THE CORRELATION BETWEEN TSUNAMI RUN-UP HEIGHT AND COASTAL CHARACTERISTICS INDEX OF PHANG NGA AND PHUKET PROVINCES, THAILAND

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ABSTRACT

By introducing Coastal Characteristics Index (CCI), data of coastal characteristics were used to understand the behavior of run-up distribution long the coast. By using SPSS software the correlation between the run-up height and CCI were found to good. After run the TUNAMI-F1 code model for far field tsunami and TUNAMI-N2 for near field of M 8.5 event from Sumatra and Nicobar island, we can obtain tsunami travel time of 1 hour and 40 minute to Khao Lak, maximum inundation height is 12.4 m, maximum wave flow inundation is 10.5 m, maximum flow velocity near shore of 20 m/s, hydraulic force of 4190 m^3/s^2, and average inundation distance of 700 m from the shoreline. The tsunami hazard map of Khao Lak was created by adding these results.

Keywords: Tsunami travel time, Coastal characteristics index, Inundation, Flow velocity, Hazard map

INTRODUCTION

The Indian Ocean Tsunami, which occurred on 26 December 2004, affected many countries around the Indian Ocean. The report of deaths in Thailand, total casualties in six provinces along the Andaman coast are approximately 5,395 with 8,457 injured and 2,932 still missing (DPM: Department of Disaster Prevention and Mitigation). The most severe tragedy occurred in Khoa Lak and Phuket province, Thailand. When deep sea tsunami rushes to shore, due to bathymetry and topography, run-up height and inundation on each region are different from each other and the cause of damages is also different. Collection of all data concerning inundation and run-up height and analysis to find out correlation between these information and some coastal characteristics are very important for future plan on tsunami countermeasures.

We can simulate this phenomenal many times by using TUNAMI code (Goto et al., 1997; Imamura et al., 2006) with initial data such as bathymetry, fault parameters, the result that we obtain will be the same. Realistic event, even though the earthquake event, occur in same place and same magnitude also generated tsunami but the affected of this event will not be same because of the characteristics of coastal areas.

In order to create hazard map of tsunami we need to obtain tsunami information. Some of information such as flow velocity, inundation height and tsunami ray path direction etc. We couldn't measure directly, the simulation model technique is useful for this case.

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METHODOLOGY

Source model

The most credible earthquake to be prepared for along the Sunda-Andaman arc, which could affect Thailand, might occur within the next 50–100 years, and an earthquake of magnitude 8.5 is expected to occur with more spatial and temporal irregularity than the megathrust events (Løvholt et al., 2006).

We can use fault parameter near Nicobar Island by using empirical equation from Wells et al. (1994) as follows:

$$M = LogA + 3.95 \qquad (1)$$

where A: rupture area, M: moment magnitude, Hank and Kanamori (1979) is given by:

$$M = \frac{2}{3} LogM_0 - 10.7 \qquad (2)$$

while M_0 is seismic moment which, can be found out by the equation as follows:

$$M_0 = \mu A u \qquad (3)$$

where μ is shear modulus or modulus of rigidity, A is fault area, and u is the average displacement on fault.

Fault parameters can be calculated as Table 1, we assumed the earthquake magnitude of 8.5 as the conclusion of Løvholt et al. (2006) and used these fault parameters as initial data for TUNAMI-F1 and N2 code model.

Table 1 Fault parameters for F1-model and N2 -model for Sumatra subduction Zone

Depth of fault top edge (km)	Fault Length (km)	Fault Width (km)	Slip Amount (m)	Strike Angle (deg.)	Dip Angle (deg.)	Slip Angle (deg.)
10	340	170	11	323	15	90

Tsunami code

Before we run model, we have to decide time step depending on grid size by checking stability CFL condition as follow.

$$dt \le \frac{dx}{\sqrt{2gh_{max}}} \qquad (4)$$

where dt = time step, dx = grid size and h_{max} = maximum water depth.

Then, after we run model TUNAMI-F1, we can obtain tsunami propagation and arriving time. After tsunami wave propagates to near shore, we have to run TUNAMI-N2 which includes bottom friction and continue operation until wave inundates the land for modeling of near-field.

By using this model, we obtained the result of inundation area of Khao Lak, Pang-Nga and Phuket province.

Bathymetric data were obtained with 1 minute mesh resolution, and time step is 1 second up to 18,000 seconds (5 hours) to run F1 model region 1. For the other regions we used, data from Dr. A. Reungrasamee., which was digitize from the map from the Royal Thai navy detail of grid size and study area as shown in Table 2 also time step is 0.8 second up to 5 hours.

