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A NUMERICAL SIMULATION OF THE 1994 EAST JAVA TSUNAMI, INDONESIA

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1. Introduction

On June 3, 1994 in early Friday morning at 01.17 AM local time (18.17 GMT on June 2) a large earthquake with moment magnitude Mw=7.6 occurred in the Indian Ocean. The epicenter was at S10.69, E113.13 or around 240 km from the southern nearest coast of East Java. The International Tsunami Survey Team (ITST) carried out the tsunami survey from June 20 to 26, 1994 and they reported results as shown in Fig.1 (Tsuji, 1995).

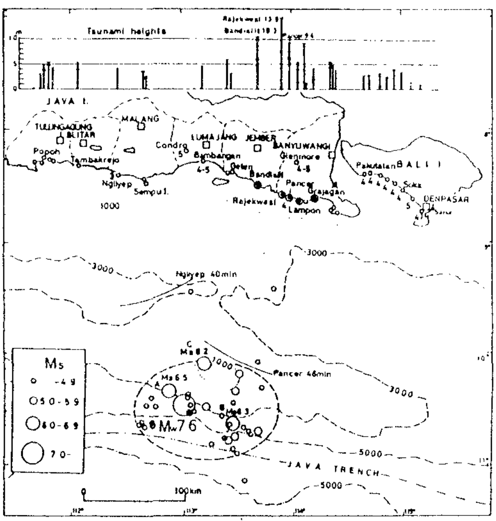

Fig. 1. Distribution of tsunami, and location of mean shock

Takahashi et. al. (1994) and Horiuchi (1995) numerically analyzed the tsunami using by the linear long wave model with spatial grid of 1800 m and 600 m respectively. They suggested that the magnitude of tsunami estimated by seismic information is much smaller than that observed along the coast, meaning the event belongs to "Tsunami earthquake".

In this study, for further analysis with more detail last information, we reexamine the source model by using different wave theory, complex fault, and more fine spatial grid.

2. Tsunami Source Model

The fault parameter of 80 km length x 40 km width and seismic moment of 3.5×10^{27} dyne-cm have been estimated from seismological analysis based upon Harvard CMT solution. Takahashi et al (1995) and Horiuchi (1995) proposed the fault model through comparison between measured and computed tsunami wave heights, which moment is larger than those by Harvard CMT as shown in Table-1. Recent geological survey has suggested a complex fault with steep and mild dippings as shown in Fig.2, generating a larger vertical dislocation of sea bottom. We therefore add a complex fault (CPX) model consisting of two neighboring fault which origins from an idea of a branch from a main fault to a sea bottom.

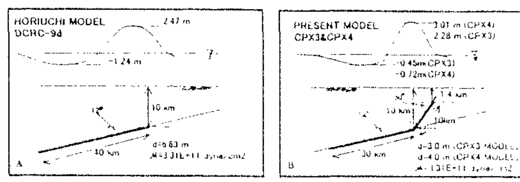

Fig.2 Fault model (a) Horiuchi, (b) Present model (CPX)

Table-1 Fault parameter

Model	Dep km	Str	Dip	Sip	Lgh km	Wid km	Dlc. m	Mo x10e27
Harvard	15	284°	12°	99°	80	40	3.31	3.5
DCRC4d	10	284°	12°	99°	160	40	9.93	21.0(6)
DCRC9d	10	284°	12°	99°	120	40	6.63	10.5(3)
Present (CPX3)	10 1.4	284° 284°	12° 60°	99° 99°	120 120	30 10	3.0 3.0	4.76 (1.36)
Present (CPX4)	10 1.4	284° 284°	12° 60°	99° 99°	120 120	30 10	4.0 4.0	6.36 (1.82)

3. Numerical Model

A two-dimensional hydrodynamics of the linear long waves and the shallow water (nonlinear) theories are used to simulate the tsunami propagation and runup. There are two equations: the depth-integrated continuity and momentum which are solved by the finite-difference method of staggered leap-frog scheme (Goto and Ogawa, 1982).

4. Study Domain and Model Condition

The nested computational region composing 3 different square spatial grids such as: large region (Java1 with 600 m), medium regions (Java2 and Jav4 with 200 m), and small regions (Java31, Java32, Java33 and Java5 with 67 m), as shown in Fig.3.

Time step is 0.5 sec, and reproduction time of 2 hour. The boundary conditions at the coast of the linear and the non-linear theories as vertical wall and runup respectively are used. The numerical simulations with two different grid systems and theories, and three different fault models shown in Table-2 are carried out. For the simulation of the linear theory, assumption of the minimum water depth (MWD) is introduced for numerical stability.

