

Regional technical workshop "Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees?"
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- 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.

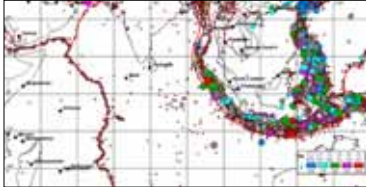
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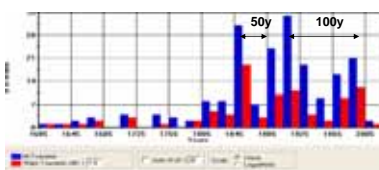
1. INTRODUCTION

- 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)



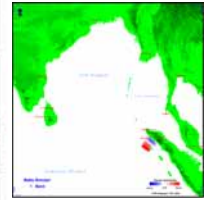
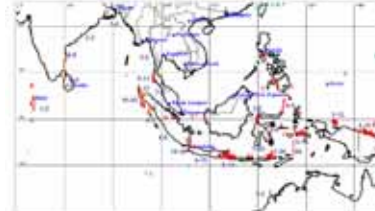
Historical:
Indian Ocean tsunamis + China sea + Western Pacific (1600-2005) → 282 events
 Only one at Arabian Sea 1945 (M=8.3 and 15m) and several at Andaman-Nicobar

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

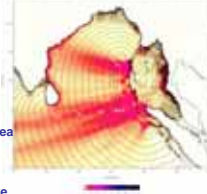
Tsunami heights along the coastal area in Indian Ocean



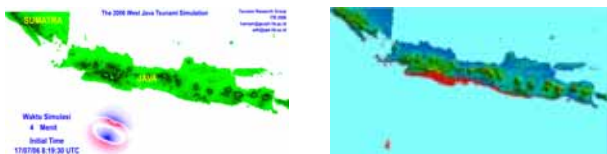
The recent large tsunamis in this area are:

- 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



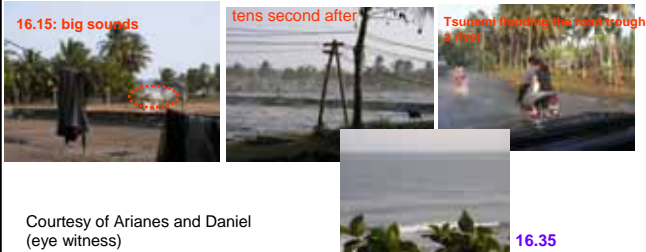
The 2006 West Java Tsunami Simulation (2.5 hours after the EQ, TRG-ITB)



16.15: big sounds

tens second after

Tsunami flooding the road through a bridge

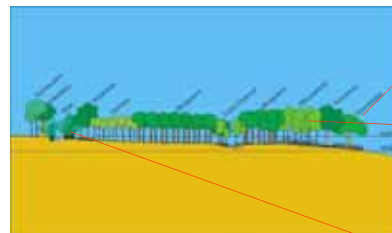


Courtesy of Arianes and Daniel (eye witness)

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 Russell 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 Russell Hanley, 2006).



4. EFFECTIVENESS OF VEGETATION 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, trees 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)

