Building Vulnerability Analysis Due to Tsunami by Using Probabilistic Tsunami Hazard Assessment (PTHA): A Case Study of Pelabuhan Ratu, Sukabumi

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Abstract. Cities that vulnerable to tsunamis, including the village of Pelabuhan Ratu on the southern coast of West Java, Indonesia, are in dire need of adequate vertical evacuation structures. However, constraints regarding to limited funding and difficulties in finding affordable land have hindered the implementation efforts of such structures in several cities. This research aims to analyze building vulnerability to tsunami disasters and identify buildings that can serve as alternative tsunami evacuation options based on Probabilistic Tsunami Hazard Analysis (PTHA) in Pelabuhan Ratu. The research methodology involves mapping the Modified Building Tsunami Vulnerability (BTV) and connecting the numerical simulation results with fragility curves assumed for the Pelabuhan Ratu area. The numerical simulations were conducted using the Cornell Multi-Grid Coupled Tsunami Model (COMCOT). Various tsunami scenarios triggered by earthquakes with different magnitudes ranging from 8.5 to 9.0, with intervals of 0.1, were considered in the numerical simulations. The research findings indicates high probability of maximum tsunami height reaching 14.85 meters in a return period of 10,000 years, and 51.77 meters in return period of 30,000 years. Based on these results, it was found that a three-story minimarket built with concrete could be used as an evacuation facility in a 10,000-year return period.

Keywords: *Building Tsunami Vulnerability, COMCOT, Numerical Simulation, PTHA, Tsunami*

1 Introduction

1.1 Background

A tsunami is a natural disaster with transient waves (occurring very rapidly and briefly) that occur due to destructive or disruptive activities at the ocean floor, altering the volume at the seabed [1]. These tsunami waves occur due to several factors, such as underwater volcanic eruptions, earthquakes causing shifts in tectonic plates, massive underwater landslides, and the impact of foreign objects like meteors [2]. The danger is exacerbated by Indonesia's geographical location, situated in an area of active tectonic plate movement around Indonesian waters. Among the active tectonic plates are the Eurasian Plate, Australian Plate, and Pacific Ocean Floor Plate. One of the many regions in Indonesia that holds significant tsunami vulnerability is the village of Pelabuhan Ratu, located on the southern coast of West Java, in the Indian Ocean. Pelabuhan Ratu lies within the convergence zone of the Enggano Plate, Sunda Strait, and West-Central Java [3].

The continuous series of underwater earthquakes occurring off the southern coast of Java, along with the difficulty of predicting when these earthquakes will happen, remains a problem and challenge, given the limited information about disasters, especially tsunamis, in that area [1]. In Pelabuhan Ratu, there is potential for a major earthquake. Previous earthquake data in the Java subduction zone indicates the presence of a seismic gap, suggesting the accumulation of strain that will eventually be released through a major seismic event [4]. Recent studies on tsunamigenic deposits along the southern coast of Java reveal that significant earthquakes have occurred in the Java subduction zone with a recurrence period of 500 years [5].

Until now, there haven't been many studies analyzing the potential tsunami hazards in the village of Pelabuhan Ratu. The village of Pelabuhan Ratu also lacks dedicated buildings for evacuation in the event of a tsunami. On one hand, the cost required to construct evacuation buildings is expensive [6]. However, the local government has established evacuation routes and temporary shelter locations for residents facing tsunami threats in coastal

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areas. Therefore, assessing building vulnerability is beneficial to identify structures that can be utilized as evacuation centers, as part of efforts to mitigate the impact of tsunami disasters. Building Tsunami Vulnerability (BTV) is one of the methods that can be employed to assess building vulnerability.

Building Tsunami Vulnerability is a method used to assess the level of building vulnerability to tsunamis. [7] conducted research using BTV to analyze the vulnerability of buildings to tsunamis in Morocco based on parameters such as tsunami height, building conditions, and coastal defense. However, this method does not consider the fragility curve of buildings against tsunamis. The calculation of BTV values for the tsunami height parameter is modified by incorporating the fragility curve, which represents the relationship between force and the probability of tsunami wave damage [6]. The earthquake scenarios used in [7] and [6] are limited to a few scenarios, without considering the long-term occurrence of tsunamis and the complex conditions of an earthquake. Therefore, in this study, the tsunami height values will be obtained using the Probabilistic Tsunami Hazard Assessment (PTHA) method.

Probabilistic Tsunami Hazard Assessment (PTHA) is a method used to probabilistically evaluate and predict tsunami hazards by considering the likelihood of earthquakes occurring in a specific region. This leads to tsunamis having a range of occurrence cycles, such as 200, 250, 300, and 500 years, with the aim of observing the outcomes of different recurrence periods and obtaining probability values [8]. PTHA has been employed to analyze tsunami hazards in China and Japan [9],[10]. Research using the PTHA method is also conducted to study tsunami disasters over extended timeframes, in order to prepare for and anticipate potential tsunamis in the future. For simulations, the COMCOT (Cornell Multi-grid Coupled Tsunami) program is used to observe tsunami propagation and its initial generation.

