Port & Harbor Damage from the March 11, 2011 Tohoku Oki Tsunami

Lesley Ewing, Sr. Coastal Engineer

California Coastal Commission

Event Summary

- March 11 at 2:46 PM
  - Magnitude Mw = 9.0
  - 2:49 pm; JMA issues "Major Tsunami" warning (> 6m)
  - 20 minutes to first wave strike
  - Up to 3 major waves hit
  - 20,000+ killed/missing

Tectonic Setting

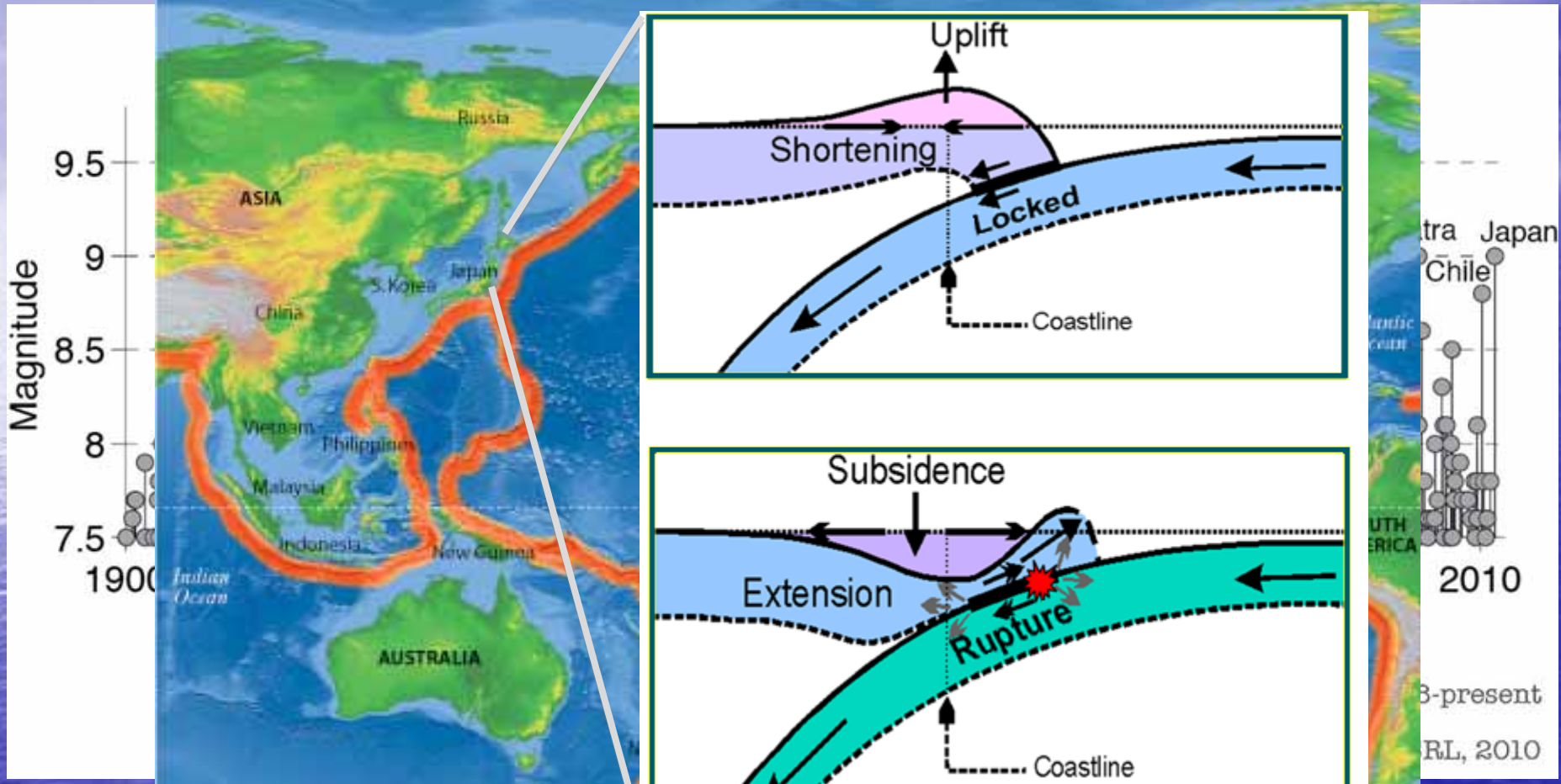
Some Comparisons:

Earthquakes can be characterized by the amount of energy released when tectonic plates move:

Earthquake	Magnitude	Moment, Mo (Joules)	Surface Energy, Es (Joules)
Virginia (2011)	5.8	6×10^{17}	4×10^{13}
Northridge (1994)	6.7	1×10^{19}	8×10^{14} (est.)
Chile (2010)	8.8	2×10^{22}	2×10^{16}
Sumatra (2004)	9.0	4×10^{22}	1×10^{17}
Tohoku (2011)	9.0	5×10^{22}	5×10^{17}

