Effect of Tsunamis Generated in Manila Trench on the South China Sea and the Gulf of Thailand

And

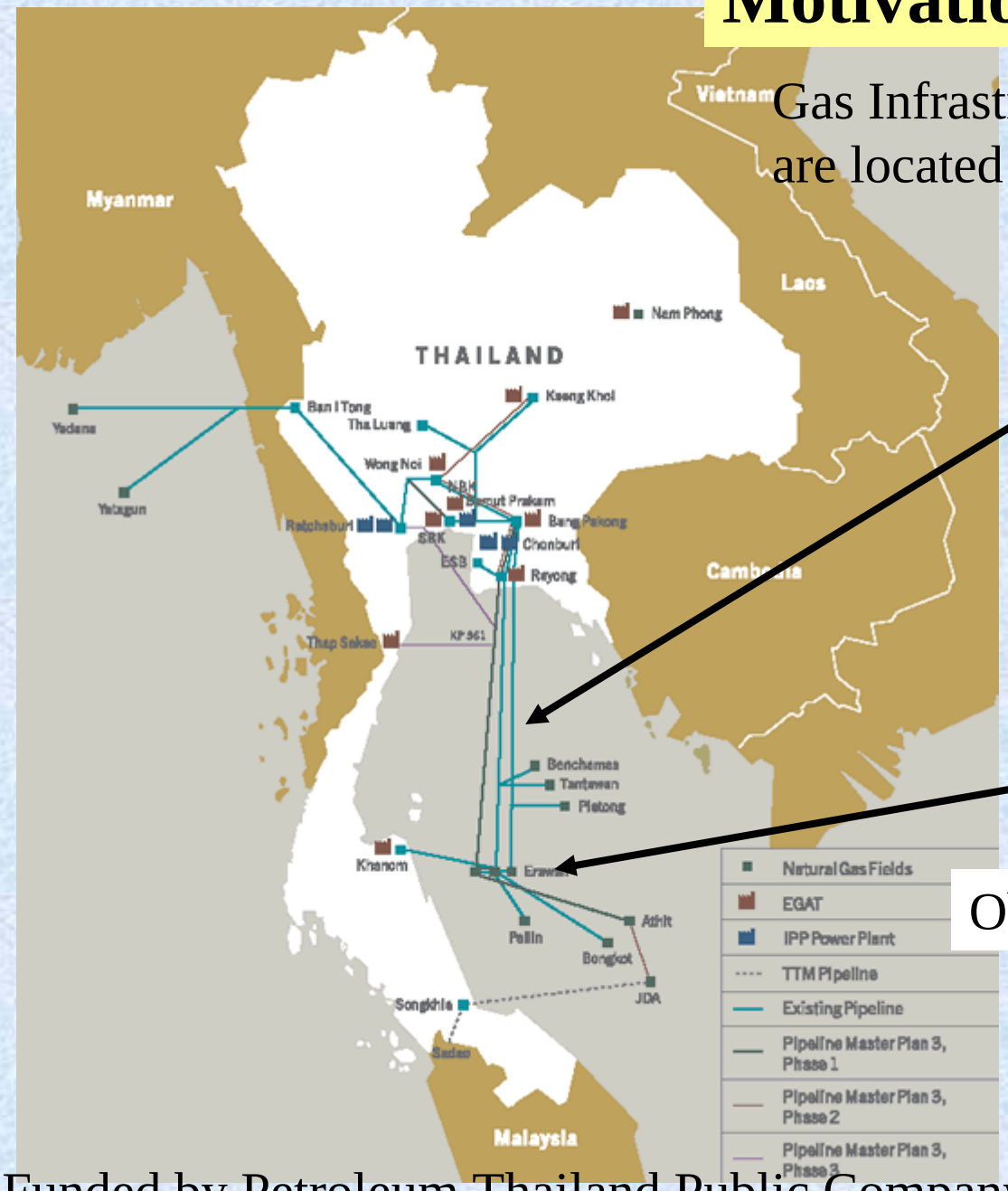
Current Research on Tsunamis in Thailand

Anat Ruangrassamee

Center of Excellence on Earthquake Engineering and Vibration

Department of Civil Engineering
Chulalongkorn University
Bangkok, Thailand

Motivation

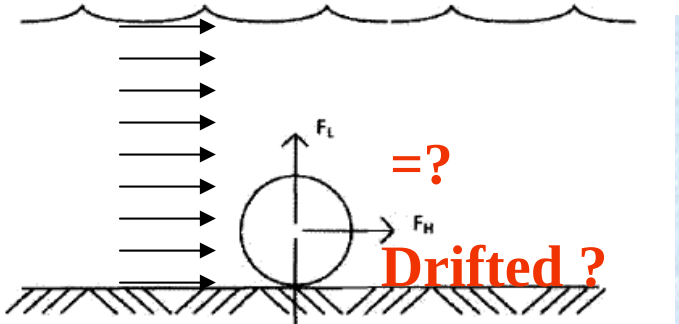


Gas Infrastructure and Petro-Chemical facilities are located in the Gulf of Thailand.

1359km-long offshore pipelines

Offshore platforms

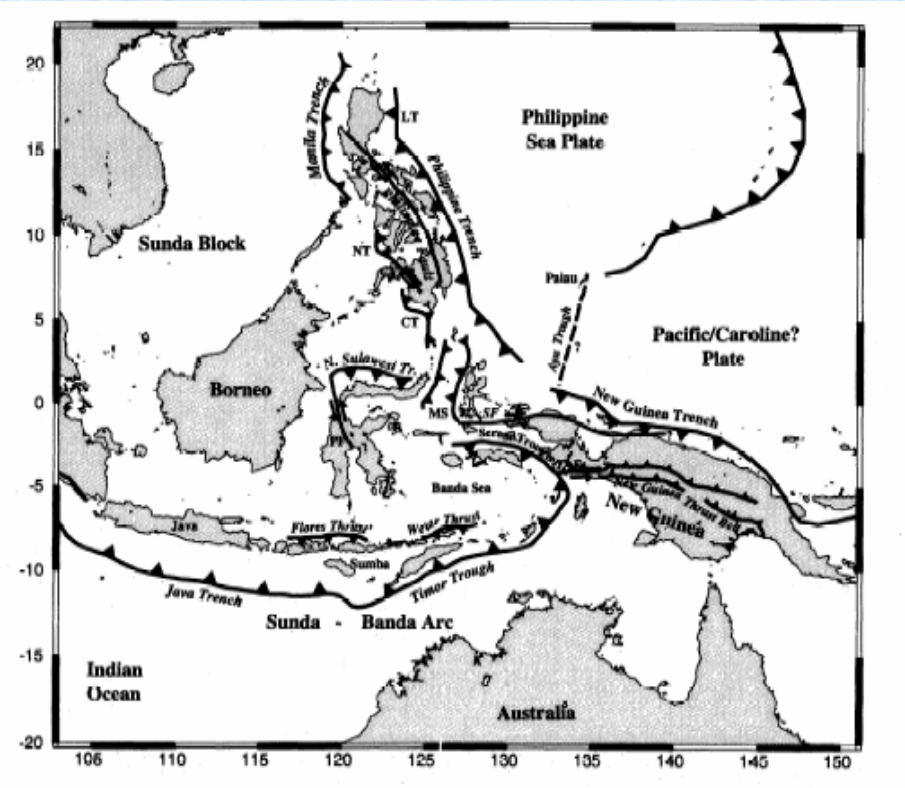
Obtain current velocity and wave height



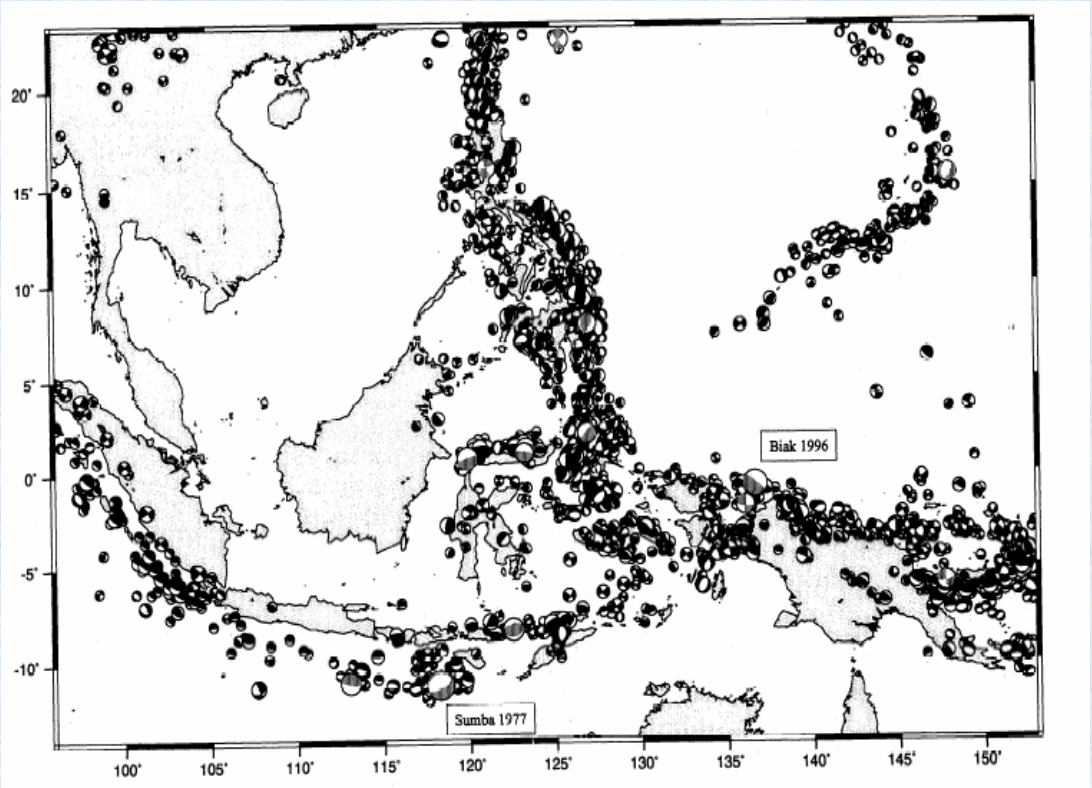
Funded by Petroleum Thailand Public Company

Background: Earthquakes in South China Sea

Tectonics

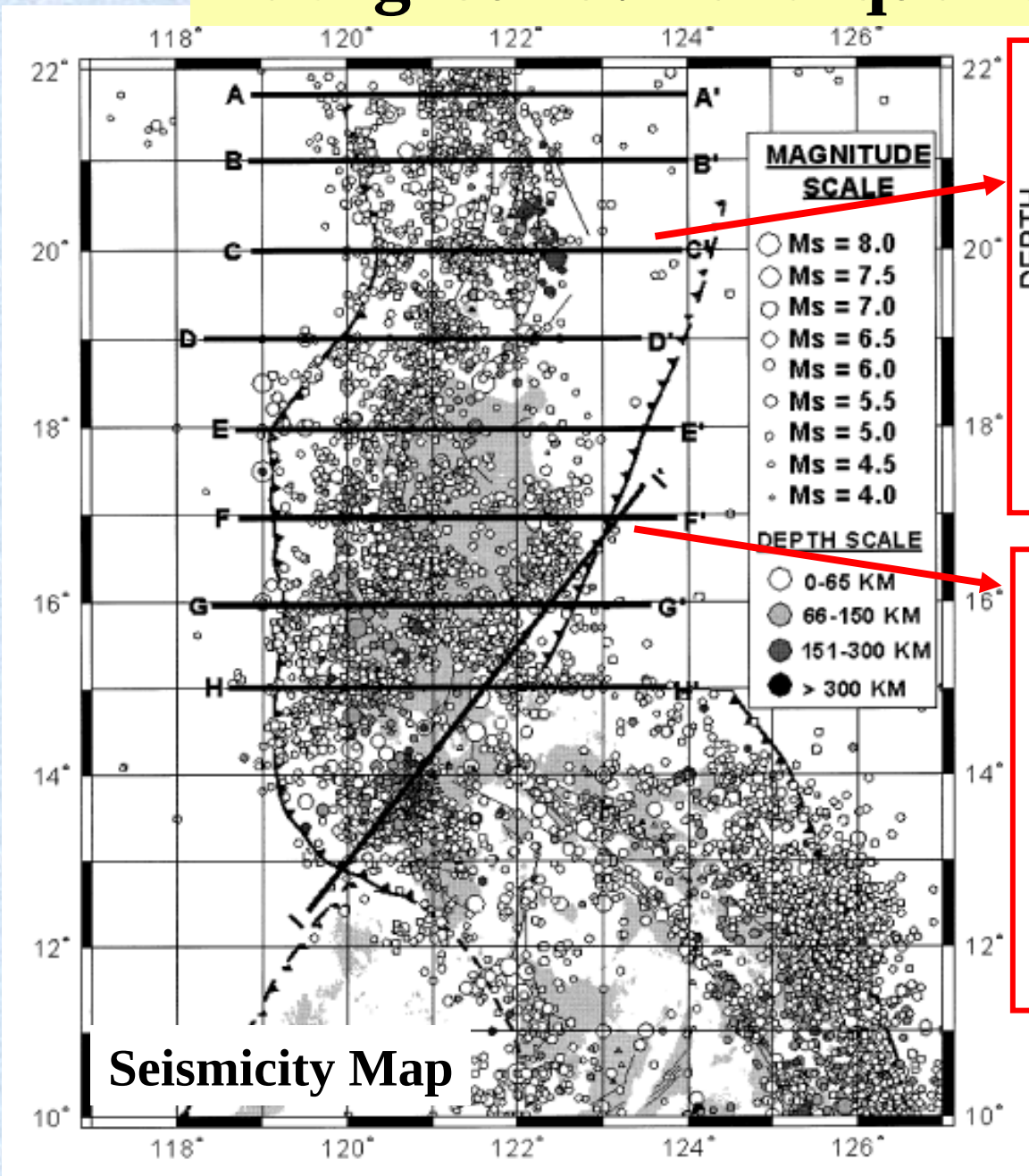


Seismicity Map

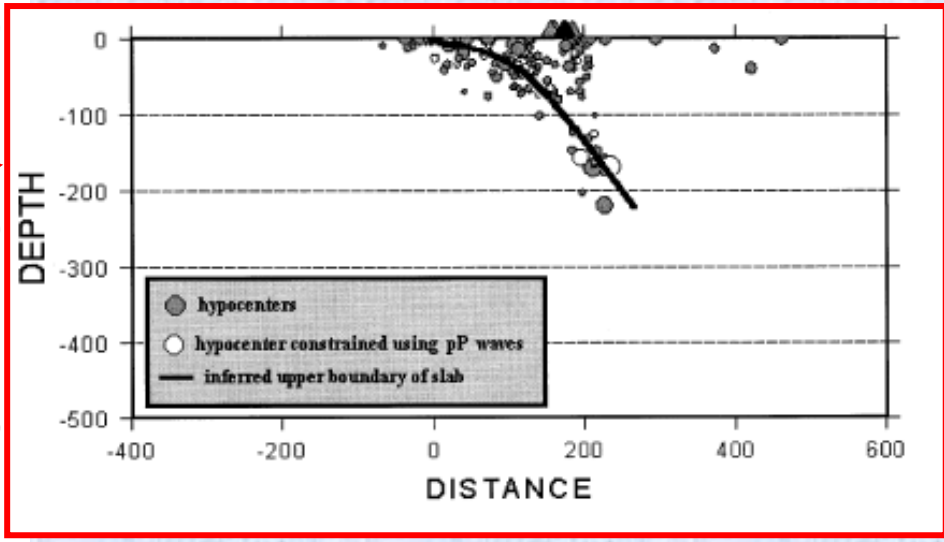


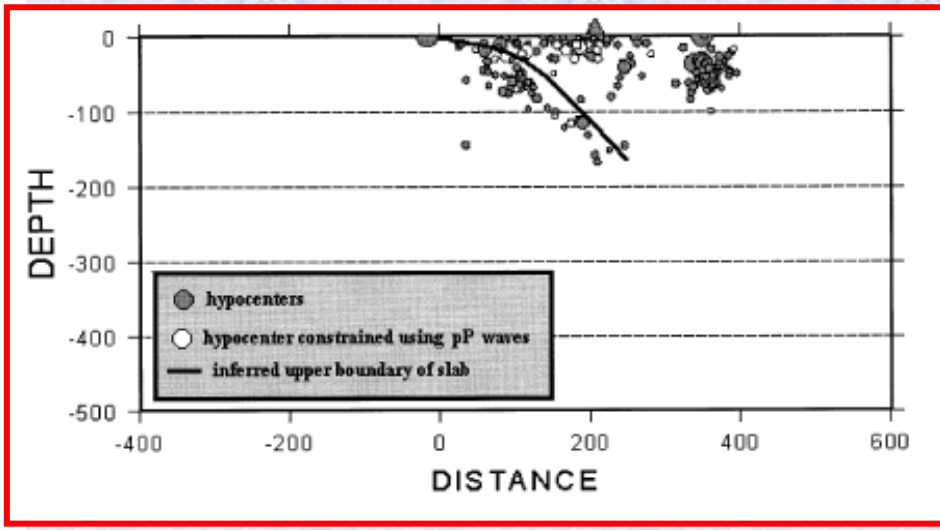
After Kreemer and Holt, 2000

Background: Earthquakes in the Philippines



Seismicity Map



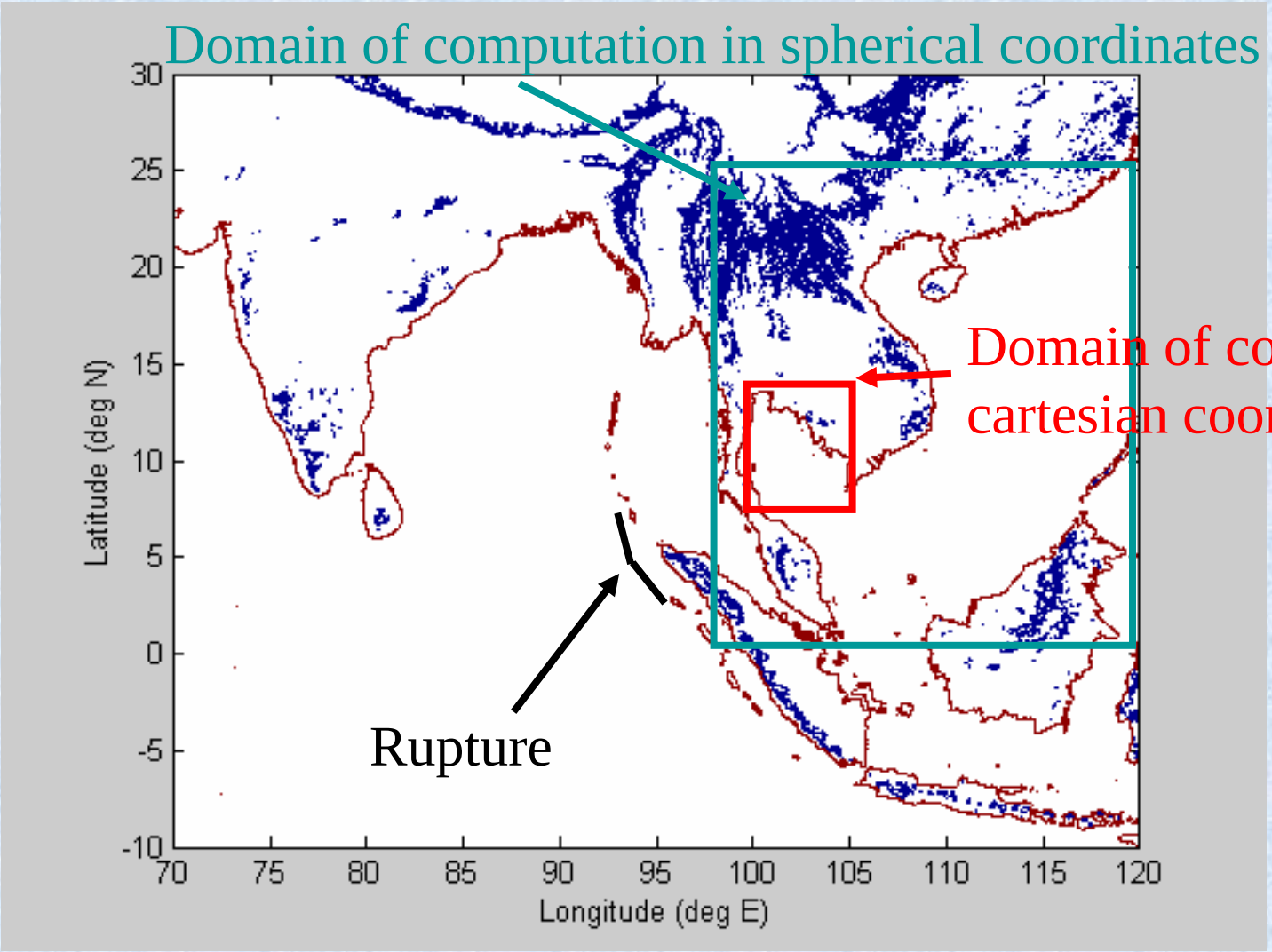


Data from 1619-1997

Bautista et. al., Tectonophysics, 2001

Tsunami Simulation

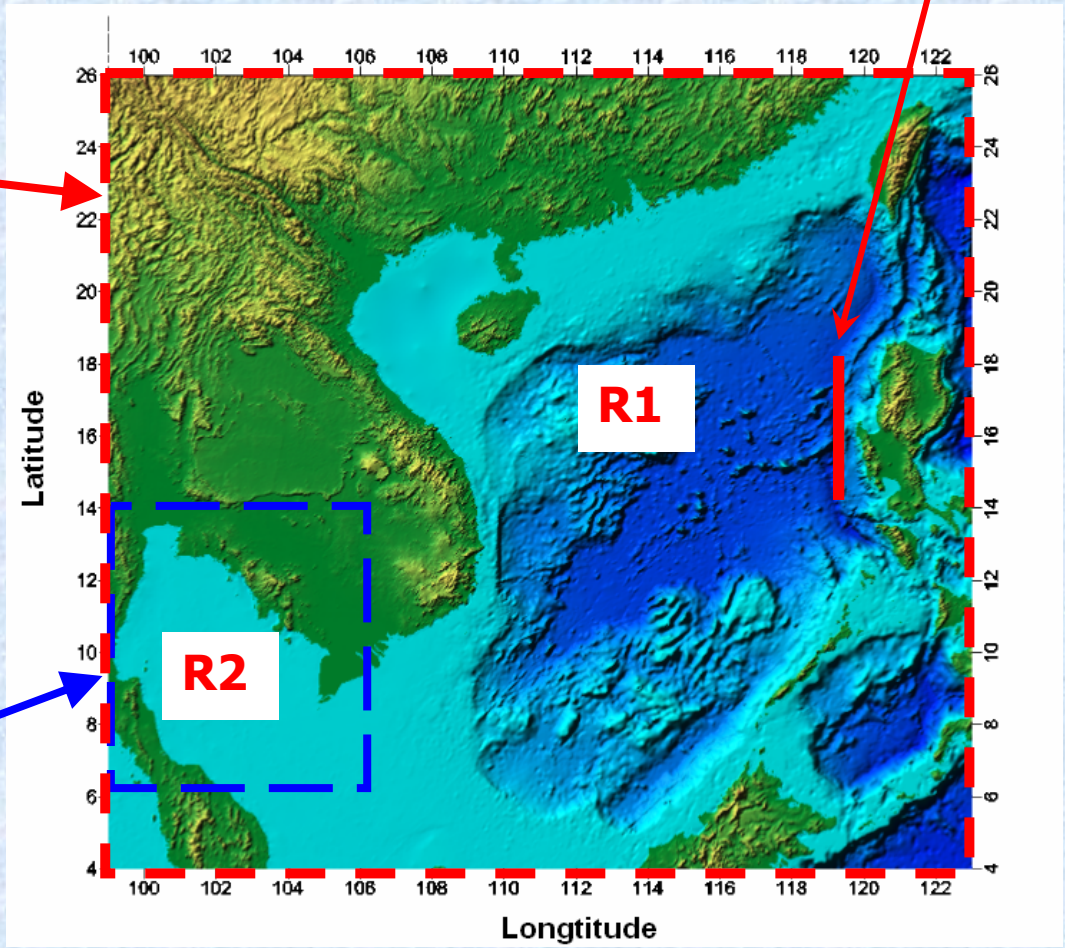
Analyzed using TUNAMI modified to simultaneously compute in spherical and cartesian coordinates.



