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Numerical Analysis of Evacuation Start in Pangandaran

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Abstract. Tsunami evacuations plan should consider the behavior of local people. In this study tsunami evacuation start was analyzed using tsunami evacuation simulation consist of evacuee generation and evacuee behavior model. Pangandaran west beach was selected as the target area due to its popularity as a tourist spot and fishery activities in West Java. Evacuation simulations were conducted using 500 evacuations agents with tsunami shelter and grand mosques as goal for the safer place. A total of six evacuation scenarios were made using a different set of evacuation triggers parameter value with the combination of influence weight and effective range. The simulation result indicates that the influence weight which made 57% of people start evacuation immediately after the earthquake happened showed an instantaneous evacuation. Simulation result that was using lower influence weight and lower exposure range showed a more gradual tsunami evacuation. The simulation gave promising results that Pangandaran people could be safely evacuating if they raise their awareness and preparedness. The low-cost simulations that were used in this study provide an insight into the behaviors of Indonesians during disaster evacuation and might use as support for tsunami evacuation planning. However, to produce more satisfactory result we need to conduct field survey and tsunami drill to gain more information of people behavior during tsunami evacuation.

1. Introduction

Indonesia is a disaster-prone country. The 2004 Indian ocean tsunami as one of the most destructive tsunamis in the world was an awakening moment about the high treat and Indonesia vulnerability to tsunami. The Indonesian government has instituted disaster management policies to counter the threat of tsunami and has installed tsunami early warning system (InaTEWS) since 2008. However, the last two tsunamis in Indonesia, Palu and Krakatau tsunami, killed around 5000 people showing much remains to be done for effective evacuation.

When tsunami in Pangandaran happened in 2006, Indonesia tsunami early warning system just in the development process. Buoy system of deep-ocean assessment and reporting of tsunami hasn't been deployed, and 160 seismograph and tide gauge networks along Indonesia water still on the processed. Survey conducted by [1] found local people felt no significant shock and some people felt a strong earthquake. Tsunami awareness and information found to be not evenly distributed, in the 2 of 5 village it was more than 90% people never been given information about tsunami. Generally, most of the respondent start to evacuate when they see tsunami wave and seeing other's people evacuated.

Study by [2] showed that in the future there is strong possibility that greater tsunami will be happening at the southern part of Java Island. Pangandaran is one of the vital areas in the southern part

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of Java Island due to its popularity as a tourist spot and fishery activities. In order to minimize the tsunami risk, the past tsunami event highlighting that well organized and rapid evacuation is crucial to save lives in a rapid onset disaster. Recent studies on natural disasters have demonstrated the need to conduct holistic evacuation studies and integrating engineering, social, psychological, and educational sciences. Unfortunately, tsunami evacuation plans in Indonesia often neglects specific local condition and personal characteristics.

Recent study by [3] had identify the rank of evacuation triggers based on its influence to make Indonesians start evacuating. In this study, we used that information as an input for numerical simulation of evacuation start in Pangandaran. We recreated several possible of tsunami scenario to find information that could not be provided by field survey. The aim is to obtain information about the evacuation start process of people in Pangandaran and comparing this result with the field survey result (conducted by [4]). Therefore, we can analyze the level of awareness and preparedness of Pangandaran people to the tsunami risk.

2. Material and Methods

2.1. Study Area

Pangandaran is situated in the southern part of west Java province. It has population of around 11,000 people. The major economic activities in Pangandaran are tourism and fisheries. These activities mostly done around the beach area. Where the west beach area is denser with hotel, tourism facilities and more popular with tourist compare with the east beach area. Therefore, the area chosen for this study was at the west beach of Pangandaran.

Pangandaran already have some facilities as a safe place for tsunami evacuation. First is a shelter located in the hilly area of Purbahayu village. This sturdy building is a 5 floor with at least 25 meter tall and can shelter many people. The second shelter location is the Pangandaran Grand Mosque, located more northern than the first shelter. The mosque is a community facility and often used daily by the local people. There also some high building near the beach area, such as hotel, which could also be used as evacuation place. However, in this study we didn’t use that place, due to on the last tsunami event many hotels collapse, which proven that these buildings did not meet with the Indonesia national standard.

The roads in Pangandaran, except the freeway route, are not very wide. Many roads are narrow with only 2.5 metre lane streets. In the real situation, evacuation by using the vehicle will resulted to a severe traffic jam. Therefore, in this simulation we only consider the evacuation by foot (walking or running).