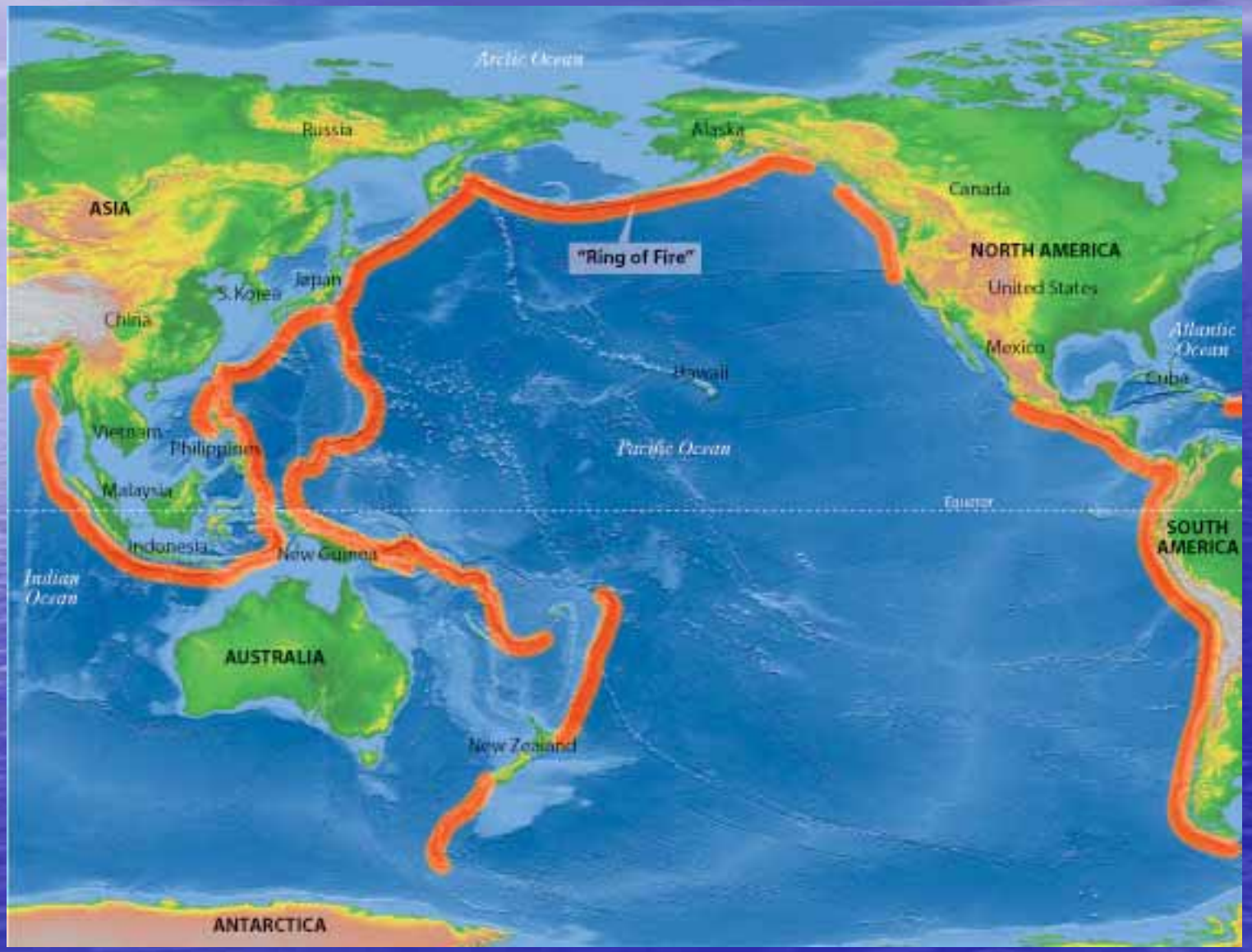
A tennis ball moving at 14 mph = 1 Joule
Energy from burning 1 barrel of oil = 6×10^{9} Joules
Hiroshima Atomic Bomb = 6×10^{13} Joules
Energy used per year in US ~ 1×10^{20} Joules

Tectonic Setting

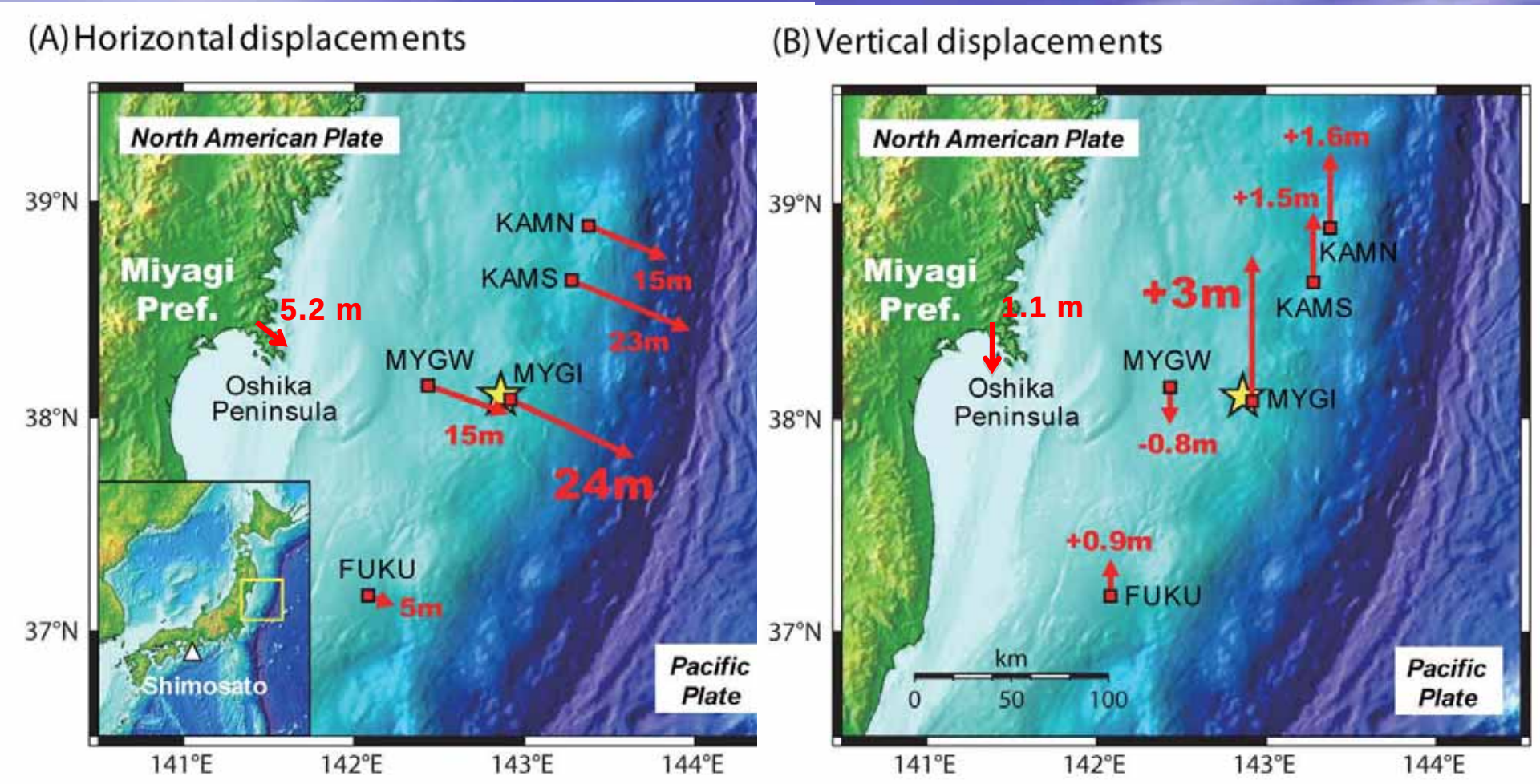


Example: Crescent City, CA (Cascadia Subduction Zone has an uplift rate of 2 to 2.5 mm/yr.