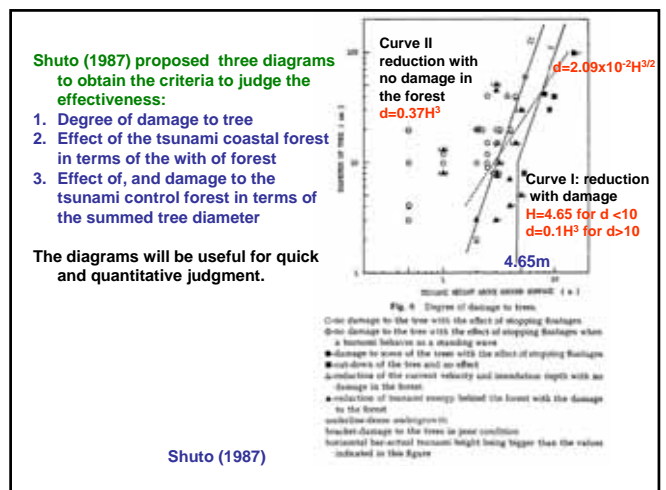
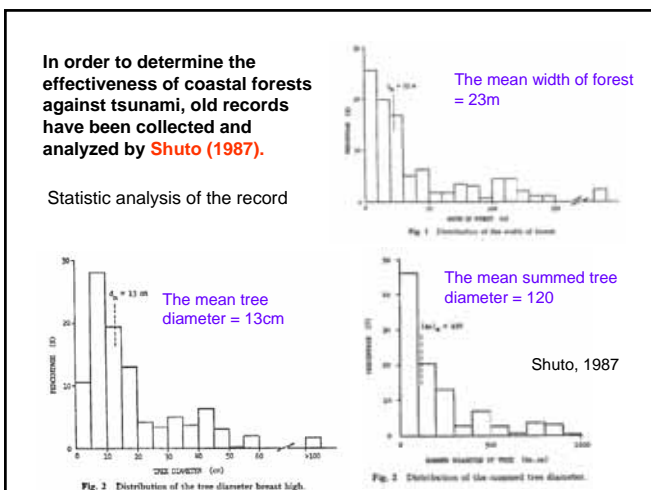
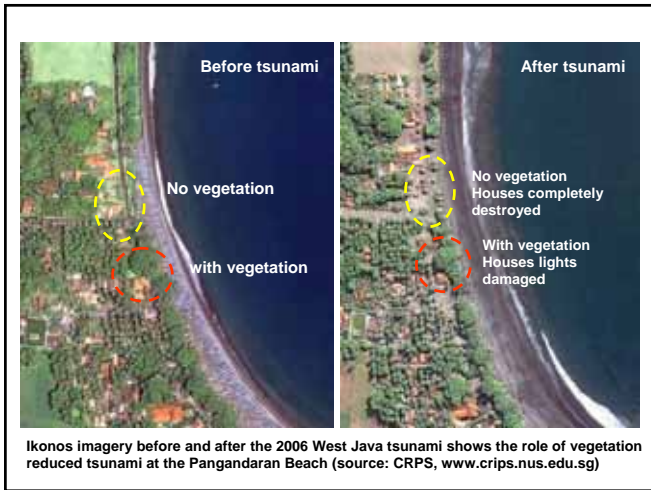


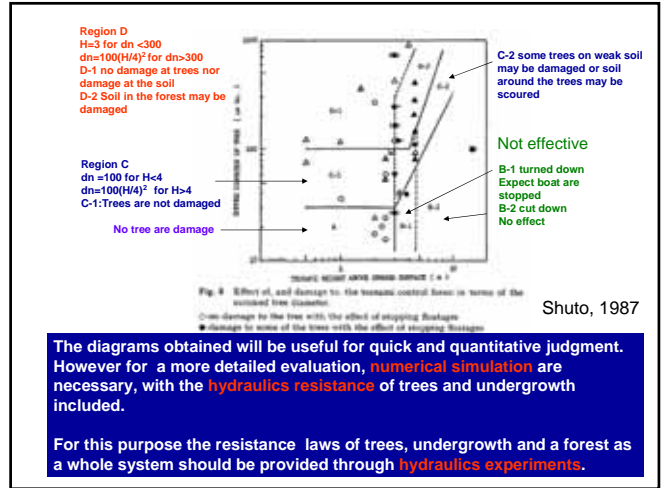
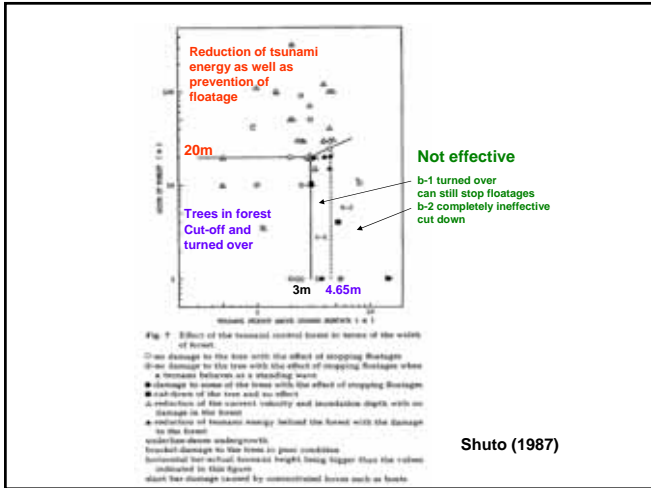
The Casuarinas trees fell down from around 30 meter tsunami heights in Lhoknga coast



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







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 $\rightarrow n$, 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 \rightarrow mangrove species, their density and tidal condition,
- Mazda *et al.* (1997): effectiveness of mangrove reducing waves \rightarrow mangrove aged, correlated to the vegetation density
- Goto and Shuto (1983): Energy head loss, Effect of a large obstacle on tsunami inundation, \rightarrow numerical simulate the tsunami on the land with a large obstacle
- Noji *et al.* (1993): \rightarrow modeled the impact force by experiment and numerical analysis on movement of rocks transported by a tsunami, $C_d=2-6$ and C_m in order of 2.