The aim of this research is to analyze building vulnerability to tsunami disasters based on PTHA analysis in Pelabuhan Ratu. The outcomes of this study will provide a building vulnerability index. The building vulnerability index can be used as an effort for disaster mitigation, such as identifying suitable alternative buildings for temporary evacuation centers based on existing structures. Another benefit is that it is expected to be utilized by stakeholders involved in pursuing one of the targets of Sustainable Development Goal (SDG) number 11, which aims to make cities and settlements inclusive, safe, resilient, and sustainable.

2 Method

2.1 Research Sites

A study on building vulnerability to tsunami waves was conducted in Pelabuhan Ratu, Sukabumi Regency, West Java, as shown in **Figure 1**. This region has a population of approximately 82,691 people, with a relatively high population density of around 399 people/km², and is situated along low-lying coastal areas. Pelabuhan Ratu comprises 10 sub-districts and covers an area of approximately 82.60 hectares. To the south of Pelabuhan Ratu lies Citepus sub-district, which spans an area of 714 hectares, as shown in **Figure 2**.

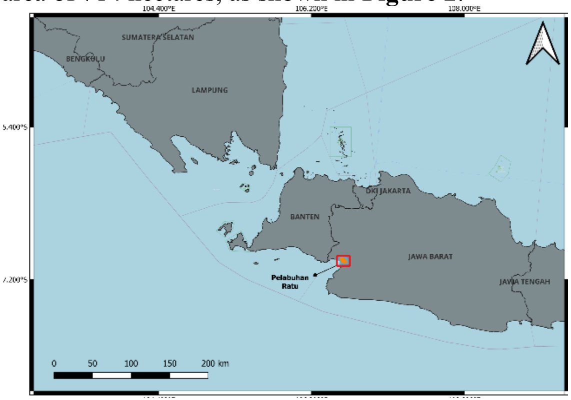

Fig. 1. Area Study

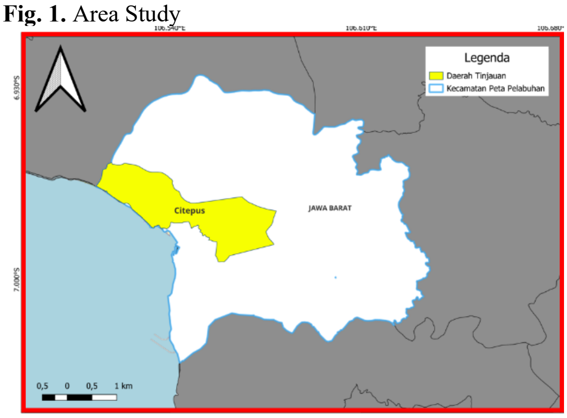

Fig. 2. Analysis of BTV at the Study Site of Citepus Sub-District

2.2 Initial Condition

The data collection method is divided into secondary and primary data. The secondary data used is the Java subduction zone as the earthquake location, which will be used as input for generating the initial tsunami wave. In this study, the tsunami wave generation source in the Sunda Fault Zone is utilized, and the earthquake mechanism is modeled using stochastic slip. Previous research by [11] has developed a method to characterize slip complexity in earthquakes by utilizing a spatially random field of anisotropic wavenumber spectrum with Von Karman autocorrelation function. The data used for slip modeling includes the length and width of the fault, measuring 630 km and 120 km, respectively. Furthermore, the fault is divided into several smaller fault patches of size 10×10 km. The earthquake parameters applied include the earthquake depth, strike, rake, and dip, which are 34 km, 296˚, 104˚, and 18˚, respectively, based on the findings of previous research [12].

2.3 Tsunami Parameter Data

The secondary data to be used in this study also includes bathymetric and topographic data. BATNAS (Bathymetry National) and DEMNAS (Digital Elevation Model National) data will serve as inputs to obtain information about ocean and land depths and heights in the simulation area. Both of these datasets are openly available and downloadable. In the tsunami wave propagation simulation, a multilayer system will be implemented to enhance the detail in the specific research area, namely Citepus Sub-District. Five layers of simulation areas will be implemented to cover a more specific region, as shown in **Figure 3**. To adapt the BATNAS and DEMNAS data to a smaller area, data interpolation is performed using the GMT (Generic Mapping Tools) program.