Tectonic Setting

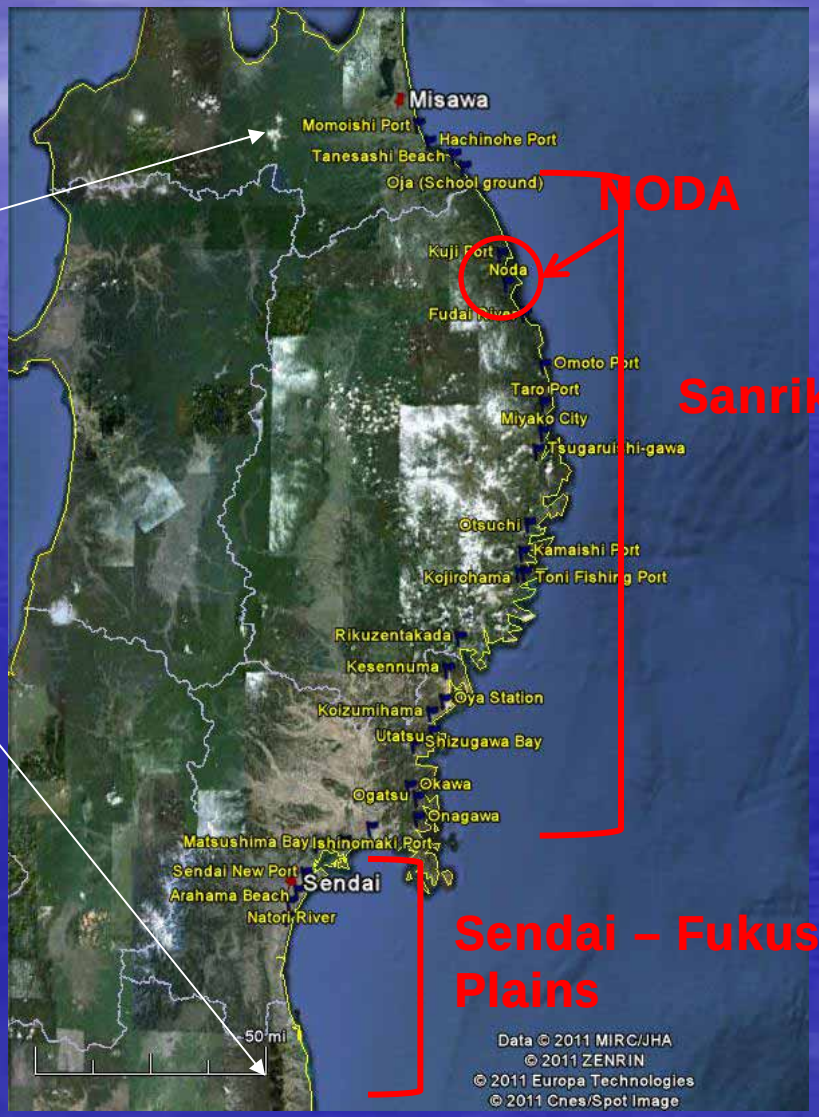


Earthquake Displacement



By comparison: 2010 Maule Chile had coastal uplift of up to 3 m

Field Investigation Area



Noda Seawall

Source:
http://w.livedoor.jp/nodamura_koushiki/d/%c4%c5%c7%c8%a4%ce%cd%cd%bb%d2

Noda Seawall

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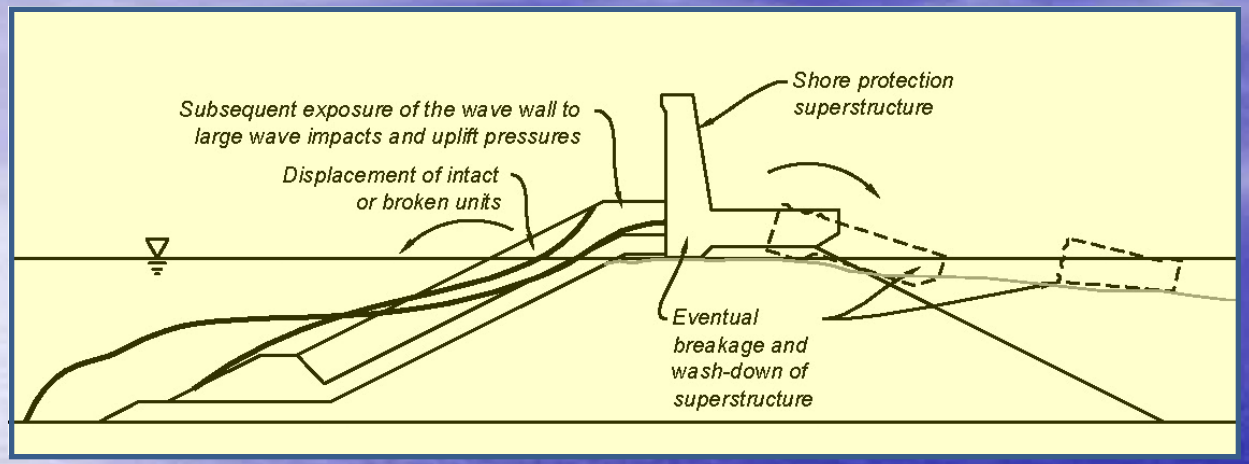
Noda Old Seawall

