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Assessing the Possibility of Implementing Mangrove Forest as Natural Fortress for Indonesian Coasts Due to Hazardous Tsunami Impacts : A Preliminary Study

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ABSTRACT

Villages at Indonesian coast have extremely terrible records of vanishing due to tsunamis impact. Many casualties have occurred and more to go if there are none preventing systems to be implemented specially. There are many preventing and warning systems due to tsunamis impact that can be implemented in Indonesian coasts. One of them is Natural Fortress, which is containing plants that have strong and reliable physical body due to absorbed and diffracted incidental big waves. Mangrove Forest which almost widely spread in coasts of the Indonesian Archipelago gives an alternative solution as Natural Fortress, to make sure this hazardous event make more less casualties then before.

Keywords: Tsunamis, Mangrove Forest, Natural Fortress

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1. TSUNAMIS HISTORY AND ZONING IN INDONESIA AND IN THE PACIFIC

Tsunami, as a word, is now generally used to describe huge waves generated by some earth shocking, by means of underwater quakes. But that is not fully true; cause there was 525m tsunami hits Alaska in 1958, which generated by landslides.

Tsunamis had been reported since ancient times, especially in Japan and Mediterranean seas. The first tsunami ever recorded was at coast of Syria in 2000BC. For Indonesia, as a region, which experience a lot of big earthquakes during last four hundred years, had been 105 times struck by tsunamis. Recently it becomes more intense, especially at southeast of Java and Sumatra; Malucca Sea and northern Papua [1]. According to Dr. George Pararas-Carayannis, former Director of the International Tsunami Information Center, there are several big tsunamis hits Indonesian Archipelago between 2000 – 40BC. But they were generated by meteor or comets impact near Australia or Pacific Ocean. He said also that one gigantic tsunami was flooding the whole Java and it produced Bali and Madura.

National Geophysical Data Center (NGDC, Colorado), have made tsunamis zoning in the Pacific (Table 1). Latief et al [2] at DCRC Tohoku University, successively made Tsunami Catalog and Zoning (Figure 1). The zones are;

- Zone A: West Sunda Arc
- Zone B: East Sunda Arc
- Zone C: Banda Arc

- Zone D: Makassar Strait
- Zone E: Malucca Sea
- Zone F: North Papua

Table 1. Names and boundaries of Tsunami Zones in the Pacific [3]

No	Name of Zone	Zone Boundaries	
1	Alaska & US West Coast	35° N - 63° N	167° E - 112° W
2	Central America	7° N - 35° N	127° W - 75° W
3	South America	58° S - 7° N	100° W - 60° W
4	New Zealand / Tonga	57° S - 11° S	160° E - 166° W
5	New Guinea / Solomon Isl.	11° S - 5° N	130° E - 165° E
6	Indonesia	11° S - 11° N	92° E - 130° E
7	Philippines	5° N - 28° N	104° E - 134° E
8	Japan	21° N - 48° N	114° E - 156° E
9	Kuril – Kamchatka	40° N - 63° N	131° E - 167° E
10	Hawaii	15° N - 35° N	171° E - 145° W

These zones have experienced tsunamis not only generated by earthquake but also by volcanoes activity and landslides. But 90% of them were generated by earthquake. It means that the corresponding vault line; which are Sunda Arc, Banda Arc, Timor Through, Makassar Strait Basin, Malucca Sea and Caroline Plate at northern Papua; are potential areas of generating tsunamis. This also means that regions or cities or villages or coasts near those areas are very much in danger of tsunamis. Latief et al [2] also had made a simple estimation of tsunami recurrences in every zones using linier regression analysis (Table 2).

Table 2. Reoccurrences Estimation of Earthquake and Tsunami at each respective zone [2].