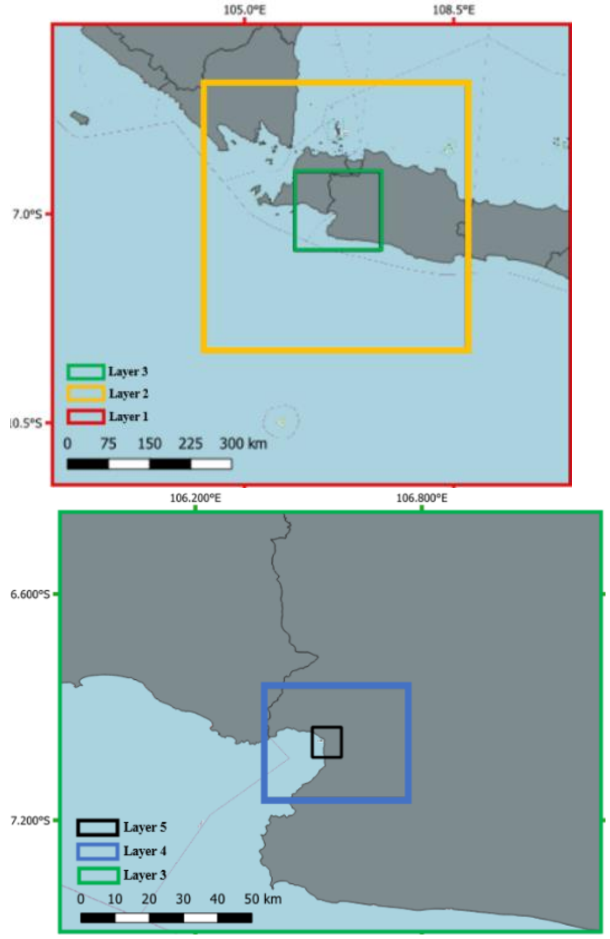

Fig. 3. Multilayer Area Simulation in the COMCOT Program

Information regarding the parameters used in the COMCOT model for the simulation area can be found in **Table 1**.

Table 1. Information on Simulation Parameters for the COMCOT Program

Layer	1	2	3	4	5
Latitude range (°)	101.7E - 110.4E	104.3E - 108.7E	105.8E - 107.2E	106.3E - 106.7E	106.5E - 106.5E
Longitude range (°)	11.5S - 3.7S	9.2S - 4.8S	7.6S - 6.3S	7.1S - 6.8S	7S - 6.9S
Grid size (m)	942.5	314.2	104.7	26.2	5
Number of grids	1045 × 937	1588 × 1615	1558 × 1424	1616 × 1280	1668 × 1728
Parent grid	None	Layer 1	Layer 2	Layer 3	Layer 4
Ratio to Parent grid	None	3	3	4	5
Coord. System	Spherical	Spherical	Spherical	Spherical	Cartesian
SWE Type	Linear	Linear	Linear	Linear	Nonlinear
Time step (second)	1	0.333	0.111	0.028	0.006
Manning	0.02	0.02	0.02	0.02	0.02

2.4 Building Classification Data

The building classification data is primary data obtained directly from observations in Citepus Sub-District in Palabuhan Ratu. There are approximately ±4,344 building units that have been visually observed in the field. **Figure 4** illustrates the distribution map of buildings based on their building class in Citepus Sub-District. Buildings are classified into five class zones, ranging from Class A to Class E, based on the type of materials and the number of floors used in construction. Buildings made of reinforced concrete, or Reinforced Concrete (RC) Buildings, have the same strength, but are differentiated only by the number of floors. The assessment of building vulnerability is based on the classification factor, which reflects the performance level of each building class against tsunami threats, considering only the building's own condition [7],[6]. The building classification in Pelabuhan Ratu is presented in **Table 2**.

Table 2. Number of Buildings According to Building Class (Fc,b) in Citepus Sub-District

Building Type	Zone Class	Building Class (Fc,b)	Quantity (unit)	Quantity (%)
Kayu lt. 1	A	5	212	4.88
RC Building lt. 1	B	4	3789	87.22
RC Building lt. 2	*C*	3	326	7.50
RC Building lt. 3	D	2	16	0.37
RC Building lt. >3	E	1	1	0.02
Total			4344	100

