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The Tsunami Run-up Assesment of 1977 Sumba Earthquake in Kuta, Center of Lombok, Indonesia

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Abstract

A strong earthquake had been occurred on Friday, August 19th 1977 in Indonesia. The earthquake is known as Sumba Earthquake because originated at under the seabed south side of Sumba Island with magnitude Mw 8.3. The earthquake had triggered the tsunami wave, which is propagated toward south side of Sumba, Sumbawa, Lombok and Bali Island. Some post disaster field survey had been conducted immediately to assess the casualty and material losses of disaster. The information of this tsunami disaster is very limited due to the situation in that time. The access of some tsunami disaster locations are very difficult because the lack of transportation facility in that time especially in Lombok, Sumbawa and Sumba Island. This research attempts to conduct again the post tsunami field survey, especially in Kuta Lombok, in order to reveal the spatial distribution of tsunami run-up. The GPS technology was utilized in this survey when identified the height and position of tsunami run-up. Based on the field survey results, the run-up depth is about 1.5 m with the positions are almost close each other. The simulation results show that the tsunami time arrival is about 20~30 minutes. The result of run-up depth is acceptable compare with the field survey result, i.e. 1.6 m depth. The run-up of tsunami reaches about 300 ~ 800 m inland from the beach line. The run-up of tsunami occurs in the west area of Kuta Beach and the all area of Seger Beach.

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Keywords: tsunami; post field survey; Sumba Earthquake; Kuta Lombok

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1. Introduction

There is also another Kuta Beach in Lombok Island (east side of Bali Island) beside of Kuta Beach in Bali Island. It is located in south side of Center Lombok District, West Nusa Tenggara Province (see Fig.1). The Kuta Lombok also has beautiful scenery and attracts many tourists to visit. In the beginning only fishermen and their family live in this place, but since 1997 the tourism activity had been developed by establishment the tourism development centre and construction of star hotel in Kuta Lombok.

The Kuta Lombok ever has suffered the tsunami disaster in 1977. Nakamura[6] reported that a strong earthquake had been occurred on Friday, August 19th, 1977 at 14h 08m local time with magnitude Mw 8.3. The epicenter is located at 11.08^0 S and 118.46^0 E, in south of Sumba Island which it make the earthquake is known as Sumba Earthquake The earthquake triggered tsunami wave which hit the south coast of Bali, Lombok, Sumbawa and Sumba Island in Nusa Tenggara Archipelago.

Immediately after disaster, the field survey was conducted by the joint team between the International Tsunami Information Center (ITIC from Hawaii) and the Institute of Meteorology and Geophysics (IMG from Jakarta) from August 25th to September 7th , 1977 as reported by Nakamura[6]. The counted victims are 107 persons dead, 54 persons missing, 1,125 persons injured and all of them are from Lombok and Sumbawa. The total damage cost is about Rp.239,474,000,- in both islands.

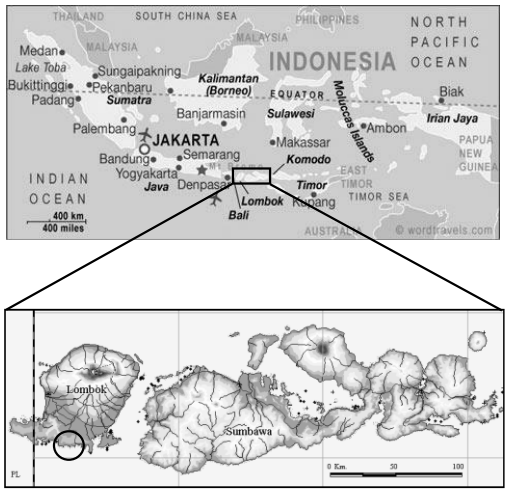

Fig. 1. Kuta Lombok Indonesia

Nomenclature

COMCOT	Cornell Multi-grid Coupled Tsunami Model
E	East
GPS	Global Positioning System
IMG	Institute of Meteorology and Geophysics
ITIC	International Tsunami Information Center
Rp	Rupiah
S	South

Kato and Tsuji[3] also conducted the field survey in October 1993. They collected and discussed the information from eyewitness about the tsunami magnitude, the explosion noise and the damage suffered. The numerical calculation was also performed to simulate the propagation of tsunami wave height from source area until the beach.

Gusman et al.[1] was also discussed the 1977 Sumba Earthquake and Tsunami. The numerical simulation was performed and validated by the recorded tide data at three locations in West Australia. The simulation of wave run-up at Lunyuk Sumbawa was also performed and validated by field survey data.