Scour



Around Buildings

Arahama Beach

Inland of protection structures

Arahama Beach

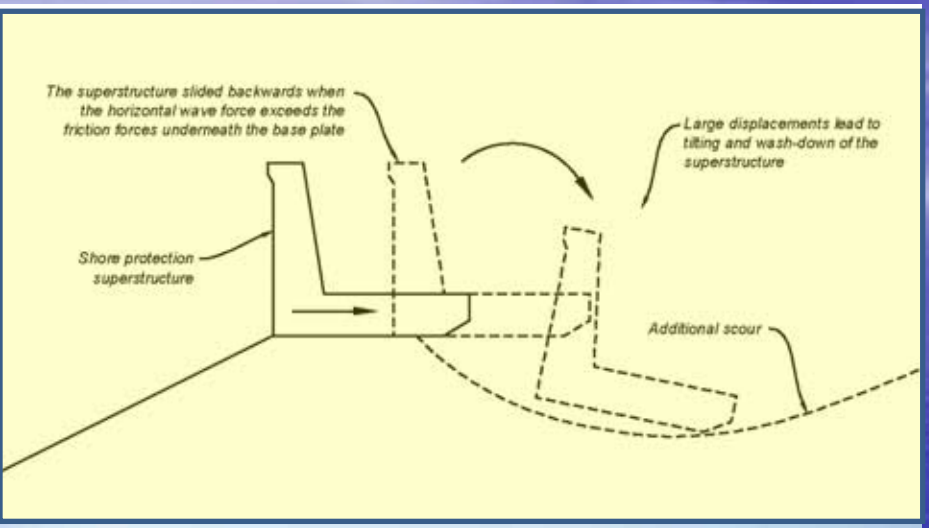
Beaches

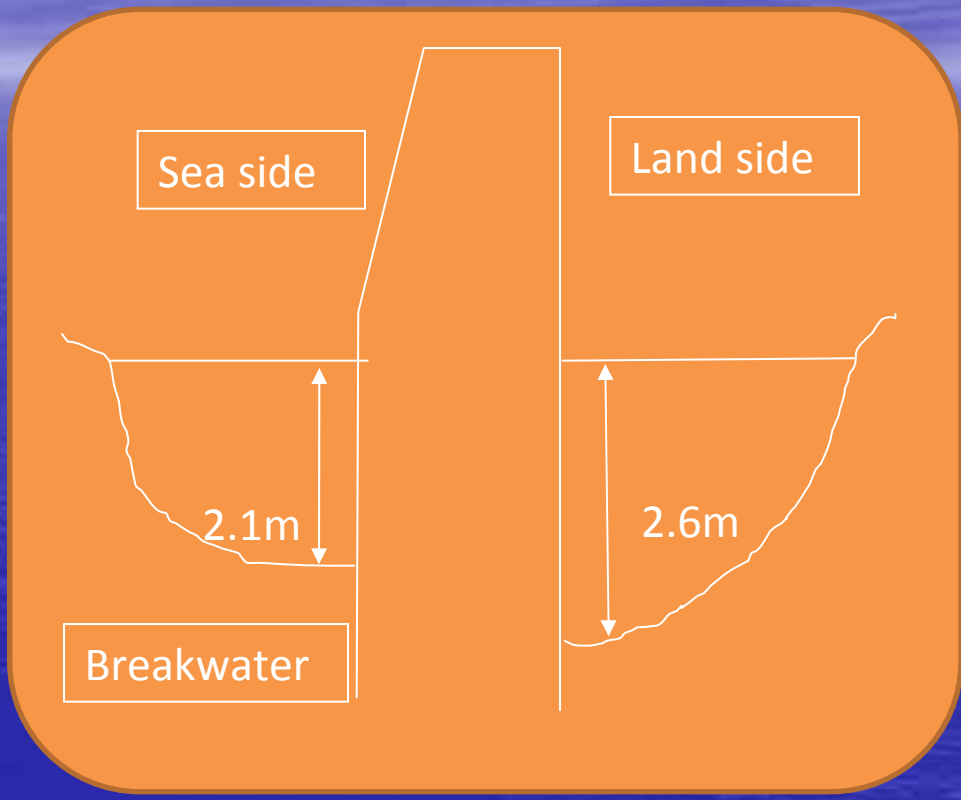
Koizumi Beach

Ends of walls and structures

Natori Beach

Scour + Impact Loads

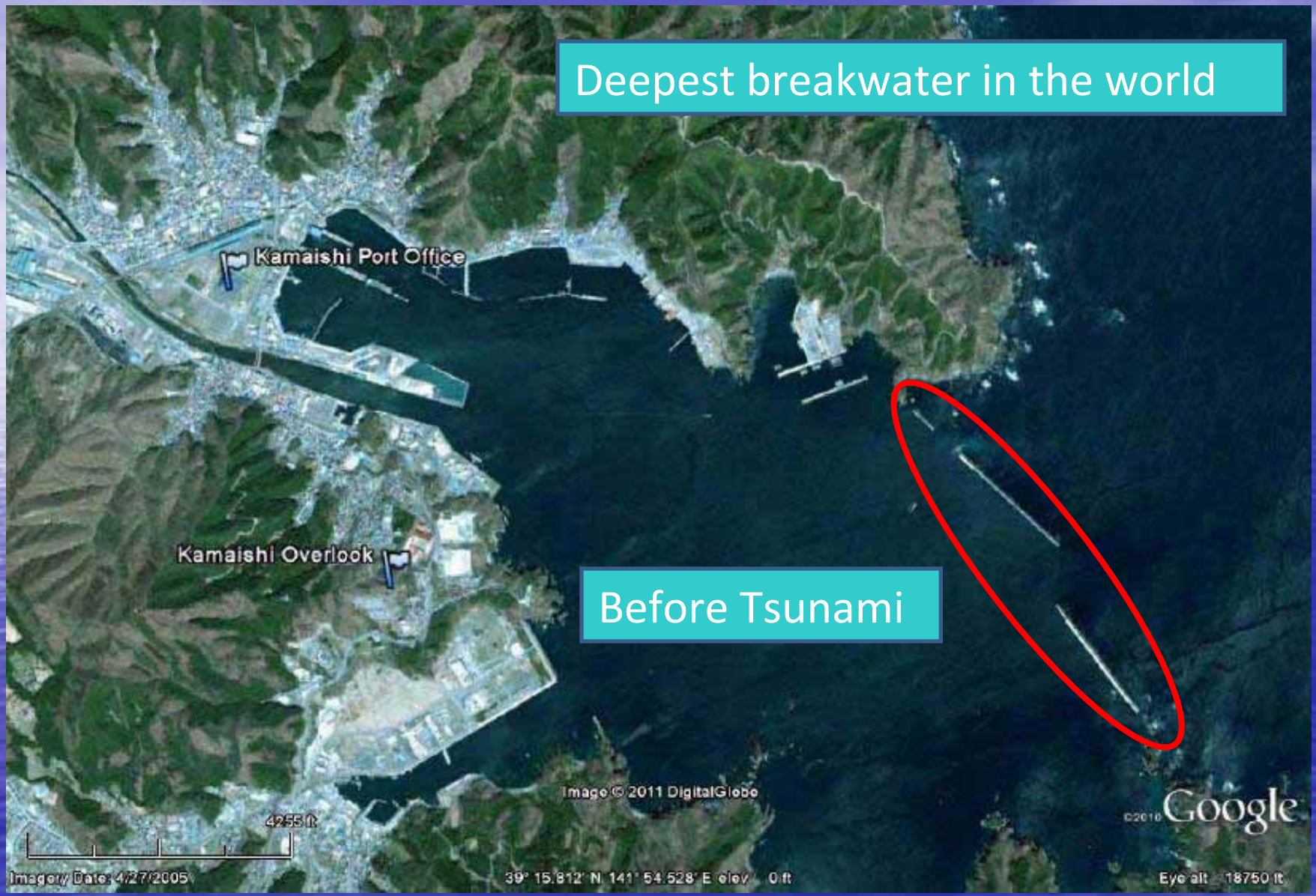




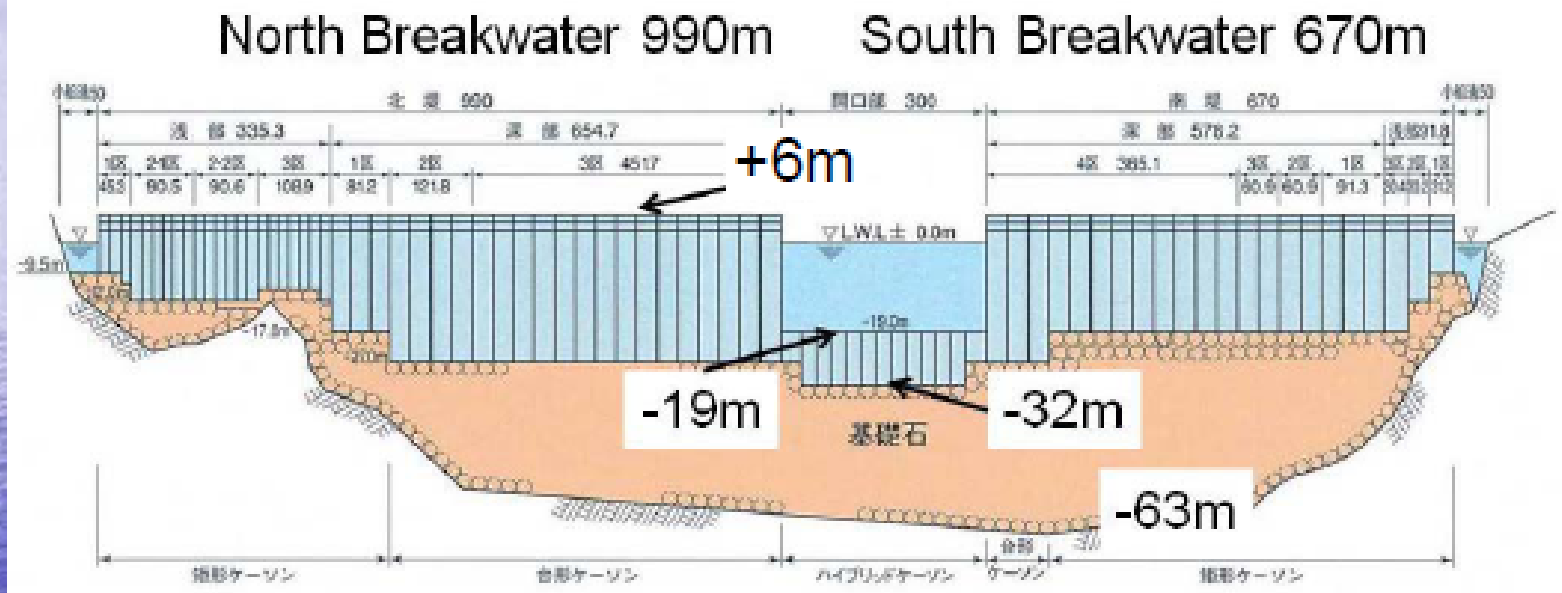
Foundations

Kojirahama (Top left),
Utuchi (Top right),
