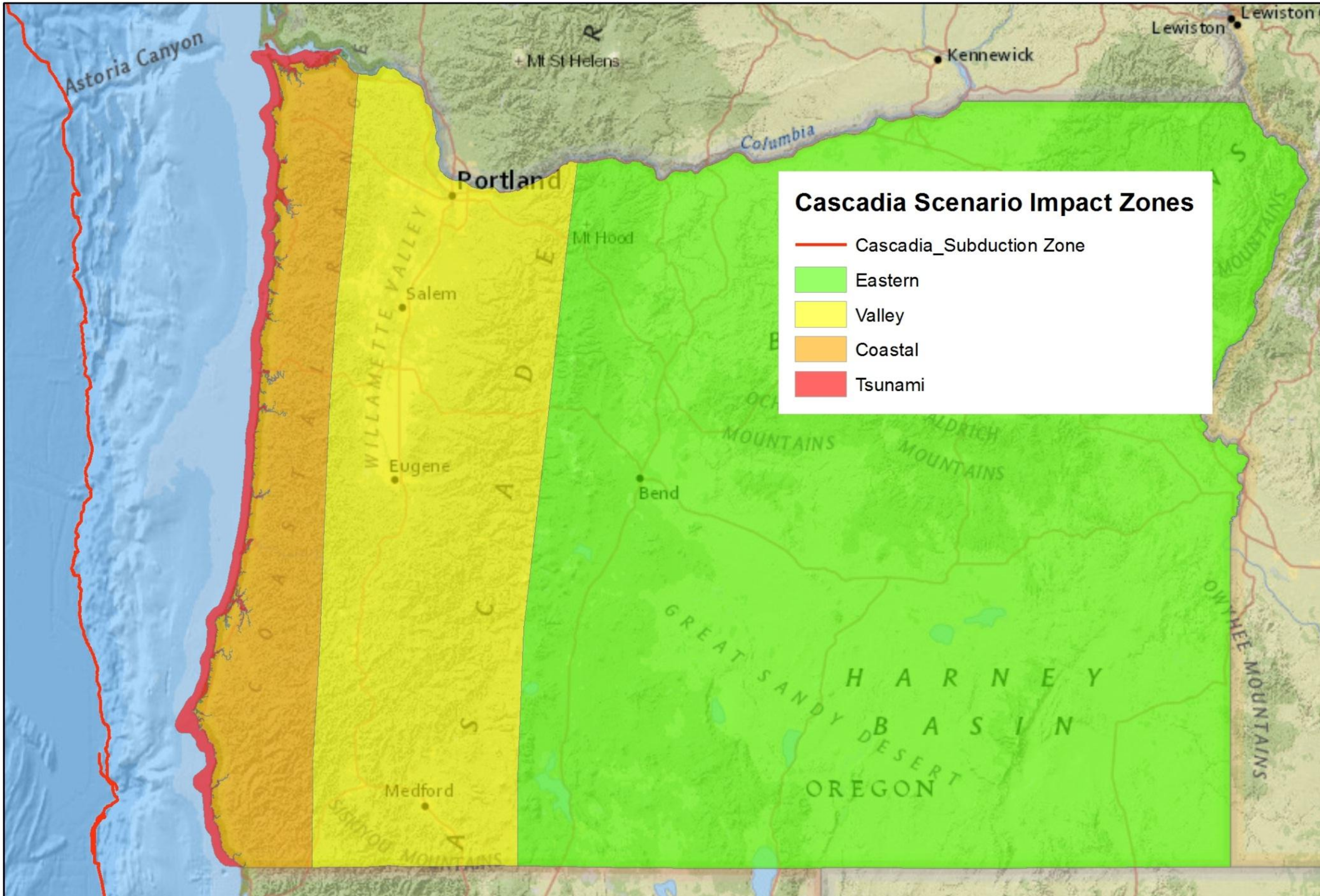


(Yumei Wang)

- **Resilience:** Save lives, Reduce Losses, Speed Recovery, & Rebuild Better
- Sustainability without **Resilience** is NOT sustainable!

