Comparison Among the Proposed Models for the 2004 Indian Ocean Tsunami

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1. Introduction: Although it passed 3 years since the 2004 Indian Ocean tsunami generated by the earthquake with more than M_w 9.2 caused devastating damage and a large number of researches and studies have been carried out to explain the tsunami source mechanisms, there are so many proposals of its source model by using several available data; seismic observation, crustal movement, tsunami runup and tidal records at the stations, which is still under discussion. As the previous major events like this, we have the difficulty to determine the best among all from all aspects. Thus, we should propose reasonable selection of the source model with a specific purpose in a targeting area.

2. Objectives: We discuss the source model to reproduce/estimate the damage to Thailand's perspective focused in the coastal area of Andaman, by using the tidal records and runup data. First is to review an existing tsunami source model as an input for a tsunami numerical simulation. Then we perform the far-field tsunami numerical simulation to obtain the required parameters from the numerical model results namely, maximum wave height, arrival time and wave period. Lastly, justify the most suitable existing tsunami source model for the tsunami damage assessment and mitigation in Thailand or modify the existing model if necessary.

3. Methodology: The 8 tsunami source models were selected to perform the 2004 Indian Ocean far-field tsunami to Thailand. The number of subsegment varies from 2 up to 22. The initial condition is calculated by the model proposed by Mansinha and Smylie (1971). Far-field tsunami numerical model is performed using the TUNAMI Code which was developed by the Disaster Control Research Center (DCRC). The model is based on the linear-long wave theory in a spherical coordinates with neglecting the bottom friction term. Three seconds temporal grid size is used to satisfy with the numerical stability condition.

4. Results: Simulation results of the maximum wave height in the computational region, from Kowalik et al, NOAA, Watts et al, DCRC, Tanioka et al, Hirata et al, Piatanesi et al and Fujii et al are shown in Figure 1.

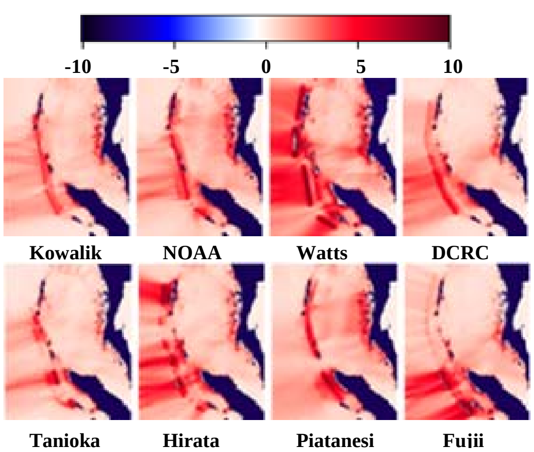

Figure 1 Maximum wave height

According to the wave height surveyed results leading by DPRI, Kyoto University, and tidal records from 2 agencies in Thailand, error computation and Root Mean Square Error (RMSE) regarding to the maximum wave height is shown in Table 1. The parameter 'K' proposed by Aida (1978) was used and described in equation (1) to (3).

Firstly, the amplitudes of the first and the second half cycles, a_1 and a_2, of the computed waves are compared with the observed records.

Given $$K_i = x_i / y_i \quad (1)$$

where, x_i and y_i are the observed and computed amplitudes of a_1 and a_2 respectively.

Then $$\log K = \frac{1}{n}\sum_{i=1}^{n} \log K_i \quad (2)$$

where, K is regarded as a correction factor to adjust the amplitudes of a_1 and a_2 computed for the model so as to fit the actual tsunami averaged over several stations. Finally, κ is defined as a measure of the fluctuation in K_i as follow.

$$\log\kappa = \sqrt{\left[\frac{1}{n}\sum_{i=1}^{n}(\log K_i)^2 - (\log K)^2\right]} \quad (3)$$

Computed K value and arrival time are shown in Table 2. Since our purpose is to reproduce/estimate the damage to Thailand's perspective focused in the coastal area of Andaman, parameters/index to discuss the suitable source model should be the maximum wave heights, arrival time, wave periods at stations; time history, and runup distribution in target area; maximum impact.

5. Discussion: DCRC's model has the outstanding maximum wave height results with the lowest RMSE and percent error. Tanioka's and Hirata's model were the most fit with the K values (the most nearly to 1). If the value of K is larger than 1, it can be inferred that the result of model's amplitude is smaller than the observed one. On the contrary, a reverse relationship will happen in case of the value of K is smaller than 1. Kowalik's model has the most minimum time different from the observed tide gauge. Only because the model itself was developed by the tsunami arrival time from the northwest, east and south tide gauges.