ZONE	Reoccurrences Estimation (years)	
	Earthquake	Tsunami
A	5 – 6	±15
B	2 – 3	10 – 15
C	9 – 10	10 – 12
D	± 20	15 – 20
E	8 – 10	± 10
F	10 – 15	-

Explicitly, Latief's estimation give so called "promise" that tsunamis in the Indonesian Archipelago can reoccurred at the same particular region from 10 to 20 years. But unfortunately it also means that more life could

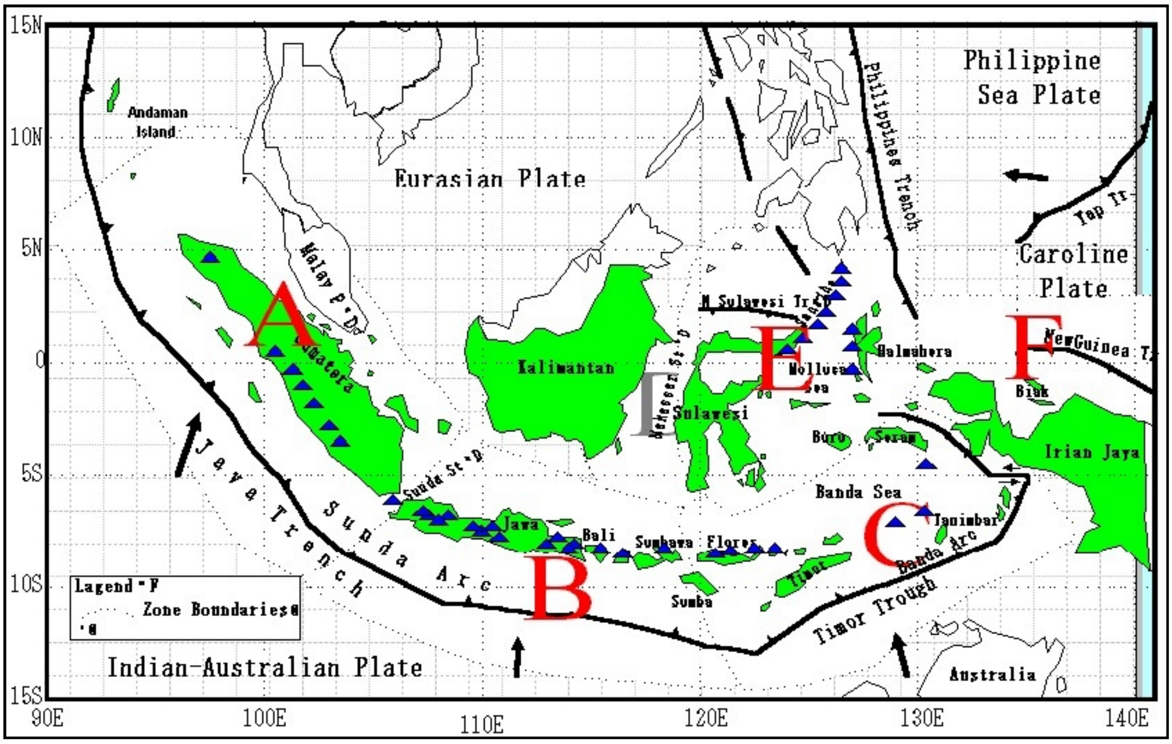

Figure 1. Tsunami Zoning in Indonesian Archipelago [2]

be lost if there are no preventing act due to the hazards.

In Japan and Hawaii, there are tools that can predict how fast tsunamis hits the coasts after the shocks. But unfortunately it will be more expensive if the preventing area becomes as big as Indonesian Archipelago, because the tools are using satellite network that will covered the whole area and have to have a very good connection with all the gauge and tide recorder that spread in the entire sea at some distance. If the Government does not realize how important these tools are, maybe it would take 10 to 20 years for them to see that all the estimation can be correct at all. And that means, more life will have to suffer.

2. TSUNAMI IN DETAILS

A. Terminology, Causes and Example

“Tsunami” is a Japanese word meaning harbor wave. It is now used to describe gravity waves in water bodies mainly due to earthquakes or events connected with them (e.g. landslides) and to volcanic island explosions or man made nuclear explosions. In the past these were called “tidal waves,” which is incorrect because tsunamis are not caused by tides. Another widely used term is “seismic sea waves,” but this excludes gravity waves due to the volcanic island eruptions and man-made nuclear explosions. Van Dorn [4] gave one definition; “Tsunami is the Japanese name for the gravity wave system formed in the sea following any large scale, short duration disturbance of the free surface.” By this definition, storm surges (wind tides) and the seiches associated with them are excluded.