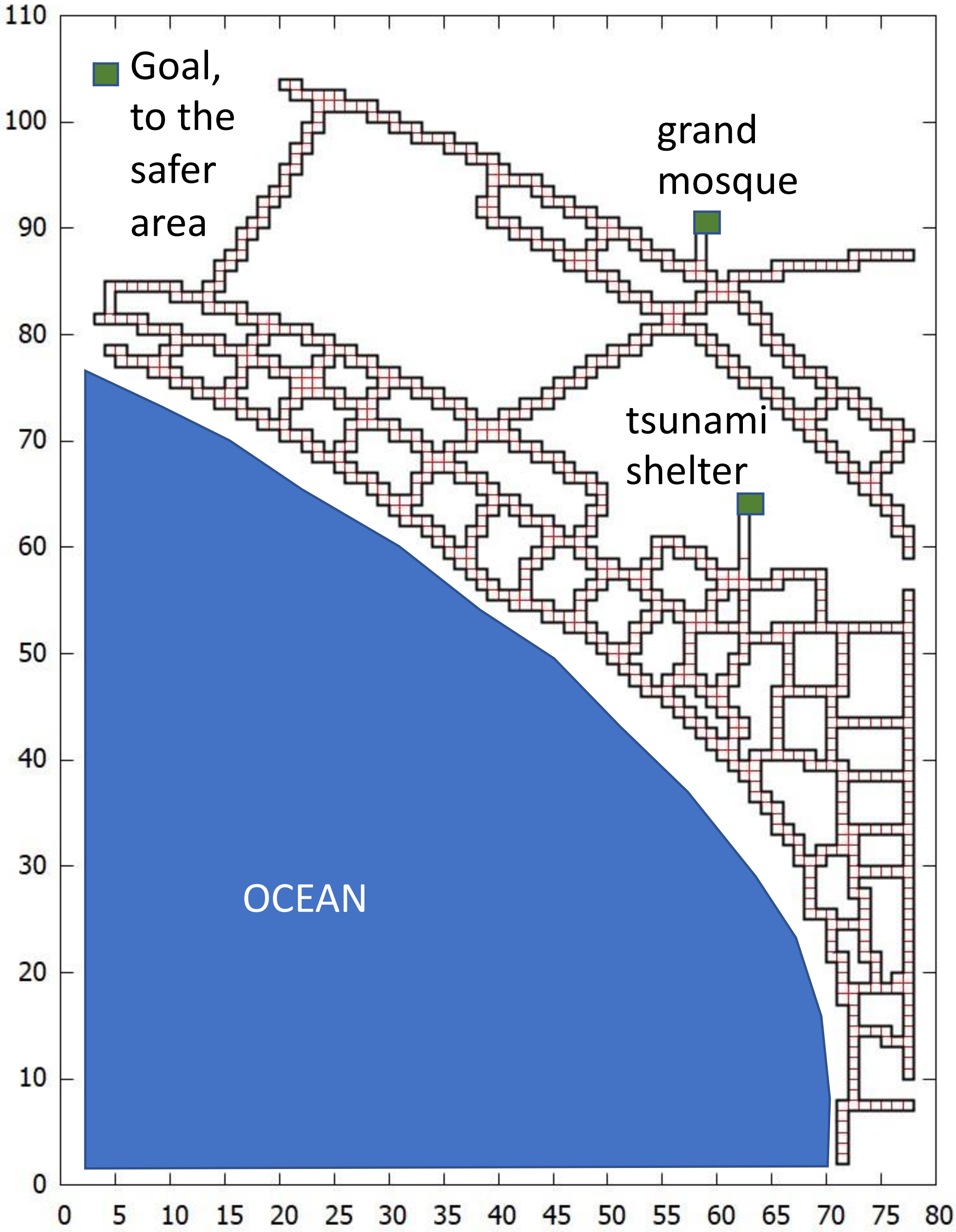

Figure 1 Environmental setting for the numerical simulation of evacuation start in west beach area of Pangandaran.

2.2. Concept of Numerical Model

This study used tsunami evacuation simulation consist of two evacuee generation and evacuee behavior model. The evacuee behavior model was developed by [5] and it combined by evacuee generation model that was developed by [6] . **Figure 2** shows the concept of evacuee generation model. When a person (i) obtains information about tsunami evacuation (X_n^t) which increases their awareness level of danger (Y_i^t).