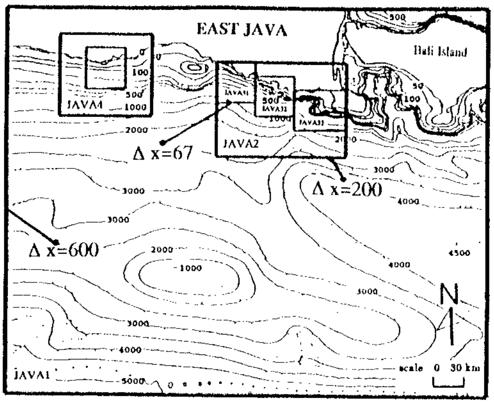

Fig.3 Model domain for nested computation

Table-2 Aida Number

Region	Theory	Model	Assumption	Aida K	Aida k
Large	Linear	DCRC-9d	Without	0.91	1.30
		DCRC-9d	With	1.35	1.36
	Non-Linear	DCRC-9d	None	0.81	1.26
		CPX3		1.43	1.30
		CPX4		1.07	1.33
Small	Linear	DCRC-9d	Without	Ov.flow	-
		DCRC-9d	With	1.85	1.52
	Non-Linear	DCRC-9d	None	0.94	1.35
		CPX3		1.58	1.38
		CPX4		1.18	1.31

5. Results and Discussions

The Aida's K and k are used to compare result among the models in order to know their reliability. It is indicated that the results simulated with a large grid size are generally smaller than those with a finer, effecting by complex geometry along the coast and shallow sea region. And the linear model without the assumption of MWD gives larger magnitude of tsunami heights and lead to the instability. That is why Takahashi et al.(1995) and Horiuchi (1995) of the linear model without MWD assumption showed the good agreement of the DCRC-9d model but present analysis with the nonlinear shows the result of DCRC-9d is larger than the measured.

Now the complex model (CPX) keeping the seismic momentum same as Harvard CMT is proposed. Through comparison of three models with the measured shown in Fig.3 and Table-2, the CPX4 shows the best agreement. It implies that the complex fault model can explain a discrepancy of momentum between tsunami wave measured and seismic wave recorded. The model of a complex fault should be limited for the case of shallowly dipping fault in a subduction zone and is not always applied to any fault. Although the CPX4 gives good agreement, at several locations such as G-Land and Tg. Purwa (Java33) where wide shallow water regions are existed the computed tsunami heights with CPX4 are smalled because of large effect of the friction in the computation.

Eyewitness in Pancer reported that the tsunami arrived at 02h 03m (46 min. after the main shock), while at Lampon and Grajagan the arrival time are around 43min. The computed result shows the first wave attacked the coastline variation of 38 min to 48 min after main shock, depend on distance of location. It is shows that arrival time was reported are still in range of computed arrival time.

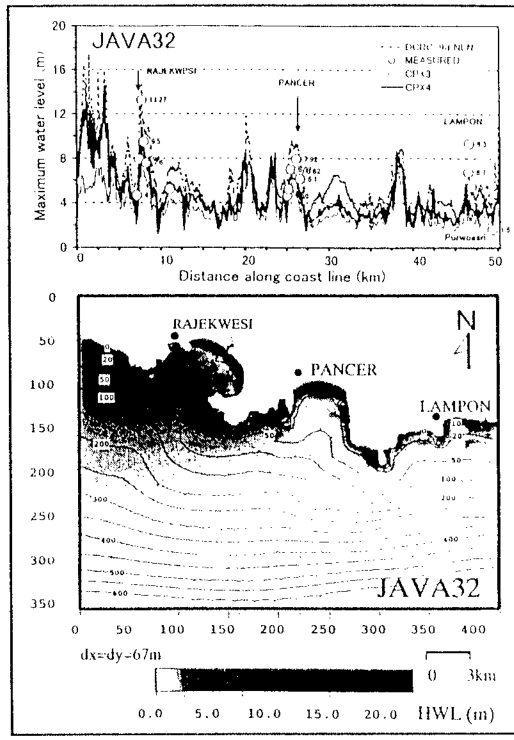

Fig. 4 Comparison between computed and measured (up) Distribution of max HWL after 120 min and sea bottom topography (down).

6. Conclusion

The CPX4 model gives rather good agreement and its magnitude is the same order of seismic one. The complex fault model can generate a large of wave height of initial source producing height runup at coast line. Finer grid size gives more accurate result and generally gives more height runup. The shallow water (nonlinear) equations could well simulated of the highest runup, however in the wide of shallow region the bottom friction more affected and damped the water discharge.

References

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