Regional technical workshop **"Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees?"**
Khao Lak, Thailand : 28 - 31 August 2006

THE ROLE OF FORESTS AND TREES IN PROTECTING COASTAL AREAS AGAINST TSUNAMIS

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Acknowledgment

We express sincere thanks very much to:

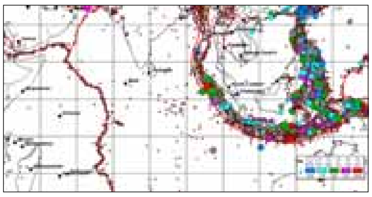
- **Prof. Fumihiko Imamura, Tsunami Engineering Laboratory, Disaster Control Research Center, Tohoku University, Japan for his suggestion to study the effectiveness of vegetation to reduce tsunami.**
- **Dr. Kenji Harada for helping us carrying out the hydraulics experiment.**
- **Mr. Haris Sunendar and Mr. Aditya Riadi Gusman for helping us preparing numerical simulations.**
- **Member of Tsunami Research Group, Center for Marine and Coastal Development Institute of Technology Bandung (ITB), and Staff of Department Oceanography, Faculty of Geosciences and Technology Mineral, ITB for their support.**
- **FAO and the government of Finland by OSRO/GLO/502/FIN Forestry programme for Early Rehabilitation in Asian Tsunami Affected Countries for their financial support to present this paper.**

LIST OF CONTENTS

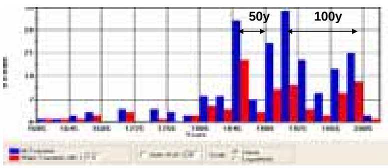
1. INTRODUCTION

- The 2004 Indian Ocean tsunami killed 283.000 people and damaged properties, livelihood and coastal resources in Asian and African countries, which facing to Indian Ocean.
- Need for protection **against the next tsunami**
- Historical tsunamis in this area and their, occurrences, strengths/ tsunami heights, and damaged on coastal area due to tsunami
- Identification of coastal vegetation (mangrove and coastal forest) and their capacities
- Effectiveness of the coastal vegetation in reducing tsunami height, flow velocity, and inundation area by analyzed:
  - the capability of forest and limit of yield of tree
  - hydraulic resistance through hydraulics experiment
  - Numerical modeling of inundation area with designed vegetation

2. INDIAN OCEAN TSUNAMIS



Tectonic setting, locations of earthquakes (small square) and tsunamis (color circles) in Indian Ocean Region (ITDB/WRL, 2005)



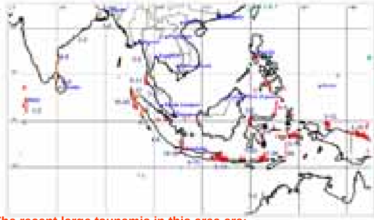
Historical:
Indian Ocean tsunamis + China sea +Western Pacific (1600-2005) ➔ 282 events
Only one at Arabian Sea 1945 (M=8.3 and 15m) and several at Andaman-Nicobar

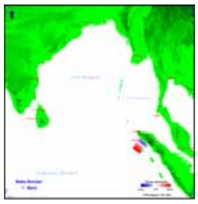
Most occurred at Indonesian And Philippine archipelagos

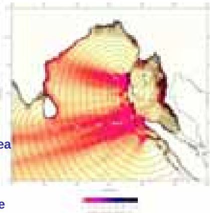
High frequency occurrences
1845-1865 (30 events)
1885-1905 (33 events)
1985-2006 (21 events)

Total casualties: 361.905
2 events gave big contribution :
1883 Krakatau=36.000 and 2004 Sumatran =283.000

Tsunami heights along the coastal area in Indian Ocean





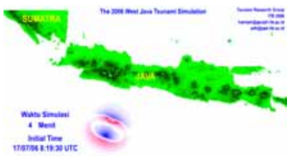


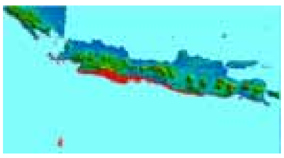
The recent large tsunamis in this area are:

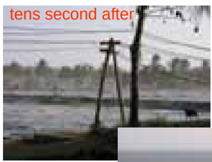
- **the 1992 Flores Tsunami (Indonesia) : 1,950 people,**
- **the 1994 East Java Tsunami (Indonesia) : 238 people,**
- **the 1994 Mindoro Tsunami (Philippine) : 78 people,**
- **the 1996 Irian Jaya Tsunami (Indonesia) : 110 people.**
- **the 1998 PNG Tsunami (PNG) : 3000 people**
- **the 2004 Indian Ocean Tsunami : 283.000 people**
- **the 2006 West Java Tsunami (Indonesia) : 600 people (?)**

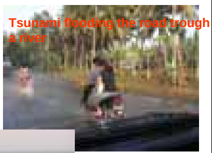
Indonesia and Philippine Archipelagos and their surrounding area
➔ very prone tsunami area (near field tsunami)
➔ travel time about several up to tens minutes,
while India, Srilanka, Thailand was attacked tsunami is far field tsunami ➔ travel time about 2 and 2.5 hours after the earthquake

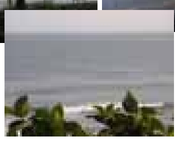
The 2006 West Java Tsunami Simulation (2.5 hours after the EQ, TRG-ITB)









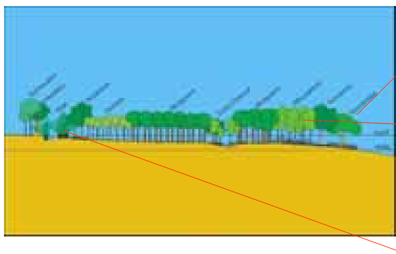


Courtesy of Arianes and Daniel (eye witness)

16.35

3. COASTAL VEGETATION

3.1 Mangrove



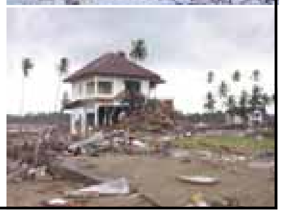
A typical zonation pattern for mangroves in Sumatra (after Whitten et al. 2000) and is also typical of the type of pattern seen elsewhere in the tropical Indo-West Pacific region where rainfall is high, and spread over the year so there is no protracted dry season (in Rassell Hanley, 2006)

- **3.2 Coastal Forest**
  - Species of the Barringtonia formation, casuarinas, cattapa.
  - Coastal forest have been replaced with coconut plantations in Aceh (Whitten et al., 2000 in Rassell Hanley, 2006).

4. EFFECTIVENESS OF VEGATATION TO REDUCE TSUNAMIS

There are opinions about the effectiveness and ineffectiveness of forest ➔ Shuto (1987):

- Affirmative views assert that a forest is effective because:
  - It stops driftwood and other floatages
  - It reduced water flow velocity and inundation water depth
  - It provides a live-saving means by catching persons carried out off by tsunami
  - It collect wind blown sands and rises dunes, which act as a natural barrier against tsunamis
- A represent negative opinion is that:
  - A forest may be ineffective against a huge tsunami, and at worst, tress themselves could become destructive forces to house, if cut down by tsunami



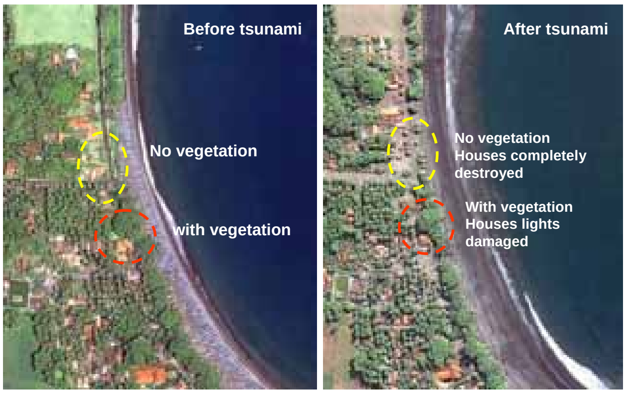
Tsunami and earthquake impact to coastal vegetation