The 1977 survey, which was conducted by IMG and ITIC Joint Team, is correct and rapid action in order to record the trails and impacts of tsunami. However, the limitation condition in that time, such as the lack of transportation facility and the survey technology, restrict the data collection. The tsunami wave height is reported in average value, there is no spatial distribution of that information which is important in run-up analysis. The survey results of Kato and Tsuji[3] also have no much improvement in data quality, especially in wave run-up condition. This research attempts to conduct again the post tsunami field survey, especially in Kuta Lombok, in order to reveal the spatial distribution of tsunami run-up. The GPS technology was utilized in this survey when identified the height and position of tsunami run-up. The survey and topographic data were analyzed to assess the tsunami run-up distribution. The tsunami simulation was also performed to assess the tsunami time arrival and the tsunami run-up distribution. The simulation results were compared with the witness interview result during field survey.

2. Methodology

The survey method follows the Guideline of Post-Tsunami Survey Field from UNESCO-IOC[2]. The survey conducted eyewitness interview, who still alive, about their experience facing the incoming tsunami wave. The witness was chosen in age minimum 10 years old in 1977 considering their awareness to surrounding. The maximum age is 50 years old in 1977 considering their healthy in recent time (86 years old now). The survey also identified the inundation wave as directed by the witness. The position was recorded by GPS device and inundation depth measured by measuring tape. The data is combined with topographic map, which is published by the National Mapping Bureau (Bakosurtanal), for next analyzing step.

The numerical simulation was performed and compared with the survey data. The simulation result will give overview of tsunami inundation in that area. The Cornell Multi-grid Coupled Tsunami Model (COMCOT), which is developed by Professor Phillip L-F Liu from Cornell University (Liu et al.[5]), was utilized in the numerical simulation of this study. The COMCOT is open source and apply the long-wave equation or shallow water equation for simulating the propagation of tsunami from source until coastal area. The model has been used to investigate several historical tsunami events, such as the 1960 Chilean tsunami, the 1992 Flores tsunami (Liu et al.[4]), and more recently the 2004 Indian Ocean tsunami (Wang and Liu[7]).

COMCOT uses a modified leap-frog finite difference scheme to solve shallow water equations in a staggered finite difference nested grid system. The shallow water equations in Cartesian coordinate system are expressed as:

$$\frac{\partial \eta}{\partial t} + \left\{ \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} \right\} = 0 \tag{1}$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x}\left\{ \frac{P^2}{H} \right\} + \frac{\partial}{\partial y}\left\{ \frac{PQ}{H} \right\} + gH\frac{\partial \eta}{\partial x} + F_x - fQ = 0 \tag{2}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left\{ \frac{PQ}{H} \right\} + \frac{\partial}{\partial y}\left\{ \frac{Q^2}{H} \right\} + gH\frac{\partial \eta}{\partial y} + F_y + fP = 0 \tag{3}$$

where, η is water surface elevation, P and Q is the volume flux in X and Y direction respectively, H is the total water depth ($\eta + h$), h is the water depth, g is the gravitational acceleration, F_x and F_y represents the bottom friction in X and Y direction respectively, f is the Coriolis force coefficient.

3. Results

3.1. Site characteristics

The Kuta Lombok Beach is located at south side of Lombok Island Indonesia at coordinate 8^0 53' 27.73" S, 116^0 16' 37.26" E. As shown in Fig. 2.a, the Kuta Lombok Beach has bay shape about 3,000 m long, stretched from west to east and bounded by the hill. The beach consists of white spherical sand, which is result of coral reef abrasion. The bathymetric in front of beach is shallow in 2/3 east part, may dry during low tide, gentle about 800 m from beach line until sea end. The rest 1/3 west part is deep and become navigational pathways of fisherman boat going in-out the bay.

The topographic of coastal area is flat and gentle; stretch maximum about 2,000 m (west part) and minimum about 300 m (east part) from beach line to the land direction. The land is bordered by the line of hill in north side. The flat area is covered by tree in west part, but almost uncovered in middle and east part. There is flat tidal area in east side behind the star hotel. Two creeks are flowing out in west part and ones in flat tidal area of east part.

The people of Kuta Village (mostly fisherman) live centrally at west part between two creeks. They live cluster around this part because have deeper water area that make easy to go in-out the bay. Some people live in east side of second creek. Many tourism facilities such as hotel, souvenir shop, and travel office were built along the coastal line in middle part. Only one star hotel exists in east part.