Tanesashi (bottom)

Kamaishi Tsunami Breakwater



Kamaishi Tsunami Breakwater



Kamaishi Tsunami Breakwater

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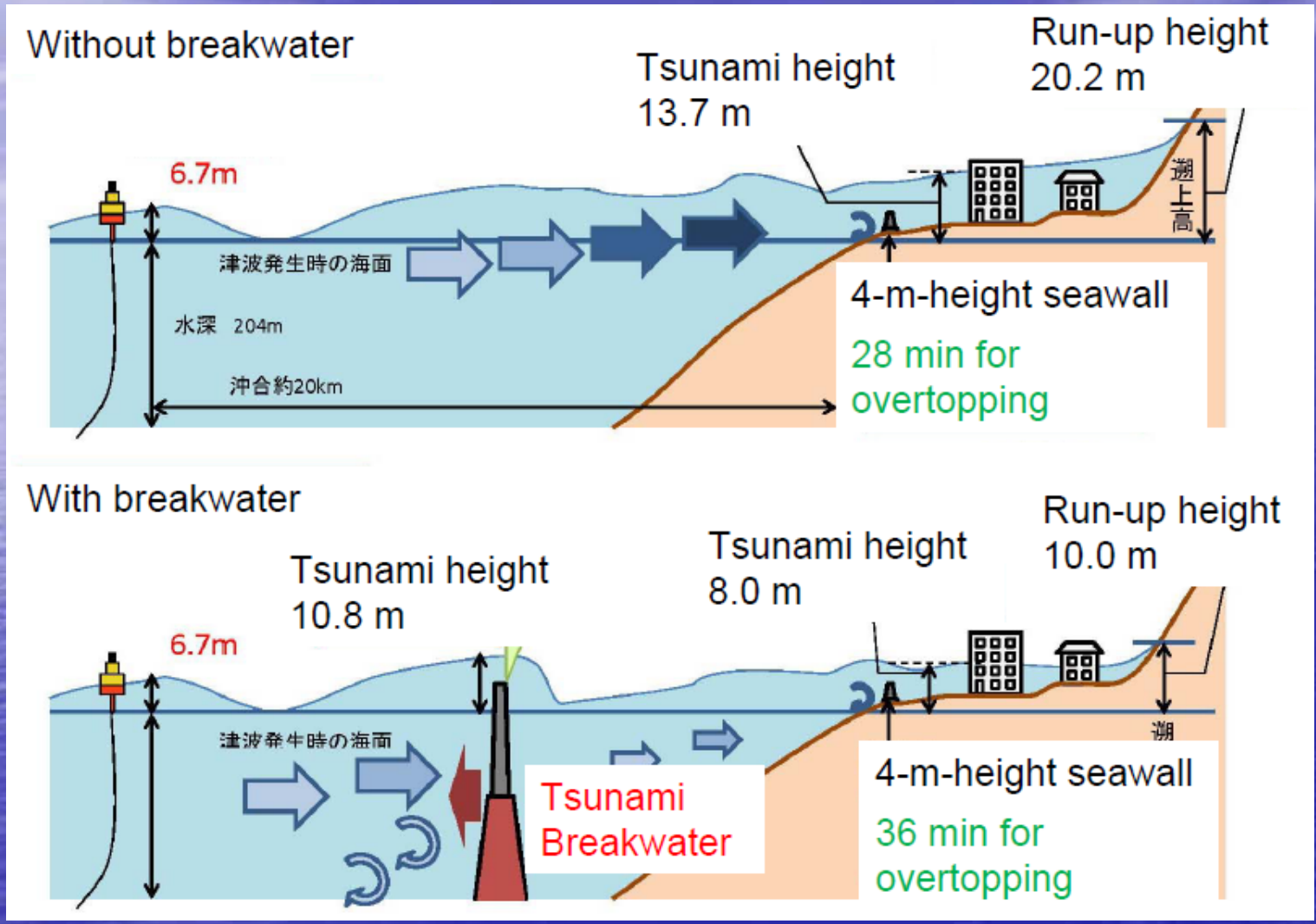


Source: Takahashi, Shigeo et al. *Urgent Survey for 2011 Great East Japan Earthquake and Tsunami Disaster in Ports and Coasts* ,Technical Note of Port and Airport Research Institute. Vol. 1231. Print. April 28, 2011