Region of Computation

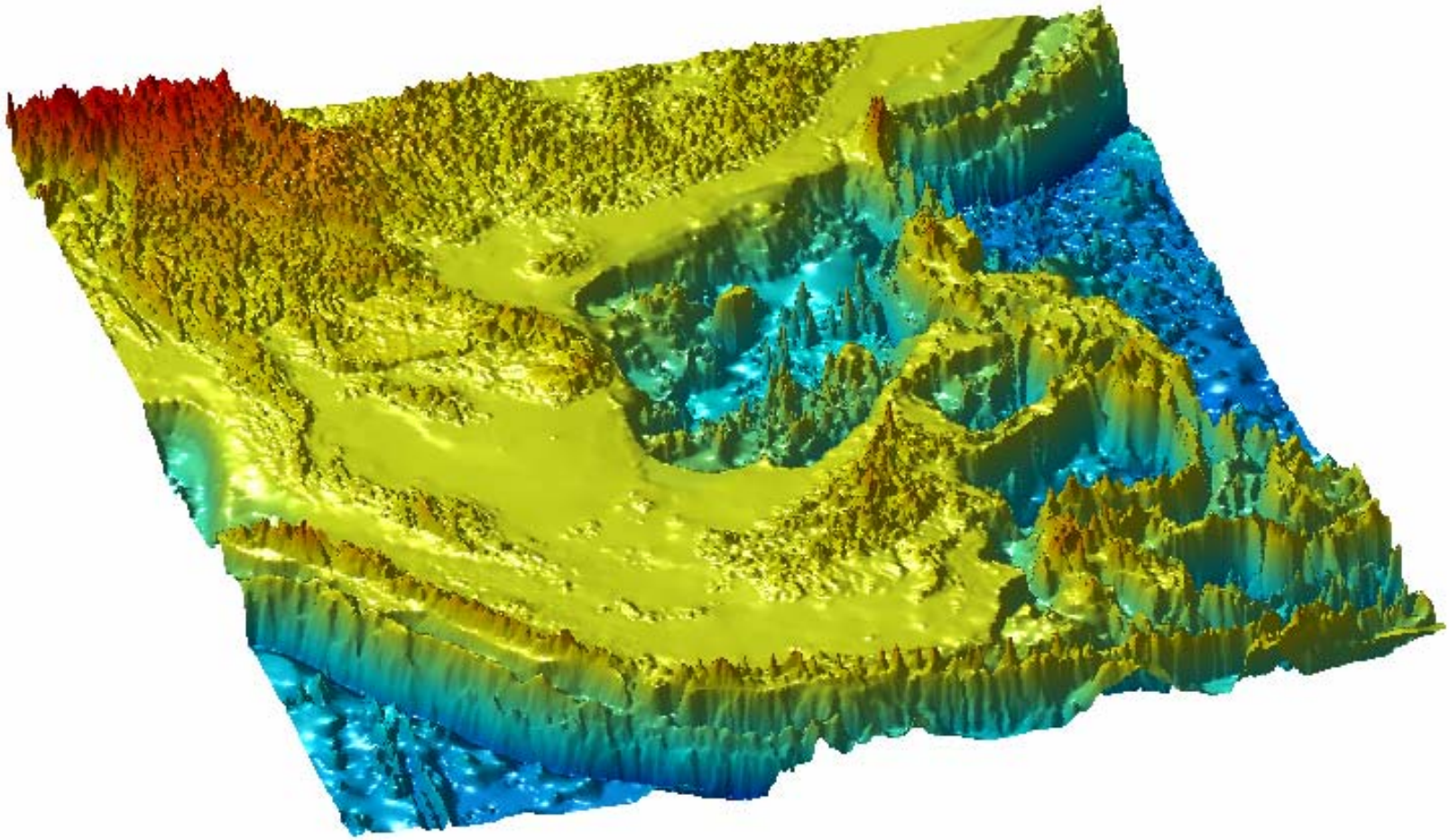
Rupture location

Domain of computation in Spherical coordinates.
Latitude 4 N -26 N
Longitude 99 E-123 E



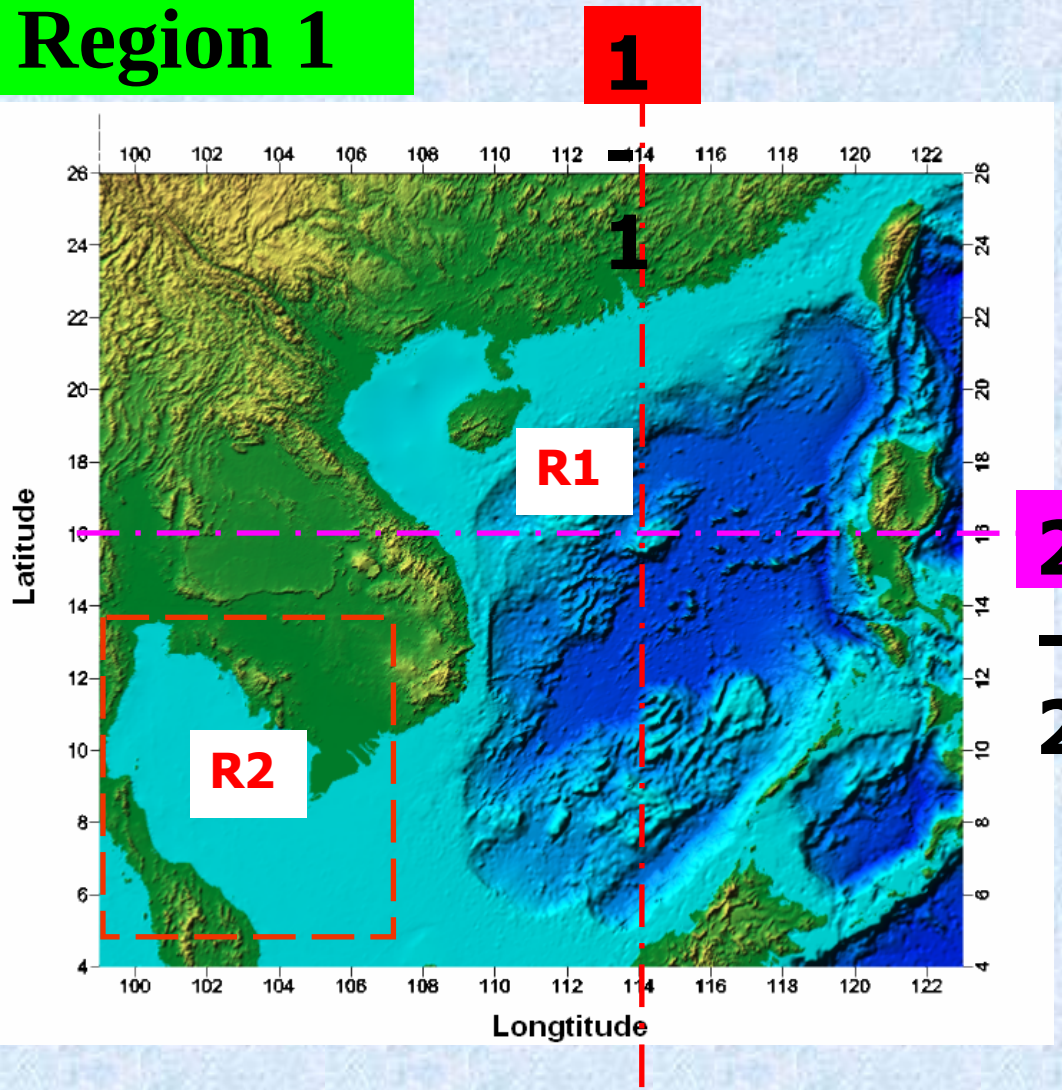
Domain of computation in Cartesian coordinates.
Latitude 6 N- 14 N
Longitude 99 E-106 E

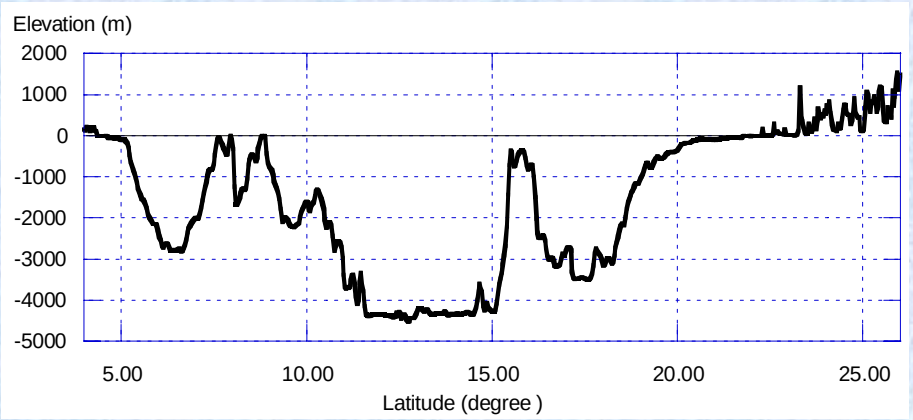
Bathymetry and Topography



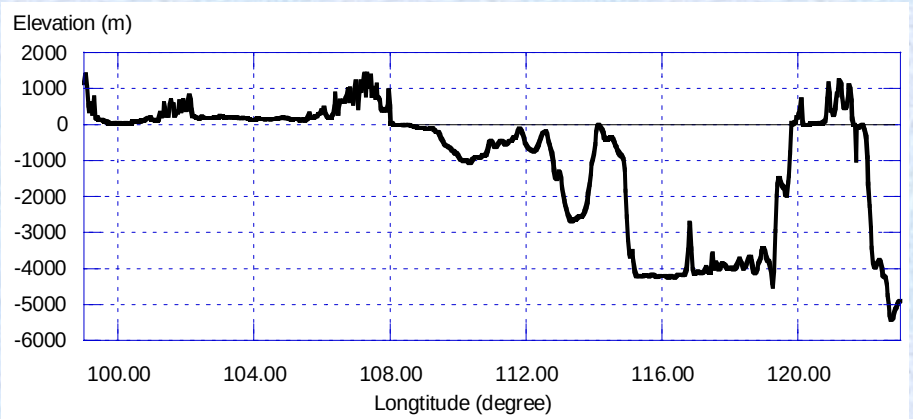
Bathymetry and Topography

Region 1





Section 1-1

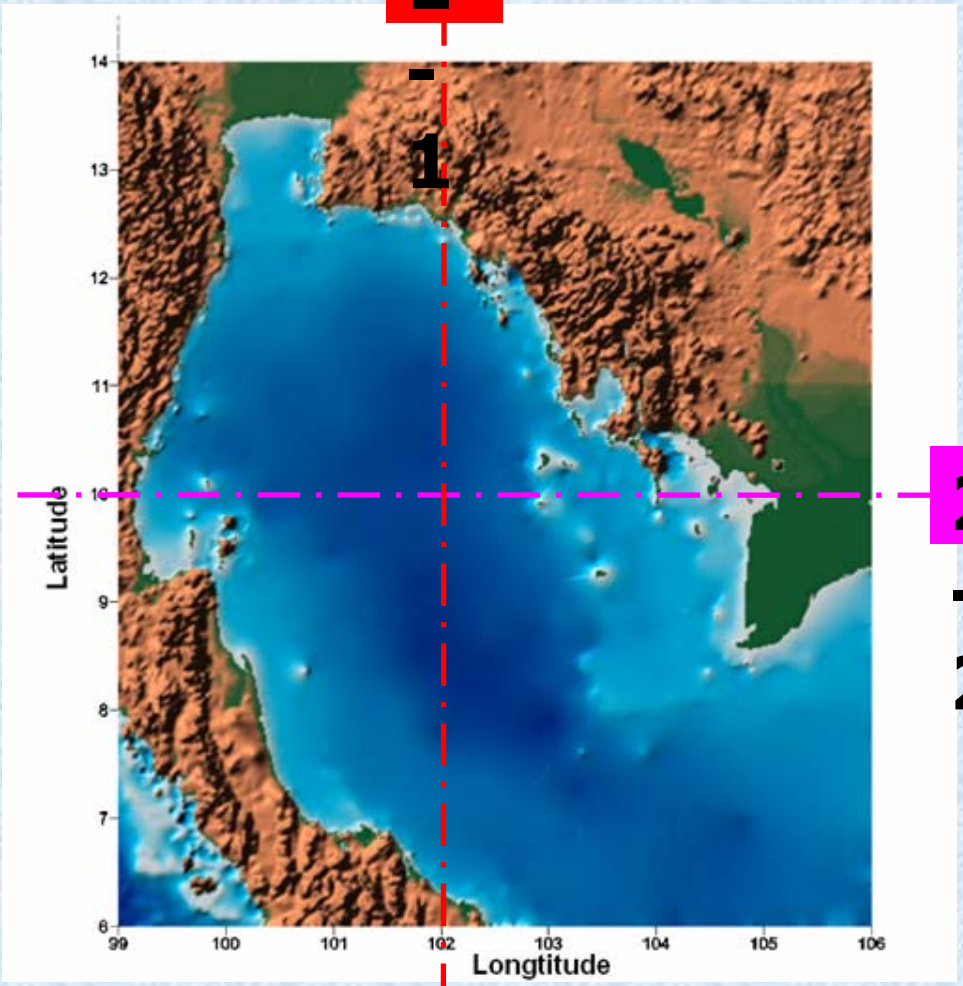


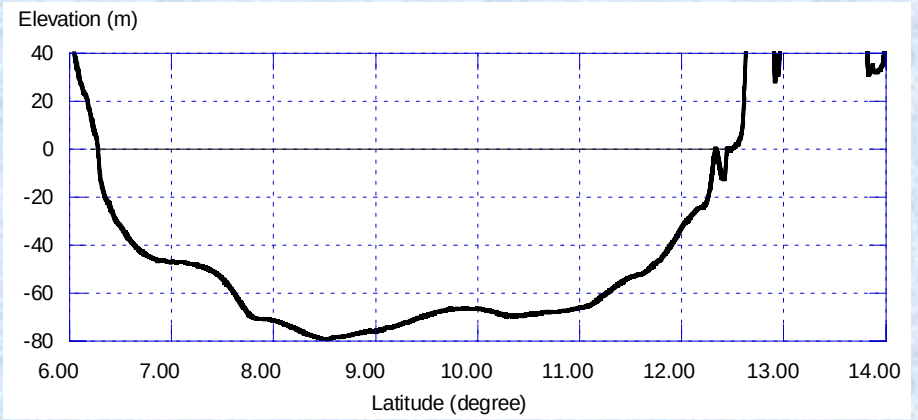
Section 2-2

Source: ETOPO2 (www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html)

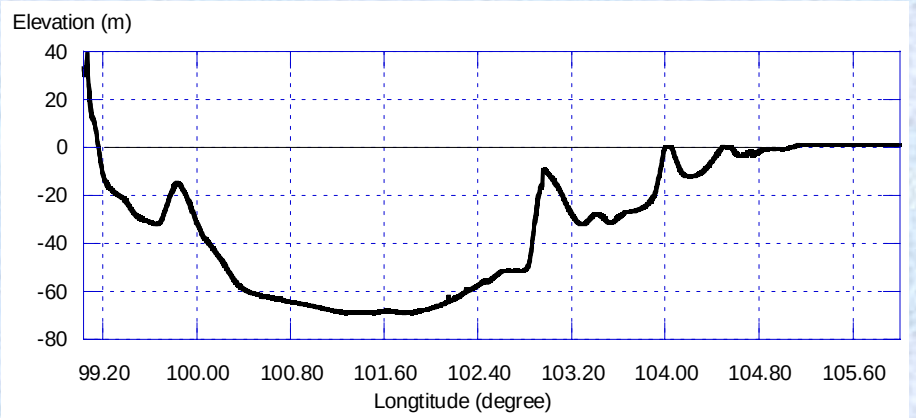
Bathymetry and Topography

Region 2





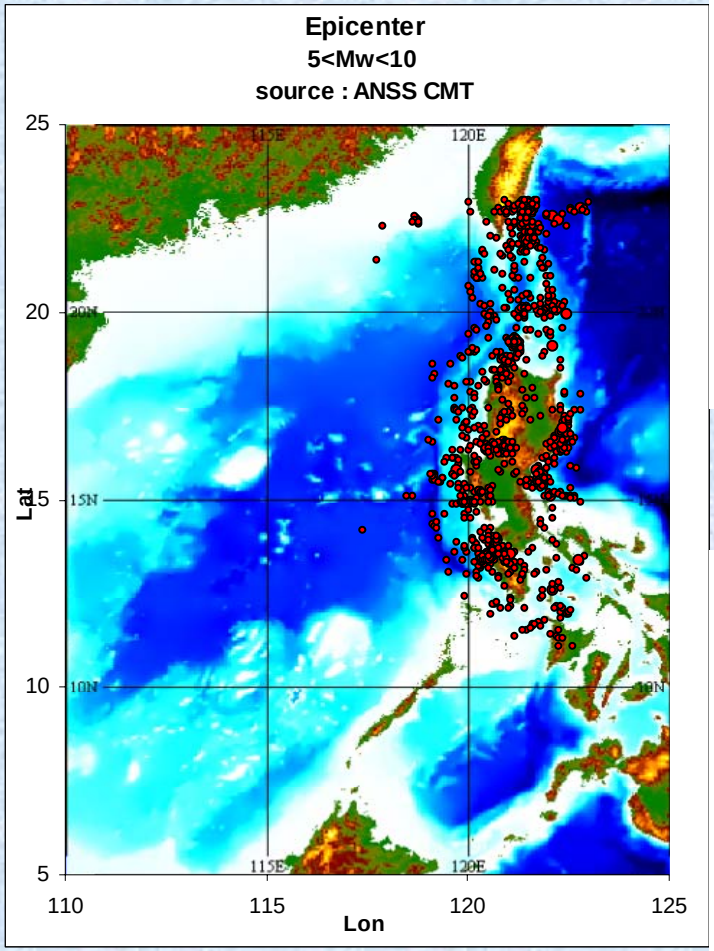
Section 1-1

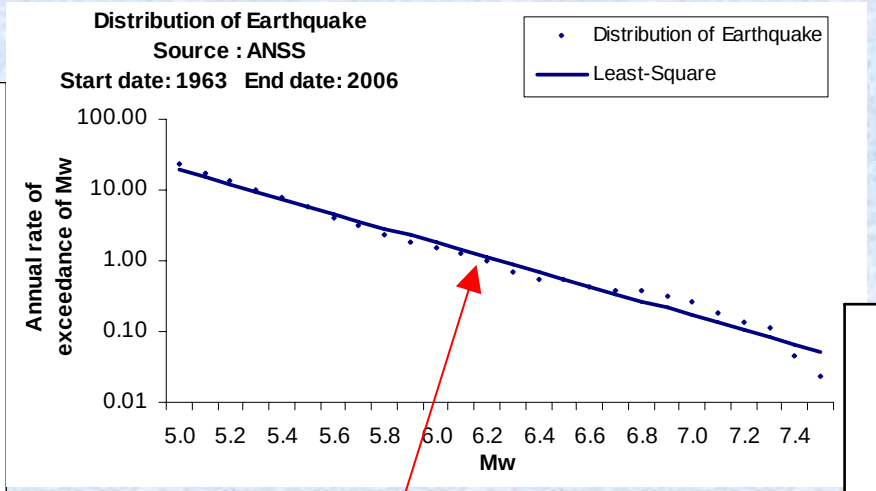


Section 2-2

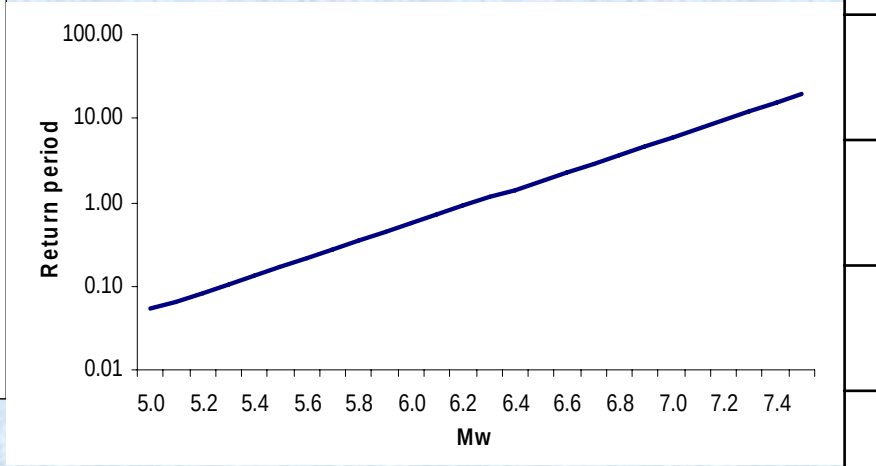
Source: Hydrographic Department, Royal Thai Navy