Source: kentyu@seftconsulting.com

Oregon Resilience Plan- Four Zones



Oregon Resilience Planning Steps

- Assess **performance** of existing critical facilities and lifeline systems, and estimate timeframes required to restore functions at present conditions;
- Develop resilience goals based on business and community needs for each zone;
- Define acceptable target timeframes to restore functions to meet resilience goals; and
- Prepare **recommendations** for statewide policies and actions to achieve the desired performance targets.

Source: kentyu@seftconsulting.com

Source: kentyu@seftconsulting.com

Current Resilience Gap & Targets

- Oregon businesses can only tolerate two to four weeks of disruption of essential services

Critical Service	Zone	Estimated Time to Restore Service
Electricity	Valley	1 to 3 months
Electricity	Coast	3 to 6 months
Police and fire stations	Valley	2 to 4 months
Drinking water and sewer	Valley	1 month to 1 year
Drinking water and sewer	Coast	1 to 3 years
Top-priority highways (partial restoration)	Valley	6 to 12 months
Healthcare facilities	Valley	18 months
Healthcare facilities	Coast	3 years

Asian Technical Committee 1 (ATC-1)

- "Mitigation and Adaptation to Climate Change-Induced Geodisasters" – **Inaugural meeting VNU, Hanoi Nov 2013**
- Prof Yasuhara, Co-chair from Ibaraki Univ. to lead special pub.
- 2014 event in Fukuoka

- Extreme events related to geotechnical engineering may be caused by climate change, particularly in Asia-Pacific Regions.
- **However, IPCC has paid less attention to Geo-disaster aspects**.
- Generally, most of natural disasters are thought to be water-related disasters, though "Geo-Engineering" provides the mitigations.

Ref. Dennes Bergado, AIT

Vulnerable Coastal Deltas

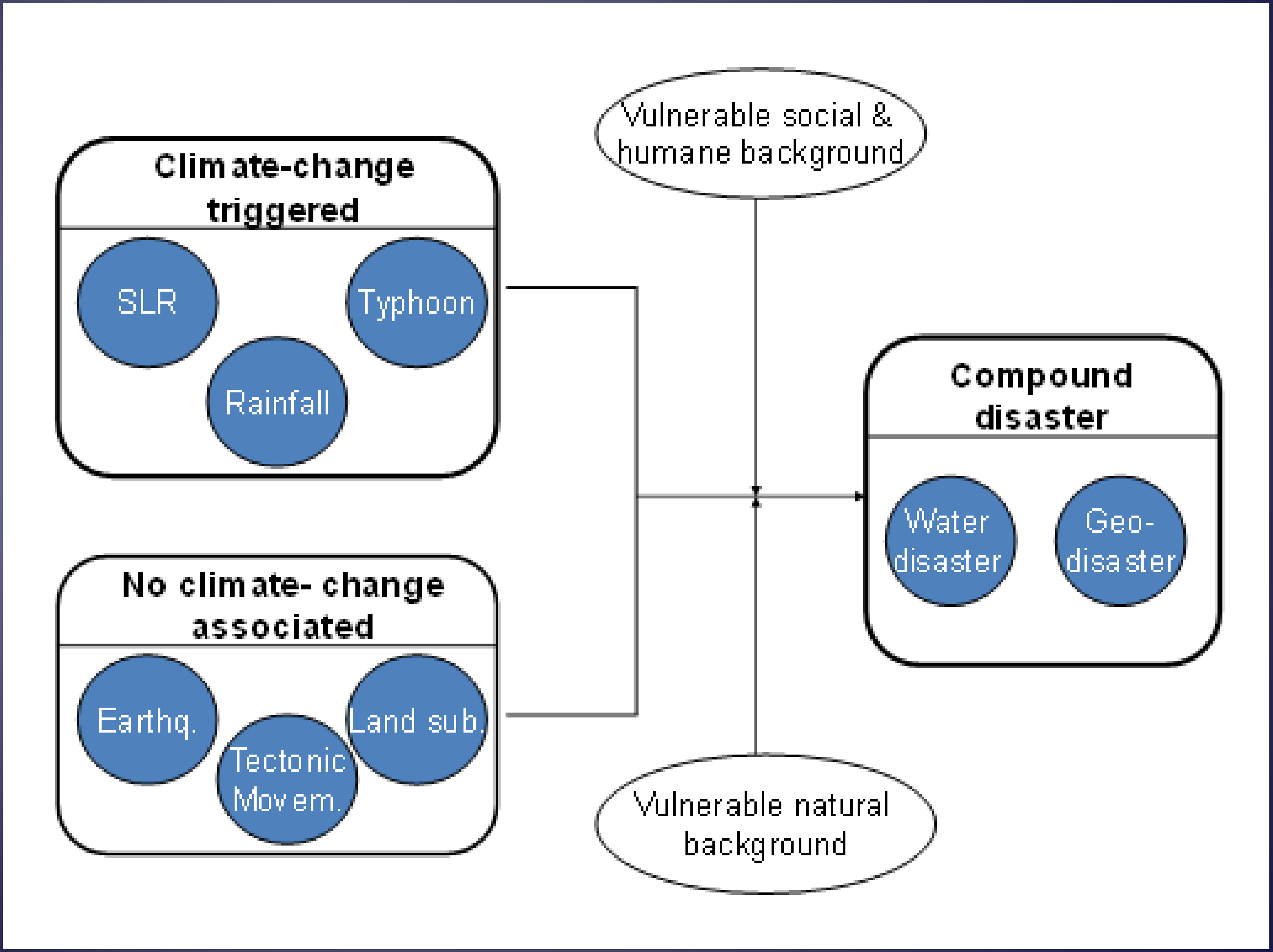
Figure TS.8. *Relative vulnerability of coastal deltas as indicated by estimates of the population potentially displaced by current sea-level trends to 2050 (extreme >1 million; high 1 million to 50,000; medium 50,000 to 5,000) [B6.3]. Climate change would exacerbate these impacts.*