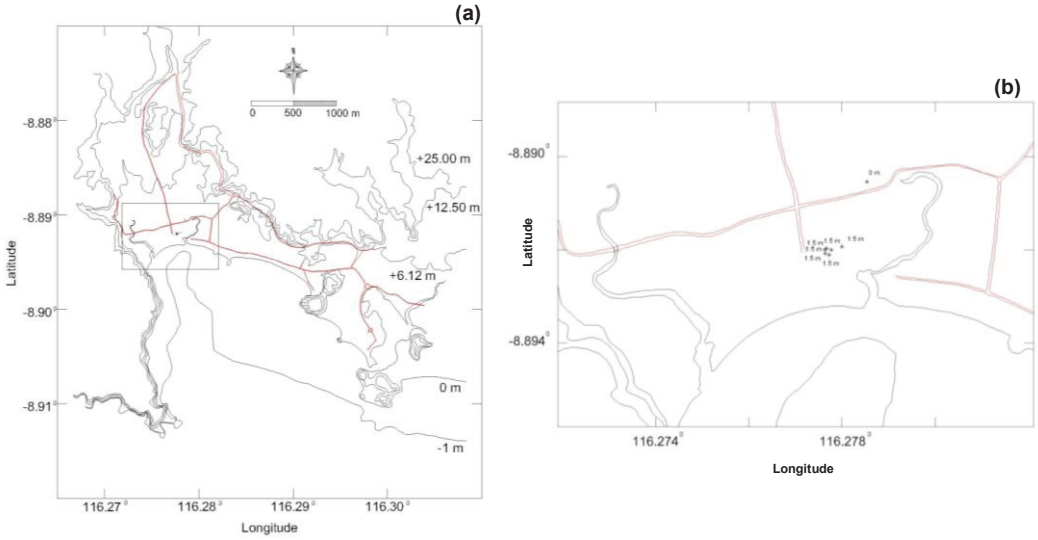

Fig. 2. (a) The characteristics of Kuta Beach; (b) The run-up depth based on field survey

3.2. Witness interview

The field survey was conducted on May 4th, 2013. There are only 7 person witnesses which can be interviewed, i.e. 5 men and 2 women. Their ages are minimum 57 (21 in 1977) and maximum 85 (49 in 1977) years old now. All witness still can communicate well even some person only capable by using local language. The witness was interviewed separately to avoid the influence of other witness. The materials of interview follow the guideline from UNESCO-IOC[2] and basically want to know their experience when the tsunami wave hit the village.

Among 7 person witnesses, one people did not directly saw and was not hit by the incoming tsunami wave. Two people saw but were not hit by the wave. Only four people were hit in condition, i.e.:

1. when run away to higher land
2. when come back to home for saving her daughter
3. when stayed at his home
4. when climbed the tree

All of last four people denoted 1.5 m of run-up depth based on their experience. They denoted same run-up depth because their positions are almost close each other as seen in Fig. 2.b.

Based on house damage, six witnesses reported the same run-up depth, i.e. was about 1.5 m, because the position of their houses are close each other. Only one witness's house was free of tsunami run-up and its position was far from the other. The village condition in 1977 is different with recent time. There were only about 20 families and their homes were clustered in one place. The house was mostly from wood and elevated about 1.5 m above the ground. Most of elevated houses were not heavy damage because the run-up surface only reached the house floor (about 1.5 m above the ground). One witness definitely states that run-up depth because she came back to her elevated house for saving her daughter when the tsunami wave inundated the village. However, that kind of house does not exist anymore in Kuta Lombok.

The interview results clearly show that the run-up depth was about 1.5 m. However, the data is not spatially wide enough because there were only small numbers of people and lived clustered in one place (west part) surrounded by forest and empty land in that time. There are not so much information about the condition of tsunami run-up in central and east part of Kuta Lombok.

3.3. Simulation Results

The numerical simulation of tsunami wave propagation and run-up was conducted by using software of COMCOT version 1.6. The simulation coverage consists of 2 areas as shown in Fig. 3. First area (Layer 01) is the large one, covers Bali, Lombok, Sumbawa, Flores and Sumba Island. Second area (Layer 02) is smaller, only 6,000 x 8,000 m wide, covers the water and land area of Kuta Bay from the Kuta Beach on the left until the Seger Beach on the right. Layer 01 was used to simulate the tsunami wave from its source location and its propagation to those islands. Layer 02 was used to simulate its propagation and run-up into the land area of Kuta. The simulation was performed in ebb tide condition according the earthquake and tsunami event.