Mangrove knocked out from around 15-20 meter tsunami heights in Jantang coast (courtesy of Higman)

Dried mangrove forest at Muewa (North Nias) due to the tectonic uplift, a picture was taken after 10 months of the event (Courtesy of Widjo Konko)

The Casuarinas trees fell down from around 30 meter tsunami heights in Lhoknga coast

First line of the trees were knocked down by 6-7 meter in heights of the 2006 West Java Tsunami at Cimanuk, Cikalong, West Java



Ikonos imagery before and after the 2006 West Java tsunami shows the role of vegetation reduced tsunami at the Pangandaran Beach (source: CRPS, www.crips.nus.edu.sg)

Tsunami broken at the first line of forest, and flowing trough vegetation

In order to determine the effectiveness of coastal forests against tsunami, old records have been collected and analyzed by Shuto (1987).

Statistic analysis of the record

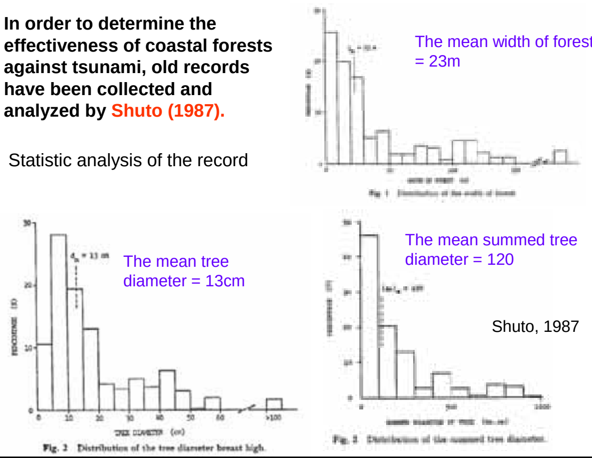


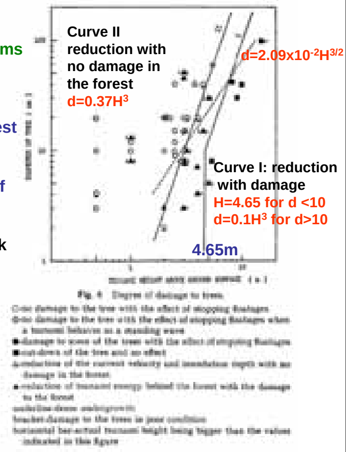
Fig. 2 Distribution of the tree diameter breast high.

Fig. 3 Distribution of the summed tree diameter.

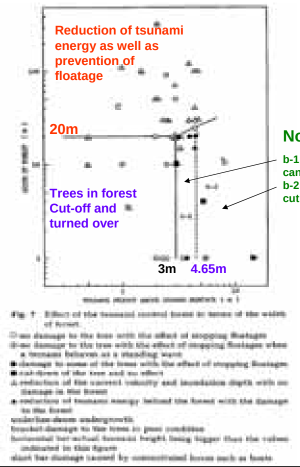
Shuto (1987) proposed three diagrams to obtain the criteria to judge the effectiveness:

1. **Degree of damage to tree**
2. **Effect of the tsunami coastal forest in terms of the with of forest**
3. **Effect of, and damage to the tsunami control forest in terms of the summed tree diameter**

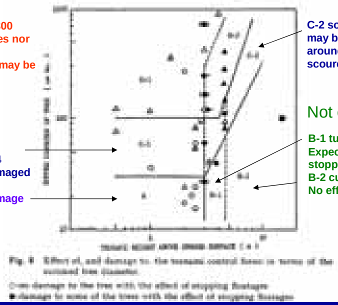
The diagrams will be useful for quick and quantitative judgment.