Tsunamis are primarily created by disturbances in the crust of the earth underlying bodies of water, and the resulting uplifting of the water surface over a large area, which forms a train of very long-period waves. They may have periods exceeding one hour, in contrast to normally occurring wind-generated sea wave, which have periods less, then one minute. When volcanic activity or landslides generate tsunamis, the wave energy tends to spread along the wave crests and the tsunamis affect mainly the areas near their shock [5].

The best example of volcanic-generated tsunami is the tsunami in Sunda Strait (between Java and Sumatera), caused by eruption of the volcanic island Krakatau on Aug. 27,1883. As for landslides-generated tsunami, the best example is the Lituya Bay Tsunami on July 9, 1958; when part of a mountain broke (following an earthquake) and fell into the bay, and the water splashed to a height of about 500m.

B. Properties of Tsunami Waves

Tsunamis fall under the general classification of long waves. Length of the waves is of the order of several hundred kilometers, although their amplitude over the deeper part of the oceans is usually of the order of a meter. Hence, it is difficult to detect them either from the air or from ships. The waves travel with a speed proportional to the square root of the water depth. In the deep ocean their speed can be several hundred km/h.

As the tsunami waves enter the continental shelf, they slow down considerably, but wave height increases. The arrival of a tsunami is sometimes indicated by a withdrawal of water, which might be preceded by short-period, low-amplitude oscillations, known as forerunners. A tsunami consists of a series of waves that approaches the coast with periods usually ranging from 5 to 90min. The wave of greatest height is nor usually the first, but mostly occurs among the first 10 or so. The main tsunami waves are followed by secondary undulations that are mainly due to resonance effects in the bays that receive energy input from the main tsunami waves. Sometimes these secondary oscillations are also referred to as tsunami coda.

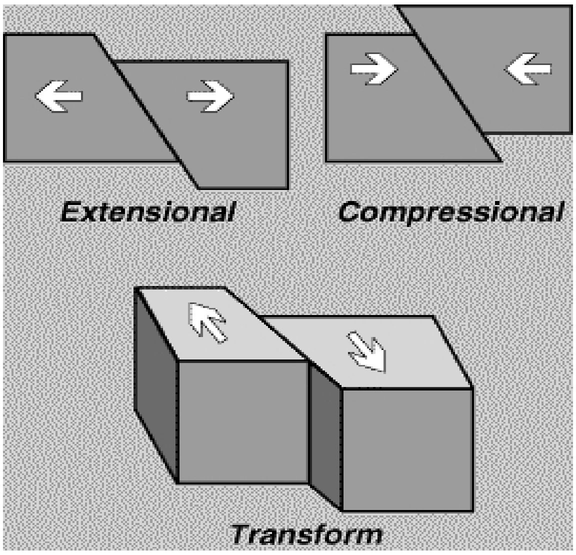

Figure 2. Movement along Fault lines (NOAA, 1996)

Heck [6] indicates that horizontal motion of the sea floor, so called transform, does not appear to generate large tsunamis. However, large “local” tsunamis may be generated by horizontal motion (Figure 2). Iida [7] shows that major tsunamis (those that cause high water levels at many different coastal locations) do not appear to occur as the result of deep-focus earthquake or the strike-slip fault type, i.e., horizontal motion along the fault line.

Tsunamis with volcanic origins have the characteristics of waves generated from a small source area. These waves spread geometrically and do not cause large wave run-up at location distant from the source, but may cause very large waves near the source.

In case of landslides as a cause of tsunami, the waves generated will spread geometrically as they propagate from their source in an open ocean, but it can be very high near their origin. Waves can be particularly high if they occur in a confined inlet, or if resonant or refraction effect exist.