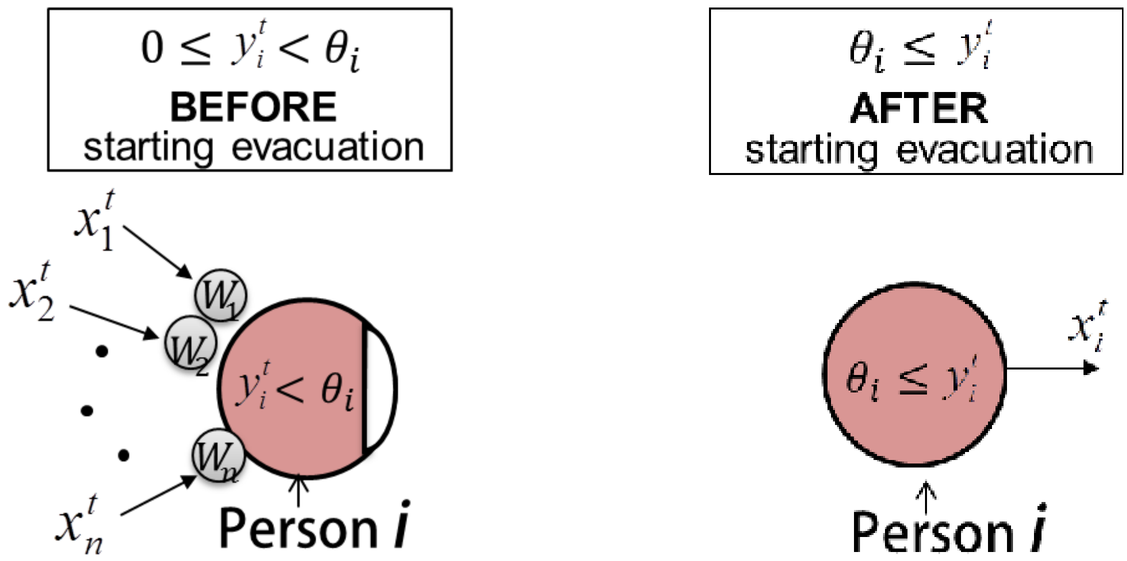

Figure 2. (left) Awareness level of danger before evacuation getting higher after exposed by the information sources (X_n^t), (right) the person become a new information source after starting evacuation.

ALoD y_i is expressed as in equation (1) where y_i^t is the ALoD of person *i* at the time step *t*, $F_{conformity}$ is the function related to the conformity bias, N is the total number of information sources, $\Delta t_G$is the time-step length of the evacuee generation model, M_{ij}^t is the function related to the spatial relationship between person *i* and the information source *j* at the time step *i*, $W_j$is the effectiveness level of the information source *j* (weight), x_j^t is the output of the information source *j* which has a value of zero or one, and *n* is the number of information sources which input a value to element *i*.

$$y_i^t = y_i^{t-\Delta t_G} + \Delta t_G F_{conformity}(t,n) \sum_{j=1}^{N} M_{ij}^t \, W_j x_j^t \quad (1)$$

After ALoD y_i reaches the upper limit θ_i , person *i* starts tsunami evacuation and behaves as new information source, which is calculated as in equation (2) and (3).

$$x_i^t = f\left(y_t^i, \theta_i\right) \quad (2)$$

$$f\left(y_t^i, \theta_i\right) = \begin{cases} 1 & if \; y_t^i - \theta_i \geq 0, \\ 0 & if \; y_t^i - \theta_i < 0. \end{cases} \quad (3)$$

From the equation, information sources x_n^t have significant effect to the ALoD. Comparison between previous study of tsunami evacuation in Ishinomaki, Japan and in Palu, Indonesia found out that the weight of information sources may vary depending on the area and local communities. The analysis from the several post-tsunami surveys questionnaire found the rank of which information source has bigger influence on the Indonesian people.

Once this person initiate evacuation then this person will become a new trigger source. This model also simulates people movement to the safest place by using the most effective evacuation route. The target area was digitized from satellite imagery from the open street map as shown in Figure 1. The shelter location determined from the google map information and the field survey by [4].