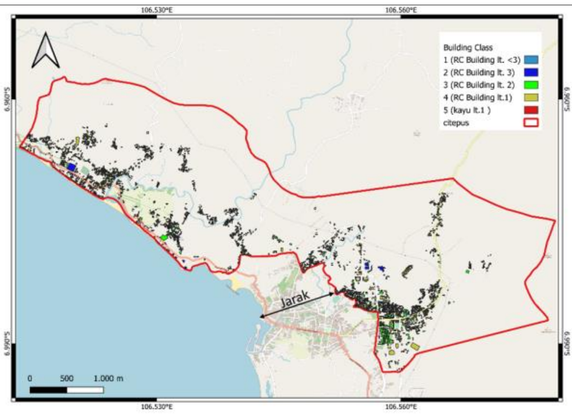

Fig. 4. Map of Building Class Distribution in Citepus Village

2.5 Cornell Multigrid Coupled Tsunami (COMCOT)

The analytical method conducted in this research involves simulating tsunami waves using the Cornell Multigrid Coupled Tsunami (COMCOT) program, utilizing a 2-Dimensional Horizontal (2DH) modeling approach. The COMCOT program has demonstrated its ability to conduct simulations with high accuracy and efficiency, as evidenced in the case of the Indian Ocean tsunami [13]. This program is capable of numerically simulating tsunami waves, providing a depiction of the propagation of tsunamis from the earthquake's epicenter to coastal regions. This approach employs the Shallow

Water Equations (SWE), encompassing momentum and mass conservation equations. The equations are then discretized using the leapfrog and upwind methods. The SWE equations are discretized in space and time for both linear and nonlinear equations in spherical and cartesian coordinates. The SWE equations can be written as follows [10]:

$$\frac{\partial d}{\partial t}+\left\{\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}\right\}=-\frac{\partial d}{\partial t} \quad (1)$$

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left\{\frac{P^2}{H}\right\}+\frac{\partial}{\partial y}\left\{\frac{PQ}{H}\right\}+gH\,\frac{\partial \eta}{\partial x}+F_x=0 \quad (2)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left\{\frac{PQ}{H}\right\}+\frac{\partial}{\partial y}\left\{\frac{Q^2}{H}\right\}+gH\,\frac{\partial \eta}{\partial Y}+F_Y=0 \quad (3)$$

Whereas η is the water surface elevation (m), t is time (s), d is the water depth (m), P and Q are fluxes in the x and y directions (m3/s), f is the Coriolis force coefficient, H is the total water depth (m), and Fx and Fy are bottom friction forces in the x and y directions.

2.6 Probabilistic Tsunami Hazard Assessment (PTHA)

The simulation results from COMCOT will then be processed using a probabilistic method to assess tsunami hazards in the future. This method can also be referred to as PTHA (Probabilistic Tsunami Hazard Assessment), which is used to determine the level of risk for a certain area over a specific time frame. The PTHA method estimates the magnitude of an exceedance level of a tsunami hazard parameter as a probability function. The equation used to calculate the exceedance level value is as follows:

$$\lambda(H \geq h)=\sum_{i=1}^{n_s} \upsilon_i \sum_{j=1}^{n_m} P\left(H \geq h \backslash m_j\right) P\left(M_j=m_j\right) \quad (4)$$

Whereas H is the tsunami height from simulation results. h is the reference tsunami height determined (in this study, values ranging from 0 m to 15 m with a data interval of 0.1 m are used). n_s is the total number of scenarios. υ is the earthquake occurrence rate calculated using the Gutenberg-Richter equation. m is the total number of earthquake magnitudes used. P is the probability percentage of occurrence for a specific return period. Mj is the magnitude of the earthquake used.

2.7 Damage Probability

In the study of building vulnerability, apart from considering building conditions, another important parameter is damage probability. This damage probability is obtained through a fragility function develope based on observations of building damage and survival during the 2004 tsunami in Aceh as can be seen in equation utilized by [14].

$$P\,(x)=\phi\,\frac{(\ln x)-(\mu')}{\sigma'} \times 100\% \quad (5)$$

Whereas P(x) is cumulative probability of the damage. ϕ is the standardized normal (lognormal) distribution function. μ and σ are the mean and standard deviation of x. This fragility curve is a graph that depicts the relationship between the probability of building damage and tsunami depth. The fragility function is formulated in the standard lognormal distribution form, with a mean value (μ) of 2.99 and a standard deviation (σ) of 1.12. This lognormal distribution is used to model the variation in the probability of building damage with respect to tsunami depth.

2.8 Building Tsunami Vulnerability (BTV)

The Building Tsunami Vulnerability (BTV) method is used to assess the level of vulnerability to tsunamis and identify locations at high risk of such disasters. BTV facilitates the mapping of research locations into high, moderate, and low-risk categories [15]. There are three parameters used in BTV analysis: building conditions, inundation zones, and coastal defense. However, in this study, the coastal defense parameter is not used as there is no coastal protection in Citepus Sub-District. The calculation of building vulnerability will be performed using the equation utilized by [7] in Morocco.

$$BTV\ (\%)=\frac{\left(F_{c.b} \times F_{w,b}\right)+\left(F_{c,i} \times F_{w,i}\right)}{\sum_{k=1}^{2}((F_{c,max} \times F_w)k} \times 100\% \quad (5)$$

Whereas BTV represents building tsunami vulnerability for a specific return period. Fc,b is the classification factor of buildings based on building conditions. Fw,b is the weighting factor for building type with a value of two. Fc,i is the classification factor of building collapse based on damage probability for a specific return period. Fw,i is the weighting factor for building collapse probability with a value of one. Table 3 provides the BTV classification used [6] in Aceh.