However we can not use directly into the tsunami cases \rightarrow 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 (%) $\rightarrow V_{oc} = \frac{V_m}{V_w} \times 100\%$

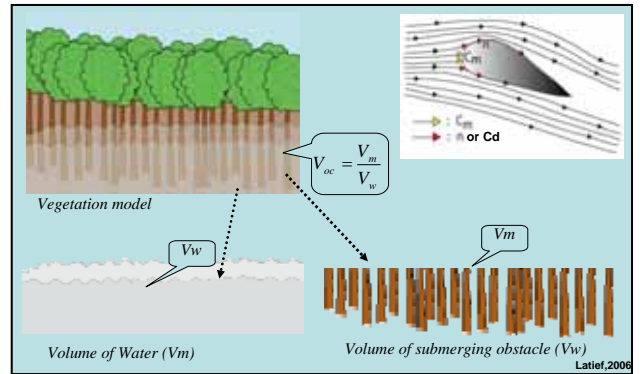
- roots = 2.74%,
- trunks = 0.75%
- leaves = 31.68%

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

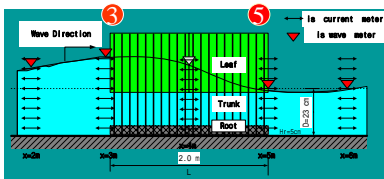
Water level and velocity in time are measured, at:
- front, inside and back of the model

This data used \rightarrow estimated n and C_M inversely

Definition of volumetric occupancy and resistance coefficients



Experimental set-up

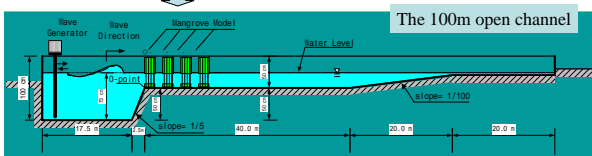


Sketch of the mangrove model and measuring position of wave gauge and current meter

ratio of volume occupied by the model (%)

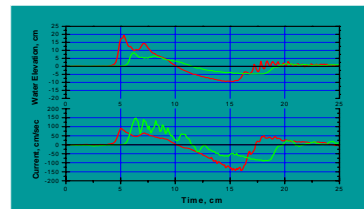
$$\frac{V_m}{V_w} \times 100\%$$

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



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

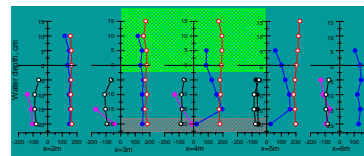
Measured water level and current



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

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

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

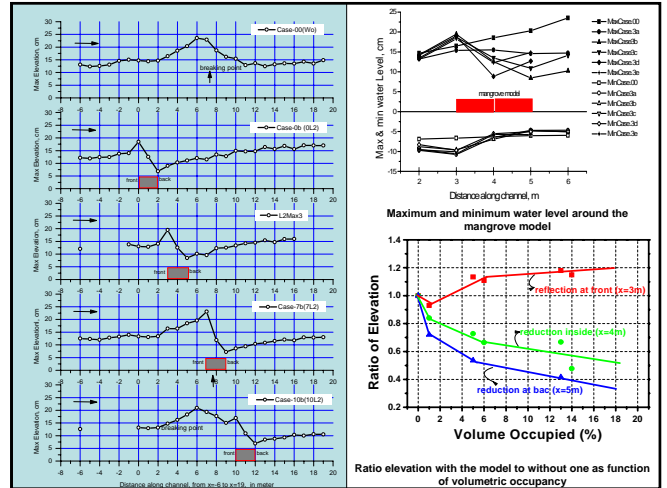
Current profiles : changed \Rightarrow normal again

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 | 2.78% | -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% |
| (preceding 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) |