Shuto (1987)



Shuto (1987)



Shuto, 1987

The diagrams obtained will be useful for quick and quantitative judgment. However for a more detailed evaluation, numerical simulation are necessary, with the hydraulics resistance of trees and undergrowth included.

For this purpose the resistance laws of trees, undergrowth and a forest as a whole system should be provided through hydraulics experiments.

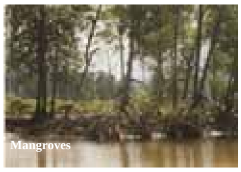
Hydraulic Resistance

- **Petryk and Bosmajian (1975): hydraulics force balance ➔ n, a flow resistance due to a drag force by vegetation.**
- **Wolanski *et al.* (1980); Wolanski, *et al.* (1992); Kanazawa and Mazda (1994): a flow field of tide on mangrove swamp and creek by using Manning coef., *n=0.2-0.4 in swamp and n=0.02-0.04 in creek***
- **Mazda *et al.* (1995): water flow in creek depending on the drag force:
- hydrodynamics in mangrove swamp changes ➔ mangrove species, their density and tidal condition,**
- **Mazda et al (1997): effectiveness of mangrove reducing waves ➔ mangrove aged, correlated to the vegetation density**
- **Goto and Shuto (1983) : Energy head loss, Effect of a large obstacle on tsunami inundation, ➔ numerical simulate the tsunami on the land with a large obstacle**
- **Noji *et al.* (1993): ➔ modeled the impact force by experiment and numerical analysis on movement of rocks transported by a tsunami, Cd=2-6 and Cm in order of 2.**

However we can not use directly into the tsunami cases➔ hydraulic exp.

Hydraulic Experiment

A species of mangrove Rhizophora



Mangroves model in the 100m channel

Mangrove Model Experiment

The mangrove model consists of :
roots = porous medium : height = 5 cm
trunks = cylindrical element : diameter =2cm, dist. =20cm
leaves = porous medium : height = 22 and 23 cm
length of model =1 m and 2 m

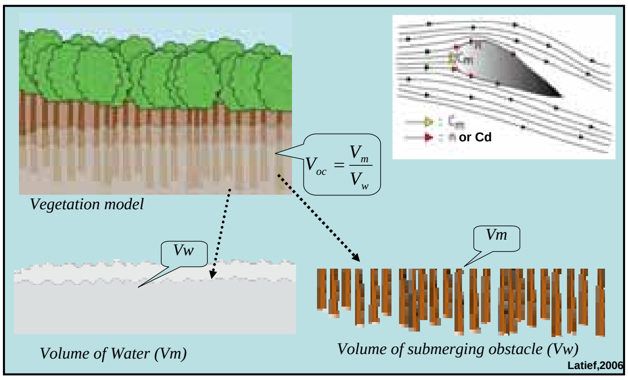
Ratio of volume occupied by the model (%) ➔ $V_{oc} = \frac{Vm}{Vw} x100\%$
roots = 2.74%,
trunks = 0.75%
leaves = 31.68%

The location of mangrove model is changed:
- before , at, and after breaking point

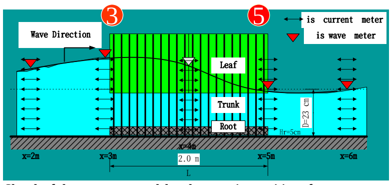
Water level and velocity in time are measured, at:
- front , inside and back of the model

This data used ➔ estimated *n* and C_M inversely

Definition of volumetric occupancy and resistance coefficients



Experimental set-up



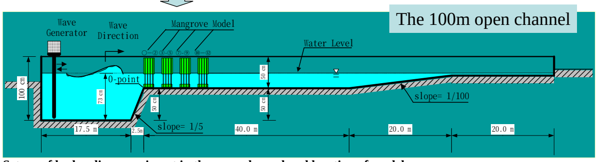
Sketch of the mangrove model and measuring position of wave gauge and current meter

ratio of volume occupied by the model (%)

$$\frac{Vm}{Vw} x100\%$$

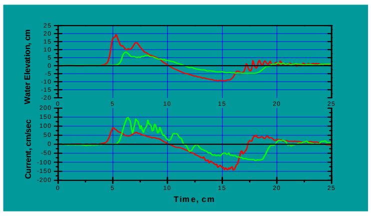
roots = 2.74%
trunks = 0.75%
leaves = 31.68%