Table 3. Factor of Building Type, Damage Probability, and BTV Classification

Factor of Building Type (Fc, b)		Factor of Damage Probability (Fc, i)		BTV Classification	
Building Type	Fc, b	P (xi)	Fc, i	BTV (%)	Classification
Wooden (1 Floor)	5	> 0.8	5	BTV ≥ 80	Very High
RC Building (1 Floor)	4	0.6 - 0.8	4	60 < BTV < 80	High
RC Building (2 Floor)	3	0.4 - 0.599	3	40 < BTV < 60	Medium
RC Building (3 Floor)	2	0.2 - 0.399	2	20 < BTV < 40	Low
RC Building (> 3 Floor)	1	0.001 - 0.199	1	BTV < 20	None
		0	0		

3 Result and Discussion

3.1 Stochastic Slip

This research uses the slipreal program to obtain the initial condition data required to understand the early occurrence of a tsunami from its source location. These values will result in an output known as dislocation, which refers to the displacement or movement of the ground due to seismic activity or an earthquake. In **Figure 5**, there is a stochastic slip modeling depicting an earthquake with a magnitude of 9.0 in scenario 3. This scenario was chosen because it yields the most significant maximum elevation when on land. On the grid with a value of 54.243 meters, the largest dislocation is generated using the slipreal method.

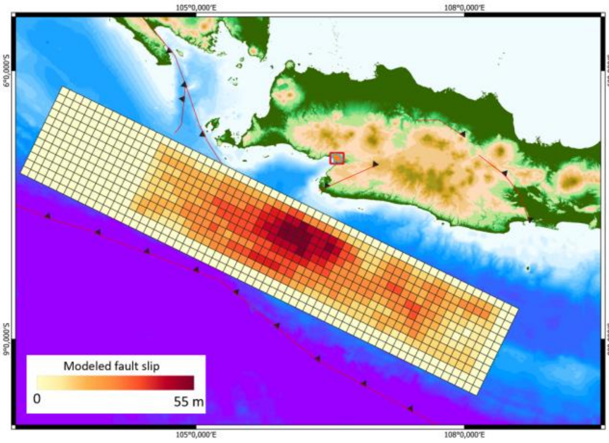

Fig 5. Slip Distribution with Mw 9.0

The sum of slip values must not exceed the energy limit set for the predetermined moment magnitude. For this research, determining the limit of sea floor uplift is not possible, thus the energy limit (M_0) established by [16] for each moment magnitude is utilized. Consequently, the slip real program is employed to obtain slip values that have been studied by [11].

3.2 Initial Condition

This initial condition serves as the starting point for stochastic slip modeling simulations. In this modeling, earthquake magnitudes ranging from 8.5 to 9 Mw, with a 0.1 interval, are employed. Each earthquake magnitude is tested with 20 different scenarios, each having diverse slip values. As a result, a total of 120 scenarios are utilized in this study. **Figure 6** displays two examples of the initial conditions used in this research, namely scenario 3 and scenario 4. The differences observed in these two figures stem from the variation in slip values generated from each respective scenario. In this study, the focus is on comparing the initial tsunami generation conditions among these scenarios to comprehend how they impact the occurrence of a tsunami from earthquakes of varying magnitudes.

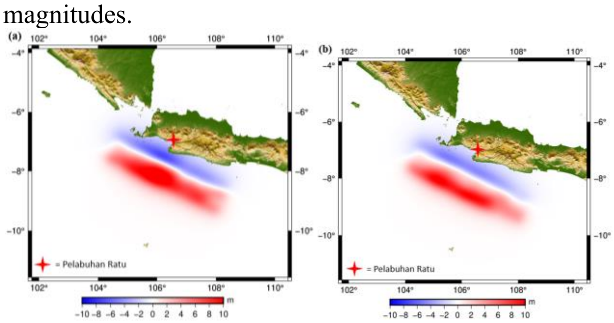

Fig. 6. Initial Condition Mw 9.0: (a) scenario 3 and (b) scenario 4

Water surface elevation is depicted in blue for descending water levels (negative values) and in red for rising water levels (positive values). The fault utilized in this simulation is a reverse fault. In this type of fault, the hanging wall (the side that moves upward) moves upward relative to the footwall (the side that remains stationary). To determine the fault type, you can refer to the USGS website, where faults are represented in a beachball diagram. The variation in scenario outcomes explains that color intensity is based on slip values that must not exceed the energy limit for the predetermined moment magnitude. Fading colors on the fault indicate a larger area compared to the more intense colors. This indicates that earthquakes are stochastic in nature with complex slip distribution characteristics.