Estimation of Return period





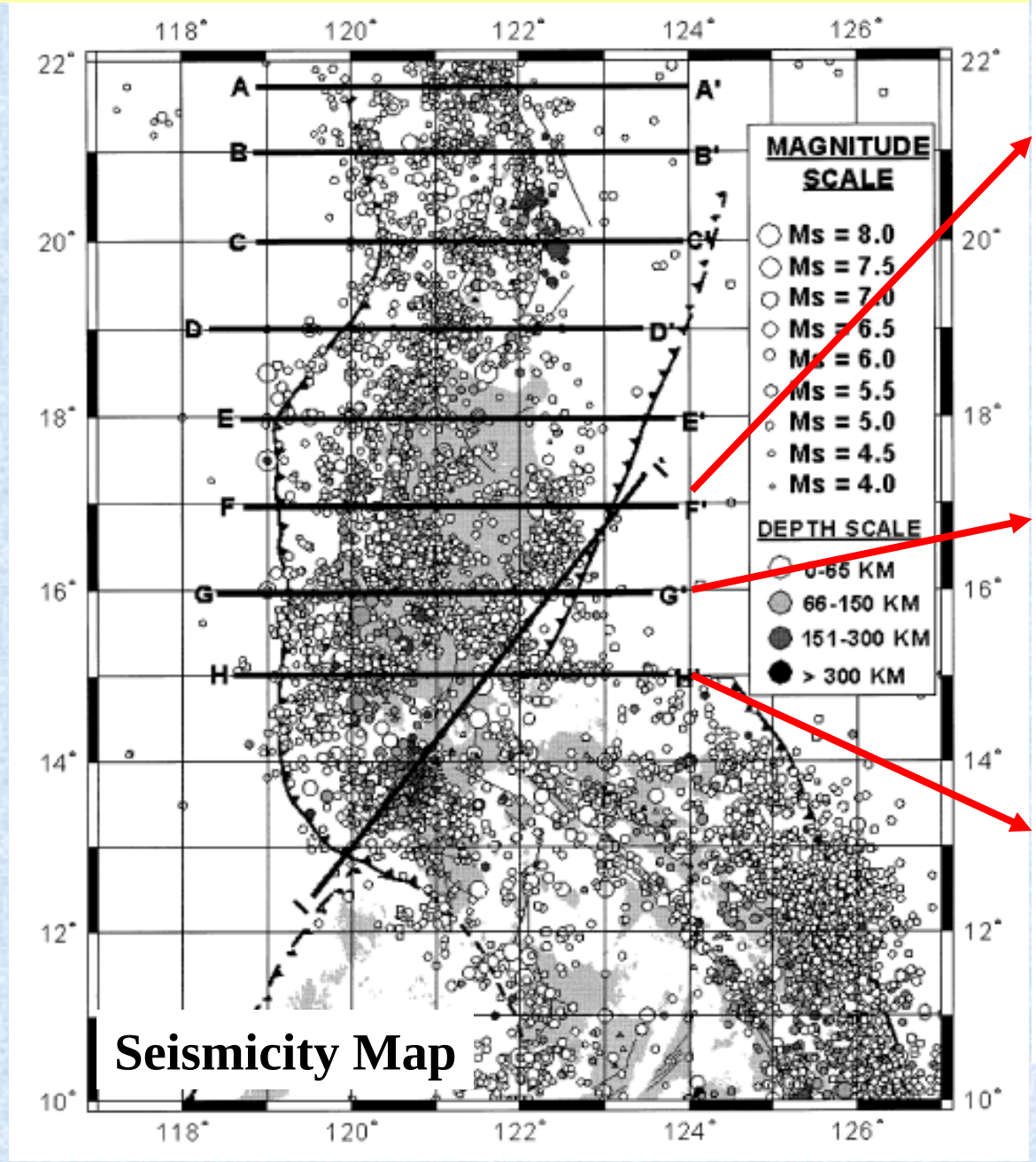
$$\log N = 6.410 - 1.026M$$



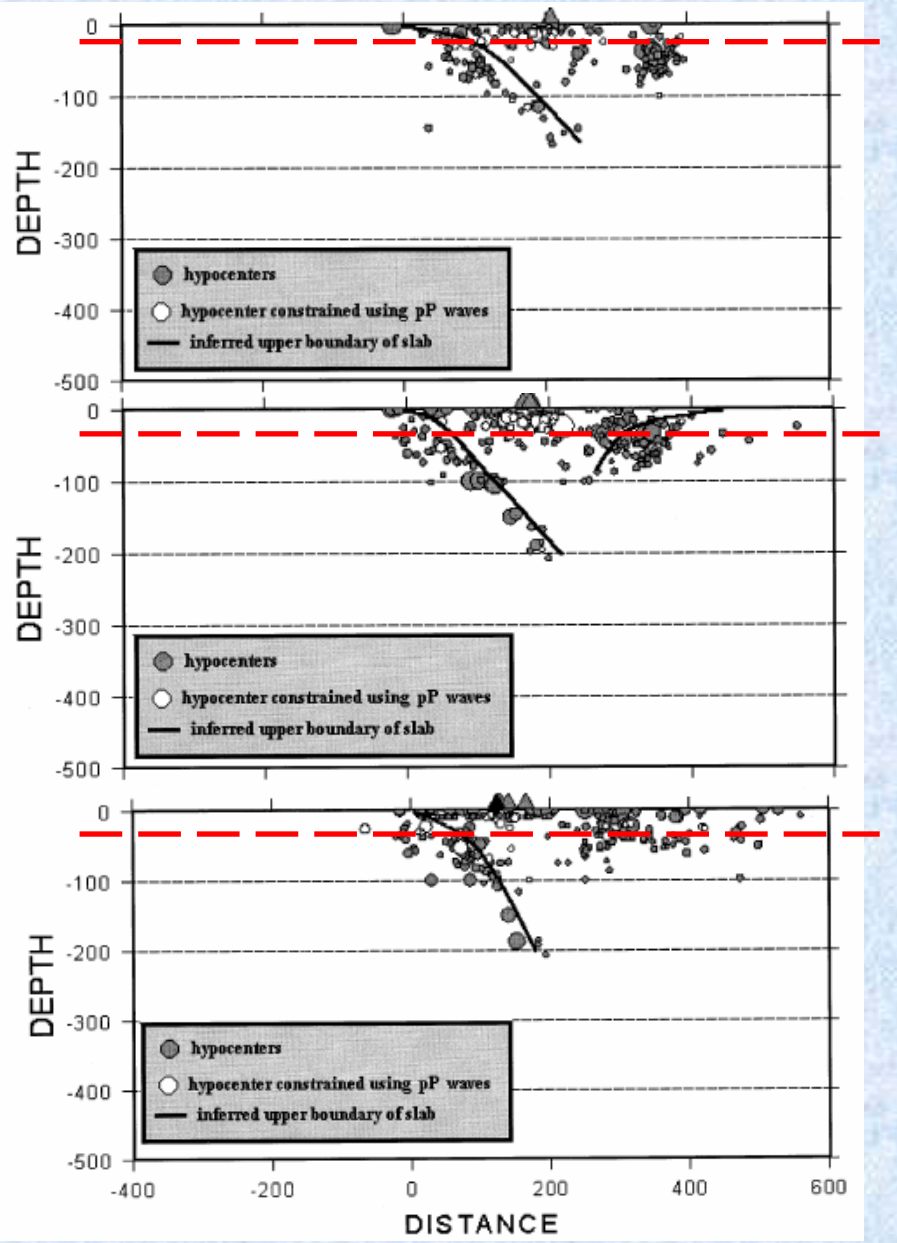
Mw	Return Period (year)
7.0	6
7.5	19
8.0	63
8.5	205
9.0	667

Source:ANSS 1963-2006

Earthquakes in the Philippines

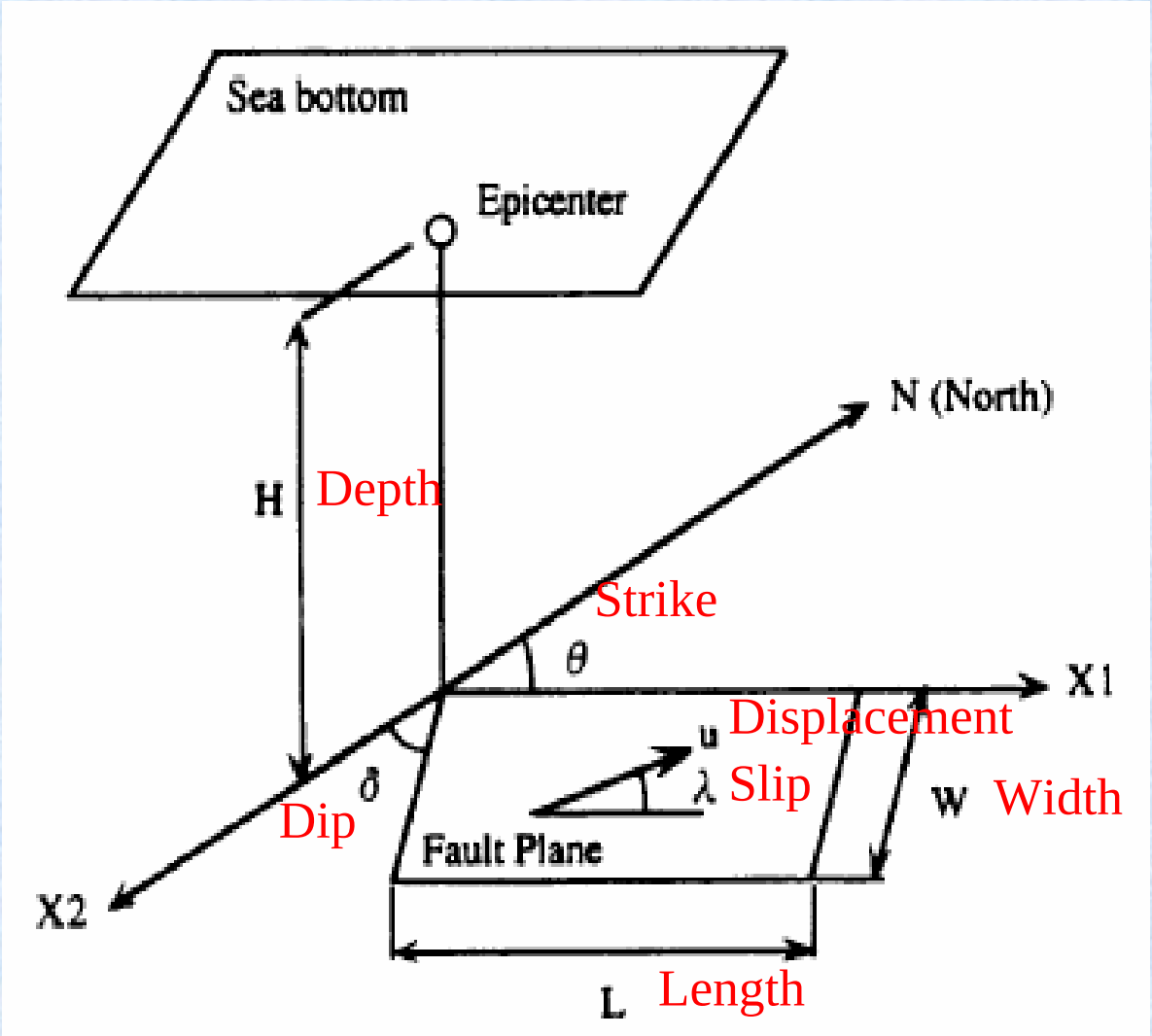


Seismicity Map



Data from 1619-1997
Bautista et. al., Tectonophysics, 2001

Fault Model



Source: IOC (1997)

Estimation of Fault Parameters

Papazachos et al.'s model (2004)
For subduction earthquakes

Length

$$\log L = 0.55M - 2.19,$$

$\sigma = 0.18$, $6.7 \le M \le 9.3$

Area

$$\log S = 0.86M - 2.82,$$

$\sigma = 0.25$, $6.7 \le M \le 9.2$

Width

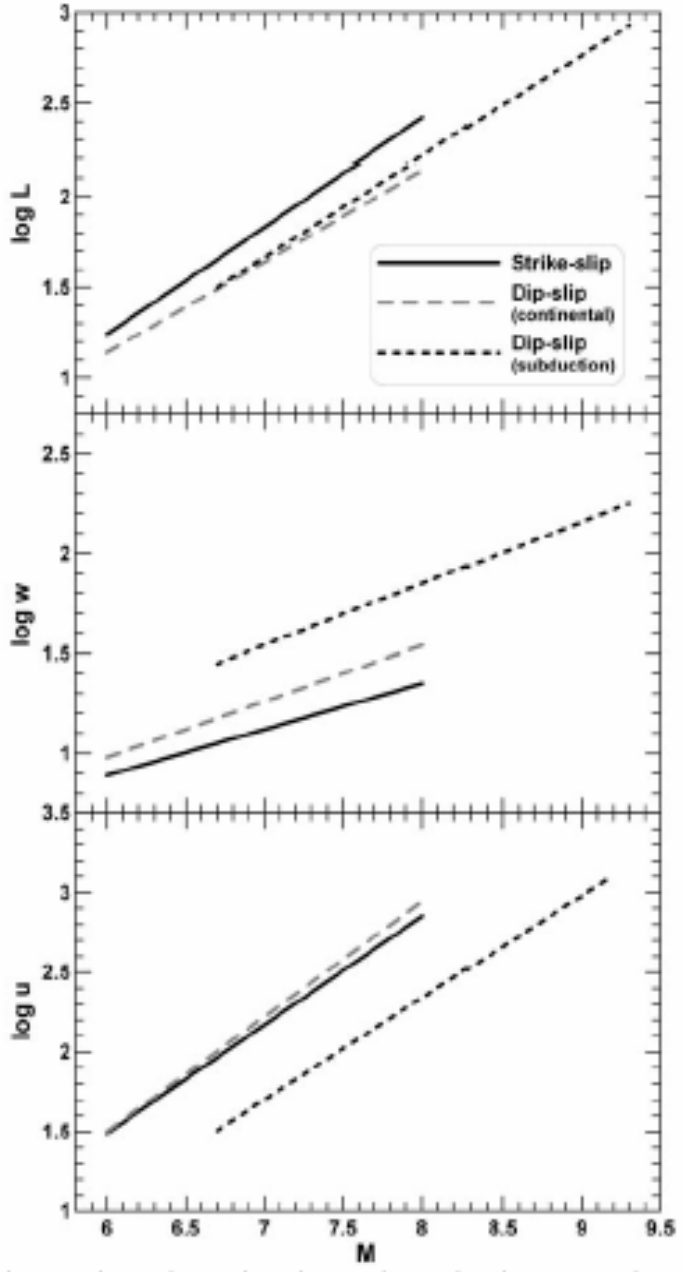
$$\log w = 0.31M - 0.63,$$

$6.7 \le M \le 9.2$

Displacement

$$\log u = 0.64M - 2.78,$$

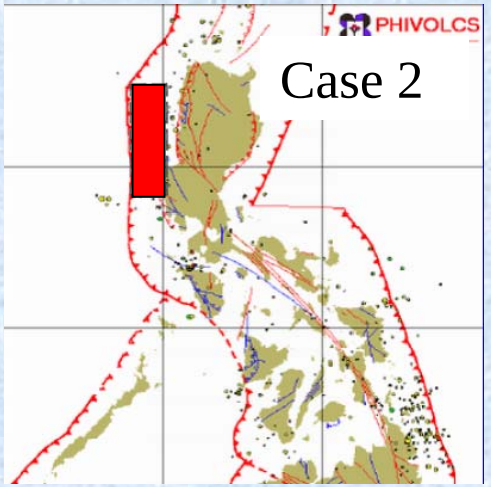
$6.7 \le M \le 9.2$

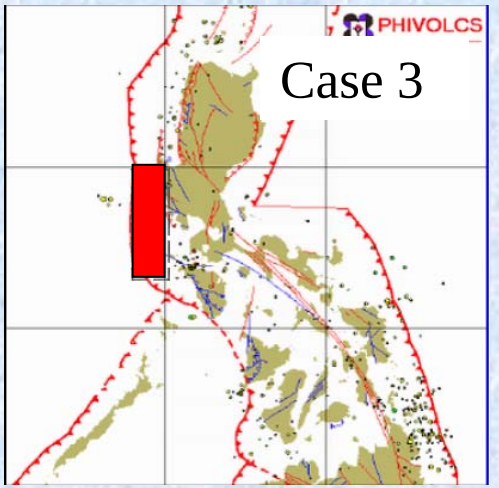


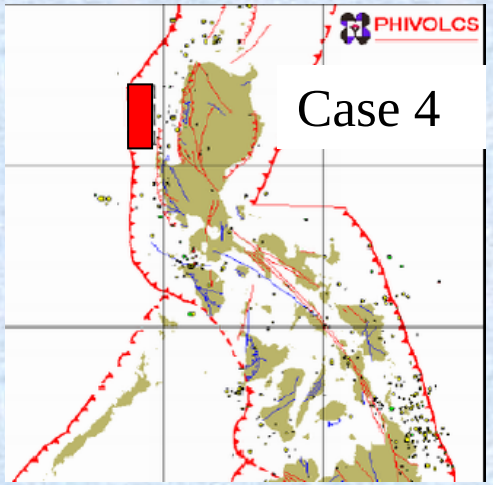
Estimation of Fault Parameters

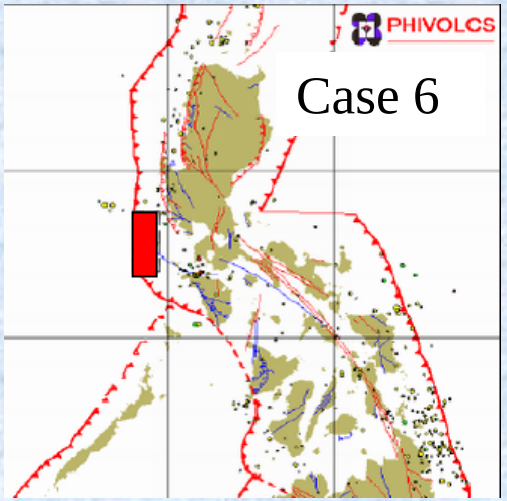
	Papazachos et al.'s model			
Mw	**L**	**Area**	**W**	**U**
(richter)	(km)	(km^2)	(km)	(m)
5.0	3	30	8	0.1
5.5	7	81	12	0.1
6.0	13	219	17	0.1
6.5	24	589	24	0.2
7.0	46	1585	35	0.5
7.5	86	4266	49	1.0
8.0	162	11481	71	2.2
8.5	305	30903	102	4.5
9.0	575	83176	145	9.5

Analytical Cases





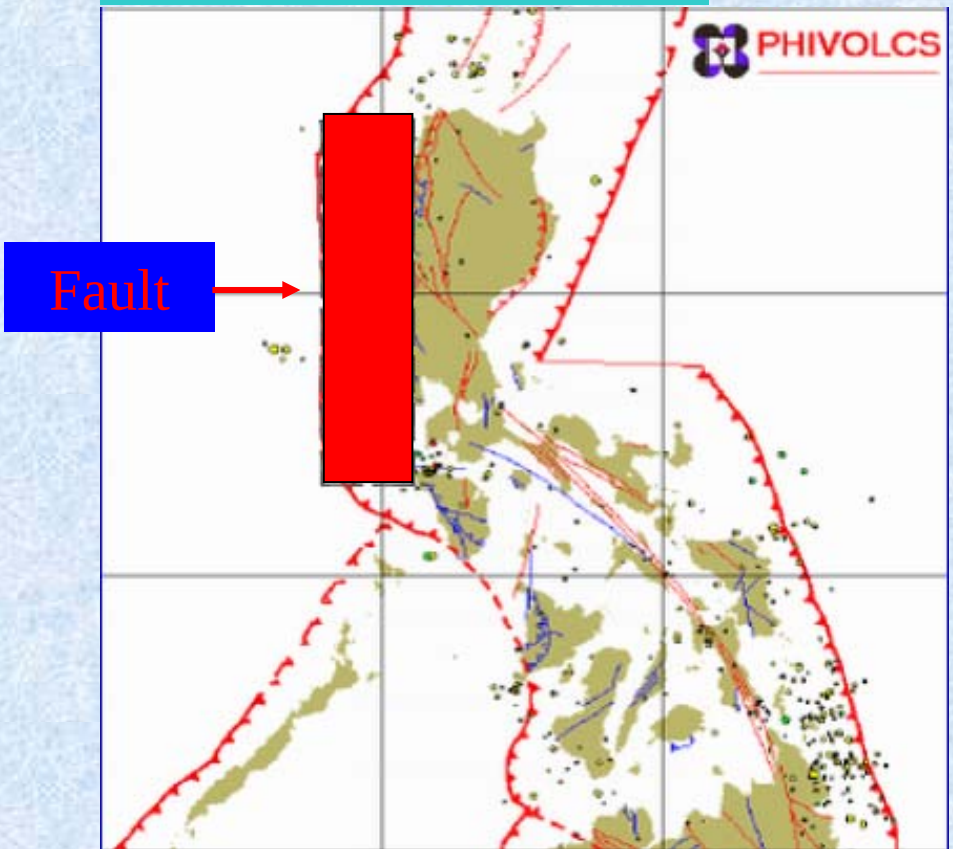




Analytical Cases

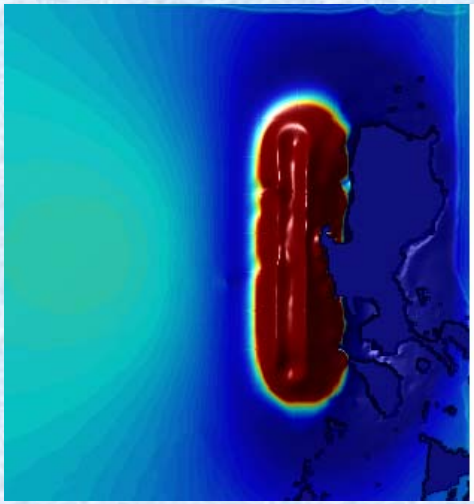
Case 1, Mw=9.0

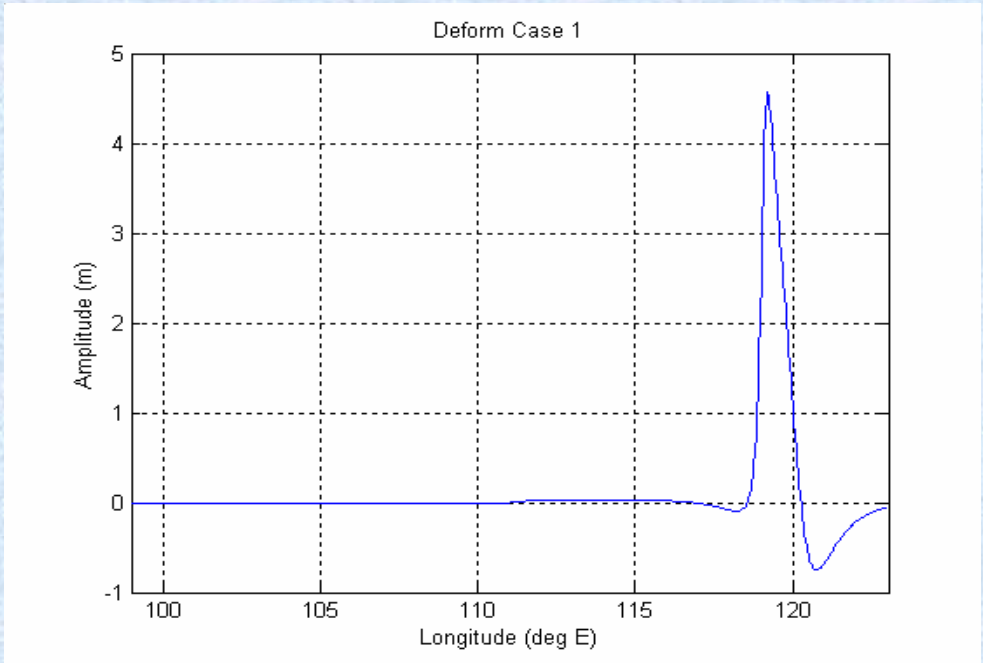
Depth (H) = 25 km
Strike (θ) = 0
Dip (δ) = 30
Slip (λ) = 90
Disp. (u) = 9.5 m



Deformation of ocean bottom

using Mansinha and Smylie's equations (1972)

