The existence of multi-story buildings to reduce tsunami effects in the city of Padang, West Sumatra

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Abstract. The need for space for shelter as well as the place of business is always increasing in urban areas. To provide enough space, it is usually done vertically. The building becomes two or more stories high. This building grows along the highway and on the beach, for cities that are on the coast. seawalls or dams are usually used to protect the driving force of the waves to shore and their construction is massive. But building prices are very expensive. However, the existence of multi-story buildings can also reduce and protect coastal areas against tsunami waves. However, not many researchers have examined this case by physically modeling it in the existing conditions. Based on that experiment research is conducted by imitating the real condition of the location of the affected waves. Simulations are carried out using models. The multi-story building model is made from styrofoam which is placed on the location map from satellite imagery. Then observed the effect of inundation and current propagation by generating waves. A single wave is generated by adjusting the height of the fall and the volume of water from the tank to the test object. The simulation results show a reduction in current propagation length and puddle depth of about 40%. The decrease in water depth is better as the floor of the building increases. As a recommendation, the multi-story building effect can help the community in determining the route and length of time for evacuation from the start of the incident to a safe place.

1. Introduction

1.1. Background and research objectives
Waves in the sea are usually caused by winds traveling up the coast. Wave height varies greatly according to the magnitude of the force of the wind. On the other hand, large waves can be caused by earthquakes, slides, and volcanic activity. Large waves or waves that can move water far to the coast are also called Tsunami and propagate up to the coast from the center of the wave generation [1],[2]. Dominant big waves occur due to an earthquake, where the stronger an earthquake, the greater the chance of a tsunami caused by an earthquake [3]. Tsunami like this are the only ones that can travel far and can be between oceans, thus endangering a wider area, as happened in Aceh December 2004 [3], [4]. Another cause of a tsunami is landslides. Landslides under the sea due to an earthquake. Although small, but can cause Tsunami such as in Papua New Guinea in 1998 with landslides on the seabed, while in Alaska in 1958 landslides [5].
The impact of the tsunami caused water to enter and inundate the land [6]. The increase in water can be repeated and dangerous. The destructive force can cause erosion around the building foundation [7]. Tsunami waves have occurred on Pangandaran Beach. This wave is smaller in scale compared to the tsunami waves that occurred in Aceh. The height of the tsunami waves in Pangandaran was around 6 meters with a wavelength of around 500 m, while the height of the tsunami waves that occurred in Aceh was up to 30 m with a wavelength of about 2.0 km [8].

Studies on attenuation, destructive force and water level have been carried out such as the construction of sea walls, construction of buildings, and the effects of mangroves [9]. According to [10], it shows that multi-story buildings are able to reduce tsunami run-up more than not [8]. Nizam conducted a preliminary study on the influence of building layout, that a collection of buildings can reduce the wave force greater than a single building [11]. Previous studies have mostly been done using building models with a single building formation, regular groups, none of which have been reviewed by involving the actual situation at the location. In fact, the combined effect of rivers, drainage, housing, buildings, and roads, and layout can reduce water propagation.

Based on the above reasons, a study was conducted by simulating real conditions in coastal areas. Models are created by creating three-dimensional buildings. The research objective was to observe the length of the water level rise and the depth of inundation on land. Simulations are carried out with variations in wave height and speed of propagation of the waves hitting the land as a real view location. The location of the research was conducted in the area of Lolong, Padang City, West Sumatra - Indonesia. The location is a relatively mild slope 1.0 - 2.0 km from the coast.

1.2. Wave
The wavelength and the speed of the wave propagation determine the magnitude of the thrust and the extent of the inundation to hit the beach. The equations of waves in the sea in general:

\[
\left(\frac{2\pi}{T}\right)^2 = g \frac{2\pi}{L} \tanh kh
\]  
(1)

In shallow seas with the approach \( \tanh(2\pi/L) = 1.0 \), so the propagation speed is

\[ C^2 = \frac{L^2}{T^2} \quad \text{or} \quad C = \frac{L}{T} \]

and wavelength

\[ L = T \sqrt{gh} \quad \text{and} \quad C = \sqrt{gh} \]  
(2)

where,

- \( L \) = wavelength (m)
- \( T \) = wave period (m)
- \( h \) = sea depth (m)
- \( C \) = celerity of wave (m/s)
- \( g \) = velocity of gravity (m/s²)