In the 2018 Palu tsunami, people can obtain the information from four evacuation start sources: ground motion, seeing evacuee, hearing evacuee and tsunami arrival. We used the same evacuation triggers for simulation in Pangandaran. The influence weight (W_i) of those sources was determine using ratio between number of people who triggered (T_i), and number of people exposed by that source(E_i), as shown in equation (4). From the previous post-tsunami survey in Indonesia, the questionnaire survey only provides percentage of triggered people (T_i), there are no sufficient information of percentage of

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people who exposed to the information sources. Thus, the exposure value (E_i) was adjusted until the simulation can reproduce similar percentage of people who started tsunami evacuation just after ground motion stopped (R_i). The range of R_i (18% - 57%), used in simulation were based on the footage analysis of evacuation in the east coast of Palu Bay during the 2018 Palu tsunami.

$$W_i \quad = W_{eq}^{id} * \frac{T_i}{E_i}$$

The first influence weight need to calculate is influence weight of ground motion (W_{eq}). Then, after the was found W_{eq} this value used to calculate another influence weight (W_i), such as seeing other people, hearing other people calling for evacuation, and seeing tsunami approaching.

We estimated the of ground shaking in Pangandaran was 160 seconds, due to its characteristic as a tsunamigenic earthquake. Since the duration of ground shaking in Palu was very short (50 seconds) than the scenario of Pangandaran case, we divided the weight by three times. The initial condition for model showed in the **Table 1**. Trigger weight is a key parameter for evacuation start model, therefore in the scenario we will used different weight value based on the footage analysis during 2018 Palu tsunami as shown in **Table 2.**

3. Result and Discussion

From the analysis of dynamic of evacuation start process during 2018 Palu tsunami conducted by [5] it was found that 1) people did not evacuate immediately after ground motion, 2) evacuation trigger influence vary by the distance between evacuees and people who area yet to evacuate, and 3) vary by the time of occurrence, that the influence of other people behavior is lower before tsunami arrival. Therefore, we did simulation using scenario that use adjustment of distance and difference influence value between early and late evacuee. The scenarios of evacuation start simulation can be seen in Table 2. The set of A scenario are combinations of effective visibility range from 10 to 110 m where the percentage of people evacuated immediately after feeling the ground motion was 18%. While the set of B scenario are combinations of effective visibility range from 10 to 110 m where the percentage of people evacuated immediately after feeling the ground motion was 57%.

Table 1. Initial condition

Target area ($m^{2)}$	1384 x 396	Start time of tsunami inundation after the earthquake occurred (s)	300
Number of people	500		
Duration of strong shaking (s)	160	Total time for analysis (s)	900

Table 2. Scenario based on the evacuation triggers weight

Scenario	Ground shaking	Seeing evacuee		Hearing evacuee		Seeing tsunami
		Weight	Range (m)	Weight	Range (m)	
A1	0.13×10^{-3}	0.25×10^{-3}	110	0.013×10^{-3}	32	0.07×10^{-3}
A2	0.13×10^{-3}	0.25×10^{-3}	50	0.013×10^{-3}	32	0.07×10^{-3}
A3	0.13×10^{-3}	0.25×10^{-3}	10	0.013×10^{-3}	32	0.07×10^{-3}
B1	0.36×10^{-3}	0.69×10^{-3}	110	0.036×10^{-3}	32	0.19×10^{-5}
B2	0.36×10^{-3}	0.69×10^{-3}	50	0.036×10^{-3}	32	0.19×10^{-5}
B3	0.36×10^{-3}	0.69×10^{-3}	10	0.036×10^{-3}	32	0.19×10^{-5}

Figure 3 shows the simulation result of scenario A1-A3. In the simulation using scenario A, if the effective range of seeing other evacuee was very limited, in this case 10 m, only less than 40% people will evacuate. While if the effective range is 110 m more than 80% people will start evacuating. Thus, from the scenario A1 to A3 the result showed that number of people who start and finish evacuation gradually increased. The result also showed the effective range of seeing other people gave significant impact to evacuation start.

Figure 4 shows the simulation result of scenario B1-B3. This scenario also gave similar information that number of people who start, and finish evacuation gradually increased if the effective range also increase. However, that is not as significant as in the scenario A1-A3. We found that if number of people who immediately evacuate is high (in this case 57%) then at last 80% of people will start evacuating. The biggest effective range, 110 m, only increasing 17% (total 97%) of people to start evacuating.

Simulation B result shows rapid evacuation start process after feeling ground motion and shows around 55% of people finished the evacuation in 5 minutes after the earthquake. From the footage this rapid evacuation was not happened during the 2018 Palu tsunami. This result probably owing to the usage of overestimate percentage of people evacuated after ground shaking. Therefore, with only 18% people triggered by ground motion probably gave more reasonable result.