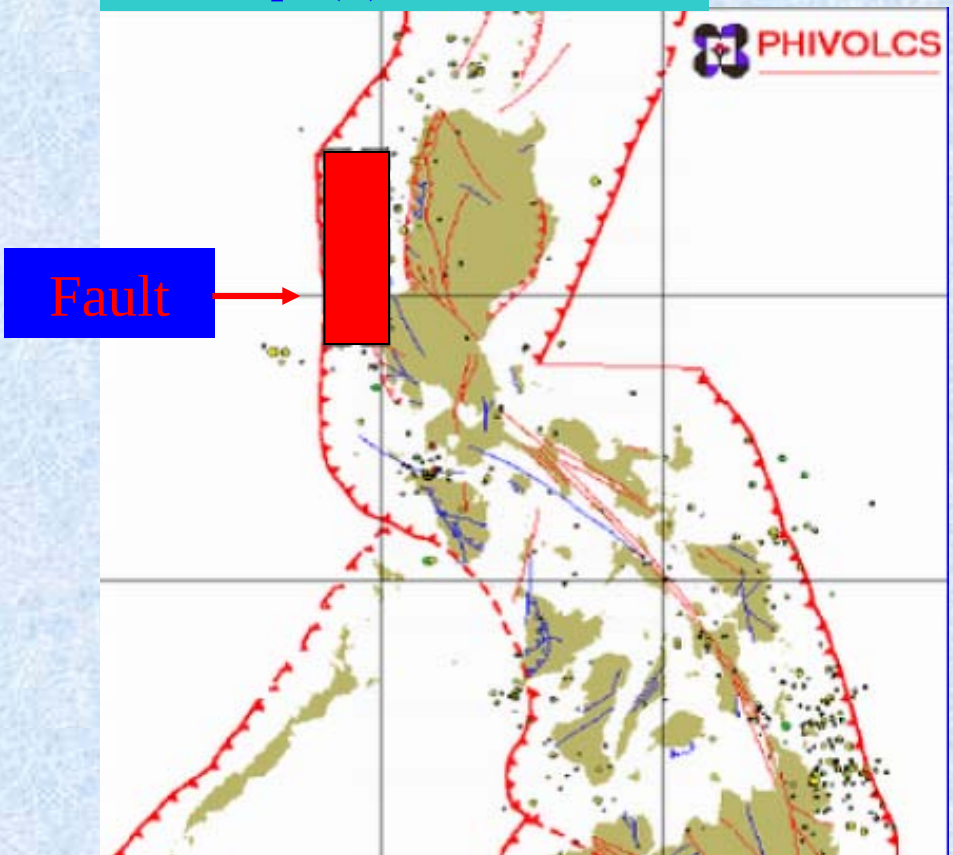




Analytical Cases

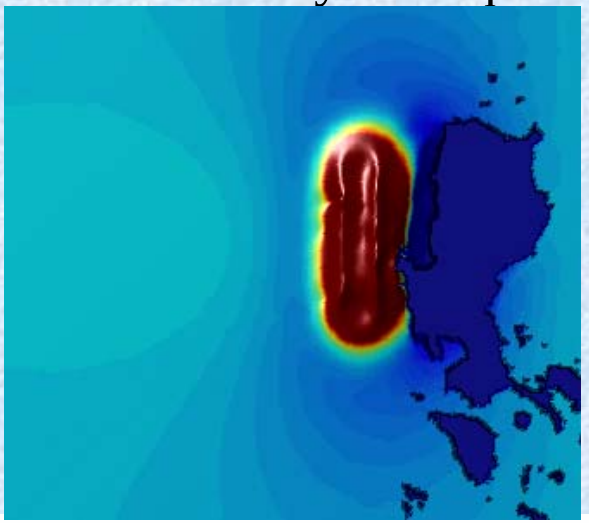
Case 2, Mw=8.5

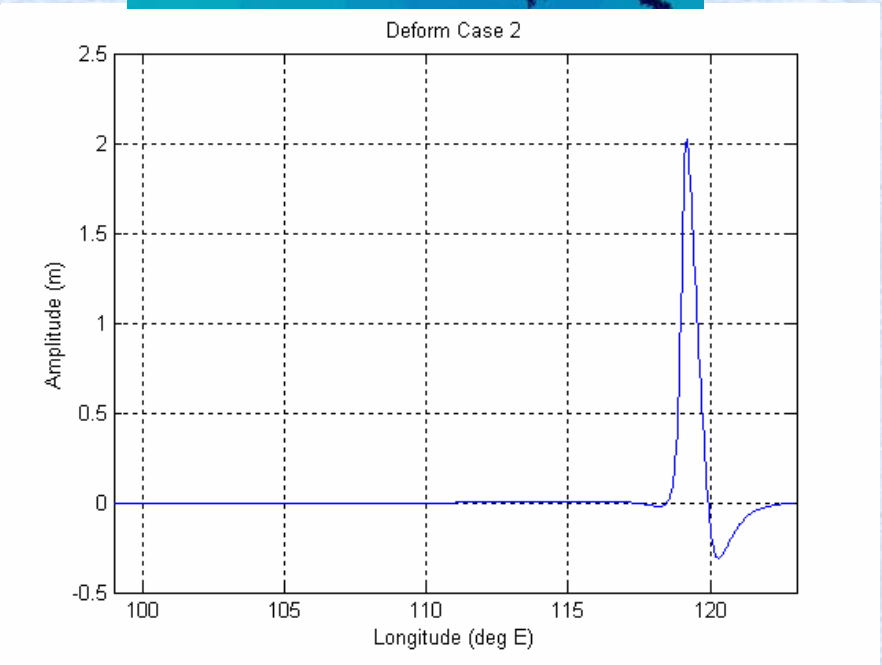
Depth (H) = 25 km
Strike (θ) = 0
Dip (δ) = 30
Slip (λ) = 90
Disp. (u) = 9.5 m



Deformation of ocean bottom

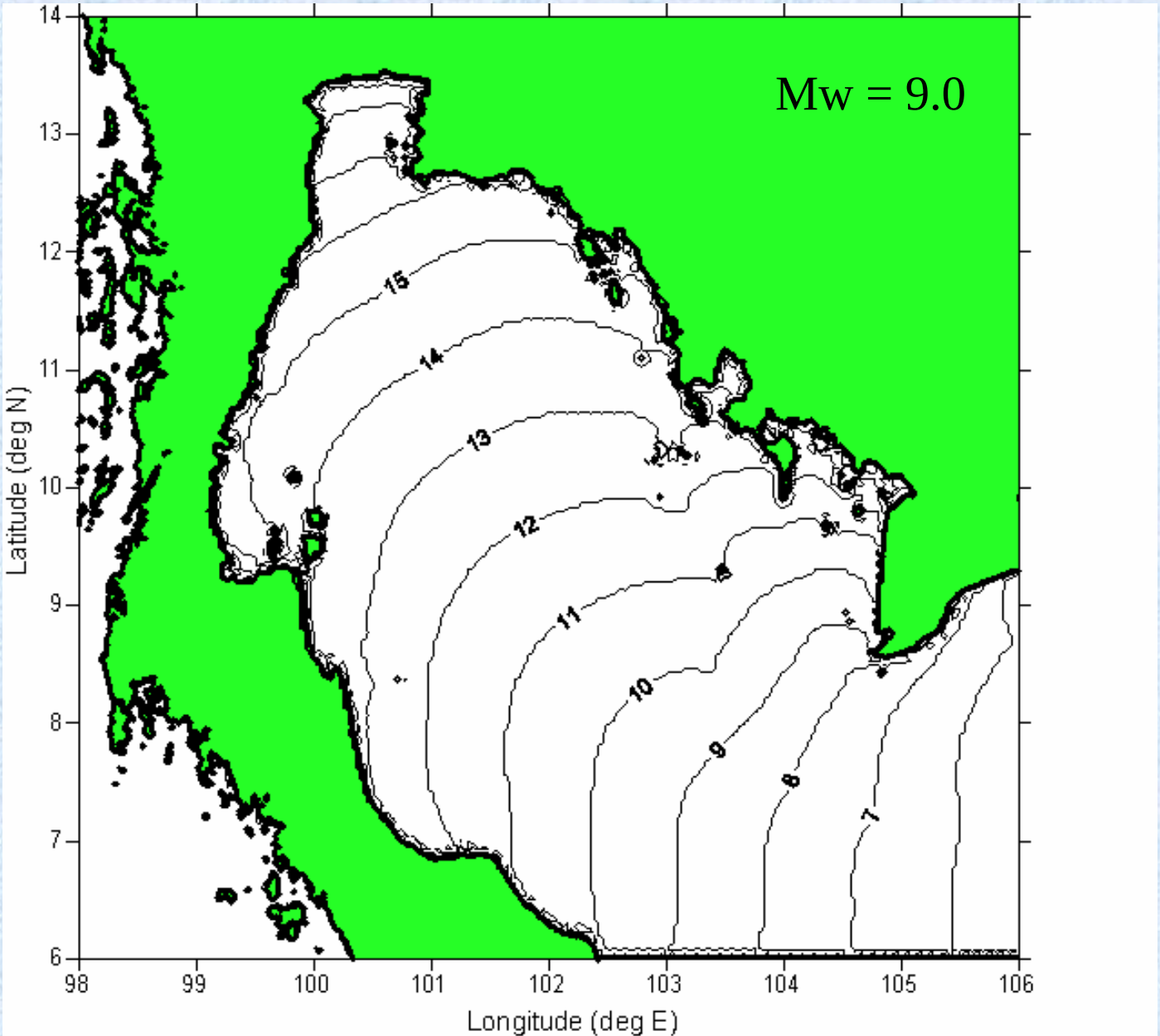
using Mansinha and Smylie's equations (1972)



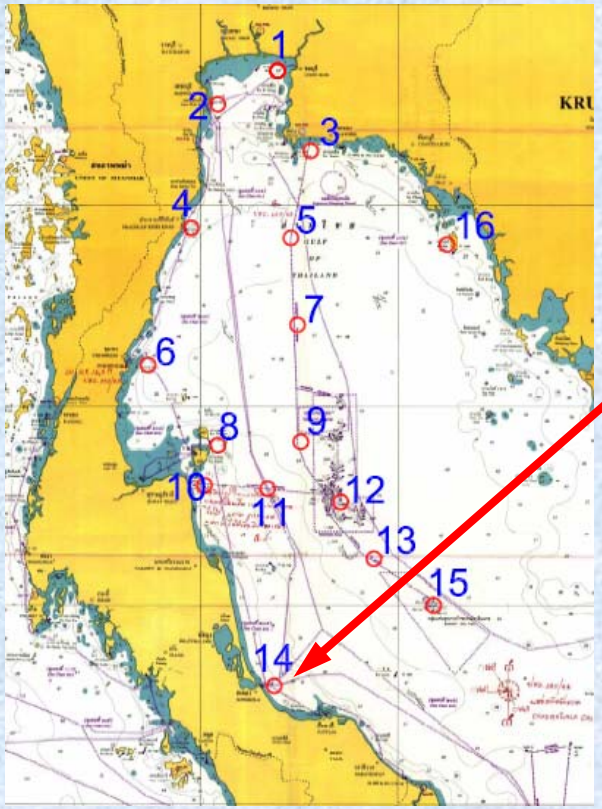


Simulation Results

Time of Arrival



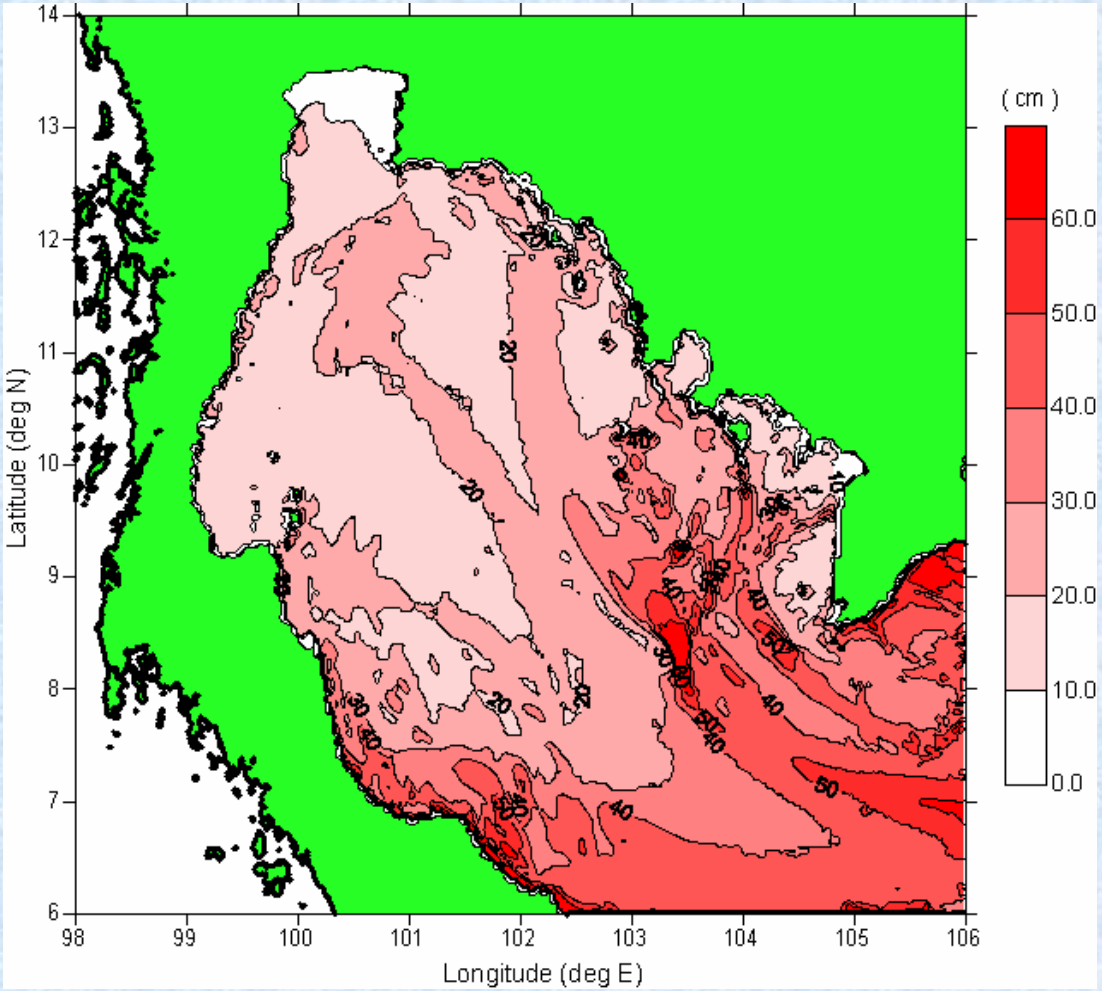
Tsunami Height



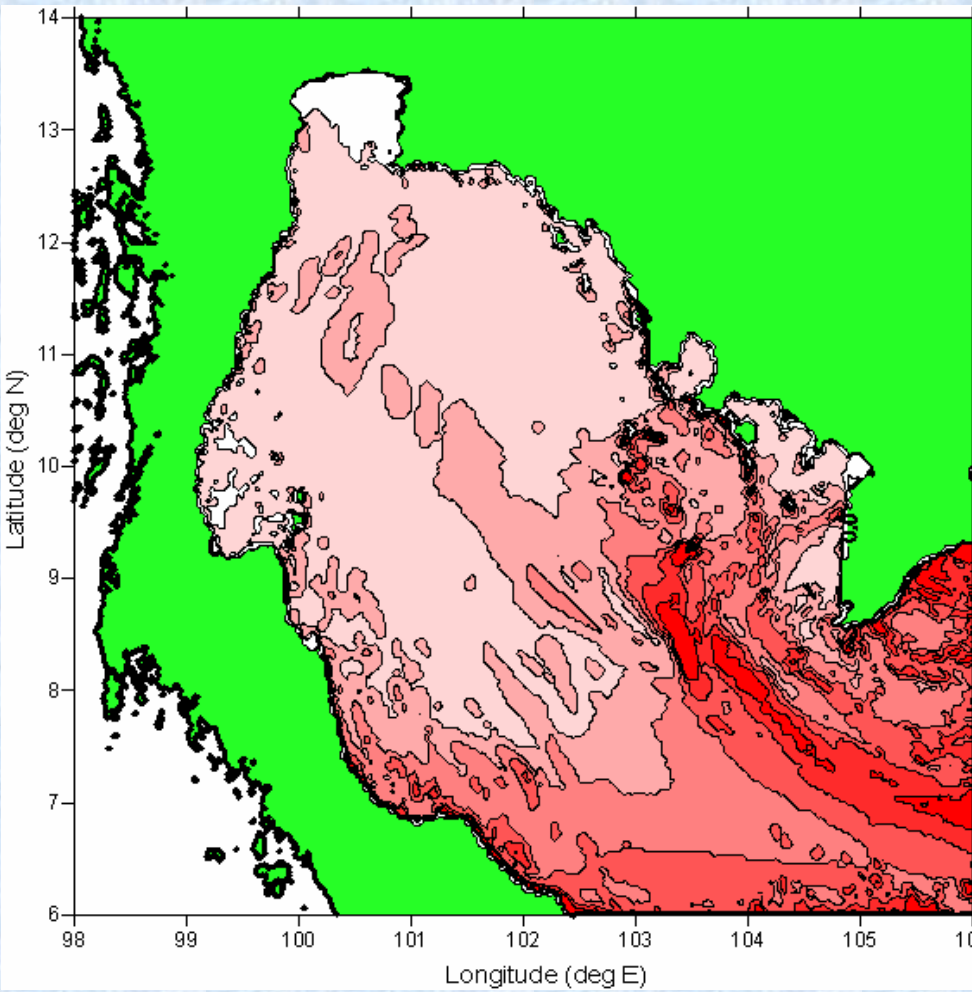
M_w	Case	Maximum Height (m)
9.0	1	0.65
8.5	2	0.20
	3	0.20
8.0	4	0.05
	5	0.05
	6	0.05