C. Tsunamis Hazarding Coasts

As a tsunami approaches a coastline, the various offshore and coastal features modify the waves. Submerged ridges and reefs, continental shelves, headlands, various shaped bays, and the steepness of the beach slop may modify the wave period and the wave height, cause wave resonance, reflect wave energy, and cause the waves to form bores which surge onto the shoreline (Figure 3). When the tsunami energy becomes trapped between a caustic and a coastline, the energy will tend to propagate along the coastline. This will excite long shore edge waves along the coastline and may substantially increase observed wave heights. When the coastline is irregular, the trapped waves may concentrate their energy at particular coastal points.

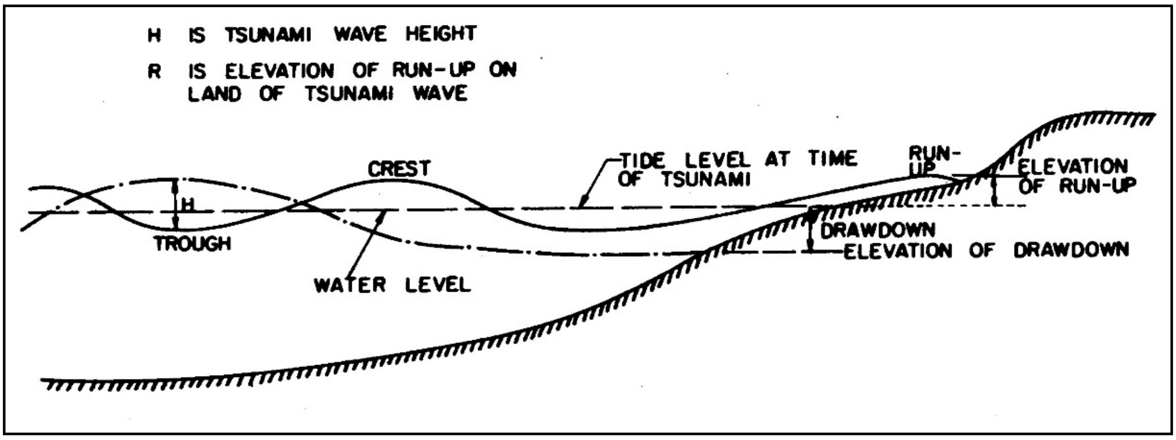

Figure 3. The illustration of tsunami wave height and run-up elevation [Wiegel, 1970]

The arrival of a tsunami at a shoreline may cause an increase in water level as much as 30m or greater in an extreme case. Increases of 10m are not common. The large increase in water level, combined with the surge of the tsunami, can impose powerful forces on shore protection structures located near the shoreline. Structures may be seriously damaged or destroyed by the tsunami. Damage may be caused by strong currents produced by waves overtopping the structures, by the direct force of the surge produced by a wave, by the hydrostatic pressure created by flooding behind a structure combined with the loss of equalizing forces at the front of a structure due to extreme draw down of the water level when the waves recede, and by erosion at the base of the structure. Major damage may also be caused by debris carried forward by the tsunami in the near shore area [9].

3. TSUNAMIS PREVENTING SYSTEMS

Due to the danger of tsunamis impact to the lives community in the coast area, nature and people so called design many systems to prevent casualties. There are three major types of tsunami preventing systems. They are;

- Electronics / Satellites
- Caustics (traditional)
- Natural Fortress

A. Electronics / Satellites

For more than a decade, a warning system has been conducted using electronics devices and satellites. For example, after the Aleutian Tsunami in 1946, ITIC made a big contribution by introducing the first electronic warning system. This system was based on a network of many detectors, which triggered by gauge or strong motions of seabed or water bodies. So if an earthquake occurs, the gauge recorder will tremble parallel to the shock and then automatically transmitted by a transmitter that locks on the gauge recorder. The information than translated to a leveling tools, which automatically announced how big the shock were. Relying on the data shock, the authority than can make decisions due to the evacuations of people near the coasts [10].