The 100m open channel



Set-up of hydraulics experiment in the open channel and location of models

Measured water level and current



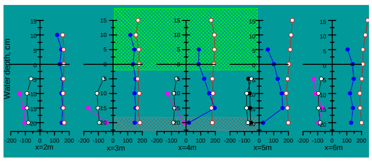
Time history of water elevation (up) and current (bottom)

Elevation:

	front	behind
	max = 20cm	max=7cm
	min= -10cm	min=-5cm

Current:

	front	behind
	max=100cm/s	max=150cm/s
	min= -150cm/s	min=-100cm/s



Vertical profile of measured current of Case-00 (open circle) and Case-3b (solid circle)

Come in current is
reduced: inside & back

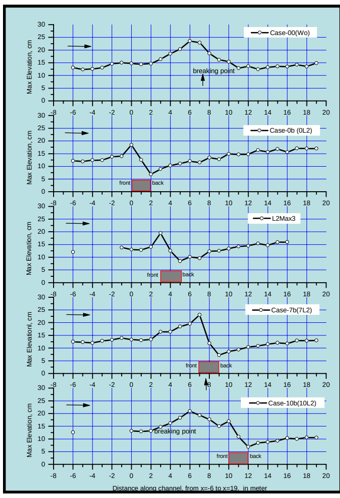
Current profiles :
changed => normal again

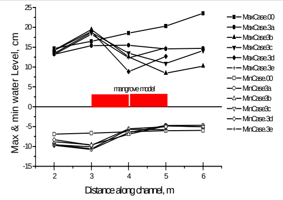
Back out current is
increased at front

Case	Parameters Dimension (cm)					
	Position Model in channel	Model Length	Root height	Distance trunk to trunk	Height of leaves portion	Water Depth
Case-00	no	no	no	no	no	23
Case-3b	300	200	5	20	22	23

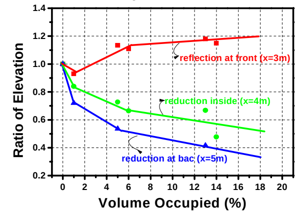
Table of The maximum & minimum elevations and maximum & minimum currents on with (Case-3b) and without model (Case-00)

Elev. & Current	Case	Distance from 0 point									
		x=2m		x=3m, front		x=4m,inside		x=5m, back		x=6m	
Elev. Max (cm)	3b	14.28	2.7%	19.46	18.1%	12.39	33.3%	8.46	58.4%	10.26	56.3%
(positive wave)	00	14.68	(decr)	16.49	(incr)	18.57	(decr)	20.34	(decr)	23.55	(decr)
Elev. Min (cm)	3b	-8.83	27.8%	-9.60	44.4%	-6.93	9.8%	-4.84	19.7%	-5.05	15.4%
(negative wave)	00	-6.91	(decr)	-6.56	(decr)	-6.31	(decr)	-6.03	(incr)	-5.97	(incr)
Current Max (cm/s)	3b	155.5	3.4%	126.5	29.8%	195.5	5.7%	160.8	19.5%	147.0	27.3%
(proceeding current)	00	161.0	(decr)	180.3	(decr)	184.8	(incr)	199.8	(decr)	202.3	(decr)
Current Min (cm/s)	3b	-139.5	56.7%	-170	70.3%	-128.8	47.2%	-72.4	35.5%	-128	35.7%
(back current)	00	-89.0	(incr)	-109.8	(incr)	-87.5	(incr)	-86.8	(decr)	-94.3	(incr)