Tsunami Height

Mw = 9.0

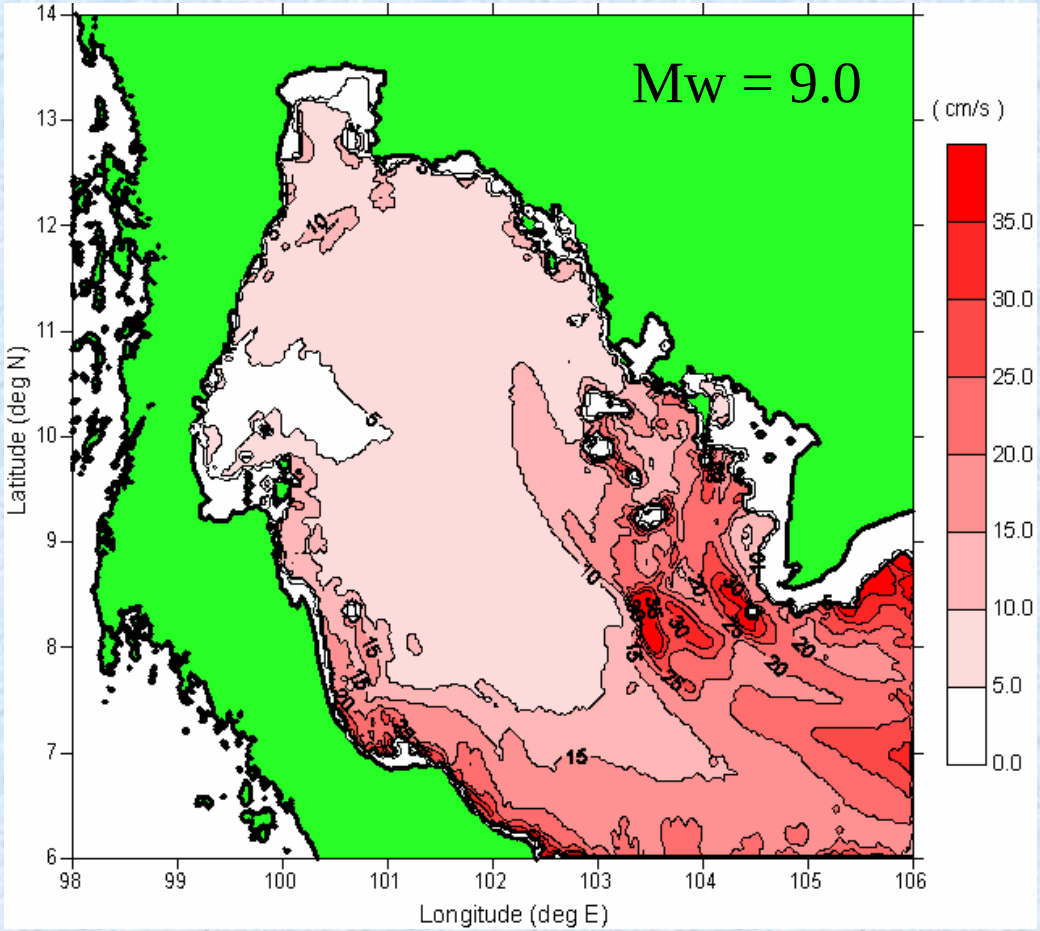


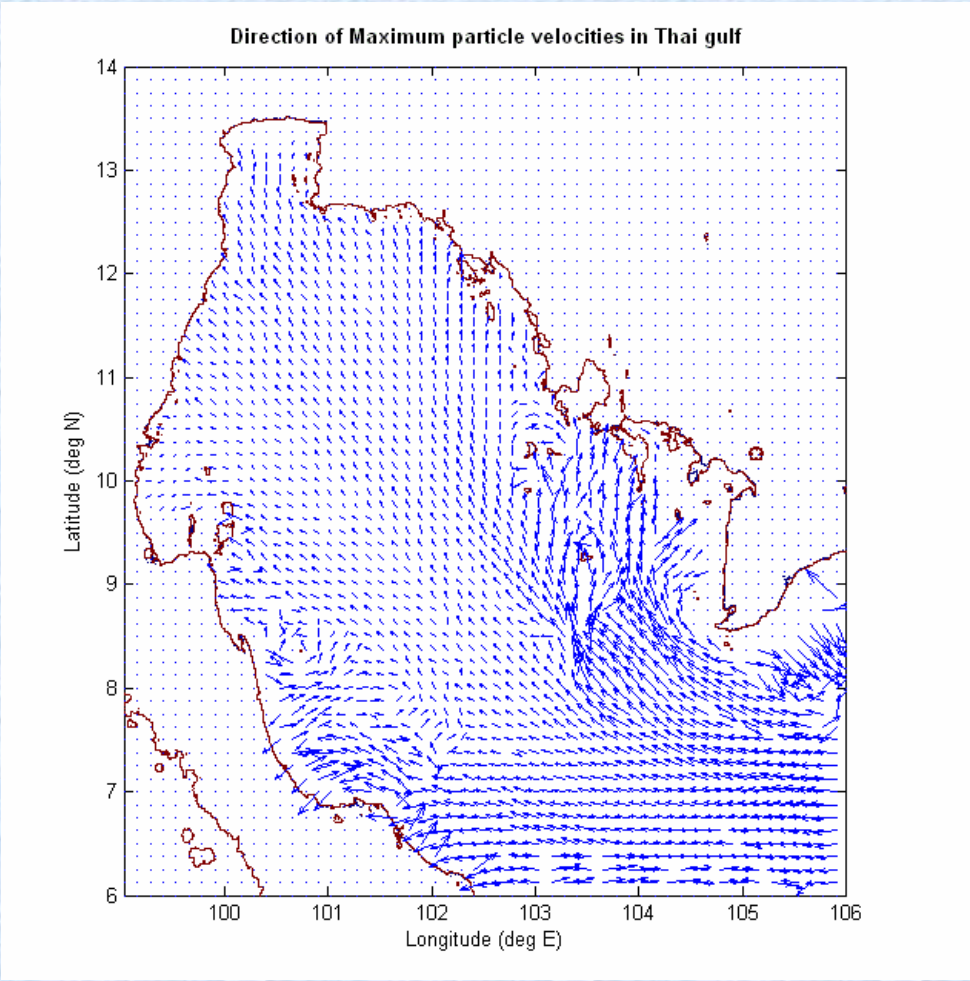
Mw = 8.5



In Vietnam, tsunami height = 3.8 m @ 20 m depth

Current Velocity





In Vietnam, current velocity = 1.7 m/s @ 20 m depth

Estimation of Current Velocity for Long Wave

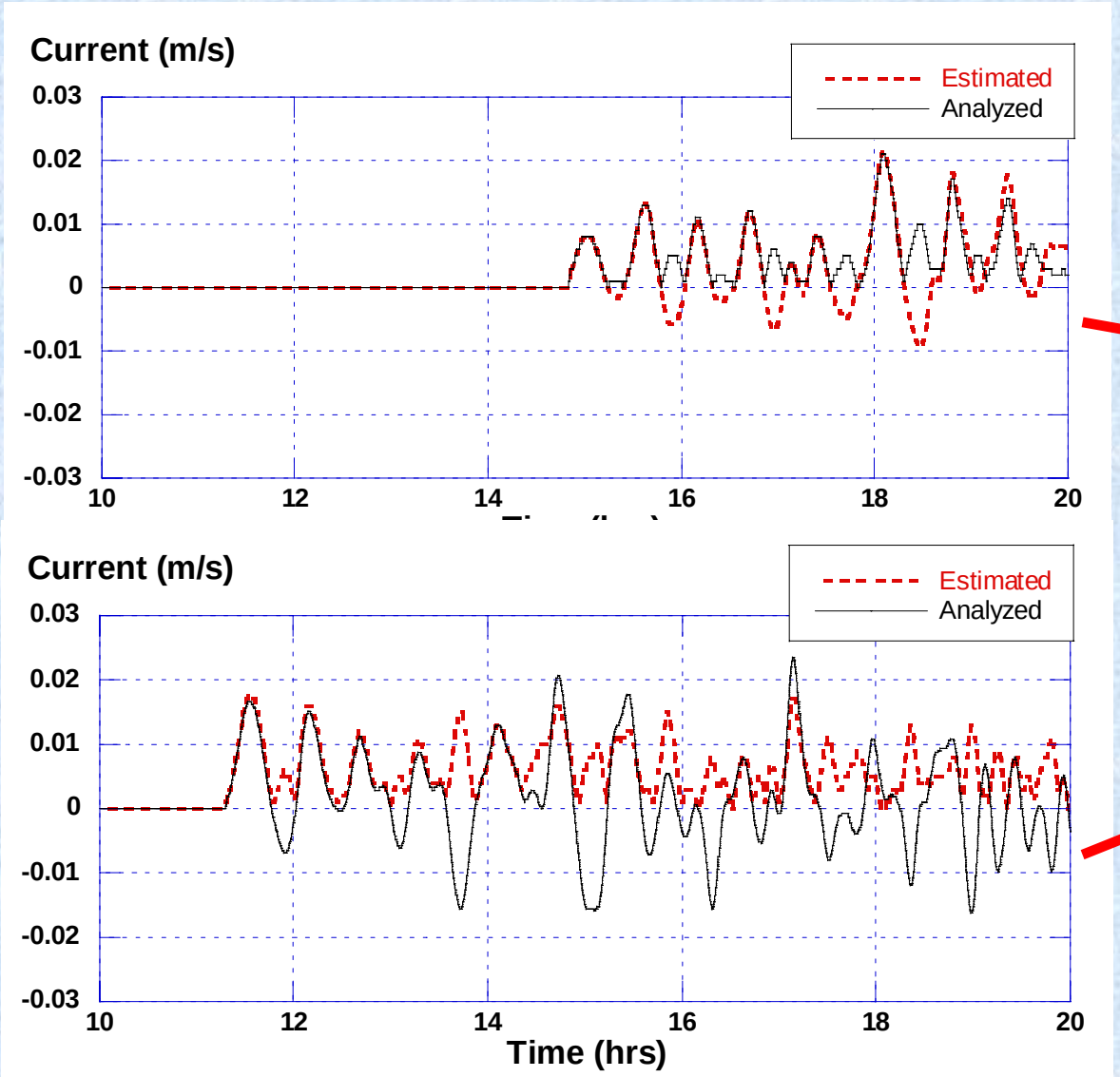
$$v = \eta\sqrt{g / h}$$

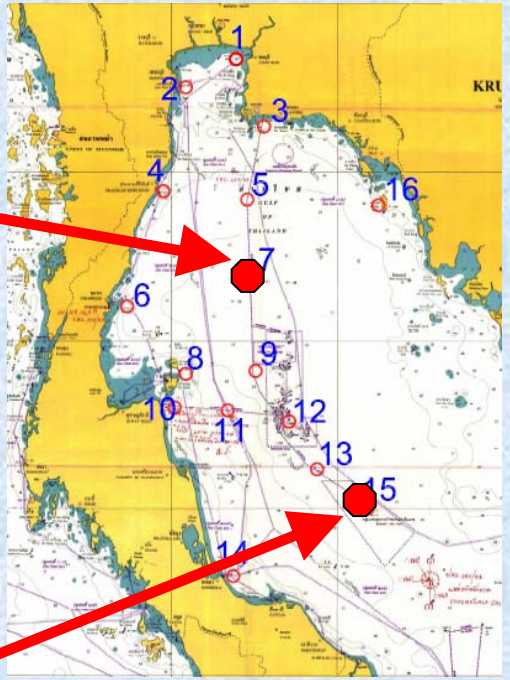
η = **wave height**

h = **water depth**

v = **current velocity**

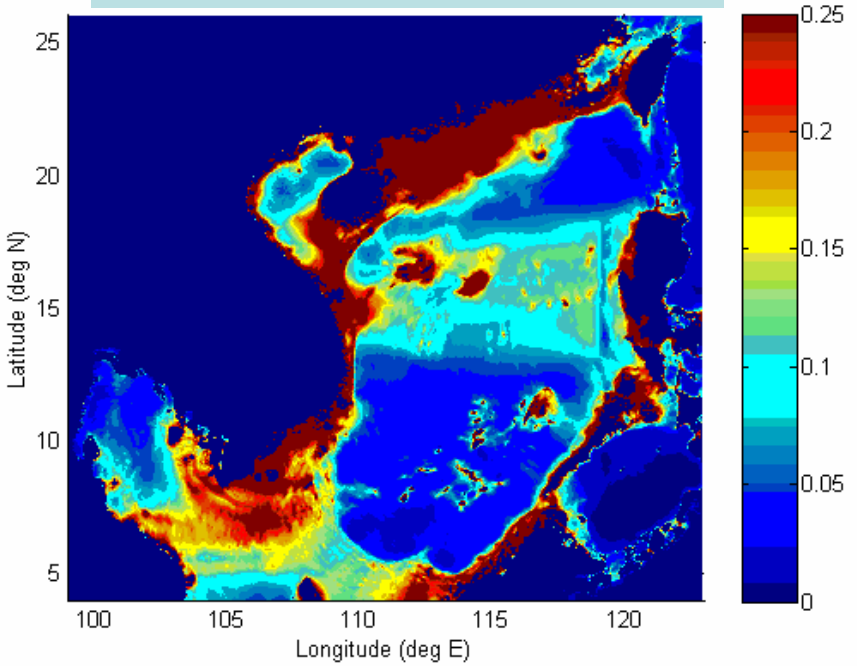
Comparison of Current Velocity

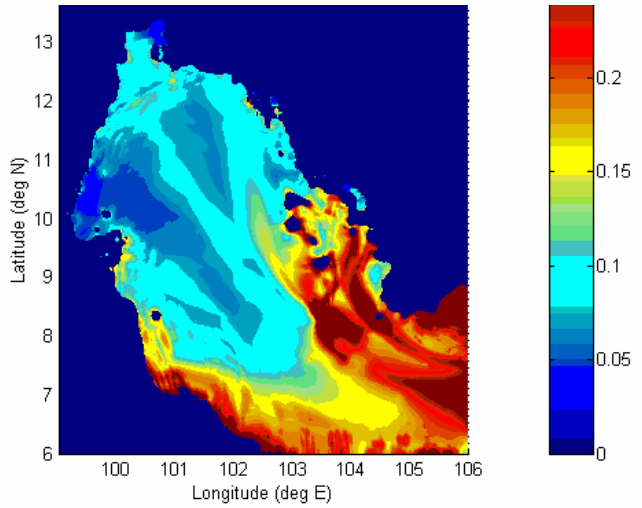




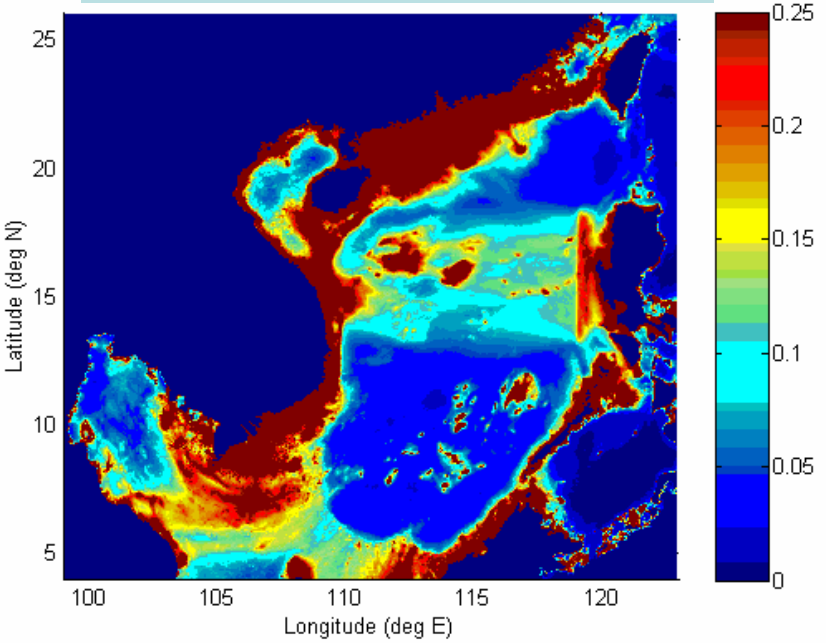
Comparison of Current Velocity

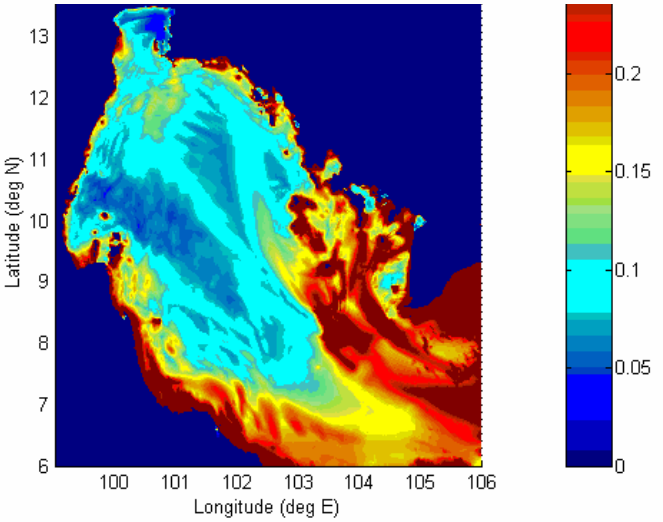
Analyzed result





Estimated result





Conclusions

1. The earthquake causes large wave height and current velocity off-shore South-eastern China, and Northwestern Philippines, and Eastern Vietnam. The Gulf of Thailand is less affected by the tsunamis generated by fault ruptures off the shore of the Philippines because of the diffraction of tsunamis at the southern part of Vietnam.

2. Towards Malaysia and Thailand, the tsunami slows down due to the relatively shallow water depth. The tsunami arrives Malaysia in about 9 hr, and Gulf of Thailand in 12 hr.

3. The maximum wave height is about 0.65 m near the shores of Thailand. And the maximum wave current is about 0.1 m/s.

Ongoing Research Projects to Mitigate Tsunami Effects

Effect of tsunamis on the Gulf of Thailand

Funded by Petroleum Thailand Public Company

Tsunami database for early warning

Funded by National Disaster Warning Center

Tsunami risk analysis of buildings in Thailand

Funded by Department of Meteorology,
Ministry of Information and Communication Technology
And Ministry of Environment
Collaboration with AIT and local universities

Tsunami load on evacuation buildings

Funded by Department of Civil Works and City Planning,
Ministry of Interiors
Collaboration with Thammasart U, AIT, KMUTT

Chulalongkorn University obtained about 3+ M USD for tsunami research in 2 years

Ongoing Projects to Mitigate Tsunami Effects

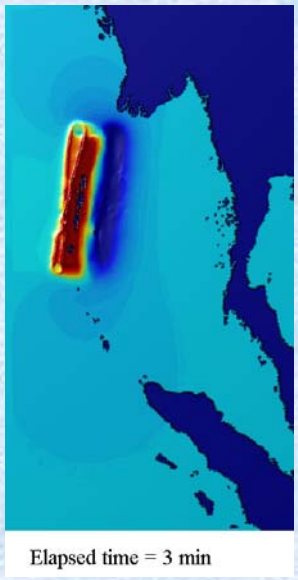
Effect of tsunamis on the Gulf of Thailand

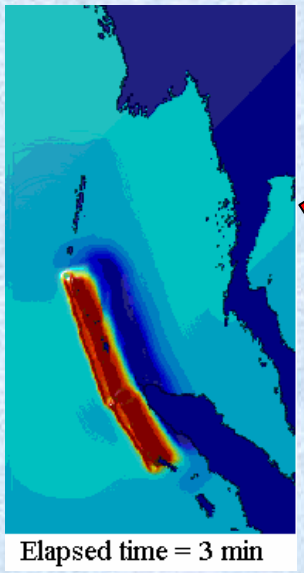
Tsunami database for early warning

Tsunami risk analysis of buildings in Thailand

Tsunami load on evacuation buildings

Tsunami Database





hardcopy

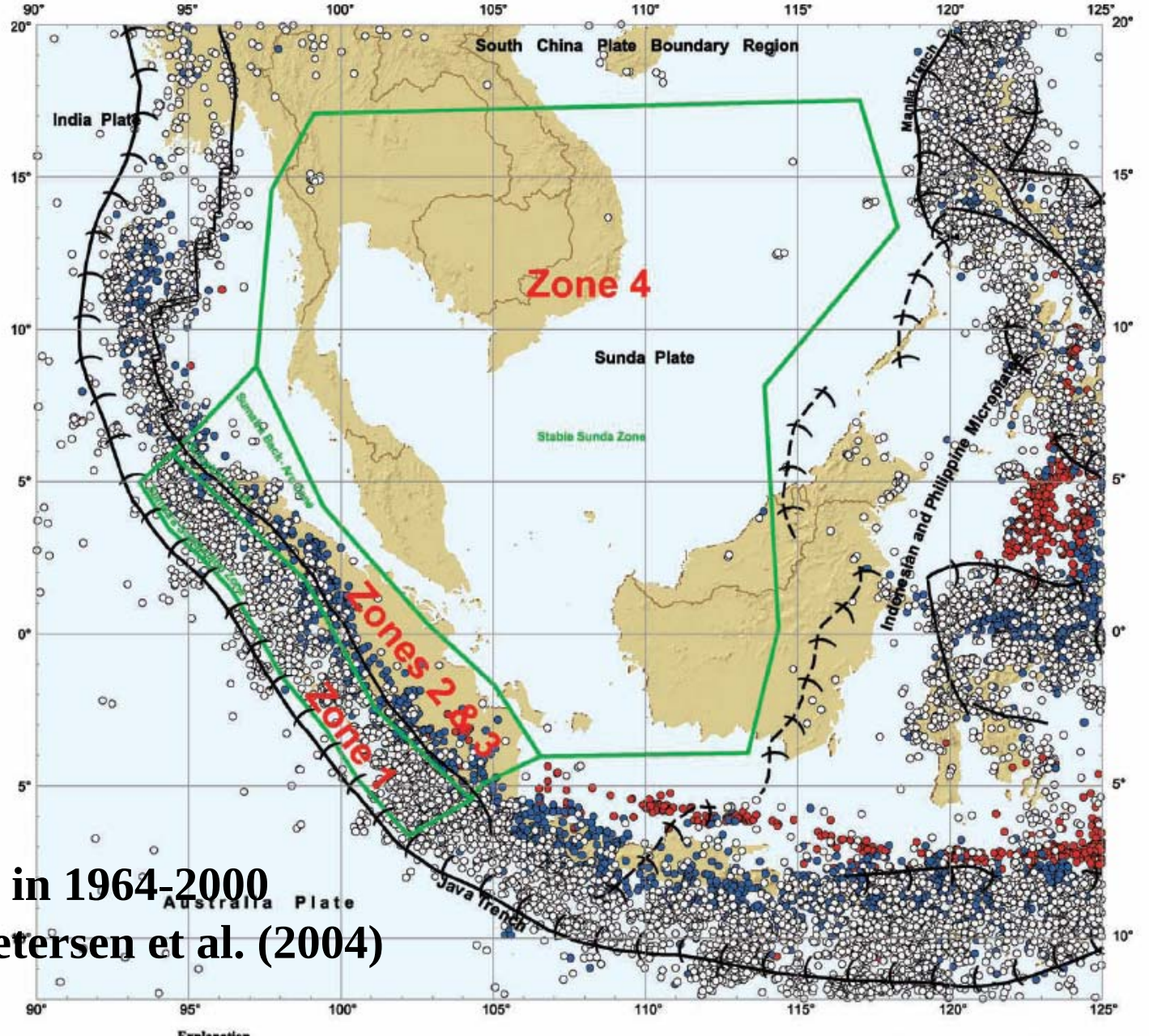
Earthquake magnitude
Depth
Location

Arrival time
Tsunami height

Database

Processing

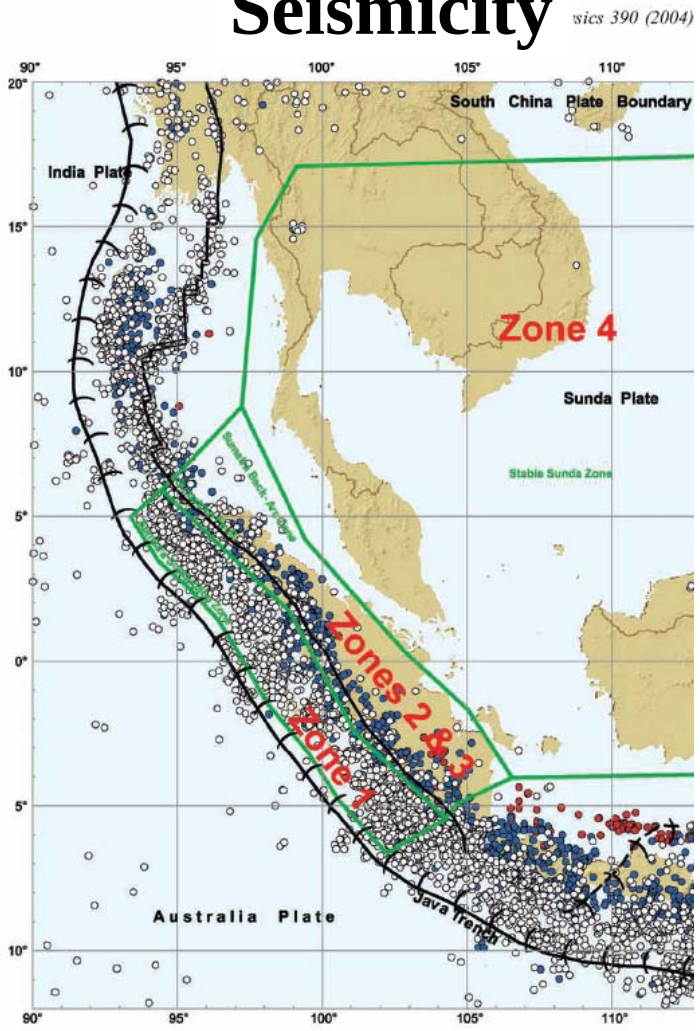
Seismicity around Thailand



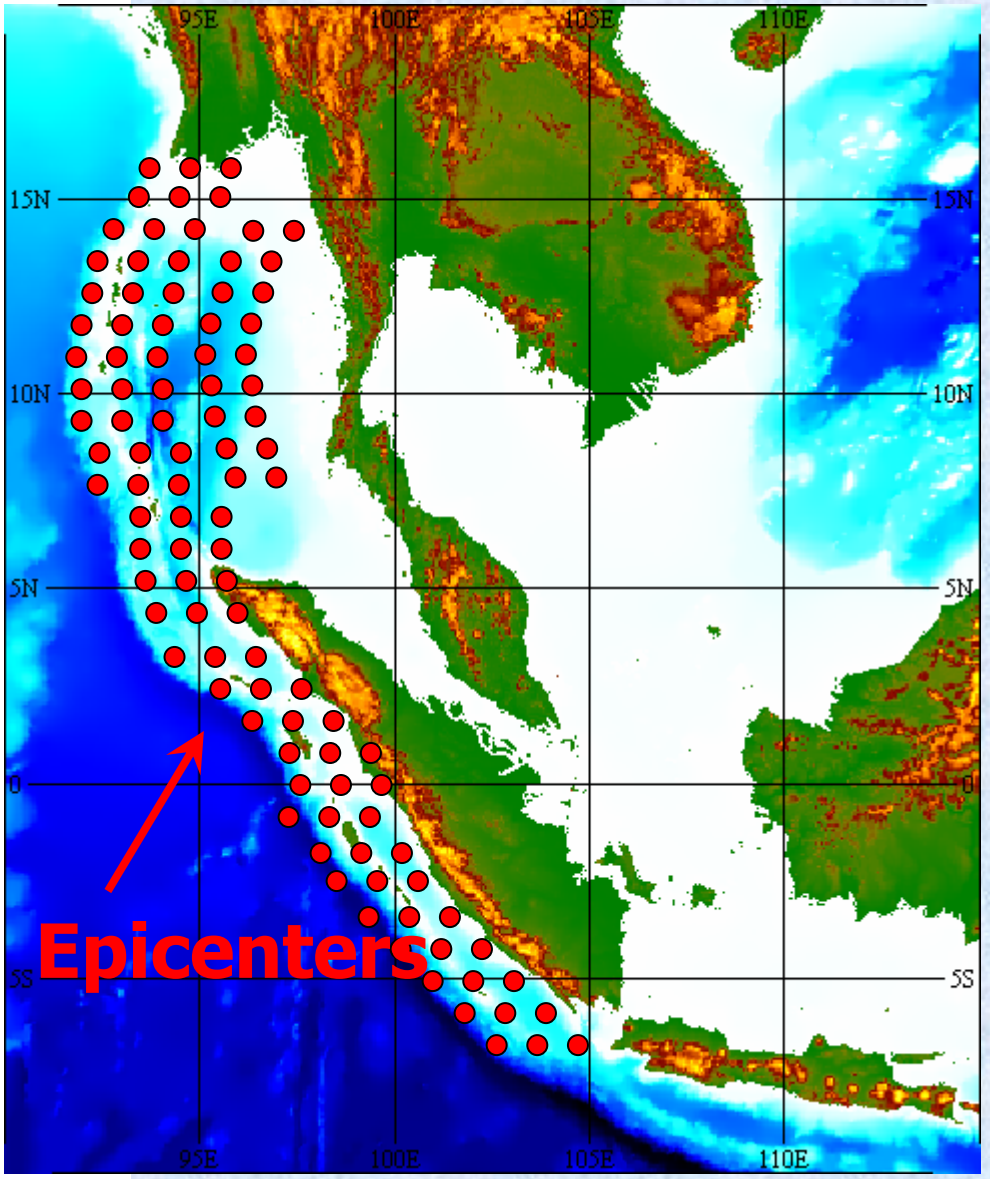
Seismicity in 1964-2000
Source: Petersen et al. (2004)

Hypothetic Earthquakes in the West

Seismicity



Petersen et al. (2004)