3.3 Tsunami Wave Propagation Process

After obtaining the initial tsunami conditions, the simulation results from COMCOT can also demonstrate the process of tsunami wave propagation. Propagation itself refers to the spread or propagation of tsunami waves from the initial wave generation to the Citepus Sub-District. The tsunami wave propagation process illustrates the movement of water over a 2-hour period (7200 seconds) with a 3-minute interval (180 seconds). This propagation of the tsunami wave is focused on the earthquake with a magnitude of 9.0 Mw in scenario 3 for both layer 1 and layer 5. The propagation process in layer 1 serves as the initial condition of the tsunami's occurrence, originating from the seismic source (fault), as shown in **Figure 7**. The propagation process in layer 5 depicts the movement of water onto the land in Citepus Sub-District, as illustrated in **Figure 8**.

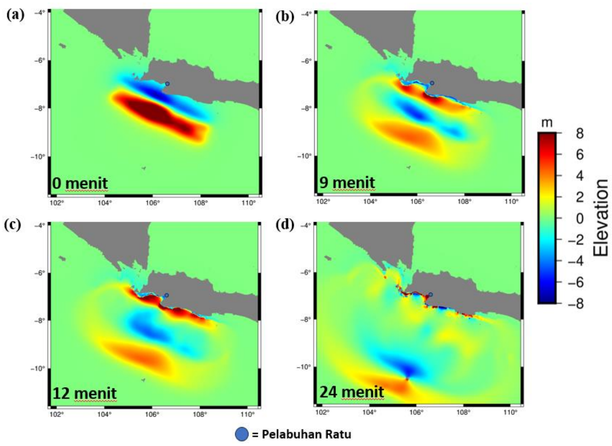

Fig. 7. Tsunami Propagation Process in layer 1 for: a) t = 0 minute, b) t=9 minutes, c) t=12 minutes, and d) t= 24 minutes

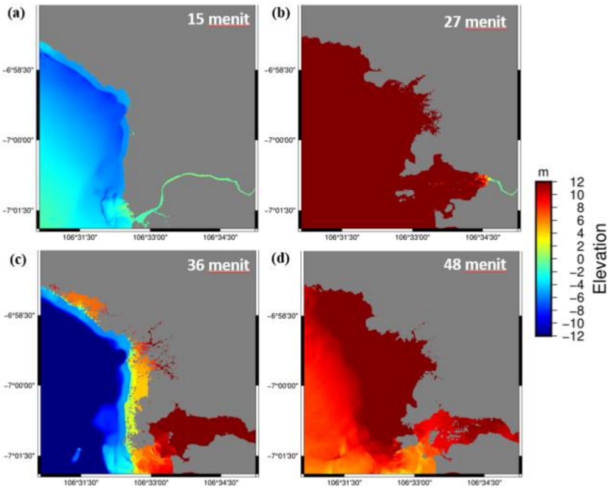

Fig 8. Tsunami Propagation Process in layer 5 for: a) t=15 minutes, b) t=27 minutes, c) t=36 minutes, and d) t= 48 minutes

3.4 Probabilistic Tsunami Hazard Assessment

Probabilistic Tsunami Hazard Assessment (PTHA) is used to calculate the likelihood of various tsunami wave heights occurring at different earthquake magnitudes and to determine the annual rate (λ) for obtaining recurrence periods. In the PTHA analysis phase, several critical data points are needed, such as tsunami wave height values for each average magnitude corresponding to each building, obtained from COMCOT simulation results. Values a and b utilize three scenarios for a (seismic activity level) and b (ratio of large to small earthquake occurrences) to assess their influence on recurrence period values. The values of a and b are sourced from [17] because if the values of a and b from fragility curve in this case, the comparison values of a and b is too far. The value of a and b based on [17] also not accurate, so it have to readjust the value of a and b. The β value represents an uncertainty consideration that cannot be deterministically predicted or linked to natural variations within a system, related to tsunami simulation and source uncertainty. The β value used, 0.7, is an average value based on [9].

The PTHA calculation that will be illustrated is for the location of a minimarket (Alfamart) situated at Raya Citepus Street Km.4, Rt.003 Citepus, Pelabuhan Ratu, Sukabumi Sub-District, West Java, 43364, as shown in **Figure 9**. This building is selected due to its intended use as a temporary evacuation site, boasting a height of 3 floors and a location at the center of a settlement, as depicted in **Figure 10**.