New Sendai Port

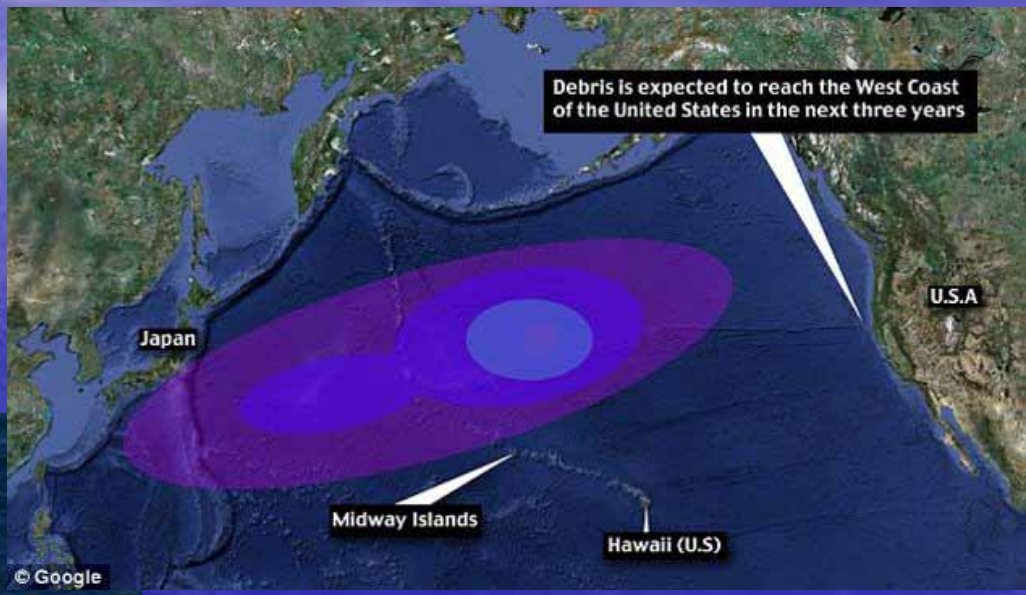
Photos: taken by Jimmy Yu, March 18, 2011

New Sendai Port

New Sendai Port

Debris Clean-up

Debris Clean-up



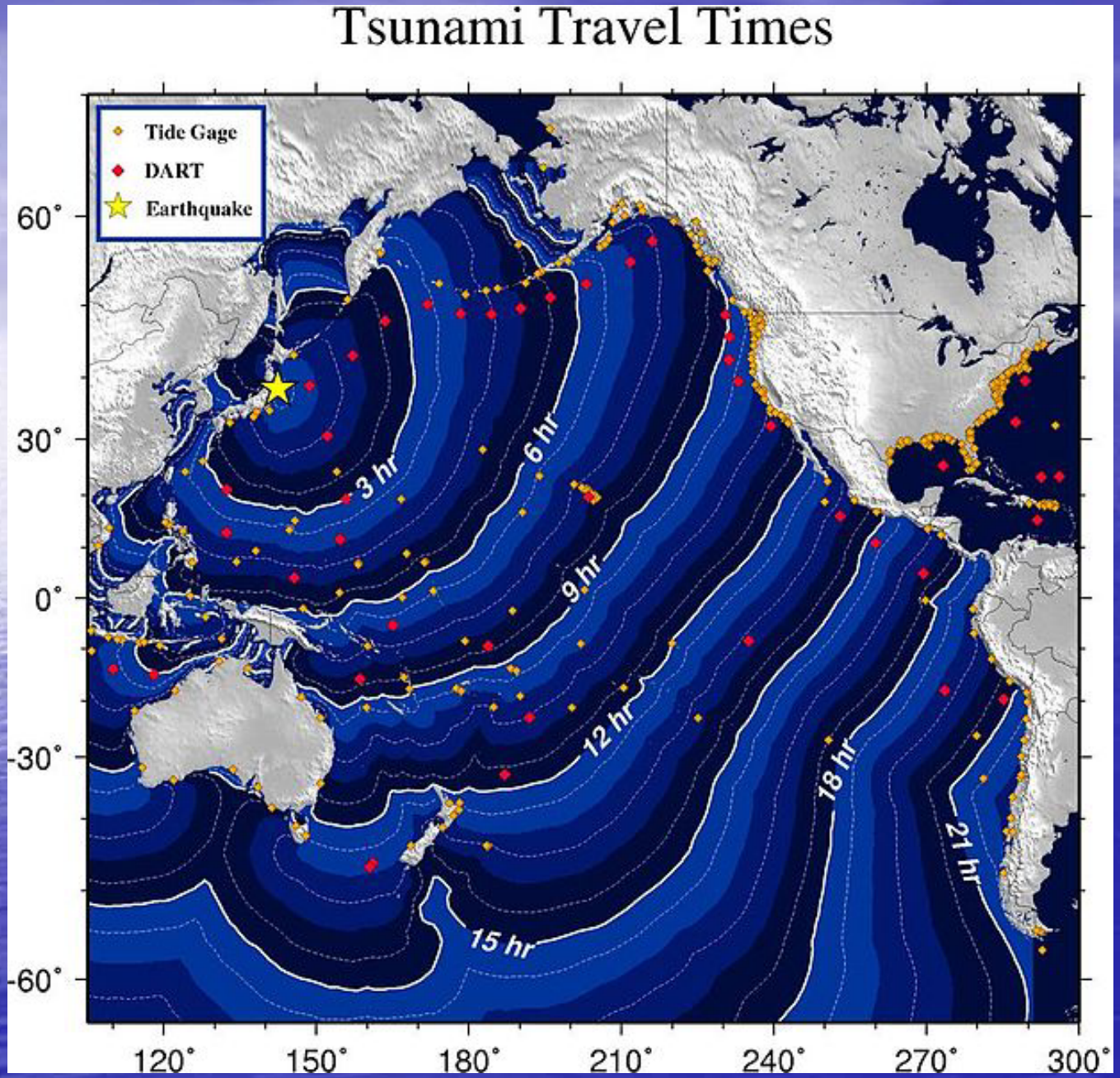
Up to 20 million tons of debris is moving across the Pacific, heading towards Hawaii, and the western coast of North America.

KITV.com/ABC; Discovery News and Yahoo.com

Crescent City, Del Norte County
Population 7,789
Area 5.3 km^2
About 32 km south of Oregon

Past Recent Tsunami History
1960 – Damage from Chilean Tsunami
1964 – Damage and fatalities from Alaskan Tsunami
2006 – Damage from Kuril Island Tsunami
2010 – high water recorded from Chilean Tsunami

Tsunami Travel Times



West Coast & Alaska Tsunami Warning Center,
National Oceanic and Atmospheric Administration

CRESCENT CITY, CA

Predicted Arrival Time: 15:22 UTC/Zulu

Predicted Max. Amplitude – 2.5 m

Observed Max. Amplitude - 2.47 m (8.2 ft)

Time of Observed Maximum Wave 16:56 UTC/Zulu

Local Time is UTC – 8 Hrs.