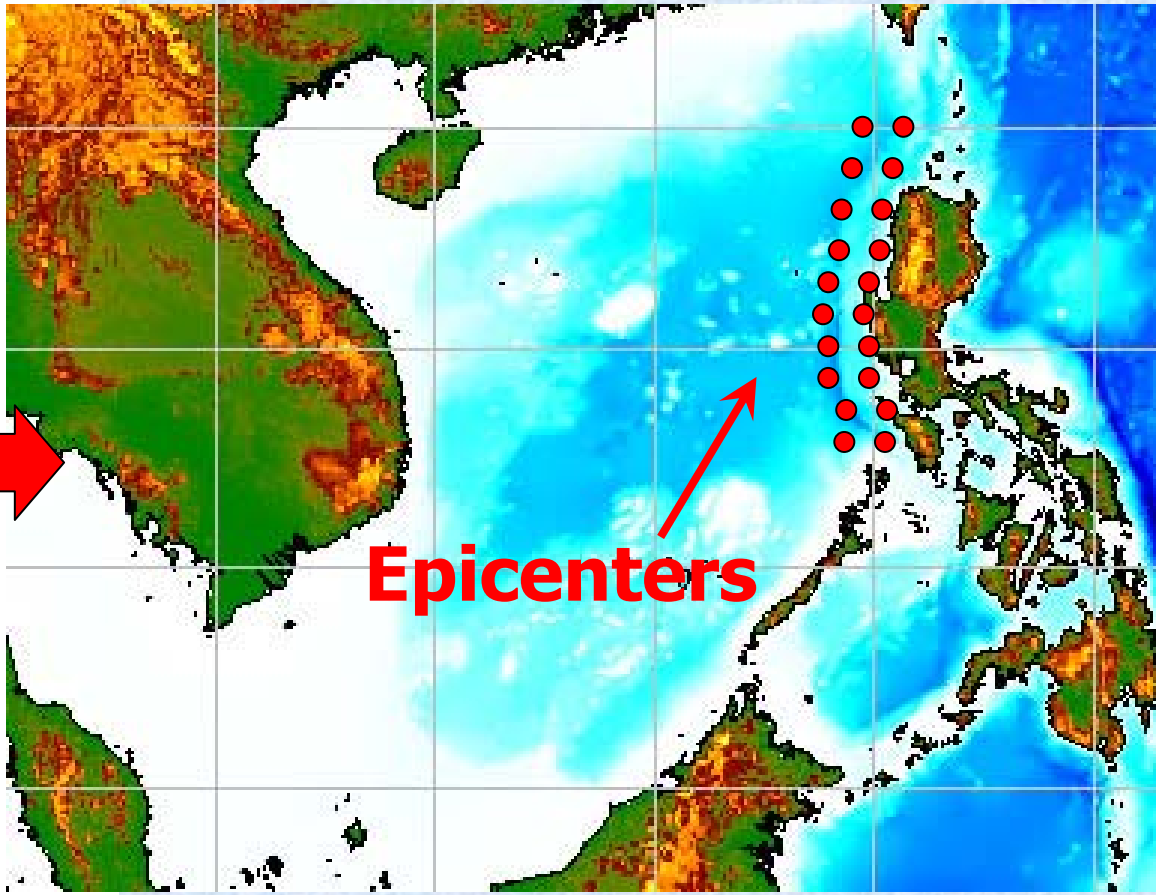


Source: GEBCO

Hypothetic Earthquakes in the East

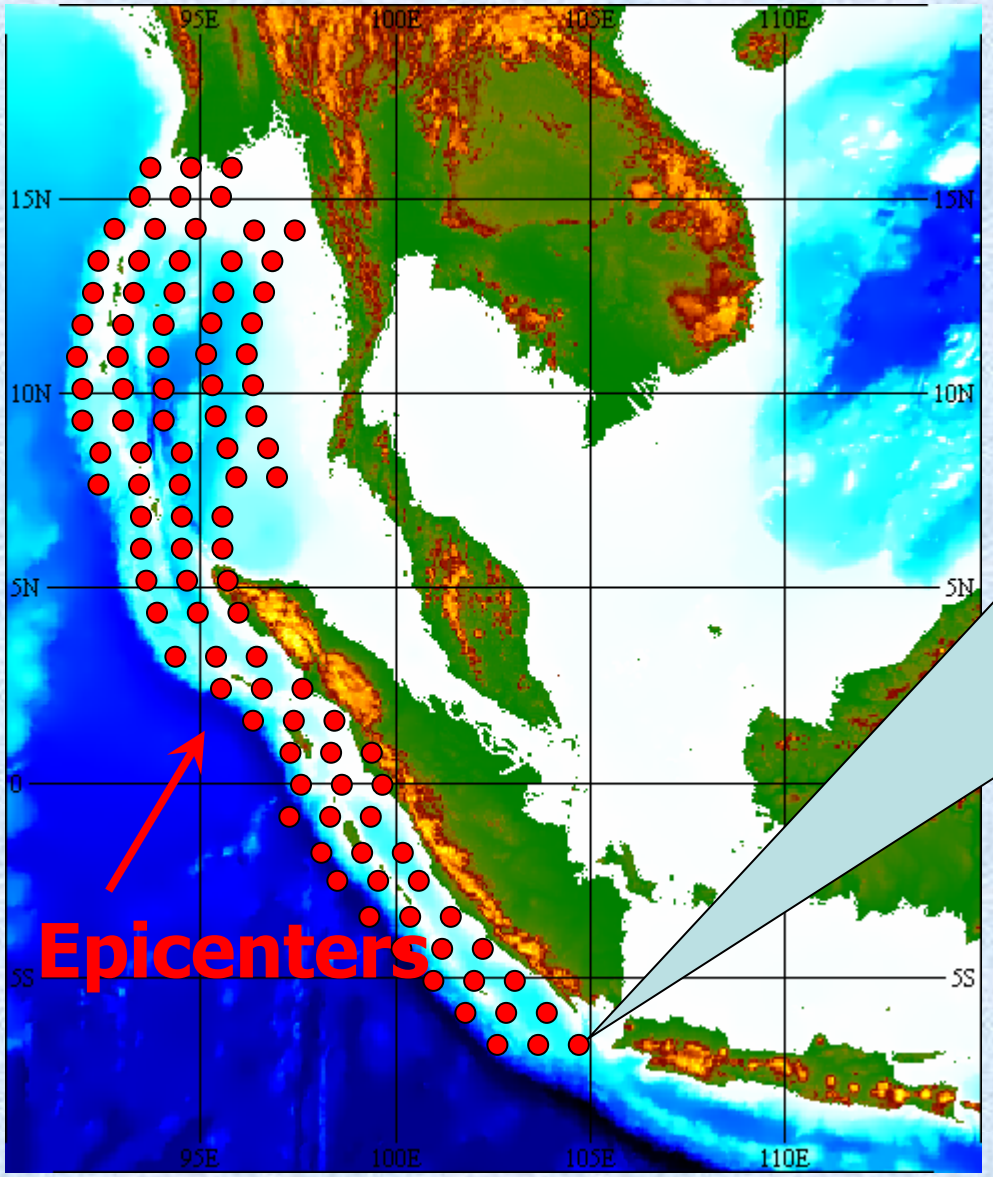
Seismicity

Petersen et al. (2004)

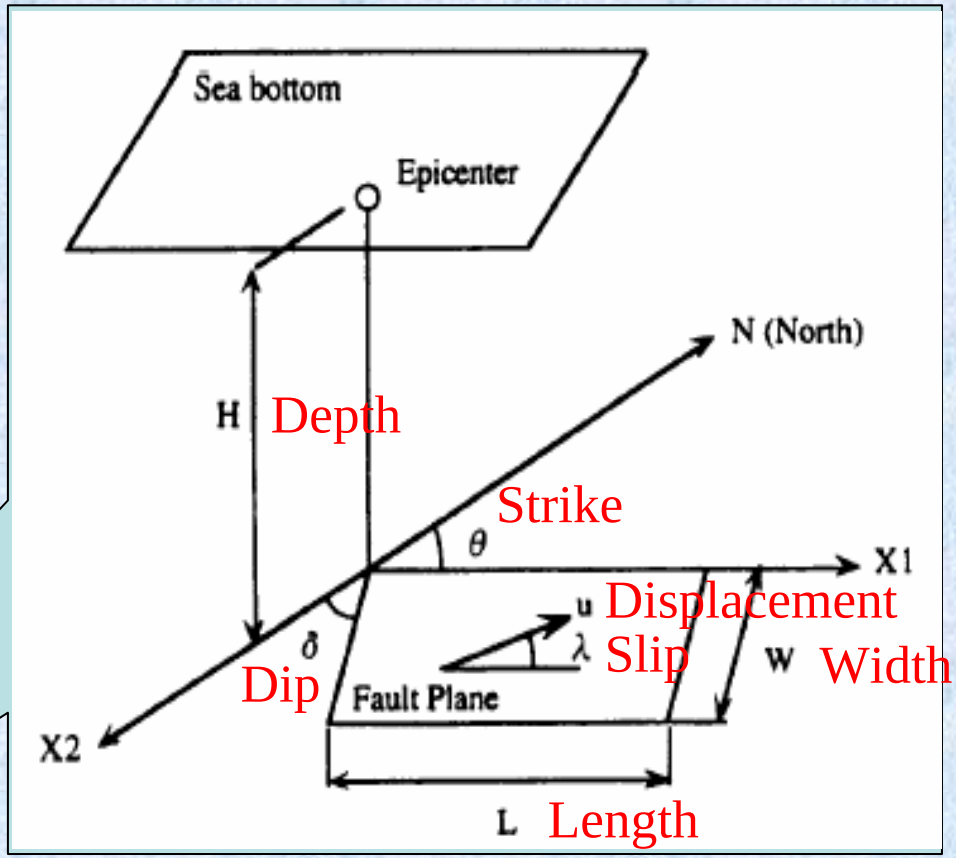


Source: GEBCO

Fault Parameters



Source: GEBCO



Cases

Mw 7 – 9

Various epicenters ➡ **About 1000 cases**

Ongoing Projects to Mitigate Tsunami Effects

Effect of tsunamis on the Gulf of Thailand

Tsunami database for early warning

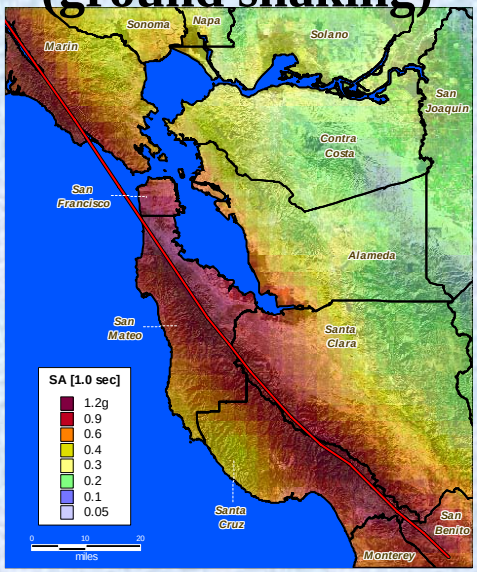
Tsunami risk analysis of buildings in Thailand

Tsunami load on evacuation buildings

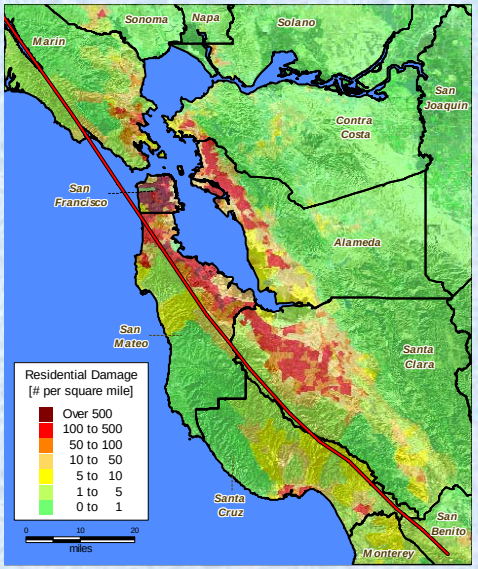
Source: HAZUS, FEMA

Earthquake Risk Analysis

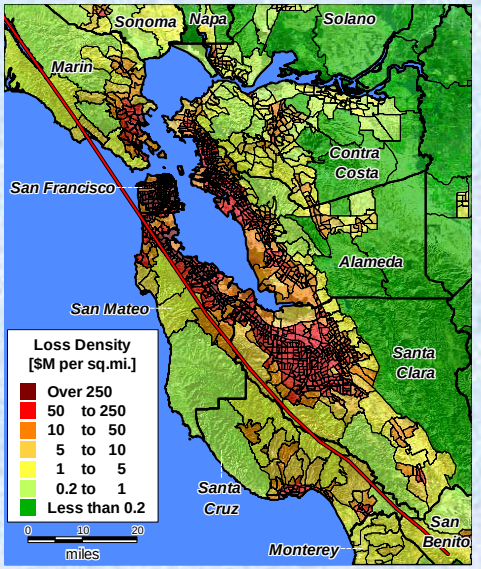
Hazard (ground shaking)



Residential damage



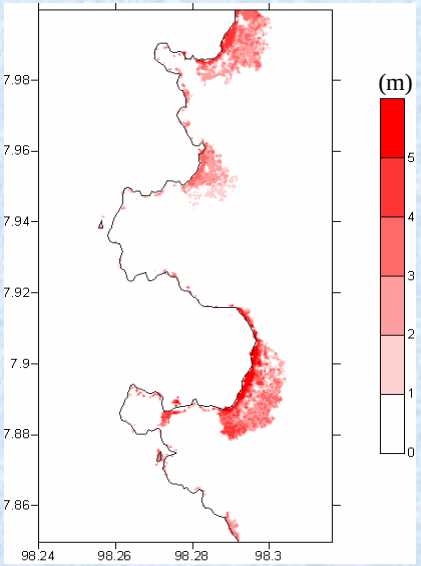
Economic loss



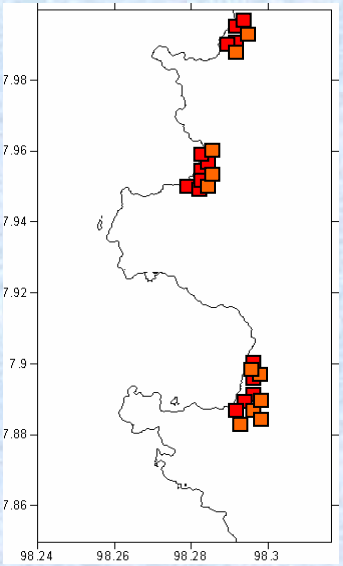
Powerful tool for disaster management and decision making

Background on Tsunami Risk Analysis

Hazard map (tsunami height)

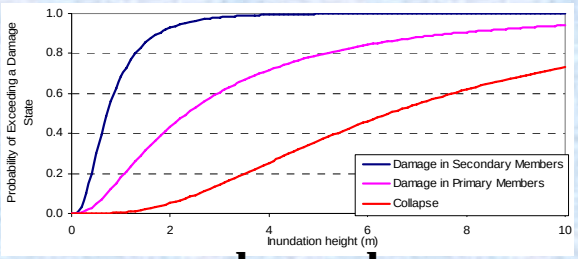


Buildings damage



prob. of damage/loss

Fragility Curve



hazard

Obtained from
- **Past experience**
- **Numerical analysis**

Developed from
- **Past experience → damage database**
- **Experiment → push-over test**
- **Numerical analysis → push-over analysis**

Powerful tool for disaster management and decision making

Structural Damage

Wall punching

Lateral bending of beams

Methodology

Observation

Inundation height

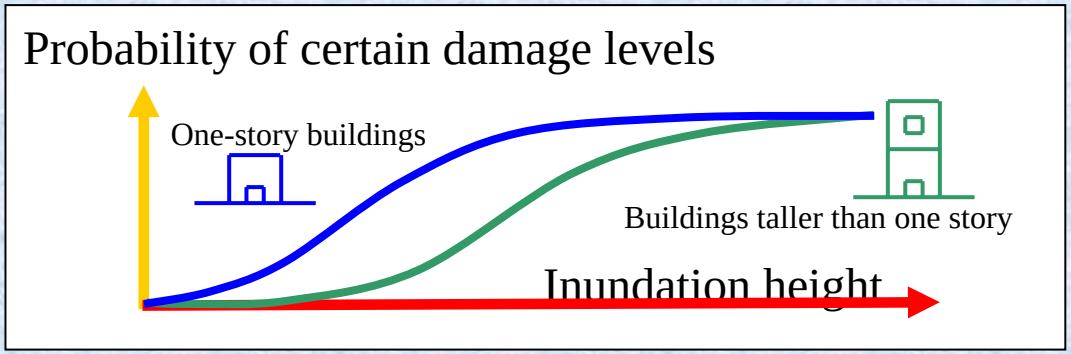
Building location

Number of stories

Function of building

Damage level based on overall damage building

- No damage
- Damage in secondary members
- Damage in primary members
- Collapse



Database of Structural Damage

Database - Microsoft Internet Explorer

(http://evr.eng.chula.ac.th/DamageSurvey/view.asp)

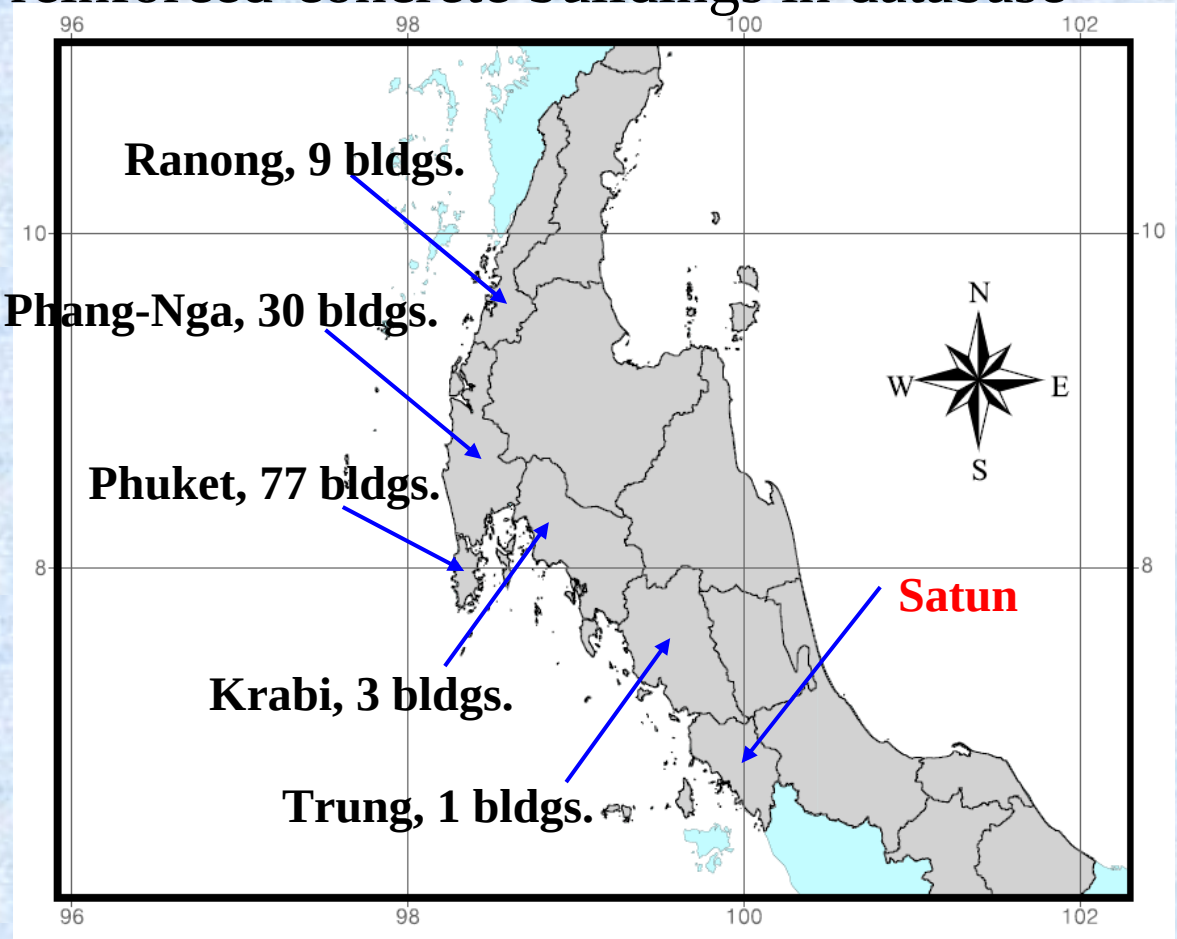
Database of Structural Damage

Reference No.	KML-A-009
Date	01/31/2005
Time	12:28
Inspector	Anat Ruangrassamee
Organization	Chulalongkorn University
Structure name	
Location	Kamala Beach, Phuket
GPS E position (UTM Datum 47)	420857
GPS N position (UTM Datum 47)	878934
Distance from shoreline (m)	
Runup height (m)	2.6
Function	Shop
Structural type	RC
Foundation type	NA
Wall type	Brick+Glass
Roof type	Tile
No. of stories (above ground)	2
No. of stories (underground)	
Plan Width (m)	12
Plan Length (m)	12

http://localhost/DamageSurvey/Photo/KML-A-009-01.JPG - Micro...