Maximum and minimum water level around the mangrove model



Ratio elevation with the model to without one as function of volumetric occupancy

From Hydraulics experiment, Latief (2000) : proposed formulas of Manning coefficient (n) and Impact force (Cm) as function of volumetric occupancy of flows trough vegetation

$$n = \begin{cases} 0.016 + 0.17 V_{oc} & \text{If} \quad V_{oc} > 0.07 \\ 0.03 & \text{If} \quad V_{oc} < 0.07 \end{cases}$$

$$C_M V_{oc} = \begin{cases} 0.67 + 6.65 V_{oc} & \text{If} \quad V_{oc} > 0.06 \\ 1 & \text{If} \quad V_{oc} < 0.06 \end{cases}$$

5. APPLICATION OF GREENBELT INTO THE NUMERICAL MODEL

5.1 Pancer Bay

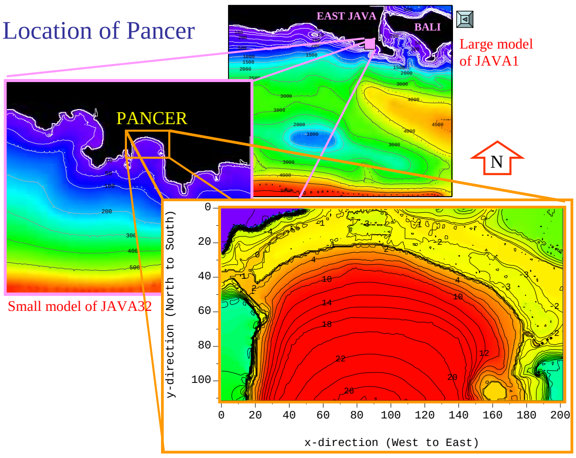
Case study: Pancer Bay, East Java ➔ because:

- the most suffered damaged, due to the 1994 east Java Tsunami
- a good measured data was available

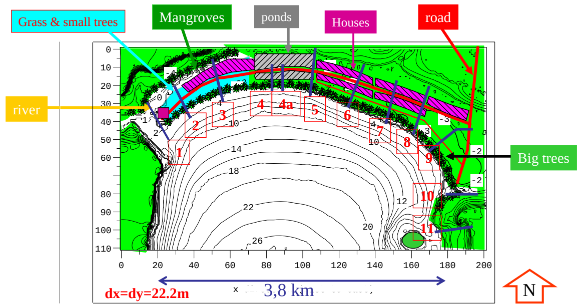
Fatalities : 136 of 238 (total) ➔ at Pancer
Population : 3,554 people (mortality ratio 3.8%)
Destroyed houses : 450 swept away, 250 heavy damaged (ratio 70%)

Tsunami heights :
Tsuji et al. (1995) : 5.7 - 9.4 m
Nayoan et al. (1997) : 4.0 - 5.0 m (above MSL)
Marimai and Tinti (1997) : 4.7 m (above MSL)

Location of Pancer



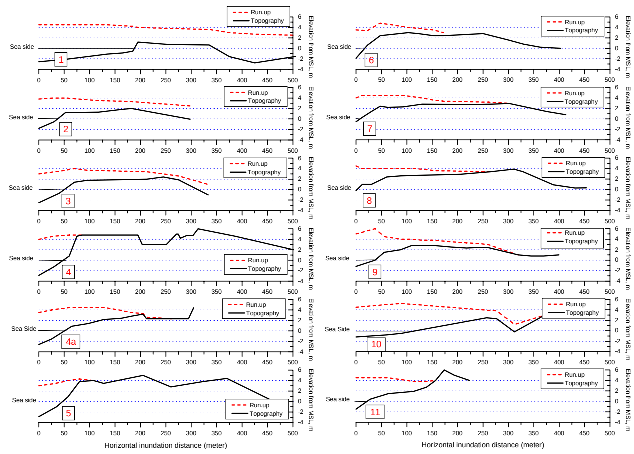
Land use in the Pancer Bay



Topography and land-use of Pencer Bay

Photos vegetation and land use
Beach profile and run-up height , at 1 up to 11

Photos of a vegetation and land use of Pancer Bay



Beach profile and run up height at several cross sectionin the Pancer bay

Numerical simulation

Governing equation (include impact force)

$$\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0$$

$$(1+C_M V_{oc})\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}\left(\frac{M^2}{D}\right)+\frac{\partial}{\partial y}\left(\frac{MN}{D}\right)+gD\frac{\partial \eta}{\partial x}+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=0$$