1.3. Inundation and Run-Up of water and damage
A tsunami that reaches the coast or land consists of a series of waves that have different frequencies and amplitudes and can mutually reinforce and seriously endanger the coast [2], [3]. The depth of the water that reaches the mainland is about 15 - 30 m with a propagation velocity of around 90 km / h and is far inland [6]. Floods due to the tsunami are categorized by two sizes, namely inundation, and run-up. Inundation is the maximum distance a tsunami travels horizontally inland. Run up is the maximum height inundated by a flood compared to the normal sea level [6]. The destructive force of a tsunami when it arrives is very large, and vice versa, and can occur repeatedly in a few days [7].
1.4. Multi-story building as a water flow damper
A multi-story building is a structural system that has more than a one-floor layer. In certain areas, it is called Ruko (meaning from home and shop) according to its function. Buildings can consist of between two and five floors. The lower part of the shophouse functions as a place for business or a kind of office while the upper floor is used as a residence [10]. The multi-story building permanently grows along the coast and the highway in the coastal area. Most of them are two-story buildings with concrete walls and a steel frame entrance. So that this building can function as a damper for water flow due to the tsunami.

2. Study locations and methods

2.1. Location and equipment
The study was conducted in the coastal areas of Padang, West Sumatra, Indonesia, namely the beaches of Lolong and Purus at coordinates 0°55′24.30″ S and 100°21′12″ E. This area is in the west directly adjacent to the Indonesian Ocean Sea, east of Jalan Raya Khatib Sulaiman, North with Kelurahan Ulak Karang and Timur Purus. Physically, the location has roads, houses, and drainage channels and arterial roads with relatively flat topography. The study location, with an area of about 120 hectare, contains many houses, schools, hospitals, and offices. Along the highway Ir. H Juanda two-story building, three floors, and six-floors. Multi-story buildings function as homes and offices. Buildings grow and develop in line with the regional economic growth rate. Building growth tends to be vertical rather than horizontal. The topography of this area is relatively mild along the 1.2 km from the coast to the east. The slope of 5/1000 m/m, then ascends as far as 2.1 km with a slope of about 8/1000 m/m. Furthermore, it is steep to very steep and ends in the Bukit Barisan hills.

The test table in Figure 1 (a) Description of the equipment and (b) wave generating device and the table with two water tanks are used to generate waves and propagate water. The water tank is adjusted by varying the slope of the tank and sliding doors. The variation in water level at the sliding gate assumes that the highest wave height reaches the shore. Then the tank tilt adjustment is to get the variation of thrust due to waves. The following is in Figure 1 (a) Description of equipment and (b) wave generating device and the table.

2.2. Methods and procedures

2.2.1 Methods The test was carried out by simulating the situation in the coastal areas of Long and Purus Padang City, West Sumatra, Indonesia, when a tsunami struck. As a basis for modeling the real conditions, a map from Google Earth 2018 is used. Location and model maps are shown in Figure 2 (a) maps of study location and (b) existing models and (c) models of modification below. The shape of the building is simplified in the form of a rectangle. The building is made of styrofoam and placed on a map of satellite photos covered in acrylic. All buildings are designed not to change shape and not shift due to the impact of the waves. The waves occur only once for each experiment. The model is made in 2 types, namely existing conditions and modifications. In Figure 2 (a) maps of study location and (b) the existing model and (c) the model of modification above is shown in Figure (b) the existing model is the idealization result of the actual conditions. Complete with river roads, neighborhoods as well as highways. The building is made with the actual elevation, namely for a one-story building an assumed elevation of 4.0 m and two floors of 8.0 m, and so on. In the modification model (3) the buildings along the highway are made 4x taller than they. The length of the building is made longer than it should be. The modification model is seen in light blue and orange styrofoam, but the buildings, rivers, and other housing are assumed to be unchanged.
2.2.2 Procedures

The initial stage of all models must have been completed complete assembly with buildings, roads, and drainage. As discussed in the methodology, there are two models created. Existing model and modification model. Then each model will be placed on the test table. Meanwhile, tank-1 is filled with water and lifted at one end until it reaches the desired slope. The slope is set for the two conditions as 10% and 15% so that the water level at the door or weir is 5.5 cm and 6.5 cm.

The next stage is dividing the model area by creating grids. The grid is planned for 4 x 5 points. Each point (joint) on the grid is attached to a small flag of colored paper. This flag is useful as an indicator of the water level after a water drain or tsunami occurs.