Observed Data

120 observed reinforced-concrete buildings in database



Distribution of observed reinforced-concrete buildings in the South of Thailand

Definition of Damage Levels

Damage Level 0: No damage

Damage Level 1: Damage in secondary members

Damage in non-structural components

Damage Level 2: Damage in primary members

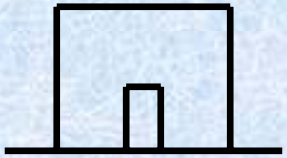
Damage in structural components

Damage Level 3: Collapse

A building cannot sustain gravity load

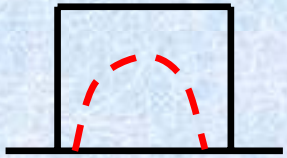
Example of Buildings with Damage Level 0

No damage



Example of Buildings with Damage Level 1

Damage in secondary members

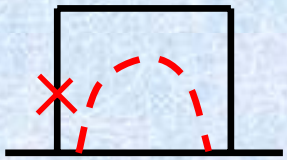


Cracks on a wall

Wall punching

Example of Buildings with Damage Level 2

Damage in primary members



Small cracks in a column

Bending failure of column

Example of Buildings with Damage Level 3

Collapse 

Severe joint failure

Absolute destruction

Methodology

Observation

Inundation height

Building location

Number of stories

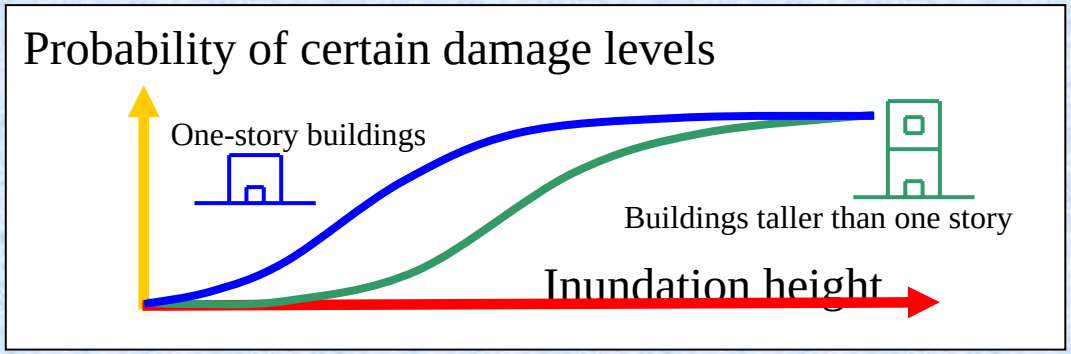
Damage level based on overall damage building

- No damage

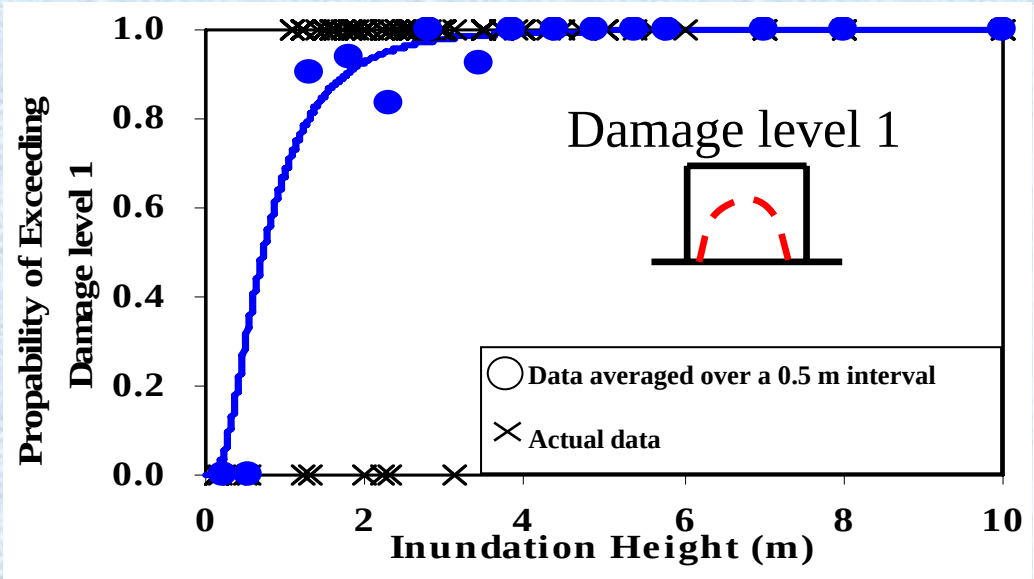
Maximum Likelihood Function

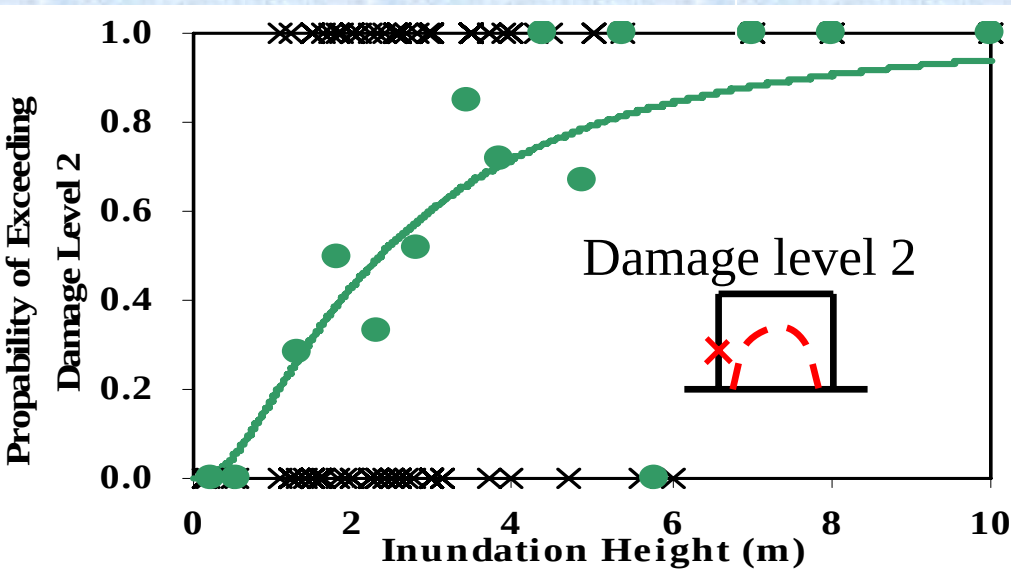
ry members

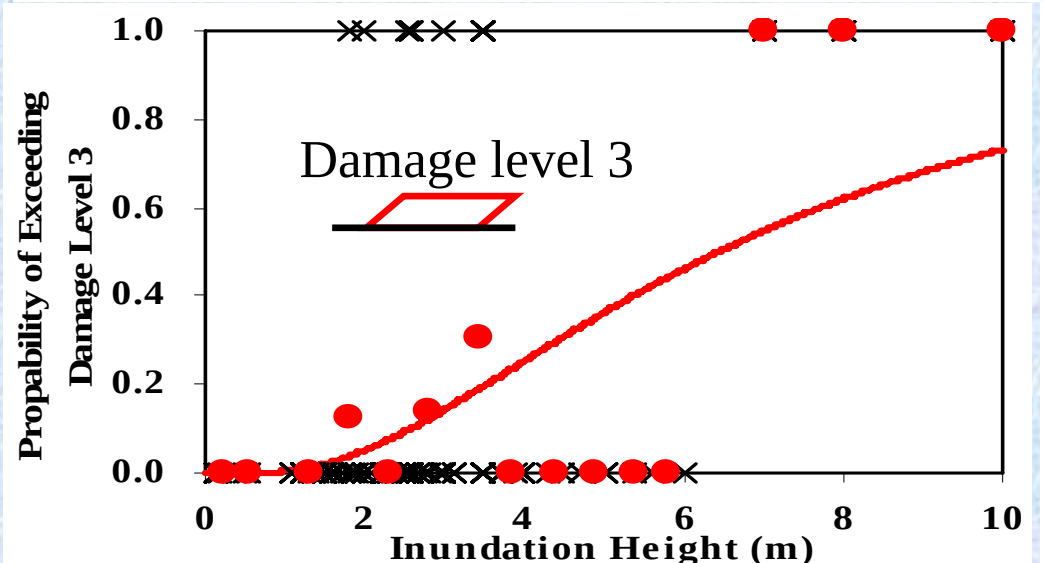
- Damage in primary members
- Collapse

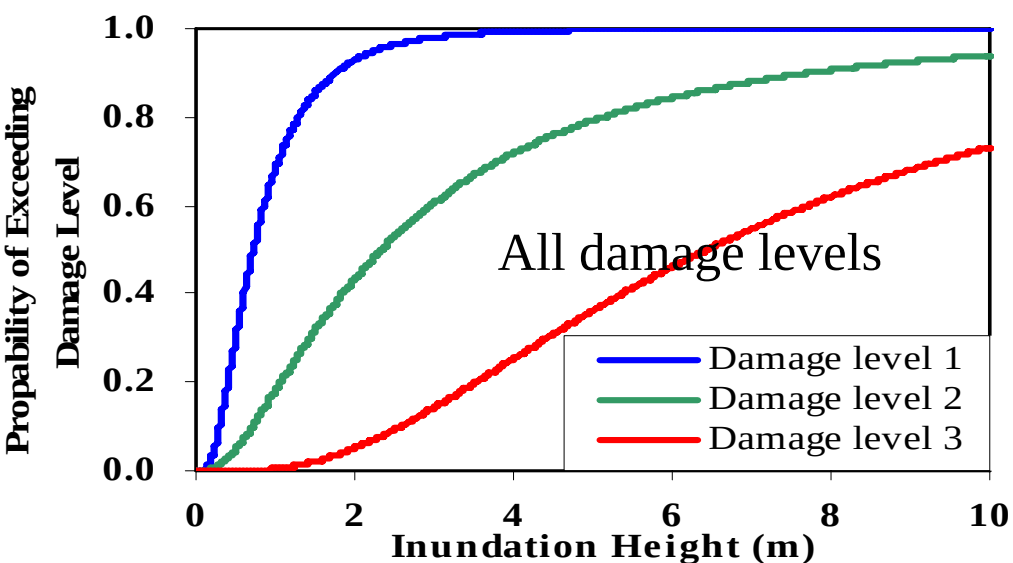


Fragility Curve of all Buildings Damaged by a Tsunami









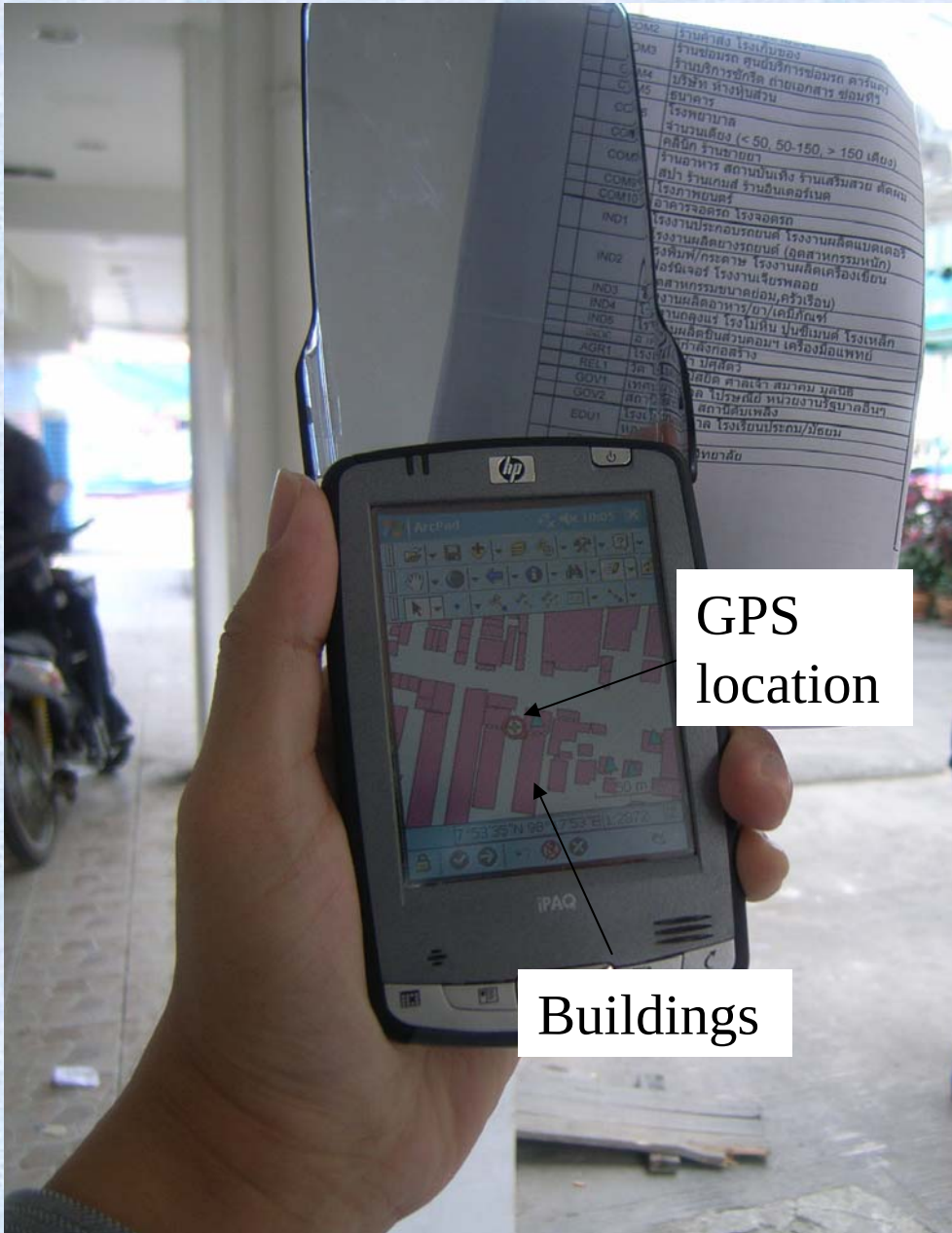
Development of Building Database in Southern Thailand

Provinces	No. of Buildings
Krabi	17,879
Trang	8,470
Ranong	7,387
Phang-Nga	11,493
Phuket - West coast - East coast	64,003 37,039 26,964
Satun	8,424
TOTAL	**117,656**

Pilot Survey

Patong Beach, Phuket

Pilot Survey



Detailed Survey Form

FS-2(REV5)

Building ID _____ วันที่_____ เวลา_____

แบบฟอร์มการเดินสำรวจภาคสนาม สำรวจโดย _____

ชื่ออาคาร		สถานที่ตั้ง	GPS Coord: เขต:
อายุของอาคาร โดยประมาณ	Age (<10 ปี, 10-30 ปี, >30 ปี)	จำนวนผู้ใช้อาคาร ลักษณะฐานราก	กลางวัน: คน ;กลางคืน: คน ☐ ฐานรากตื้น ☐ ฐานรากวางบนเสาเข็ม ☐ NA
หมายเลขภาพถ่าย (พร้อมวางไม้สตาฟท์) หน้า_____ หลัง_____ ซ้าย_____ ขวา_____			
เปอร์เซ็นช่องเปิด (โดยประมาณ) หน้า_____ หลัง_____ ซ้าย_____ ขวา_____			
ขนาดเสา		จำนวนชั้นของอาคาร	

No. of occupants (day & night)

% of opening

No. of stories

ชนิดโครงสร้างหลัก

วัสดุโครงสร้าง
- ☐ ไม้
- ☐ เหล็ก
- ☐ คอนกรีต
- ☐ อิฐก่อ

ประเภทโครงสร้าง
- ☐ โครงสร้างพื้น-คาน-เสา
- ☐ โครงสร้างพื้น-คาน-เสา มีผนังอิฐก่อ
- ☐ โครงสร้างกำแพงรับแรงเฉือน
- ☐ ชิ้นส่วนสำเร็จรูป
- ☐ กำแพงอิฐก่อรับน้ำหนัก

ผนังอาคาร
- ☐ อิฐก่อ
- ☐ ผนังเบาสำเร็จรูป
- ☐ ผนังกระจก
- ☐ ไม่มีผนัง
- ☐ อื่นๆ ระบุ _____

ลักษณะการใช้งานตาม Hazus _____

Occupancy Type

	HAZUS Occupancy	
	RES1	บ้านเดียว
	RES2	บ้านเคลื่อนที่ได้ (Mobile home)
	RES3A	บ้านแฝด 2 Units
	RES3B	ทาวเฮาส์ 3-4 Units
	RES3C	ทาวเฮาส์ 5-9 Units
	RES3D	ทาวเฮาส์ อพาตเมนต์ ดอนโด 10-19 Units
	RES3E	อพาตเมนต์ ดอนโด 20-49 Units
	RES3F	อพาตเมนต์ ดอนโด +50 Units
	RES4	โรงแรม บังกะโล รีสอร์ท
	RES5	หอพักในมหาวิทยาลัย เรือนจำ ที่พักทหาร ตำรวจ
	RES6	บ้านพักคนชรา
	COM1	ร้านค้าปลีก ร้านขายของ
	COM2	ร้านค้าส่ง โรงเก็บของ
	COM3	ร้านซ่อมรถ ศูนย์บริการซ่อมรถ คาร์แคร์

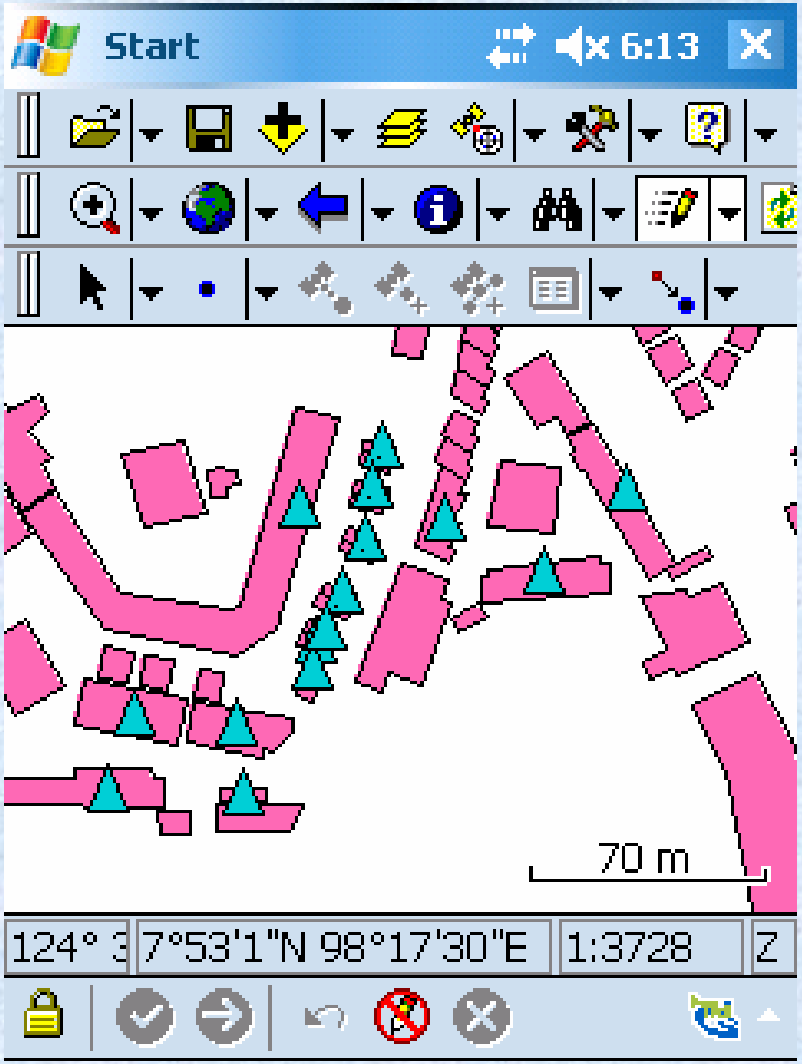
ประเภทโครงสร้างตาม Hazus

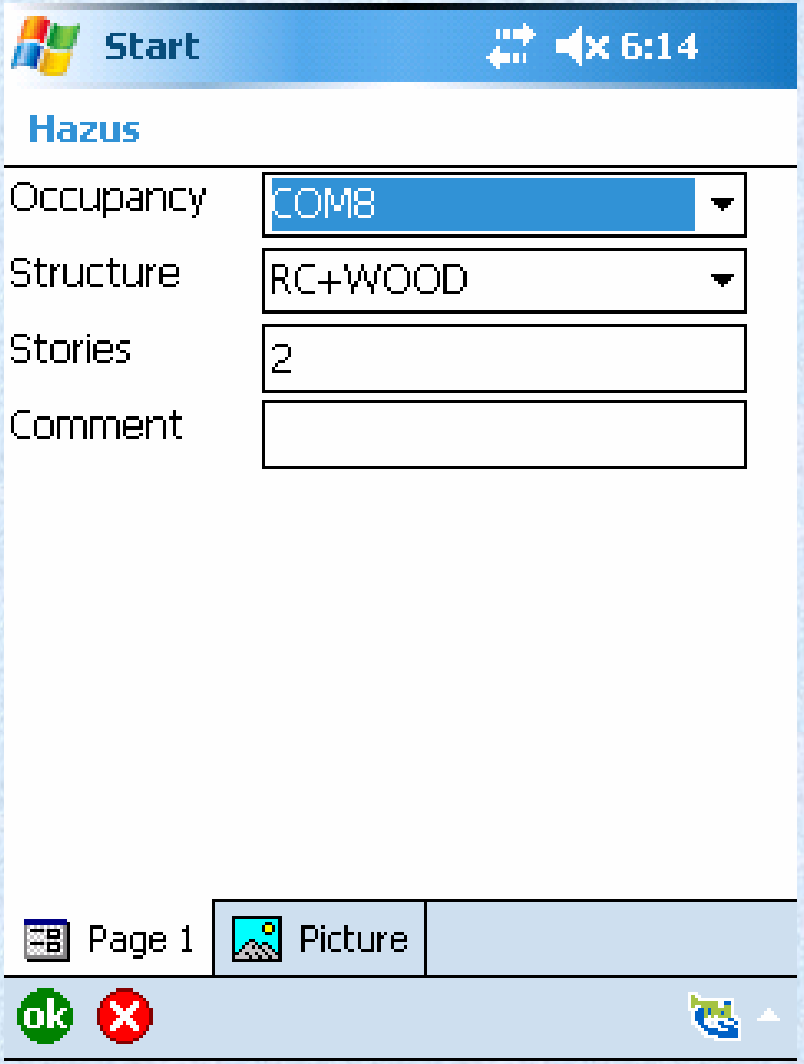
Structure Type

Wood structure
- ☐ W1 พื้นที่
- ☐ W2 พื้นที่ _____

Steel structure
- ☐ S1L (1-3 ชั้น)
- ☐ S1M (4-7 ชั้น)
- ☐ S1H (+ 8 ชั้น)
- ☐ S2L (1-3 ชั้น)
- ☐ S2M (4-7 ชั้น)
- ☐ S2H (+ 8 ชั้น)
- ☐ S3 อาคารโครงสร้างเหล็กขนาดเล็กเสาอาคารเป็นเหล็กกล่อง 1 ชั้น
- ☐ S4L (1-3 ชั้น)
- ☐ S4M (4-7 ชั้น)
- ☐ S4H (+ 8 ชั้น)
- ☐ S5L (1-3 ชั้น)
- ☐ S5M (4-7 ชั้น)
- ☐ S5H (+ 8 ชั้น)

Quick Survey Form





Ongoing Projects to Mitigate Tsunami Effects

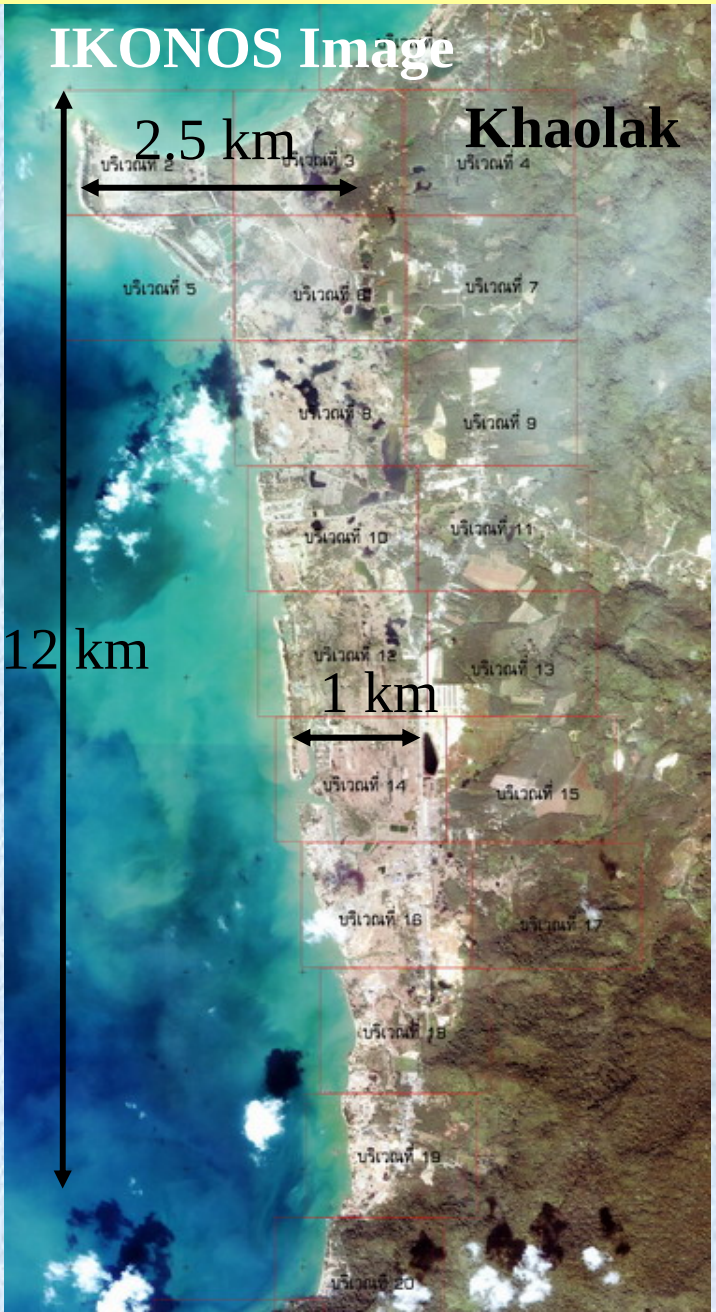
Effect of tsunamis on the Gulf of Thailand

Tsunami database for early warning

Tsunami risk analysis of buildings in Thailand

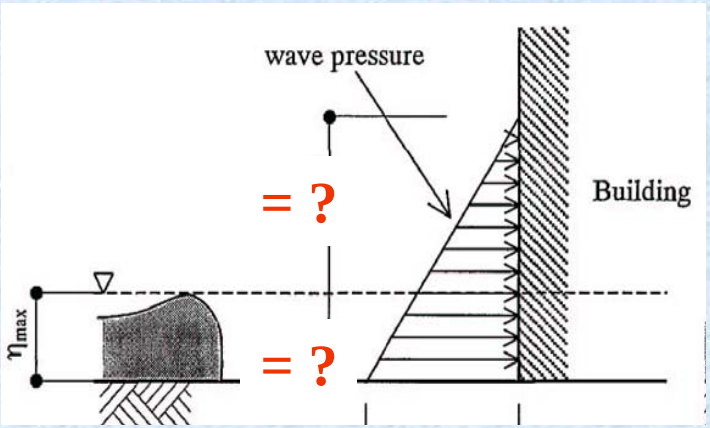
Tsunami load on evacuation buildings

Development of Design Guideline for Evacuation Buildings



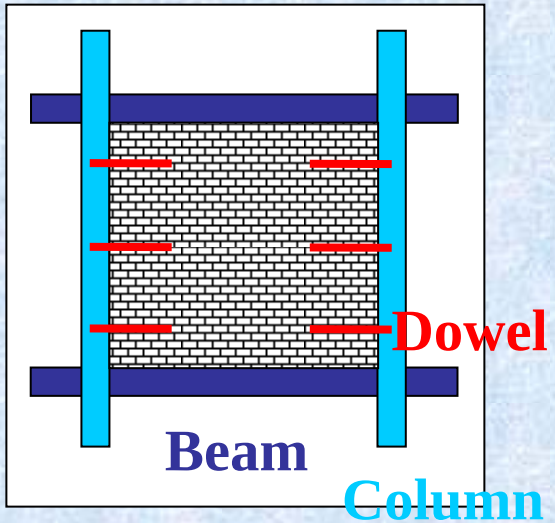
In some areas, inundation extends more than 2 km from the shoreline. A vertical evacuation would be necessary.