(During Daylight Savings, Local time is UTC – 7 Hrs.)

Aerial image of Inner Boat Basin from Google Earth

Aerial of boat damage courtesy of T. Williams

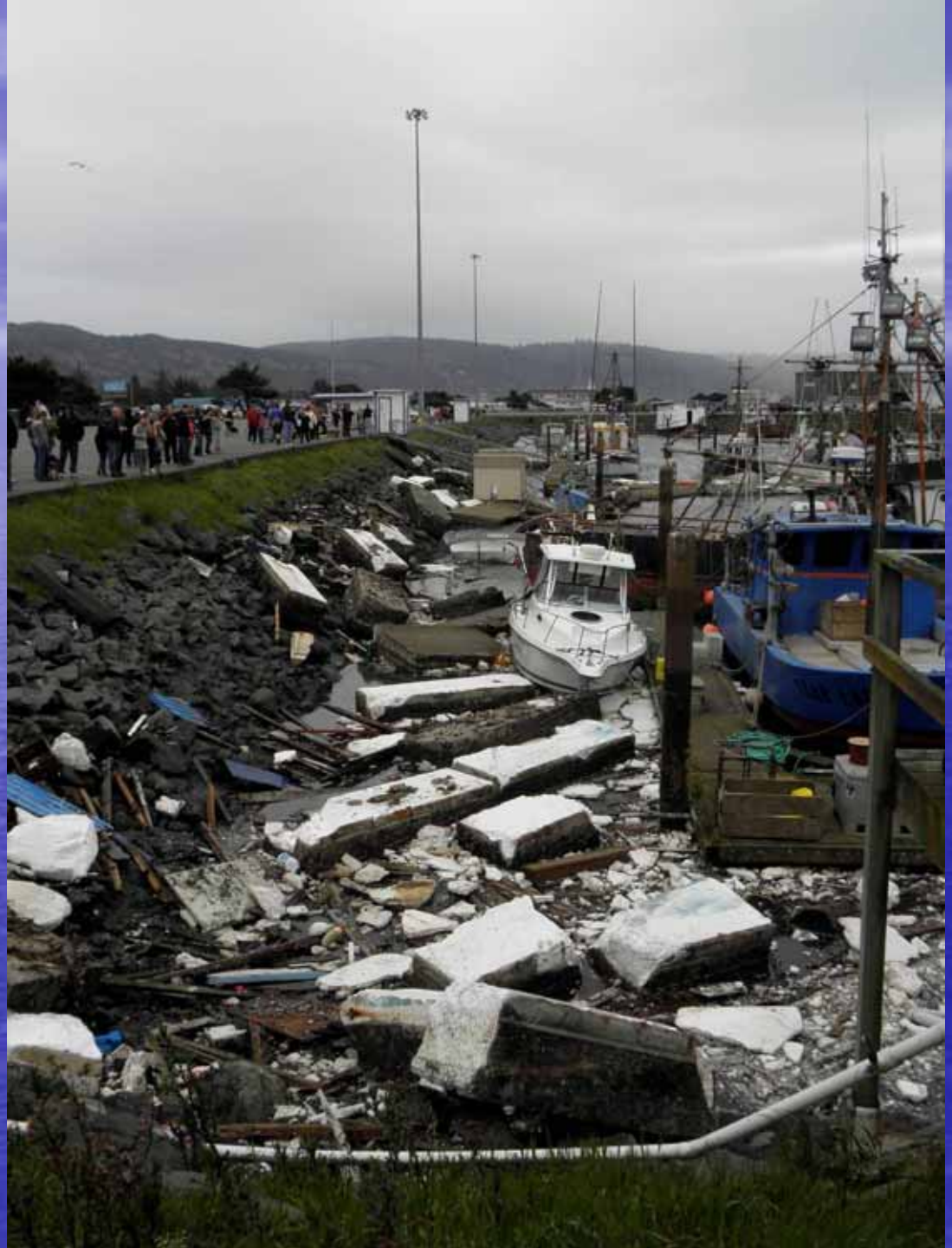
CRESCENT CITY, CA

Predicted Max. Amplitude – 2.5 m
Observed Max. Amplitude - 2.47 m (8.2 ft)

CRESCENT CITY, CA

Mean Tide Range 1.5 m
Diurnal Tide Range 2.1 m

Aerial image of Inner Boat Basin from Google Earth
Aerial of boat damage courtesy of T. Williams




FLAMINGO
ANACORTES


INCIDENT
COMMAND
CENTER


Placing Boom at Elk Creek,
afternoon of March 12, 2011


Placing Boom at Elk Creek,
afternoon of March 12, 2011


Placing Boom at Elk Creek,
afternoon of March 12, 2011


Placing Boom at Elk Creek,
afternoon of March 12, 2011
SEACOR-ENV.COM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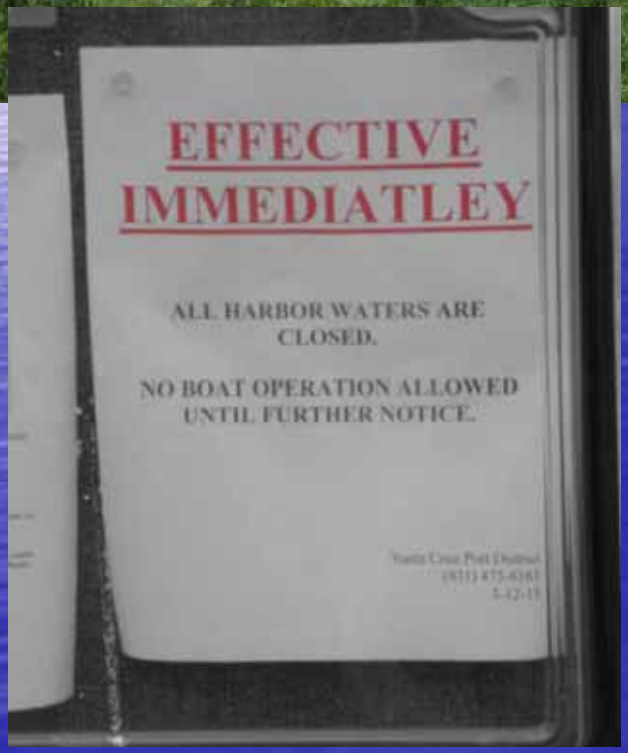

STATE OF CALIFORNIA—NATURAL RESOURCES AGENCY EDMUND G. BROWN, JR., *Governor*

CALIFORNIA COASTAL COMMISSION

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April 13, 2011
Revised April 18, 2011

THE TOHOKU TSUNAMI OF MARCH 11, 2011: A PRELIMINARY REPORT ON EFFECTS TO THE CALIFORNIA COAST and PLANNING IMPLICATIONS

To: Coastal Commissioners and interested parties
From: Lesley Ewing, PE, Sr. Coastal Engineer

This memorandum is intended to provide the Commission with an understanding of tsunami creation, propagation and landfall effects and the implications to coastal California, drawing strongly from the most recent Tohoku tsunami. The discussion includes:

- Tsunami science and detection
- Tsunami warnings and response
- Tsunami damage to the California coast from the Tohoku tsunami

A detailed damage report, variety of reference materials, useful web sites and links are provided at the end of this report.