CCI (Coastal Characteristics Index)

Base on the hypothesis, the energy of tsunami will be reducing by friction which occurred along the ray path of tsunami wave propagation. When tsunami wave reach to shoreline and inundated coastal area all infrastructure, properties and land used are also play role as huge friction to tsunami wave. Then if we assemble all of these frictions together and create some equation as index to show the coastal characteristics, as we mention before that tsunami run-up height in different coastal areas are difference. If it have some correlation between run-up height and this index may be we can roughly estimated how high of tsunami run-up and inundation in the future. Firstly I set up the coastal characteristics index equation by assemble all frictions together as follow.

The Coastal Characteristics Index (CCI) formula as shown in below was created and a field survey data also included obtained CCI values.

$$CCI = \frac{\theta}{90} + \varphi + (W * L + B)/1000 \qquad (5)$$

where θ average angle slope of the beach on affected area (flat plain = 0, perpendicular to mean sea level = 90), W the wideness of mangrove or seaside forest perpendicula to shoreline, L the lenght of mangrove or seaside forest long pararell with shoreline (W*L = the amount of mangrove per km^2), B total length of building or some properties within 1 kilometer along the coast area, φ = Structure or shape of the shore (0 for shape like convergence valley, 1 for small slope or low steepness and 2 for high slope).

Table 2 Detailed grid size of studying areas (Source: A. Reungrasamee, Chulalongkorn Univ.)

Region No.	Grid Size		Latitude (N)		Longitude (E)		Bathymetry file name	No. of Grid		Number of Grid on Upper Region			
			from	to	from	to				Start		End	
	m	s	d-m-s	d-m-s	d-m-s	d-m-s		X	Y	X	Y	X	Y
1	2	0	2-00-00	18-00-00	90-00-00	100-00-00	region1	300	480	-	-	-	-
2	-	15	5-59-45	9-30-00	95-59-45	99-00-00	region2	721	841	181	121	270	225
3	-	5	8-32-25	9-11-31	97-26-55	98-20-00	region3_kl	637	469	350	612	561	767
4	-	1.67	8-36-58.33	8-50-00	98-00-08.33	98-18-00	region4_kl	643	469	400	56	613	211

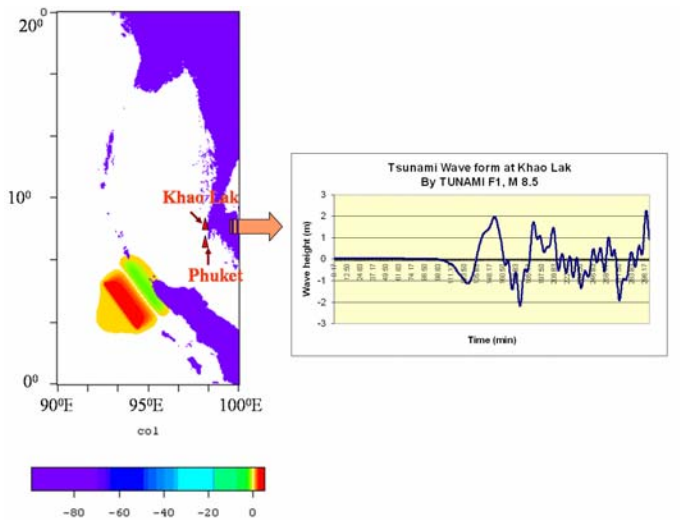

Figure 1 Tsunami source for F1-model (M 8.5) and the tsunami wave form at Khoa Lak.

RESULT AND DISSCUSSION

The initial sea surface elevation used for this studied has shown as Figure 1. The initial sea surface displacement is copied from the bottom deformation. The delay of rupture along the fault is not including

(Løvholt et al. 2006). Simulation for tsunami with source between Sumatra and Nicobar Island with magnitude of 8.5 gives the traveling time from the source to Khao Lak coastline, which is 100 min or 1 hour and 40 min (Figure1) show that the first wave which comes to shoreline of Khao Lak, is a negative wave.

After we evaluate the accuracy of F1- model result and if it is satisfied, we can continue to N2 - model or inundation model next. From Figure 2 the maximum velocity occurring in the sea near shore is 20.04 m/s and maximum height of this tsunami is higher than that in Khao Lak areas. The highest is more than 12.35 m, while inundation height is 10.44 m. These results on arriving time of tsunami, velocity, inundation area, and inundation wave height and tsunami wave direction are important as parameters to create a hazard map. Finally, we can obtain the result of model for inundation areas of Khao Lak and Phuket areas as shown in Figure 2.