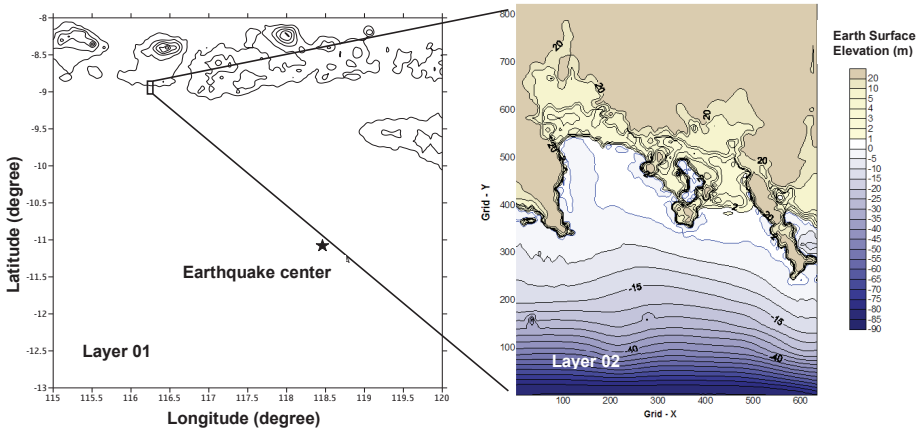

Fig. 3. The simulation area

The result of Layer 01 simulation in Fig. 4 shows that the initial wave height is about 3.6 m, which is consist of 0.6 m positive elevation and 3.0 m negative elevation. The wave height varies between 0.1 ~ 0.5 m along its propagation. The tsunami wave propagates and reaches the south of Sumba Island in about 5 minutes, south of Sumbawa Island in about 10 minutes and south of Lombok Island in about 20 minutes. However, the result of Layer 01 simulation does not clearly show the result along the coast line. Therefore, it needs the simulation in Layer 02 which has the larger scale.

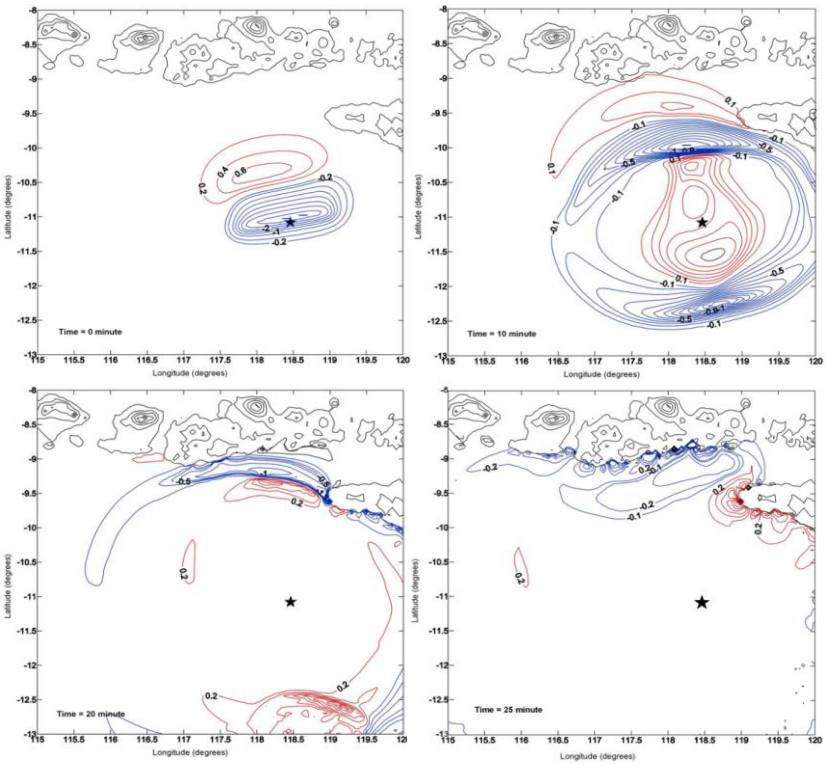

Fig. 4. The result of Layer 01 simulation

The Layer 02 simulation uses the artificial wave data (*fse.dat*) for its initial wave. The artificial wave was made based on the result of wave propagation simulation in Layer 01 at 20th minutes, i.e. the wave length is 3,000 m and the water depth is 80 m in front of Kuta Bay. The wave height was assumed 5 m based on the interview result. The simulation results are showed as the water surface elevation (the WSE). The WSE is above the still water level when it is in sea area and the WSE is above the earth surface when it is in land area (the run-up depth). There are 4 levels of run-up depth are showed, i.e.:

- The elevation 0 ~ 1 m = the water depth until 1 m, the adult people is still can walk, the water surface reaches the ¼ height of house wall.