Opening is very effective.



Tsunami force on buildings with openings

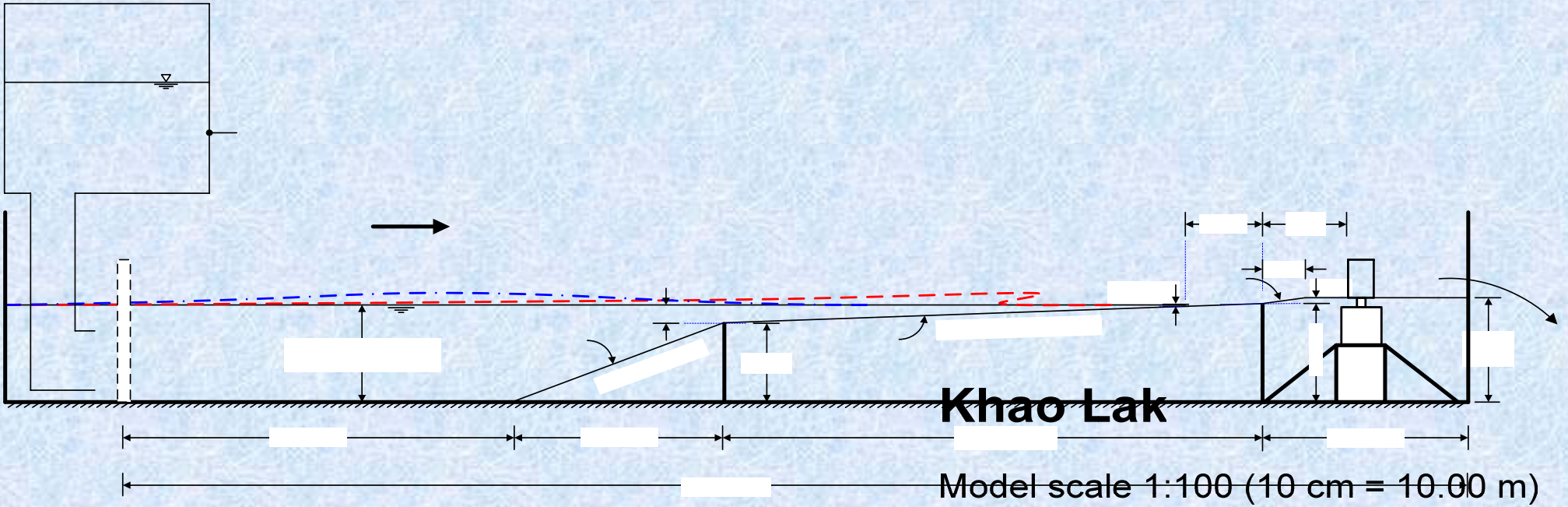
Damage of Building w/wo Opening



Building with opening

Experimental Setup

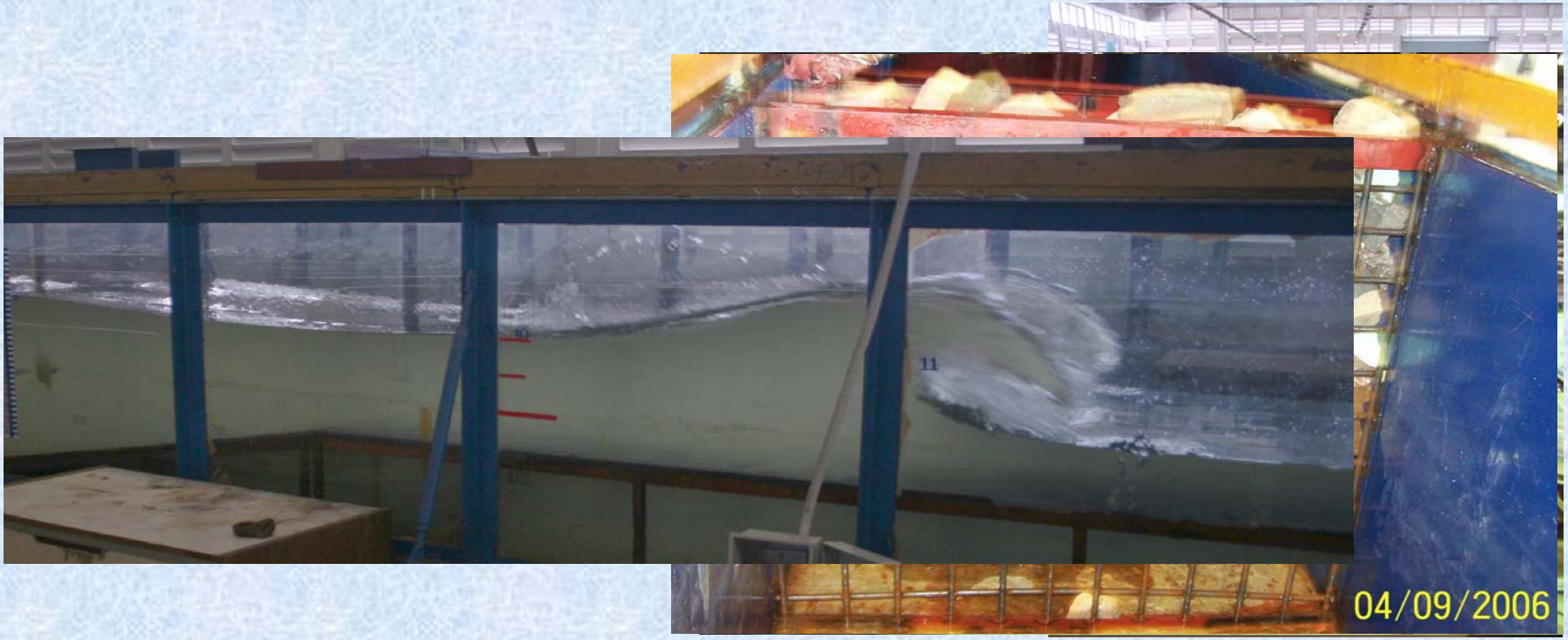
Scale 1:100



Water tank

Experimental Setup

Length 40 m, Width 1 m, height 1 m



Instrumentation

- ✓ Wave guage (Wave height)
- ✓ Propeller (Velocity)
- ✓ Pressure sensor (Pressure)
- ✓ Load cell (Base shear force and bending moment)

Experimental Parameters

- ✓ Beach slope (Khaolak and Phuket)
- ✓ Building shapes (square, rectangle, and octahedron)
- ✓ Percentage of opening for (0%, 25% 50%)
- ✓ Wave height (3 cm. – 8 cm.)

Building Models

Building shapes

15 cm x 15 cm x 15 cm

24 cm x 15 cm x 15 cm

Dia. 15 cm x15 cm

Opening

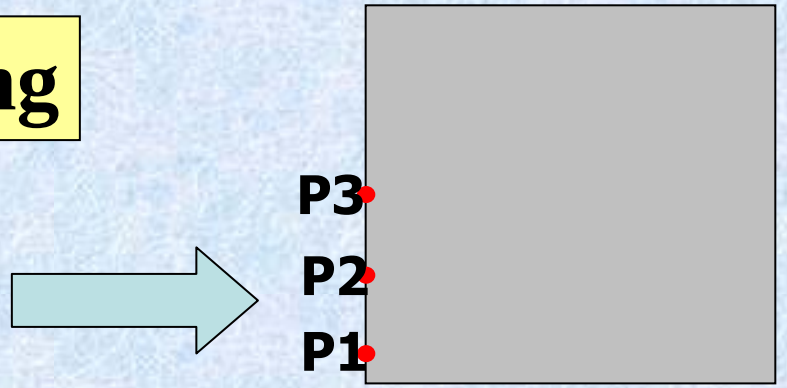
Wave at Building

h = 30 mm

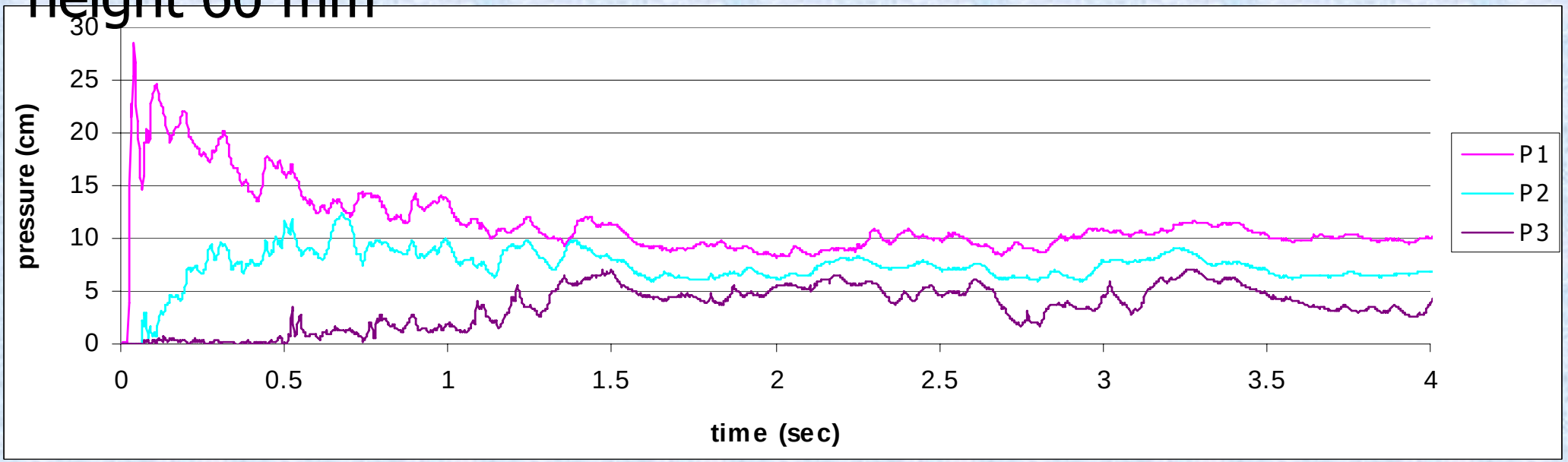
h = 60 mm

h = 80 mm

Pressure on Building



opening 25%, wave height 60 mm



Effect of Opening on Base Shear Force

Square

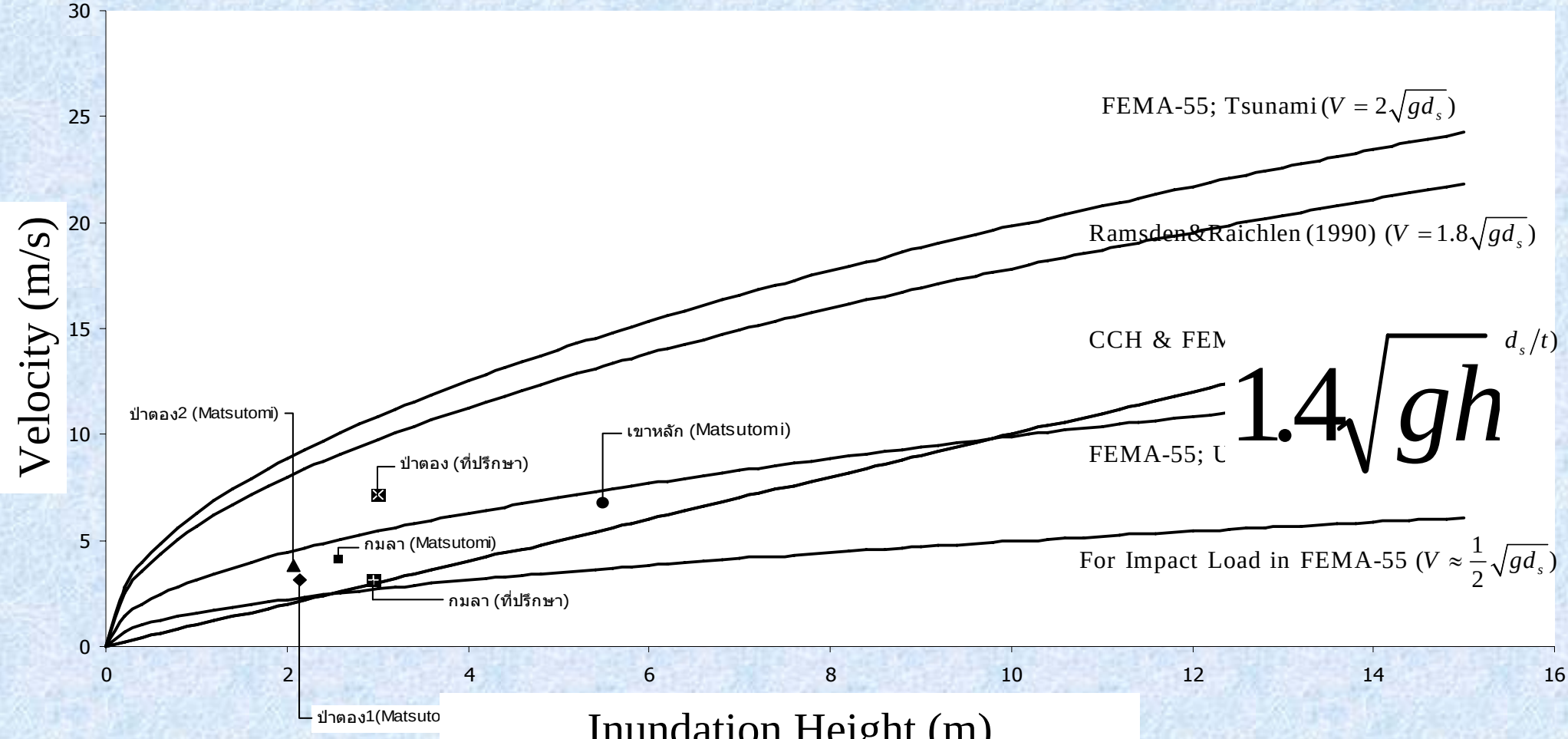
Khaolak

opening	Wave Height		
	30 mm	60 mm	80 mm
00%	0.84 (100%)	1.73 (100%)	2.37 (100%)
25%	0.70 (83%)	1.50 (87%)	2.13 (90%)
50%	0.43 (51%)	0.90 (52%)	1.37 (58%)

Phuket

Opening	Wave Height		
	40 mm	60 mm	80 mm
00%	0.70 (100%)	1.85 (100%)	3.77 (100%)
25%	0.52 (75%)	1.58 (85%)	3.22 (85%)
50%	0.44 (63%)	1.15 (62%)	2.67 (66%)

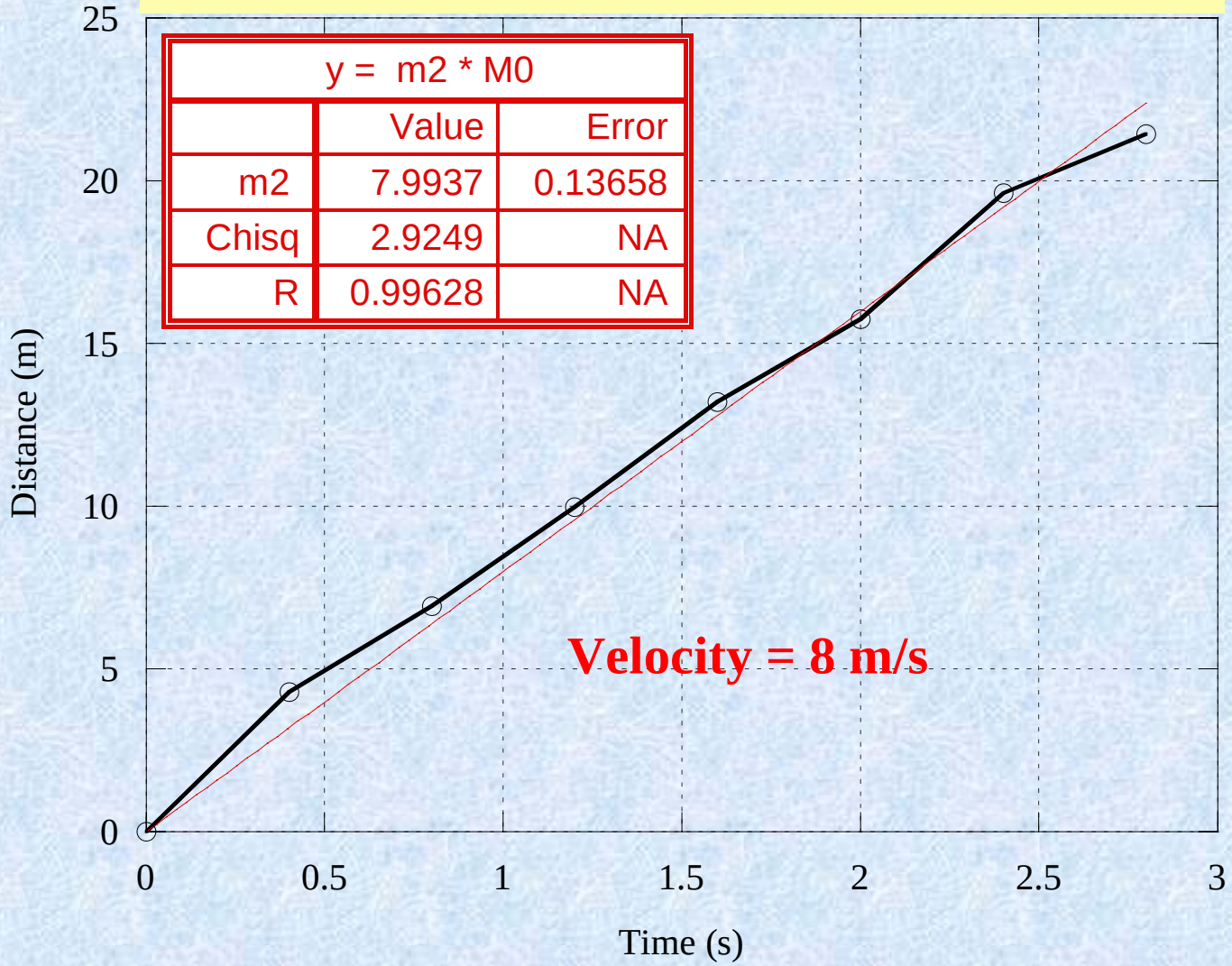
Comparison of Velocity



Estimation of Velocity from Available VDOs

Source: Wave of destruction website
Location: Khaolak

Estimation of Velocity from Available VDOs



Source: Wave of destruction website

Location: Patong Beach

Distance: 18.15 m

Time: 0.04 (s/frame) x 51 (frame) = 2.04 second

Velocity: 18.15 / 2.04 = 8.90 m/s

Evacuation Building Designed using Tsunami Loads

Fender elements are used to absorb the energy transferred from ship impact

Designed by Amorn Pimanmas, SIIT, Thammasart University

Case Study –
Building of Meteorological Department

NEED CALIBRATION WITH AN ACTUAL CASE

wave height = 4.4 m above ground

Velocity of wave (From Matsutomi and VDO)

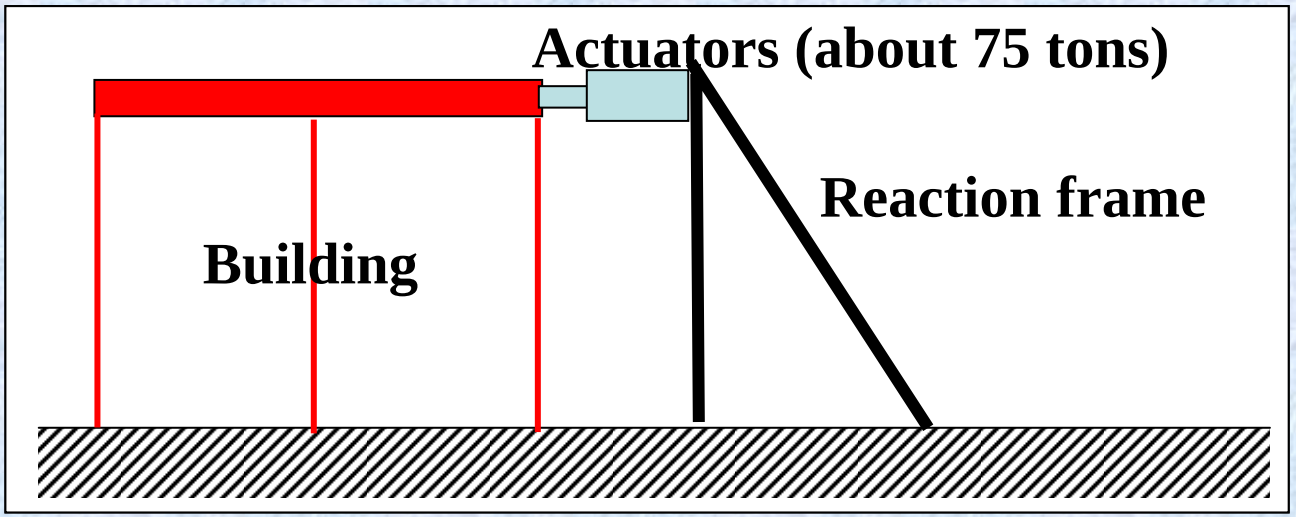
= 6 - 8 m/s

Distance from shoreline = 220 m

Elevation of first floor = 0.90 m

Case Study – Building of Meteorological Department

Full-scale push-over test will be conducted on 24 – 26 Dec 2007



Objectives:

- Determine the capacity of the building
- Estimate the tsunami force on the building at the time of 26 Dec 2004 tsunami
- Get the estimate of tsunami velocity
- Verify material modeling of RC buildings for lateral load analysis (seismic design)

Center of Excellence in Earthquake Engineering and Vibration
Department of Civil Engineering
Faculty of Engineering
Chulalongkorn University
Bangkok, Thailand
http://evr.eng.chula.ac.th
Tel: +66-2-218-6571
Fax: +66-2-251-7304