Unfortunately, this system can only be built and implanted in big area such as Indonesian Archipelago with a very expensive budget. That’s way only big countries have implanted this kind of system, they are; Japan, US and Russian.

B. Caustics (traditional)

Long before Haas [8] separates tsunamis into four types (Table 3), people in a couple of fisherman villages at Polmas district, South Sulawesi, Indonesia, have a strong believes that if the land shocks the coconut tree until the coconut fell in the ground, it means that they have to drag their boats for 50 to 100m from the shoreline, cause that area will be flooded by waves from the sea.

Table 3. Typology of Tsunami Events [8]

Tsunami Type	Physical Clues	Approximate time For evacuation	Maximum Credible Preventive Action
I	Visible slumping or sliding	Less then 1 minute	Almost none
II	Severe Earth temblors	5 to 10 minutes	Ambulatory persons can be evacuated
III	Noticeable Earth shocks	15 to 30 minutes	Some persons can be evacuated
IV	None	45 minutes to 12 hours	Most persons can be evacuated and up to 75% of all movable properties

C. Natural Fortress

Coral reefs are commonly known as regular wave absorber [11], but there are facts that they can be as useful as breakwaters. In some earthquake-experienced coast in Philippines Archipelago, there are many cases involving coral reefs as natural breakwaters protecting the coasts from tsunamis.

Palm and Coconut trees, so called Palm Forest, in some instances may offer some protection against a tsunami surge. Groves of trees alone or as supplements to shore protection structures may dissipate tsunami energy and reduce surge height. Groves of coconut palms may withstand a tsunami surge but may be sheared off by debris carried forward by the tsunami; other types of trees may be easily uprooted and flattened.

Matuo [12] calculated that trees could be broken by water velocities of 2m/s or greater, but did not analyze specific types of trees. He indicated that trees broken off by higher velocity might add debris to the surge and increase the damages resulting from the surge.

4. MANGROVE FOREST

A. Terminology

The word Mangrove is derived from a combination of Portuguese word for tree (**mangue**) and the English word for a stand of trees (**grove**) [13] The term is ecological and is used to include both shrubs and trees that occur in the intertidal and shallow subtidal zones of tropical and subtropical tidal marshes (Figure 4).

Figure 4. Example of Mangrove Forest [13]

Mangrove Forest contains more than one species of plants. In Indonesia there are 7 common Genera of mangroves plant, i.e., *Rhizopora* spp, Avicennia spp, *Sonneratia* spp, *Bruguiera* spp, *Xylocarpus* spp, *Ceriops* spp and *Exoecaria* spp.

Mangroves are usually found in saline lagoons. They occur most commonly in estuaries such as those produced by tropical rivers. Mangroves are shallow rooted and lack well-developed taproots as a result of the high salt concentrations as well as the water-saturated, organically rich anaerobic substratum [11].

B. *Morphological Adaptations*

Dawes [13] pointed out that most mangroves have adapted to their environment due to:

a. Development of mechanical adaptation for attachment in soft and loose substrata. There are two types of roots, for anchoring (it develops a thick protective cork layer and grows into the anaerobic substratum) and for feeding. The latter are small, temporary horizontal fibrous roots that have root hairs
b. Formation of respiratory roots and aerating devices
c. Evolution of vivipary. It means that the embryo initiates germination from the seed while still on the tree. It is considered of special importance since the developing radicle and hypocotyls can respond more rapidly by anchoring in a substratum when washed ashore. In some species (*Rhizophora* spp), the radicle sinks directly into the mud after falling from the tree.
d. Use of specialized means for seeds dispersal. The dispersal properties of the mangrove propagules have been correlated with mangrove zonation.