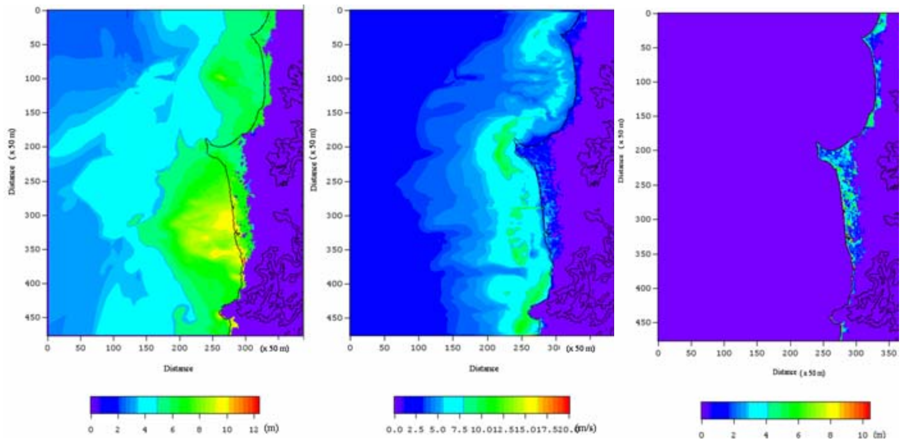

Figure 2 (Left) Maximum wave height of tsunami shows the highest of tsunami wave and inundation area at Khao Lak. (Middle) Velocity of tsunami wave. (Right) Inundation area of Khao lak shows maximum inundation height.

The correlation between run-up height and the coastal characteristics index

The correlation can be found out by using linear regression from SPSS software, and the result is shown below.

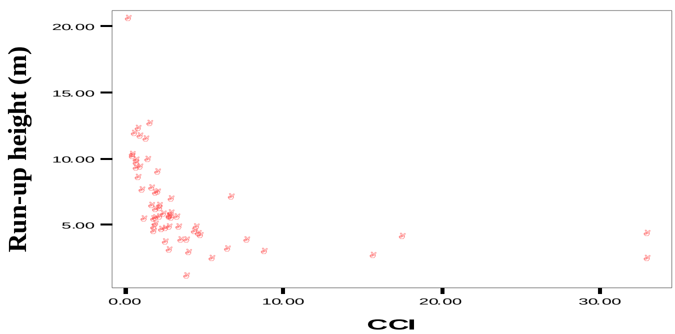

Figure 5 Scatter plot of CCI and Run-up height.

We found that Pearson correlation co-efficient of run-up height and coastal characteristics index (CCI) is -0.378 that means it has correlation with negative way and equation of regression is

$$Y = -0.649X + 7.884. \qquad (6)$$

This equation can explain that if X changes 1 unit, it will cause Y value to change about -0.649 unit. The square of the correlation coefficient (R^2) = 0.143 means this regression equation can explain run-up height distribution is 14.3 % or the CCI affects run-up height by 14.3% with standard error 4.8991, which shows small error or on the other hand, this regression equation is highly credible.

When we use ANOVA test, F has significant level 0.05 and degree of freedom 1 and 84 is 4.00, while F value from calculation = 24.096. That means calculation value is greater than F value obtained from critical table, and calculation value of F is under critical. That means "CCI and run-up height have a significant correlation together". If we find out F value by using significant level 0.01 and degree of freedom 1 and 84 equal to 7.08, while F value from calculation we obtained is 24.096, which means F value that we obtained from calculation is greater than the value from table, which means "There is a close correlation between run-up height and CCI". The result of the test is that at least one of the dependent variable (CCI) has significant correlation with independent (run-up).

Hazard Map of Khao Lak

As the result of the TUNAMI-N2 model, all information that we obtained can be used to create tsunami hazard map of Khao Lak area as showns in Figure 6.

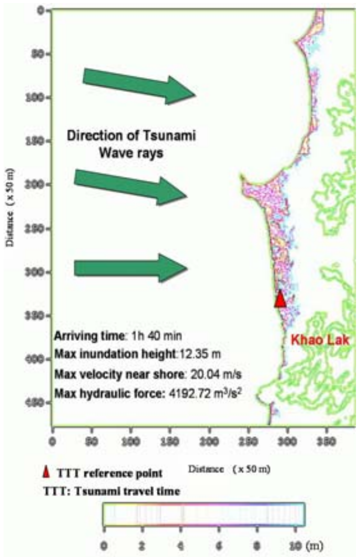

Figure 6 Hazard map of Khao Lak, Pang-Nga Province.

CONCLUSIONS

The Coastal Characteristics Index (CCI) is an equation to obtain index values by using all important parameters in a coastal area and correlate with the run-up height obtained from the field survey.

Run-up height had negative correlation with coastal characteristics index (CCI). Mangrove forest is the most important parameter in the CCI to reduce energy of tsunami run-up height.

Simulation for tsunami with source between Sumatra and Nicobar Island with magnitude of 8.5 gives the traveling time from the source to Khao Lak coastline, which is 100 min or 1 hour and 40 min. The maximum velocity occurring in the sea near shore is 20.04 m/s. The highest is more than 12.35 meters, while inundation height is 10.44 m. Inundation distances are extended a maximum of about 2.5 km far from coastline of Pakarang cape and an average of about 700 m from shoreline.

We could create a hazard map by using intensity of tsunami run-up height, tsunami direction wave ray, arriving time, velocity, hydraulic force and maximum inundation wave height.

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