(After IPCC AR 4, 2007)

Ref. Dennes Bergado, AIT

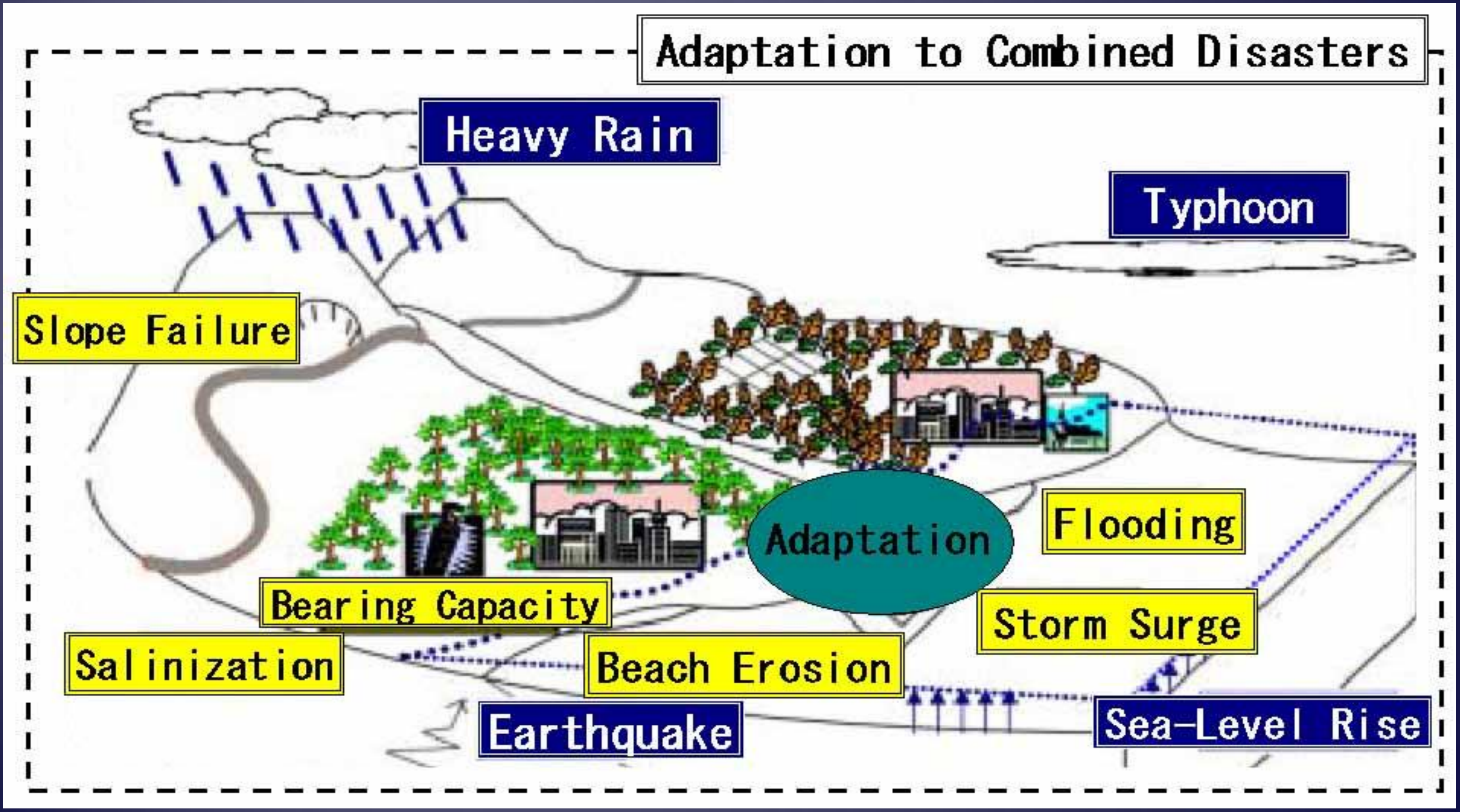
Compound Disasters

Ref. Dennes Bergado, AIT



"Compound Disasters"

Ref. Dennes Bergado, AIT



Comparative results from different approaches

	Researcher	Methodology	Results
Hydraulic approach	Kawagoe & Kazama (2009）	･Evaluation of probability of slope failure occurrence using climate change-induced precipitation and geographical information	･Indicate locations where climate change-induced slope failure increases ･Specify areas where countermeasures are urgent
Geotechni-cal approach	Chen & Mitani (2012)	･Quantitative estimation of slope risk and its economical loss by considering torrential rainfall-induced occurrences	･Specify areas where global warming-triggered risk and economic loss by slope failure increases