C. *Ecological Roles*

There are four major roles of mangrove swamps [11, 13];

a. Mangroves aid soil formation by trapping debris
b. Mangroves filter land runoff as well as removing terrestrial organic matter
c. Mangrove serves as habitats for many species of small fishes, invertebrates and various epiflora and epifauna
d. Mangroves are major producers of detritus that will contribute to offshore productivity

D. *Possibility of Implementing Mangrove Forest As Natural Fortress*

For staying alive, mangrove needs a quite coast, a lot of fresh waters and mud. There are 5 basic requirements for extensive development of mangrove forests.

a. Tropical temperatures. The average temperatures of the coldest should be higher than 20°C with seasonal temperature range not exceed 5°C

b. Fine-grained alluvium. The most extensive stands of mangrove occur along deltaic costs or in estuaries where soft mud consisting of fine silt, clay and organic matter is available for seedling development
c. Shores free of strong wave and tidal actions
d. Salt water
e. Large tidal range is important because with a gentle gradient of the sub-stratum will not erode during tidal change.

These unfortunate needs, had make the spreading of the Mangrove forest through the entire archipelago not too wide (Figure 5). This also means that the possibility of implementing it as natural fortress due to the hazardous tsunami had been decreases. But with the help of researches in *Bioengineering* field, maybe the unfortunate needs can be reduced so the possibility of implementing Mangrove forest as natural fortress for Indonesian coasts due to hazardous Tsunami impact, can be increased. This physical of Mangrove will be more effective to absorb and diffract waves larger than its self; maybe even more effective than palm trees.

The physical of Mangrove, both as individual plant and as forest, give alternative ways to absorb and diffract incidental waves such as tsunamis surge.

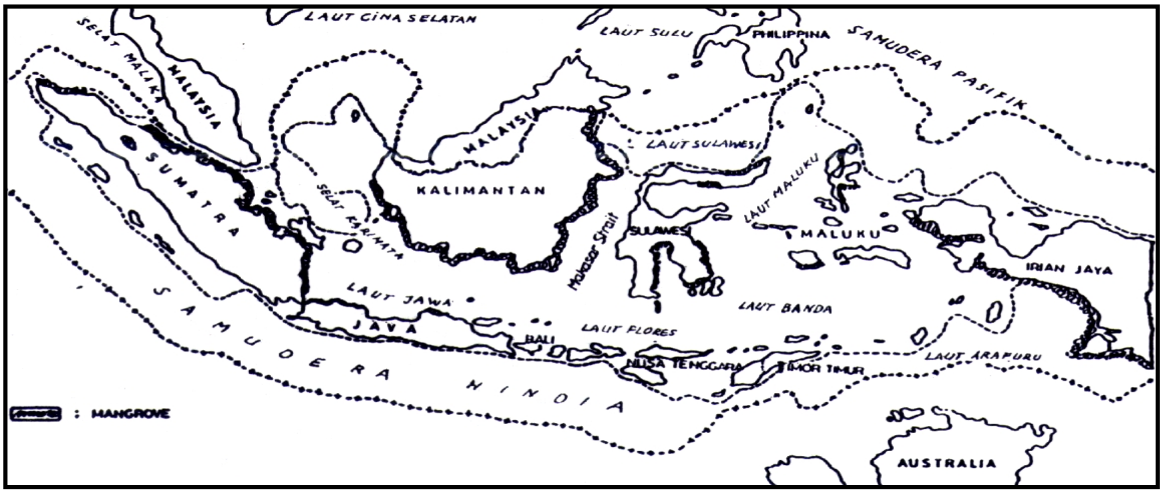

Figure 5. Spreading of Mangrove Forest in Indonesian Coasts [14]

F. CONCLUSION

Corresponding to the natural physical of Mangrove, implementing Mangrove forest, as natural fortress due to tsunamis surge in the coasts is more than possible if Mangrove, as an individual plant, can be so called “reassign” by bio-engineered technologies to become more flexible; such as can live in area with bigger waves, little support of fresh water and mud.

But that also means a lot of work have to be done in many fields, i.e., bioengineering for finding a better Mangrove, Marine Hydrodynamic for finding the exact percentage value of absorbance and diffractions by Mangrove forest due to tsunamis surge, Marine Science and Geo-Physics for assessing land soils in the coasts that suits Mangrove forest, and last but not least Agriculture and Forestry for finding planting systems which in the future can produced a thicker Mangrove forest.

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