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

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

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

5. APPLICATION OF GREENBELT INTO THE NUMERICAL MODEL

5.1 Pancer Bay

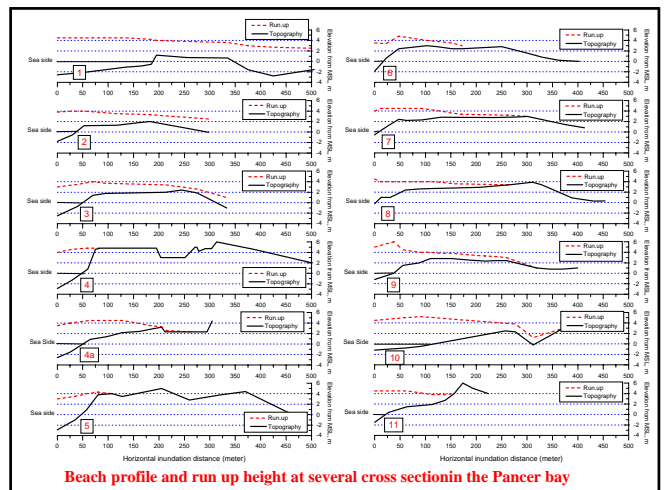
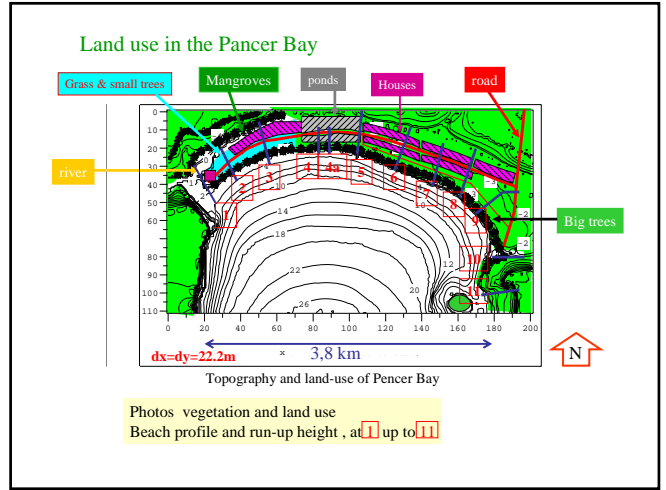
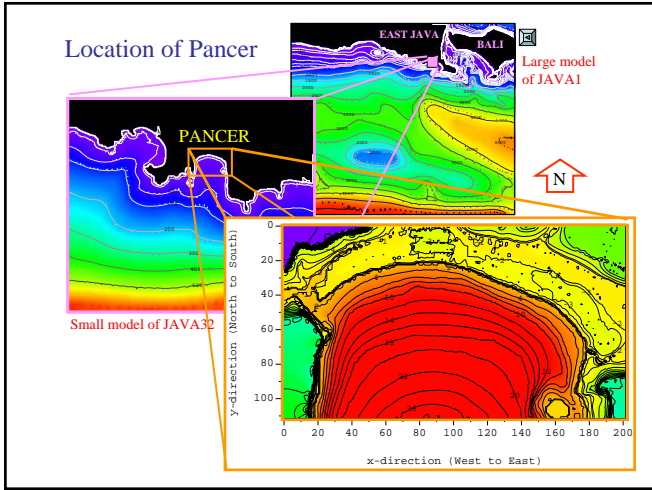
Case study: Pancer Bay, East Java → because:

- 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)



Numerical simulation

Governing equation (include impact force)

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

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

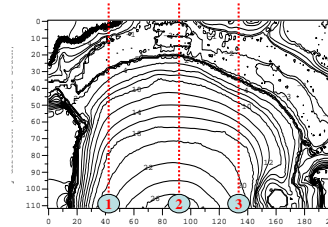
$$(1 + C_M V_{oc}) \frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left(\frac{MN}{D} \right) + \frac{\partial}{\partial y} \left(\frac{N^2}{D} \right) + gD \frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{7/3}} N \sqrt{M^2 + N^2} = 0$$

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

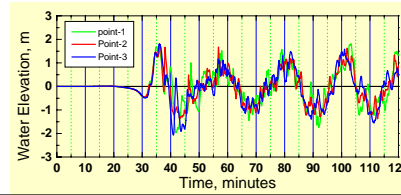
Study area, conditional and input model



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

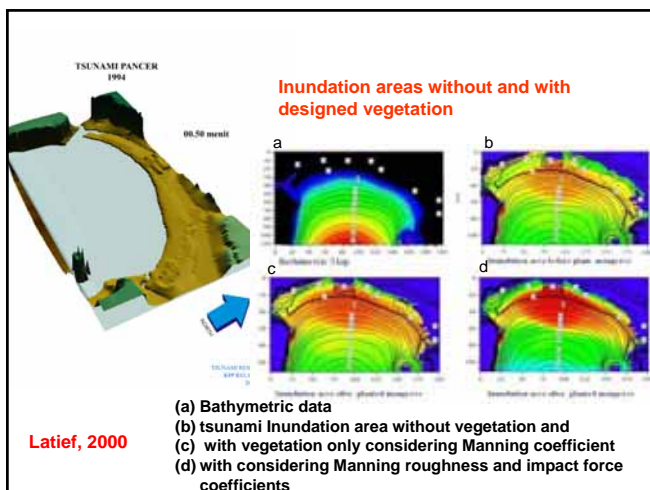
B.C.:
 - on the land: wet and dry BC
 - Characteristic B.C.
 for flowing in and out the area.