TABLE OF CONTENTS

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times PST	Observed First Arrival Times PST	Aprox. Time of Maximum Amplitude PST	Current (knots)*	Damage	Unofficial damage estimate (UNK=unknown)	Description
Smith River			1.5-2.0		730	950	15-20	N		Strong surges and bores flowing up river
Crescent City Harbor	2.5	2.47	2.7-3.0	723	734	853	8.2	Y	$36,000,000	Destruction of harbor; 16 boats sunk
Klamath River mouth	2.36		2.0-2.5					N		One fatality, body found April 2 near Astoria, OR
North Spit/Port of Humboldt Bay	1.33	0.97		722	734	900	1.5	N		One boat knocked from moorings
Noyo River Harbor			0.8-1.0			930	15-25	Y	$4,000,000	50 small docks damaged and sunk; boats damaged
Dolphin Isle Marina, Noyo River			0.6-0.8				15-20	Y	UNK	Numerous docks and boats damaged/sunk
Albion			0.6-0.8				5-10	N		Bore traveled up river
Waldo Point Marina (Sausalito)	0.37		1.2-1.5				15-18	Y	UNK	Broken PVC sewer line
Berkeley Marina			0.6				8-9	Y	$125,000	Damage to docks; no boat damage
Marina Bay Yacht Harbor (Richmond)		0.35			845	1015-1100	5-6	Y		Four buoys displaced
Emery Cove Yacht Harbor (Emeryville)			0.4-0.6			1030	4-6	N		Bore observed entering bay near Emeryville
San Francisco Marina	0.73	0.62		808	812	1000	7	Y		Two piles broken; boats heeled over
Pillar Point Harbor	0.92		0.7				7-15	Y	UNK	Minor damage; abalone raft broke lose; floats moved from docks
Santa Cruz Harbor	1.01		1.6-1.9			1114	20-25	Y	$23,000,000	Multiple docks destroyed; 20 ships sunk, 100 damaged
Rio Del Mar/Aptos (Santa Cruz Co.)	1.62						5-10	N		Bore traveled up Aptos Creek in video
Moss Landing Harbor			2	744	840	1100	15-25	Y	$1,020,000	209 timber piles damaged; 85 characterized as severe.
Morro Bay Harbor	1.18	1.6			810	930,1130	15-20	Y	$500,000	Three piles and three finger docks broken; damage to ships
Oceano Dunes SRA	0.73		0.7-1.0		830	1430		N		NOTE: no damage but evacuated over 100 recreational vehicles
Santa Barbara Harbor	0.48	1.02			829	1800/2400	10-20	Y	$70,000	Damage to crane and bait barges; damage to several boats
Ventura Harbor	0.88		1.3		800	1151/12?	10-15	Y	$150,000	Damage to dock and a number of boats; injury during boat docking
Channel Islands Harbor			0.9-1.2		830	1000	8-10	Y	UNK	Damage to docks by boats
Marina Del Rey			0.9-1.0		830	1000	6-8	Y	UNK	Three small dingies sunk; minor dock damage
Ballona Creek			0.4-0.6				8-10	N		Video of bore traveled at least 1.7 mi upstream
King Harbor (Redondo Beach)	0.65		0.6-0.7		900	1215	10-15	Y	$15,000	One dock destroyed and five boats damaged
Port of Los Angeles	0.39	0.49		833	840			Y	UNK	Minor damage to docks/boats.
Port of Long Beach								Y	UNK	Minor damage to docks/boats.
Long Beach Marina-Shoreline			0.6-0.7			1000	8-10	Y	UNK	Couple boats and a dock destroyed; debris boom destroyed
Two Harbors (Catalina)						1330	12-15	Y	UNK	Several docks and 10 boats damaged
Huntington Harbor	0.71				900		8-10	Y	UNK	Boat pulled off mooring. Possible scour to Hwy 1 bridge.
Dana Point Harbor			0.6		839	1630	10-15	Y	UNK	Pylon damaged when boat hit
Mission Bay - Quivera Basin/Lifeguard HQ					900	1630	5	Y	$800	Lifeguard dock damaged
Mission Bay - Quivera Basin/Seaforth Marina						1530	6-8	Y	$136,000	Bait dock destroyed; 13 boats damaged; 26 piles damaged
Ocean Beach			1			1530		N		Family knocked into water during Advisory, were rescued
Shelter Island-South Harbor Police Dock			0.8			1815	12-15	Y	$110,000	Pontoon patrol boat sunk; damage to docks and other boats
Harbor Island West Marina			0.3			1500-1600	10-15	Y	UNK	Damage to docks

Wilson, R., Dengler, L., Borrero, J., Synolakis, C., Jaffe, B., Barberopoulou, A., Ewing, L., Legg, M., Ritchie, A., Lynett, P., Admire, A., McCrink, T., Falls, J., Rosinski, A., Treiman, J., Manson, M., Silva, M., Davenport, C., Lancaster, J., Olson, B., Pridmore, C., Real, C., Miller, K., and Goltz, J., 2011, The effects of the Tohoku Tsunami on the California Coast; 2011 Seismological Society of America Annual Meeting, Memphis, TN; poster session.

Contingency Planning: The What Ifs .....

... Events Exceed Design Conditions
... Site Conditions Change
... Excessive Loads
... The Unexpected Happens

Taro Bay

2011 tsunami elevations
~28 m north section
~20 m south section

Historic Tsunami Elevations

Lessons Learned

- Lessons came from observing structural response to extreme conditions
- Breakwaters and walls did help mitigate damage to harbor areas
- Strong connections, good foundations and scour protection can help prevent structural failure
- Many protective structures were overtopped but had little damage
- Designs should consider "what if" scenarios

Further Study

- Beach Response
- Scour behind linear or irregularly shaped structures
- Performance of different armor units
- Performance of vegetated buffers & event intensities
- Evacuation Response with Shore Protection
- Ongoing Use of Contingency Planning – What Ifs

Questions

Fishing Anchorage neat Okawa