- The elevation 1 ~ 2 m = the water depth until 2 m, the adult people starts to drown, the water surface reaches the ¾ height of house wall.
- The elevation 2 ~ 4 m = the water depth until 4 m, the adult people must able to swim, the water surface reaches the house roof.
- The elevation 4 m above = the water depth more than 4 m, the adult people must able to swim, the one storey house is below the water surface.

The result of Layer 02 simulation shows that the run-up of tsunami wave occur in the west area of Kuta Beach and the all area of Seger Beach. The run-up reaches about 300 ~ 800 m inland from the beach line as shown in Fig. 5. The run-up depth occurs between 1 ~ 2 m depths in those areas and specifically the run-up depth is 1.6 m in the witness location. Based on the witness interview results, the run-up is 1.5 m depth. Therefore, the simulation result is acceptable compare with the witness interview result.

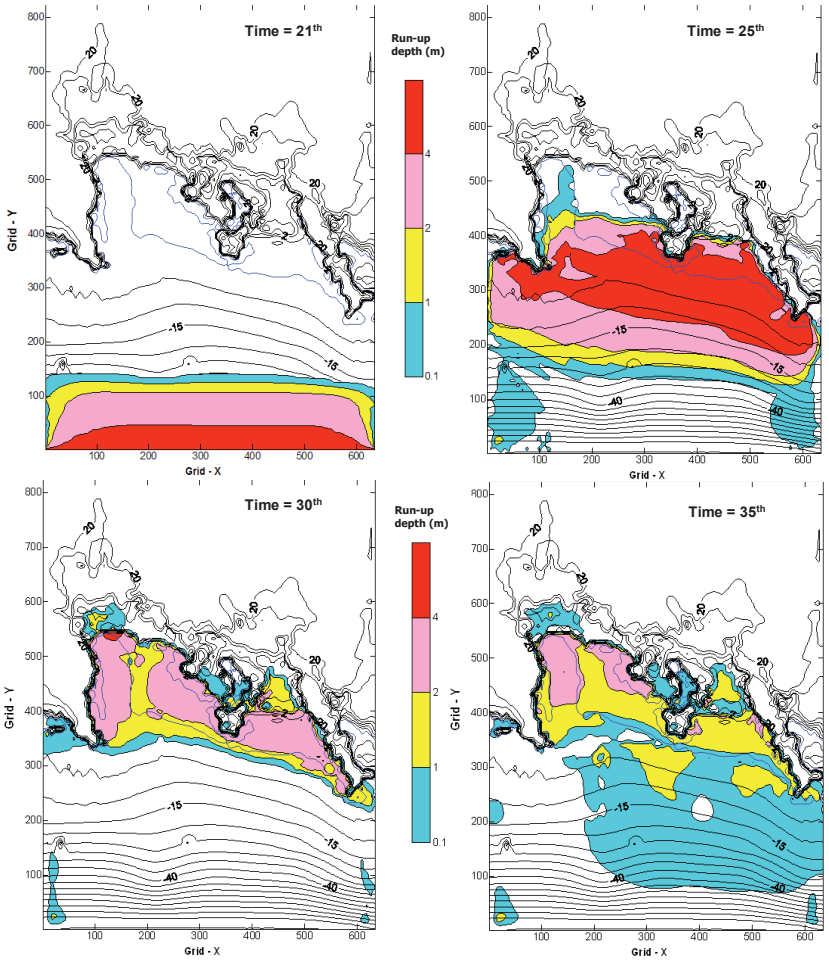

Fig. 5. The result of Layer 02 simulation in minute- 21th, 25th, 30th and 35th

4. Conclusion

The field survey of 1977's Sumba Earthquake Tsunami in Kuta Lombok was conducted and presented. Based on the field survey results, the run-up depth is about 1.5 m with the positions are almost close each other. The simulation results show that the tsunami time arrival is about 20~30 minutes. The result of run-up depth is acceptable compare with the field survey result, i.e. 1.6 m depth. The run-up of tsunami reaches about 300 ~ 800 m inland from the beach line. The run-up of tsunami occurs in the west area of Kuta Beach and the all area of Seger Beach. However, the spatial distribution of run-up simulation can't be verified due to the less people live in the event of tsunami.

Acknowledgements

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