Fig. 9. Temporary Evacuation Building Plan

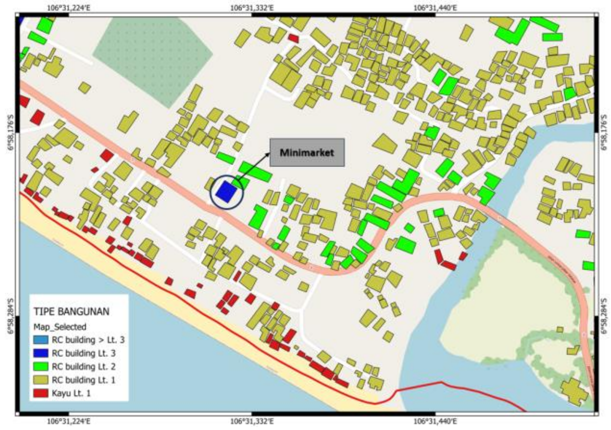

Fig. 10. Location of Mini Market Observation Point

Furthermore, hazard curves are generated for the existing temporary evacuation building based on the potential tsunami wave heights, and comparisons are made based on the predefined variations of a and b values. The aim of comparing these a and b values is to gauge their sensitivity and influence on both λ and the recurrence period of a tsunami. These curves compare values such as planned water heights, annual rate of exceedance (λ), and return period (t), as illustrated in **Figure 11**.

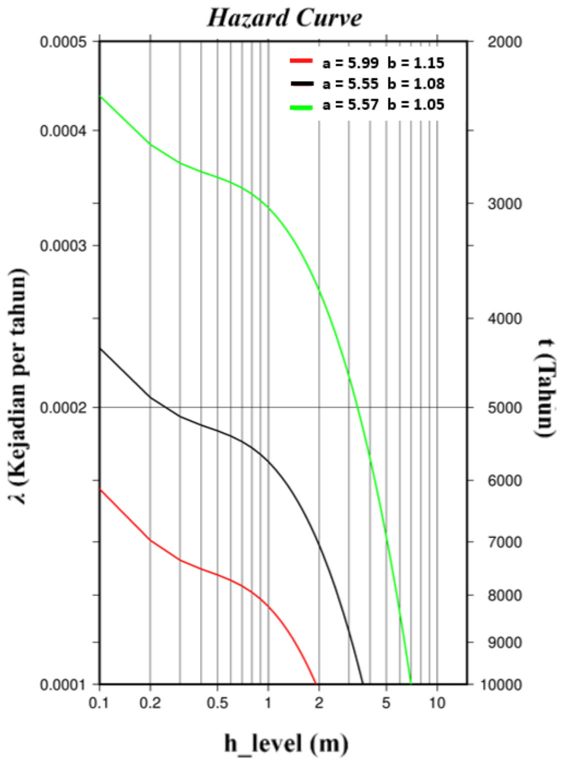

Fig. 11. Hazard Curve Based on Differences in Values of a and b

This demonstrates that the values of a and b indeed bring about significant changes in the recurrence period value. Furthermore, the non-linear nature of the graph is attributed to the pronounced influence of the varying magnitudes' interrelations on the graph's outcomes.

3.5 Damage Probability

Damage probability aims to assess the likelihood of structural damage to buildings caused by a tsunami disaster using the inundation depth approach. In this approach, the tsunami height at each building location is a crucial factor in calculating the damage probability. The calculation of damage probability is carried out using The Standardized Lognormal Distribution Functions, where the input data utilized are the mean (μ) and standard deviation (σ). This data has been obtained from previous research conducted by [14]. This approach allows for estimating to what extent the inundation depth can impact structural damage to buildings, providing vital information for tsunami disaster mitigation efforts.

Table 4 contains the results of the calculation of inundation depths obtained from the return period analysis with recurrence periods of 10,000 years and 30,000 years. These inundation depths have been divided into 6 different classes based on research conducted by [6]. This information is used to explain the potential level of building damage that may occur due to the inundation depths at each building location during the 10,000-year and 30,000-year recurrence periods. These recurrence periods is not significance in this case but used based on value of a and b that adjusted from [17].

Table 4. Damage Probability Based on the Number of Buildings

Damage Probability	Factor of Damage Probability (Fc, i)	Vulnerability	10000 Tahun		30000 Tahun	
			Quantity (Unit)	Quantity (%)	Quantity (Unit)	Quantity (%)
> 0.8	5	Very high	349	8.03	1164	26.80
0.6 - 0.8	4	High	200	4.60	42	0.97
0.4 - 0.599	3	Normal	173	3.98	50	1.15
0.2 - 0.399	2	Low	147	3.38	56	1.29
0.001 - 0.199	1	Very low	431	9.92	422	9.71
0	0	Not Affected	3044	70.07	2610	60.08
	Total		4344	100	4344	100

Based on the data provided in Table 4, it can be observed that there are buildings classified based on the probability of damage for the 10,000 years and 30,000 years recurrence periods. For the 10,000 years recurrence period, there are 3,044 buildings with a probability of damage level of 0, whereas for the 30,000 years recurrence period, there are 2,610 buildings with a probability of damage level of 0. From this fact, it can be inferred that the area is not affected by tsunami waves due to its high topography. There is a decrease in the percentage of buildings with a probability of damage level of 0 from 70.07% to 60.08%, indicating an increase in building damage. Furthermore, for the 10,000 years recurrence period, there are 349 buildings, while for the 30,000 years recurrence period, there are 1,164 buildings with a probability of damage level of 5. This indicates that buildings located at these points have a high probability of experiencing maximum impact based on inundation depth.