Ref. Dennes Bergado, AIT

Examples of geotechnical responsive measures

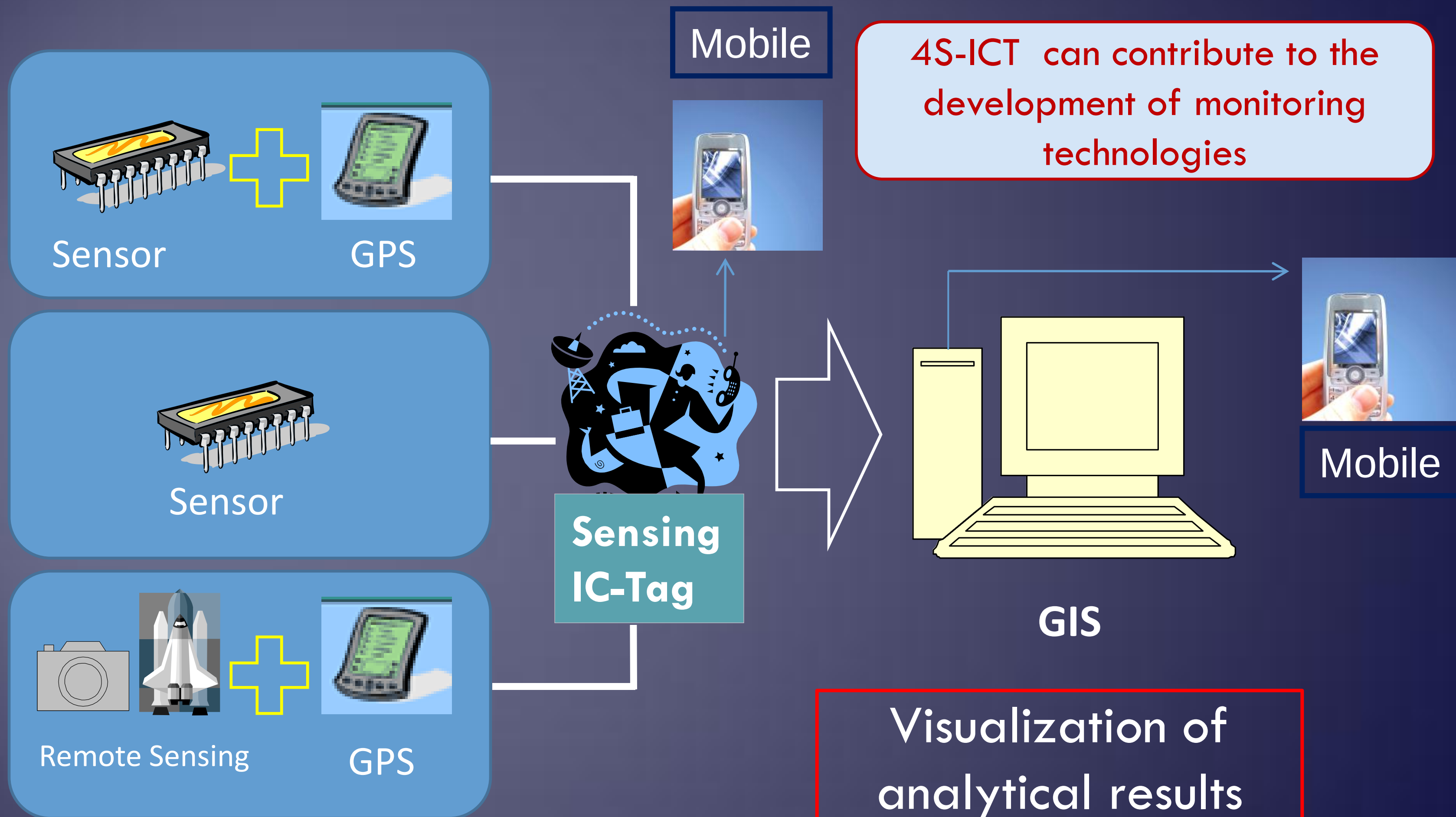
Response		Responsive measure	Geotechnical responsive measure
Mitigation		・Emission control of GHG ・Utilization of emissions trading ・Development of renewable energy	・Underground containment of GHG ・Development of geo-materials to absorb GHG [*2] ・GHG absorption, fixation using thinned woods
Adaptation	Protection	・Control of external force triggering the impacts of climate change	・Multiple protection using soil improvement and earth reinforcing techniques
	Accommodation	・Moderate response to climate change by accepting the impacts to some degree	・Construction of highly robust structures ・Easily replaceable wall structures if damaged
	Retreat	・Retreat from regions undergoing impacts of climate change	・Early warning system utilizing ICT ・Construction of robust shelters and refuges using geosynthetics
Synergy of mitigation and adaptation		・Early warning system based on future climate prediction [*1]	・Monitoring system using ICT ・Early warning system using ICT
		・Development of inovative geo-materials	・Application of geo-materials to absorb GHG for geo-hazard reduction

(*1Tamura & Mimura: J. of IEICE, 93-1, 61-66, 2010, *2 Komine et al.: Geotechnical Eng. J., 7-1, 151-156, 2012)