Simulation area and the initial waves points

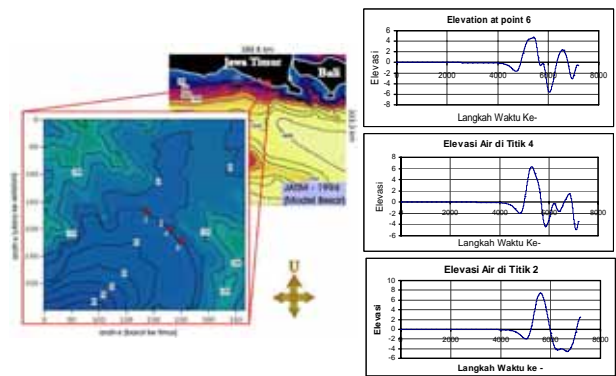


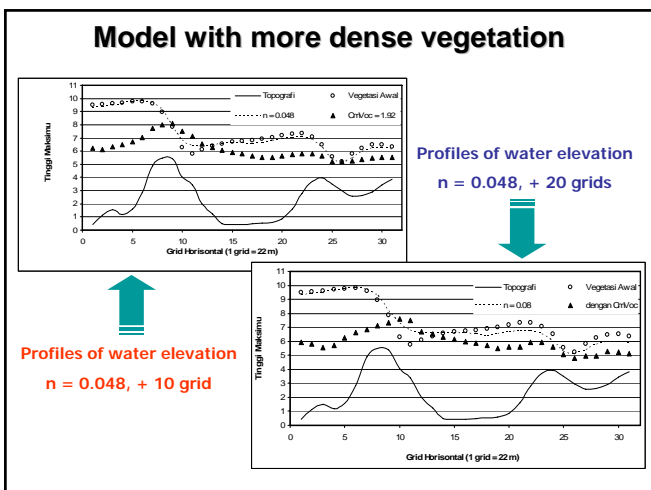
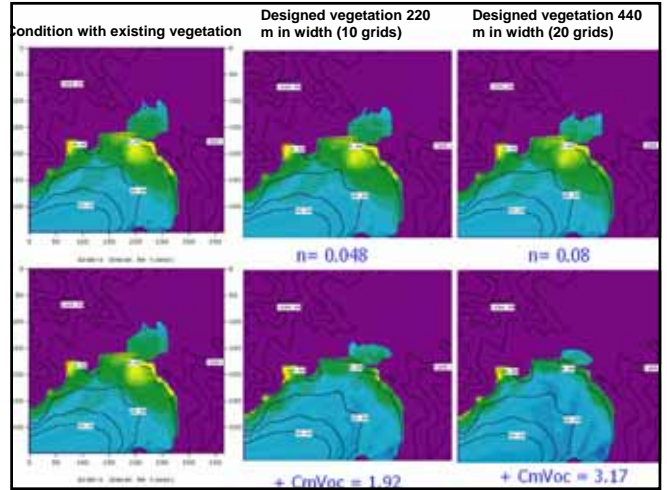
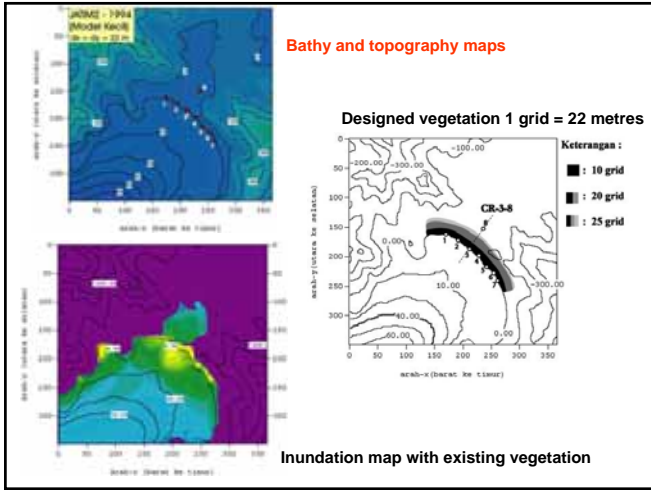
Initial waves profiles from CPX4 Model (Latief & Imamura, 1998) as historical elevation: at point 1,2,3 (in the bay)

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



5.2 Bandialit Bay





6. Conclusions

- 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.
- Vegetation (mangrove and coastal forest) can be used as a greenbelt except coconut trees.
- 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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