The test stage, where at this stage the sliding door is opened suddenly and water slides into the test object. Then the water receded through the side channel and the water entered again into tank-2. Each test is carried out by observing the behaviour and recording the water level. The water level is measured from the bottom to the height of the wet flag at every 20 points. For the next running, the flag must be replaced with a new one and experimented again. The test is carried out three times for each model and slope variation. After that, data analysis and contour drawing were carried out.

Figure 1. (a) Description of equipment and (b) wave generating device and the table

Figure 2. (a) maps of study location and (b) model of existing and (c) model of the modification
contour drawing is a curved line representing the same water depth at the study site. Drawing is done
with AutoCAD. The same procedure is carried out for the modified model.

3. Result and discussion

3.1. Result

After running the test using a wave generator, the water flow direction in the model, and the water run-up in each grid that has been measured are obtained. From the direction of the flow and height of the water can be made the same high level of the pool using AutoCAD software. Here are the test results Figure 3. Contour lines for existing and modified models at 22 m wave height.

(1) Existing model (2) Modified model

Figure 3. Contour lines for existing and modified models at 22 m wave height

In the existing model, the farthest water depth is eight meters at a distance of 1.0 km. In the modified model, at a distance of 1.0 km, the water depth or run-up is about 4.0 m. Also, the contour lines are almost parallel and parallel so that the depth is almost even in each distance traveled. But in the existing model, the water depth or run-up is higher.

In another experiment for a wave height of 26 m with the same water volume and a larger tank slope, namely 15%. An overview of the water depth or run-up in each model is obtained as shown in Figure 4: Contour lines for existing and modified models at 26 m wave height below. It can be seen...
that at the beginning of the wave, the depth was quite large and decreased to a depth as high as the houses of residents.

In the existing model, the depth is still 10 m for the distance that is more than 1.0 km, while in the modified model for the same distance the depth is less than 6 m. Contour lines look tight at a distance between 300 to 600 m. This indicates that the current after crossing the resistance is somewhat even. This means that the building can reduce the incoming waves.

![Figure 4. Contour lines for existing and modified models at 26 m wave height](image)

### 3.2 Discussion

When viewed from Figure 3 Contour lines for existing and modified models at wave height 22 m and Figure 4 Contour lines for existing and modified models at wave height 26 m. The image shows the water depth line in the existing model is still tenuous. This means that the rise in water level at the beginning to the end is rather linear with the distance. However, it can be seen that the difference in the existing model is that the flow depth on the beach is still high. For the area to the right, initially, the inundation was high and then gradually receded. It is also seen in areas with high buildings (hotels) enough to reduce the water depth compared to without high buildings. For example on the map on the right. This can also be seen for the modified model, where the contour lines are tight in an area as far as 300-600 m from the coast, meaning that the effect of multi-story buildings makes the attenuation of waves quite significant. So that at a distance of 900 m the water level is already shallow when compared to the existing model. This is also consistent with the results of research by Nurhasanah for multi-story buildings [8] and sea walls [10] and Nizam for structured buildings[11].
The relationship between the inundation – run-up from the coast can be seen in Figure 5. Distance with water depth. The image shows that a small distance of 500 m from the shore, the run-up is still high. This means that this area is still very risky, while for areas more than 500 m the water level has decreased. Even for the modified model, both for waves with small thrust and large, the depth obtained is smaller than 10 m. This depth is much shallower than without a multi-story building. This clearly shows that the effect of multi-story buildings is already significant. All of this can be seen in the black line showing the existing model and the green line showing the modified model. The amount of water level drop after 600 m is almost 40% lower than the existing model.

Figure 5. Distance with water depth

So as a whole it can be stated that the impact of multi-story buildings will reduce the height of inundation. Inundation can be reduced with increasing building height and building length.

When observed from the contour lines of all experiments it can be used as a reference to determine a safe area for evacuation. Indirectly, it can prolong the arrival time of the puddle, so that by 1.5 km it can be taken for 10 minutes. Assuming the speed of movement of people is 10 km/hour [2].

4. Conclusion
1. From the results and discussion, it can be concluded that the higher the building the greater the attenuation that occurs. This resulted in the length of water propagation to land less than nearly 40% of the existing conditions.
2. The greater the wave height and the thrust the better the damping occurs. This is indicated by the lowering of the contours the farther the distance from the beach.
3. As a recommendation, the multi-story building effect can help the community or government in determining the route and length of time for evacuation from the start of the incident to a safe place.

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