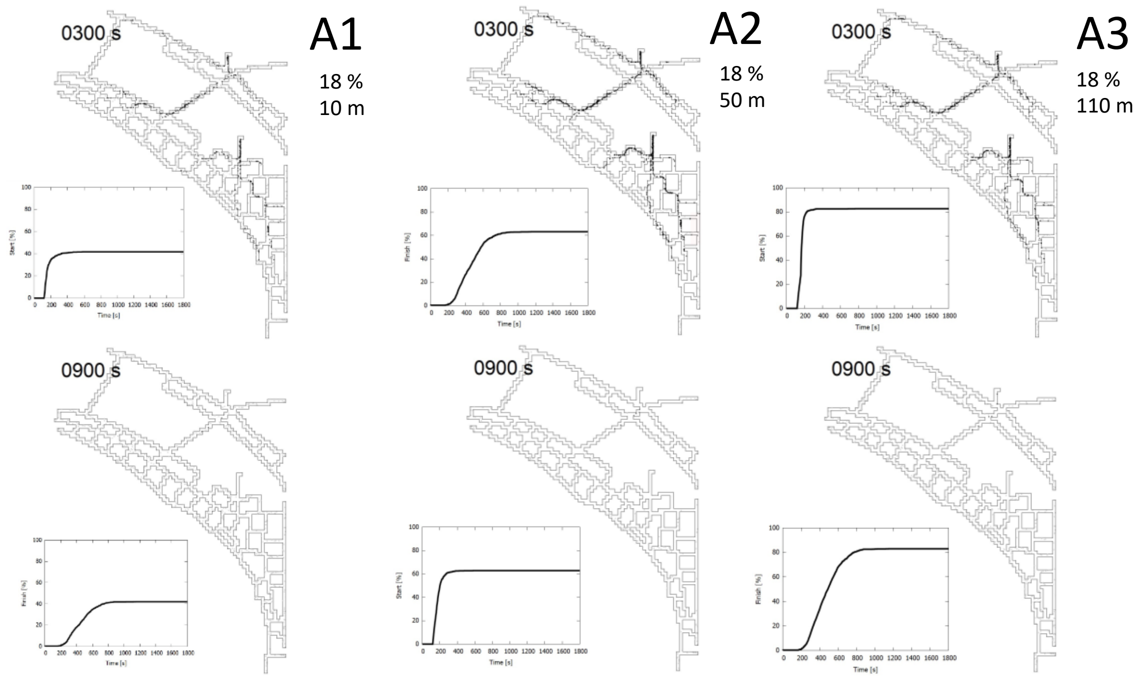

Figure 3. Evacuation simulation result using scenario where only 18% of people triggered only by feeling the ground motion.

The comparison with the survey result by [4] show a worrying fact. First was regarding the evacuation route. In the model, it situated that people will always choose the most effective route. Where the model judging the effective route by the distance between people and goal area (shelter). However, when Pangandaran people were asked to draw, which route they will take to evacuate most of them choose the grand mosque as a shelter. Based on the distance, choosing grand mosque was not the effective route because it is farther than the shelter. This fact shows that 1) people might be choose the more familiar location to feel safe, 2) their awareness regarding the shelter and evacuation route still needs to be improved and 3) they never, or rarely, joined the tsunami drill.

Second was regarding to people level awareness of danger. In the questionnaire, showed in Figure 5a, when they were asking in the case of an earthquake without tsunami warning what will they do. More than half of them (54.3%) said they will evacuate immediately if the earthquake was “somewhat big" and 30% of them answered they will not evacuate immediately. This behavior was quite surprising, considering Pangandaran people were experiencing tsunami attack in 2006 generated by a shallow earthquake with a small ground motion. We were expecting they will be more aware and tend to evacuate immediately after feeling ground motion.