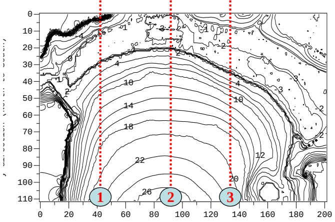
$$(1+C_M V_{oc})\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\left(\frac{MN}{D}\right)+\frac{\partial}{\partial y}\left(\frac{N^2}{D}\right)+gD\frac{\partial \eta}{\partial y}+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=0$$

Where:

$$V_{oc}=\frac{V_m}{V_w}$$

V_{oc} is volume occupied
V_m is the model volume
V_w is the water volume

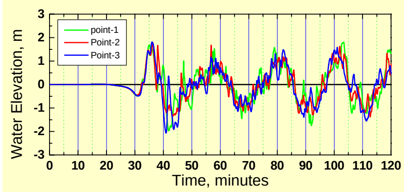
Study area, conditional and input model



Simulation area and the initial waves points

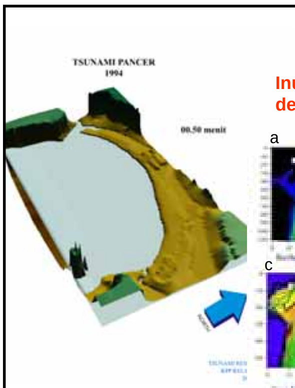
Study Area = 4,5 x 2.5 km²
meshes numbers: 202x112
meshes size =22.2 m

B.C.:
-on the land: wet and dry BC
- Characteristic B.C.
for flowing in and out the area.

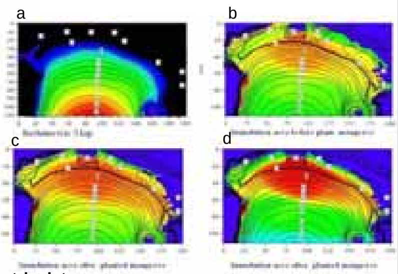


Initial waves profiles from CPX4 Model (Latief &Imamura, 1998) as historical elevation: at point 1,2,3 (in the bay)

wave height = 4 m (+2 to -2)
wave period= 18 - 20 min.



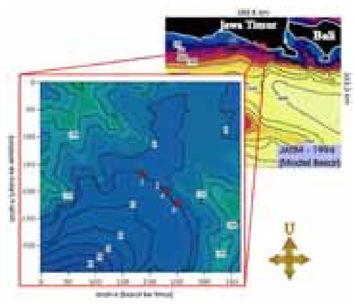
Inundation areas without and with designed vegetation

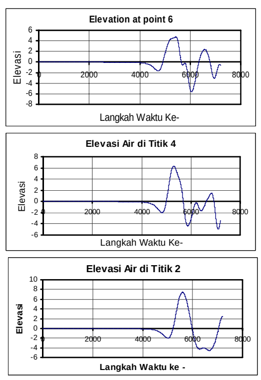


Latief, 2000

(a) Bathymetric data
(b) tsunami Inundation area without vegetation and
(c) with vegetation only considering Manning coefficient
(d) with considering Manning roughness and impact force coefficients