3.6 Building Tsunami Vulnerability

The Building Tsunami Vulnerability (BTV) analysis can be conducted using the equations used in the BTV calculation based on [7]. The data utilized in the calculation process consists of building condition classes obtained from a survey of building locations. Factor of Damage Probability (Fc, i) or the inundation classes obtained from the damage probability calculation, as shown in **Table 4**, are also incorporated so it can be used to calculate BTV. The outcomes of the Building Tsunami Vulnerability calculation for each building in Kecamatan Citepus can be observed in **Table 5**.

Table 5. Calculation of BTV Class

BTV Class	BTV (%)	Classification	10000 Years		30000 Years	
			Quantity (Unit)	Quantity (%)	Quantity (Unit)	Quantity (%)
4	BTV ≥ 80	Very High	536	12.34	1109	25.53
3	60 < BTV < 80	High	694	15.98	575	13.24
2	40 < BTV < 60	Medium	68	1.57	47	1.08

1	20 < BTV < 40	Low	2	0.05	3	0.07
0	BTV < 20	None	3044	70.07	2610	60.08
Total			4344	100	4344	100

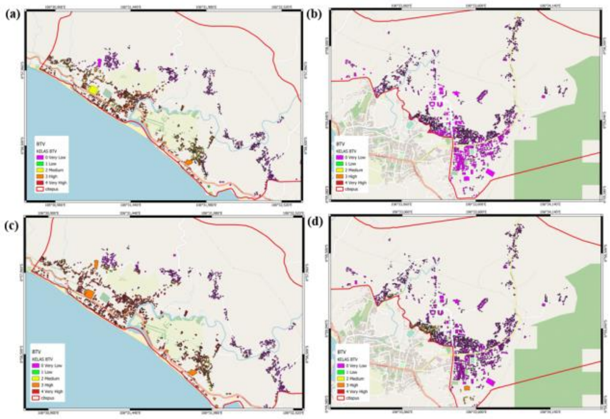

Fig. 12. Map of Building Vulnerability Distribution Based on **a)** Left Side and **b)** Right Side Recurrence Period of 10000 Years, **c)** Left Side and **d)** Right Side Recurrence Period of 30000 Years

The results indicate that for the 10,000-year recurrence period, there are 536 buildings categorized as having very high vulnerability, which constitutes 12.34% of the total buildings. This implies that these buildings have a significant potential to experience damage exceeding 80%. On the other hand, there are also buildings classified with very low BTV classes, totaling 3,044 buildings or 70.07%. This indicates that these buildings have a higher level of safety and a low potential for damage, less than 20%. Furthermore, for the 30,000-year recurrence period, the BTV values exhibit an increase in terms of vulnerability. In the very high vulnerability category, there are 1,109 buildings, comprising 25.53% of the total buildings. This represents a 13.19% increase, indicating a higher potential for significant damage in the event of a tsunami. A decrease is observed in the very low vulnerability category due to the increased tsunami height with longer recurrence periods, leading to more extensive damage.

4 Conclusion

The initial conditions for generating tsunami waves based on stochastic analysis involve slip modeling on faults to determine slip displacements during earthquakes. In this study, 20 scenarios per magnitude range from 8.5 to 9.0 Mw with a 0.1 interval were used. The slip values are obtained using the slipreal program developed by Mai and Beroza in 2002.

The potential hazard arising from tsunamis in Citepus village is quite high due to the earthquakes along the Sunda Megathrust fault zone occurring right in front of the Pelabuhan Ratu area. The results of Probabilistic Tsunami Hazard Assessment (PTHA) analysis provide information about tsunami heights at buildings over specified return periods. There is a possibility of maximum tsunami height reaching 14.85 meters within a 10,000-year period and 51.77 meters within a 30,000-year period.

In determining the Building Tsunami Vulnerability (BTV), data such as inundation depth (tsunami height) classes from simulations and building classes from surveys are essential. These values classify buildings and determine which ones can be used as evacuation shelters. According to this study, the 3-story concrete-built minimarket is identified as a potential evacuation shelter within a 10,000-year return period. This minimarket, located along the coastline within a residential area, proves effective for evacuation purposes.

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