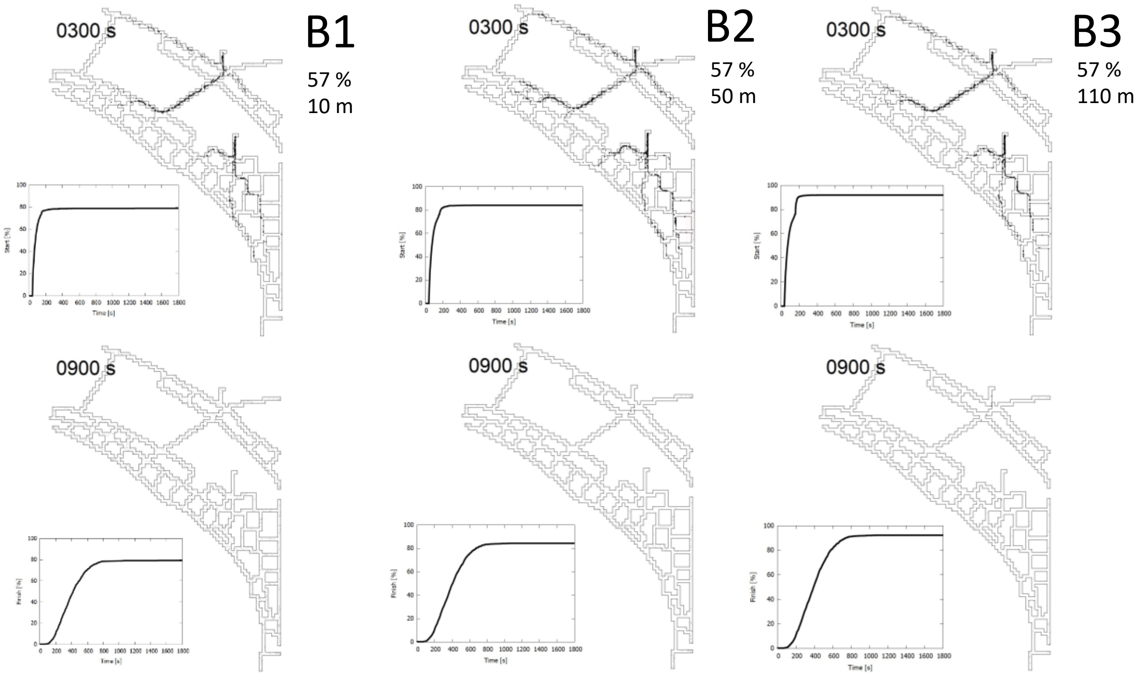

Figure 4. Evacuation simulation result using scenario where only 18% of people triggered only by feeling the ground motion.

Third was the importance safe behavior after receiving tsunami early warning information. From figure 5b, they were asking of their action in the case they receive tsunami warning without feeling the earthquake. A large number of people (76.1 %) want to find more information before evacuating. This behavior could be dangerous, especially if we reflect to the last two tsunami event in Palu and Krakatau. In the Palu event, people only fell a weak ground motion, while in Krakatau event there was no ground motion at all. Therefore, it would be a safer option if people willing to start evacuating even if they do not feel the ground motion.

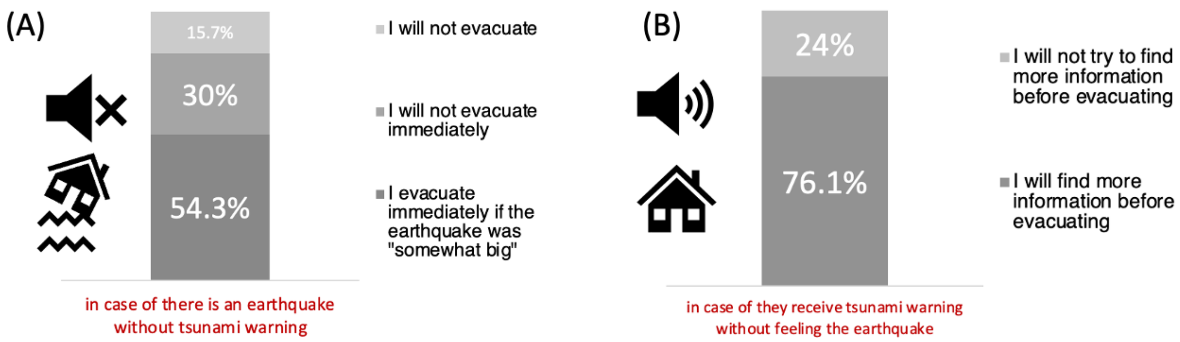

Figure 5. (a) Percentage of people when they were asking in the case of an earthquake without tsunami warning what will they do. (b) receiving tsunami warning without feeling the earthquake.

4. Conclusions

Numerical simulations in the west beach of Pangandaran shows the adjustment timing and distance should be made. The evacuation start simulation should use difference influence value between early and late evacuees and smaller effective range than 110 m. The simulation can reproduce the tsunami evacuation start to an extent. However, to produce satisfactory result we need further research of better adjustment to the number of triggered people by feeling ground motion. The simulation result show that if the future tsunami happened, if 57% of people start evacuating immediately after feeling ground motion, at least more than 90% of them will successfully reach the shelter. However, the evacuation start was modelling the safe and logical behavior of people, on the contrary the survey result did not show the similar result. This model provides information that Pangandaran people could be safely evacuating if they raise their awareness and preparedness. One of the things that could be done are by disaster education and consistent tsunami drill.

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