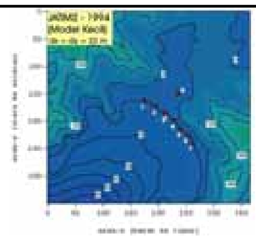
5.2 Bandialit Bay



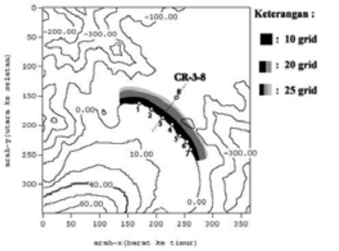


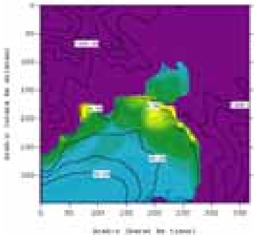
Tsunami Elevations on the shore

Bathy and topography maps



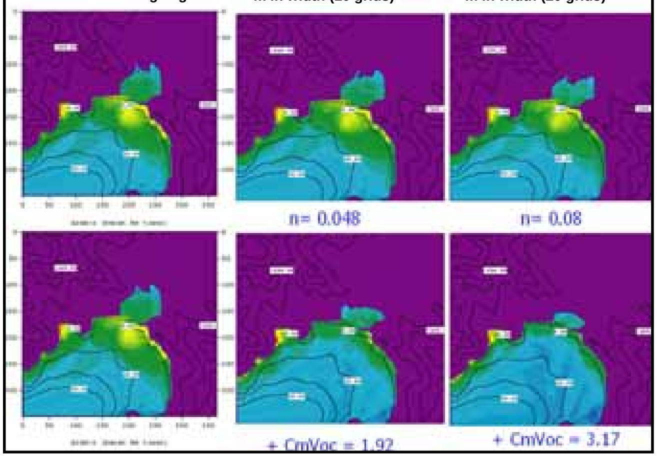
Designed vegetation 1 grid = 22 metres



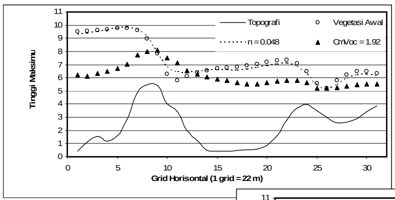


Inundation map with existing vegetation

Condition with existing vegetation | Designed vegetation 220 m in width (10 grids) | Designed vegetation 440 m in width (20 grids)

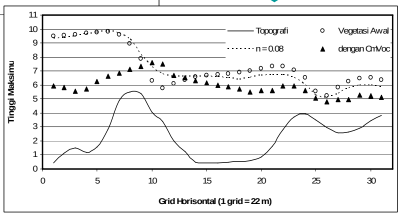


Model with more dense vegetation



Profiles of water elevation

n = 0.048, + 20 grids



Profiles of water elevation

n = 0.048, + 10 grid

6. Conclusions

1. Historical tsunami in Indian Ocean:
   - Indonesia and Philippine ➔ near field tsunami ➔arrival time varies from several minutes up to tens minutes.
   - Thailand, Malaysia, Bangladesh, India, Srilanka, and others➔ the arrival time varies from 1-2 hours up to tens hours, ➔ they still have some spare time for evacuations
   - Tsunami height depend on the tsunami source (earthquake magnitude, distance of the source), bathymetry and coastal morphology.
2. Vegetation (mangrove and coastal forest) can be used as a greenbelt except coconut trees.
3. Effectiveness of forest to reduce tsunami depend on wide, dense and structural of the forest and typical trees (such: height and diameter breast height of tree). Shuto (1987) suggested that diameter effective to reduce tsunami height of 4.65 m is 10 cm, if H= 7m, the diameter effective is about 34.3 cm (for H=10m ➔d=100cm). For tsunami height of 3 meter the effective wide of forest is 20 meter.

4 For detail evaluation of the effectiveness, numerical simulation are necessary with hydraulic resistance of trees and undergrowth included, the hydraulic resistance should be provided through hydraulic experiment.

5. Numerical simulation of inundated area show that the vegetation can reduce tsunami heights and current pressures. The inundated area and tsunami run-up will be decreased when the density of installed greenbelt increases.

Thank you for your kind attention

Q/A

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