Ref. Dennes Bergado, AIT

Ref. Dennes Bergado, AIT

Integrated ICT: 4S-Technology

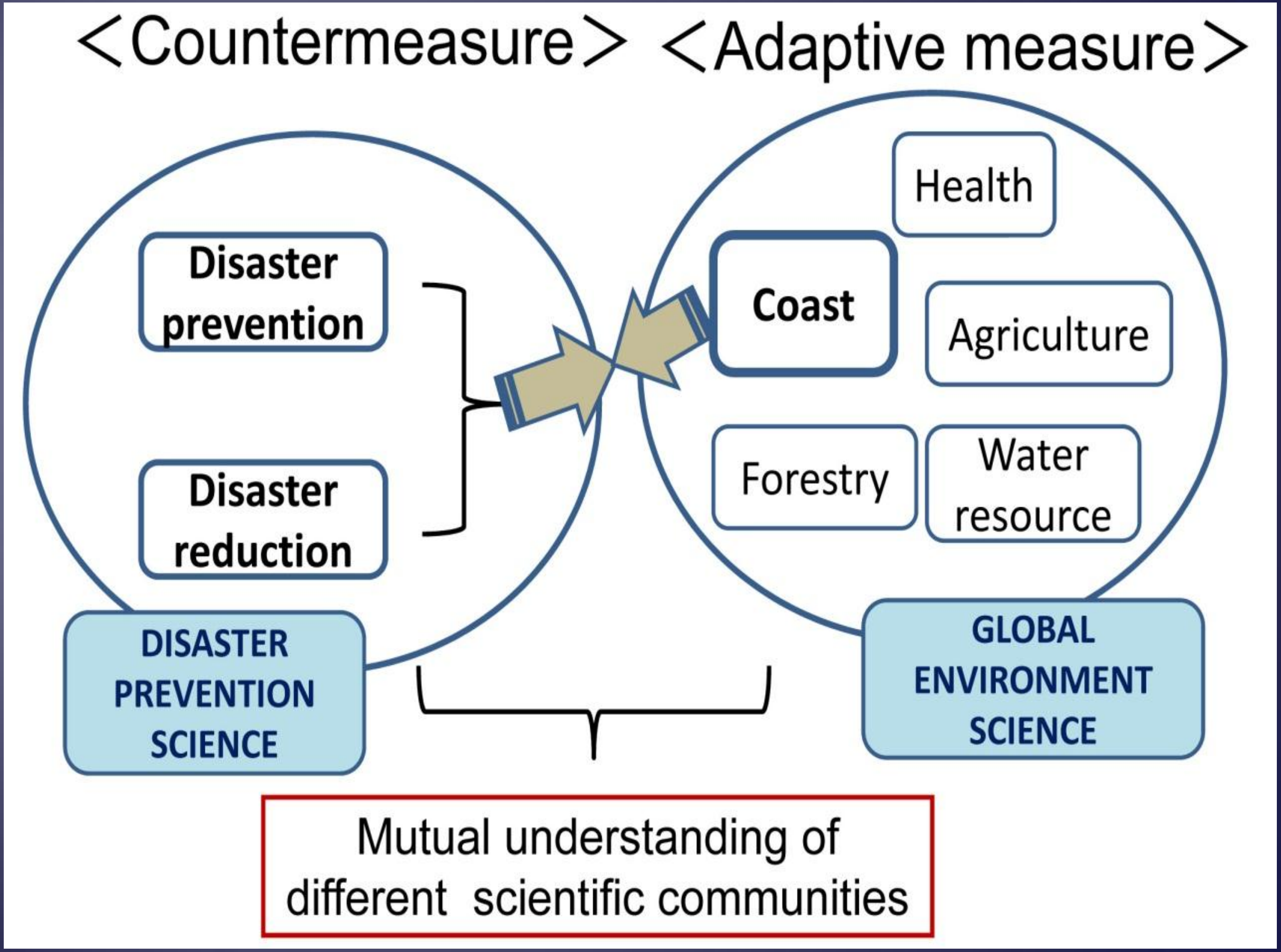


Collection of information

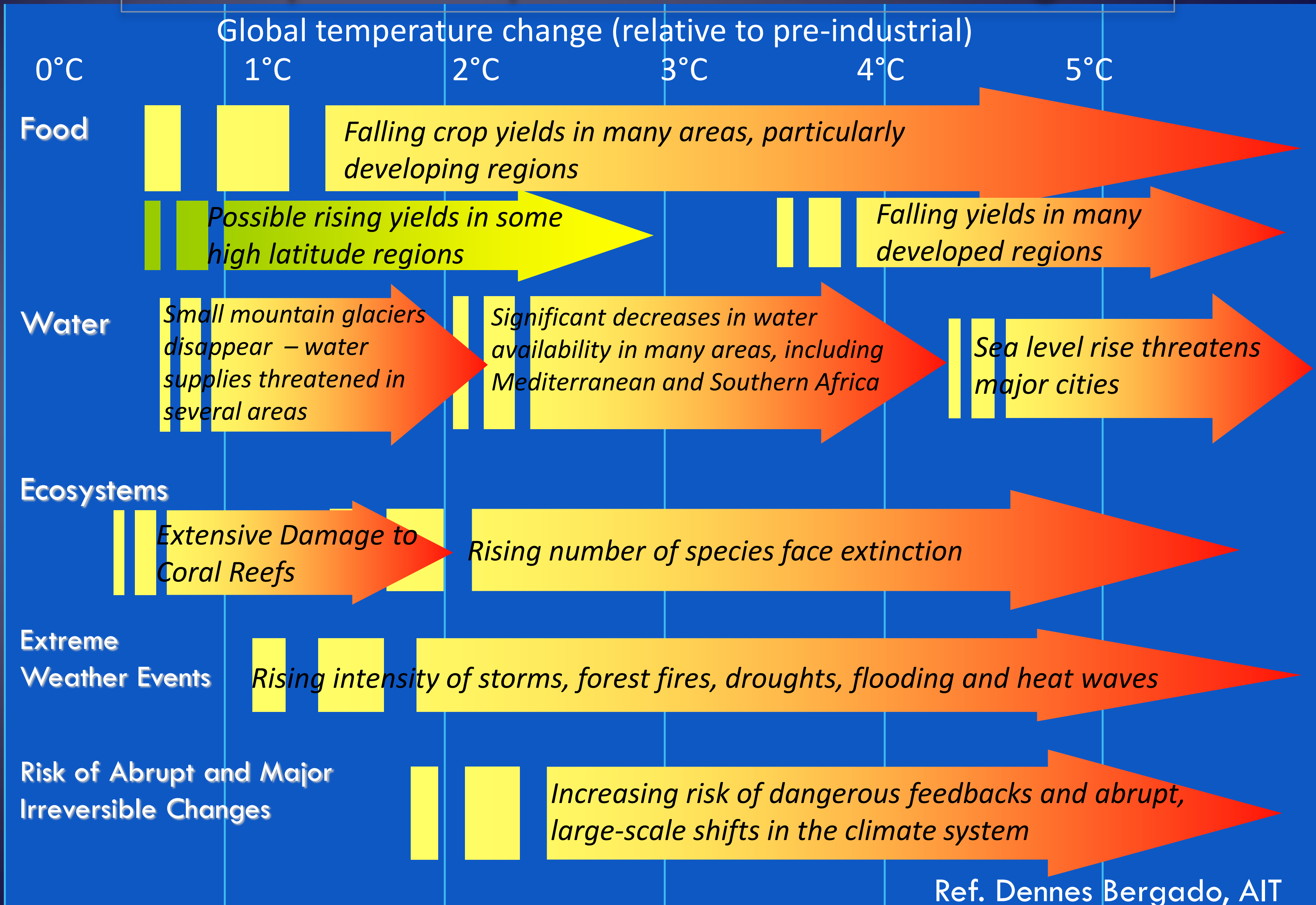
(supported by Dr. Yuji Kuwahara and Dr. Osamu Saitoh)

Collaboration & cooperation between two sciences & engineering

Ref. Dennes Bergado, AIT



Projected impacts of climate change



Future outlook of climate change geo-issues

NGOs and Advocacy Groups devoted to public interests have multiplied exponentially. Thus, human well-being can be improved while protecting the environment such as:

1) Investments in ecosystem conservation
2) Management system to promote recovery of marine life
3) Watershed restoration schemes
4) *Prevention of riverbank and coastal erosion*
5) *Risk assessments of lateral spreads, debris flows and landslides*
6) Forecasts of flooding and flood protection schemes
7) Promote waste containment systems
8) Construct water supply reservoirs

Ref. Dennes Bergado, AIT

Goals of ATC-1(FY2013 – FY2015)

- Collection of case studies
- Database construction
- Publication of book(s)

} Develop Roadmap for ATC-1

- International Symposium

  ⇒The roles of geotechnical engineering in DRR should be clarified and serve as a strategy for performance goals

- Detailed activities will be led by Prof. Bergado

Ref. Dennes Bergado, AIT

Conclusion

Figure 4. General scour. Yamamoto-cho, Japan. Case TN-12.

- Historical empirical approaches for scour are diverse.
- Tohoku data increased reliability of predictive liquefaction scour.
- New ASCE 7 tsunami chapter provides best practice procedure.
- Tsunami scour and erosion need more validation measurements.
- ASCE 24 flooding scour provisions need a general erosion procedure.
- DRR of hydraulics hazards can be advanced through geo-risk reduction:
  -elevated foundations, ground treatment & tsunami/coastal barriers
- FEMA is modeling financial benefits of code compliant foundations for DRR.

Hydraulics & Geotechnical collaboration for tsunami and floods provides a lens for assessing loss drivers and innovating balanced soft/hard mitigations.

Thank you.

mathew.francis@urs.com