Initially, the models proposed by DCRC, Tanioka, Hirata and Fujii provide the proper maximum wave height results. Their depth, dislocation, dip and slip angle of each model segment that directly affect to the targeting areas were compared. We finalized those parameter as depth equal 10 km, dislocation equal 10 m, dip and slip angle equal 10 and 100 degree respectively.

As the affecting segment DCRC and Hirata's model was located at the same longitude (92.88^{o}E) resulting too slow arrival time at a coast in Thailand. Whereas, Tanioka's model resulted too fast arrival time at longitude 93.80^{o}E. By the way, Kowalik's model which was located at longitude 93.30^{o}E provided the most appropriate arrival time.

The first attempt was to apply those adjusted parameter to the affecting segment only. The second attempt was to apply to all subsegments and move further to the East. The final attempt was to apply only to the affecting segment at the same time move further to the East. The re-computed maximum wave height implied that the modification provided nearly the same results for the most case. However, much improvement was obtained when compared to the tide gauge data. Even all of the modification could improve the arrival time. Nonetheless, DCRC#1 had much clearly reduced the wave amplitude in Tarutao station while the other remained nearly the same.

Finally, the modified DCRC#1 provided the most acceptable result as a validation of the concerning perspective. Moreover, modification was also simply done with Hirata's model as having similar fault parameter to the DCRC's model. The longitude of all the subsegments were moved 0.43^o eastward. Satisfied value of K as high as 1.02 was obtained.

Table 1 Comparison of maximum wave height

Source model	PhangNga, Thailand		Phuket, Thailand	
	RMSE (m)	Error (%)	RMSE (m)	Error (%)
Kowalik	2.70	26.80	5.12	83.74
NOAA	2.57	30.90	3.46	68.06
Watts	8.39	107.47	5.01	96.34
DCRC	1.17	12.54	0.93	14.22
Tanioka	3.84	39.81	2.29	38.48
Hirata	2.86	27.44	1.68	31.57
Piatanesi	3.53	40.87	4.31	74.52
Fujii	2.34	18.91	1.88	36.18
DCRC#1	1.34	11.67	0.99	15.58
Hirata#1	2.17	23.29	0.72	12.31

Table 2 Comparison of K value and arrival time (t, min)

Calculated parameters	a_1		a_2	
	K	t_{o-c}	K	t_{o-c}
Kowalik	0.49	4.00	0.46	10.25
NOAA	0.62	4.13	0.40	11.25
Watts	0.32	18.50	0.60	21.00
DCRC	0.60	11.88	0.60	16.63
Tanioka	1.48	5.38	1.43	4.38
Hirata	0.58	13.63	0.85	15.88
Piatanesi	0.55	6.38	0.48	12.13
Fujii	0.52	8.88	0.59	15.75
DCRC#1	0.66	7.38	0.75	14.63
Hirata#1	0.54	10.00	1.02	13.38

Tendency of an improvement in the calculated value of K can be seen for the first negative and the first positive tsunami wave consecutively. The value of K was getting better step by step from the first model was proposed in 2005 (K = 0.32) to the present model proposed in this study (K = 0.66). On the other hand, the more concern was focused on the propagating positive wave. Since Hirata's model provided a very good K value, thus the value was higher than those proposed in 2007. The value of K was finally improved as high as 1.02. It can be implied that the resulted tide gauge by the modified Hirata's model will provide almost exactly the same as the observed one.

6. Conclusions: Results from the simulation; wave height, arrival time and wave period were used as a tool in order to judge and modify those source models. Each model has its own benefit and drawback, based on the point of purpose. Therefore, DCRC's model was modified, as shown in Table 3, so as to improve the overall performance. The model was enhanced in the most view, K and arrival time, meanwhile, remained the same satisfied error of wave height. Nevertheless, this is the most suitable tsunami source model at present as Thailand's perspective. Near-field simulation with a finer grid including land area will help to improve the model results.

Table 3 Fault parameters of the modified DCRC's model

Fault Parameter	DCRC#1					
	Fault 1	Fault 2	Fault 3	Fault 4	Fault 5	Fault 6
Lat (^{0}N)	3.03	4.48	5.51	7.14	8.47	9.63
Long (^{0}E)	94.90	93.82	93.30	92.74	92.28	91.97
Strike (degree)	323	335	340	340	345	7
Dip (degree)	15	15	10	15	15	15
Slip (degree)	90	90	100	90	90	90
Length (km)	200	125	125	55	145	200
Width (km)	150	150	150	150	150	150
Dislocation (m)	14	12.6	10	11	7	7
Depth (km)	10	10	10	10	10	10

Near-field tsunami numerical model will conduct by using the modified source model from this study. Purpose is to compute for an inundation area in order to compare with the existing satellite images and runup height which will be used as a data to establish a fragility function for the damage assessment in Thailand based on the numerical results.

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