Tsunami Evacuation Route Planning Research in Pelabuhan Ratu Village, Sukabumi Regency

Rizky Hamidah [1,*], Teuku Mahlil [2], Cut Salsabila Putriansyah [3], Melati Ayuning Putri [4], Muhammad Raihan Prawiranegara [5], Nurminda Safa Aufasani [6], and Teuku Muhammad Rasyif [7]

{ rizkyhamidah07@gmail.com [1], tmahlil.civ@gmail.com [2], cutsalsa1104@gmail.com [3], imelati1999@gmail.com [4], raihanprawira@gmail.com [5], aufasanisafa@gmail.com [6], teuku.mrasyif@universitaspertamina.ac.id [7]}
Faculty of Infrastructure Planning, Universitas Pertamina, Kebayoran Lama, South Jakarta 12220, Indonesia [1, 2, 3, 4, 5, 6, 7]

*Corresponding Author

Abstract. Pelabuhan Ratu Village lied on the coast of Sukabumi, southern part of West Java with a relatively high level of geological hazard due to the active Cimandiri fault. The fault has an upward fault mechanism that put the village in risk of tsunami. This research has a purpose to reduce tsunami impact to people of the areas by planning scenario for tsunami evacuation routes and escape building. The evacuation route and escape building scenario was developed by referring to tsunami inundation modeling scenario due to the M8.5 earthquake [12]. The evacuation routes scenario was carried out based on the ability of weak people to run, which is 3.2 km/hour, with evacuation time is 13 minutes after tsunami warning [2]. This research produced a design of four evacuation routes with distance between 453 until 607 m and one escape building with capacity for around 2000 people

Keywords: Coastal, Disaster mitigation, Escape building, Evacuation route, Tsunami.

1 Introduction

Based on UU No. 24 Tahun 2007, it is stated that natural disasters are a series of events caused by nature and have an impact on human life, including earthquakes, tsunamis, volcanic eruptions, floods, droughts, hurricanes, and landslides. The arrival of natural disasters that cannot be predicted with certainty can bring losses to the affected communities, to the extent that they can take human lives. Therefore, to minimize the impact of the disaster, mitigation scenarios are needed through a multi-disciplinary approach.

Mitigation is defined as an effort to reduce and prevent the risk of loss of life and property through both structural and non-structural approaches [5]. Structural mitigation is an effort to reduce disaster risk through physical development and technical engineering of disaster-resistant

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buildings, while non-structural mitigation is an effort to reduce non-physical disaster risks such as policies, community empowerment, institutional strengthening, awareness [10].

Indonesia is an archipelagic country which is geographically located on the Eurasian, Indian-Australian and Pacific plates. Due to its geographical location, Indonesia is a country that is prone to tectonic earthquakes and volcanoes. Both of these activities have potential to trigger tsunami waves. One of the causes of the tsunami disaster is due to a tectonic shift under the sea caused by earthquake at shallow center along the subduction area. The plates of the earth's crust are pushed up and down giving potential energy to the water mass so that there is a drastic change in sea level in the affected area [13].

Several major tsunamis have occurred in Indonesia including Indian Ocean Tsunami in Aceh (2004), Pangandaran tsunami (2006) and Palu tsunami (2018). Those tsunami event had claimed hundreds to thousands of lives. In addition to casualties, the tsunami can also cause many other damages such as construction failures, changes in land surface, and sea level intrusion. One of the areas that are prone to tsunami disasters is the coastal area. Sunarto dan Marfai [11], stated that areas in Indonesia that are prone to the threat of a tsunami were including the west coast of Sumatra, the south coast of Java to the east of Bali and to the north include the coastal areas of Papua and Sulawesi. It definesthat Sukabumi area to have a relatively high level of geological hazard. One of the efforts to reduce the risk of a tsunami disaster that may occur in the future is to prepare evacuation routes and tsunami escape buildings. An evacuation route is a pathway to direct people to a safe place when a natural disaster such as tsunami occurs. Good evacuation routes can be used with large numbers of people and in the shortest amount of time [4]. This study aims to plan tsunami evacuation route and tsunami escape building in Pelabuhan Ratu Village area, Sukabumi Regency based on information of tsunami inundation heights [12].

2 Research Methods

Fig. 1. Pelabuhan Ratu Village
Source: http://kebudayaan.kemdikbud.go.id/

The research location is Pelabuhan Ratu Village. Geographically Pelabuhan Ratu Village is located at coordinates 6º58'54.44" South Latitude and 106º32'45.87" East Longitude. Administratively, Pelabuhan Ratu Village is located in Pelabuhan Ratu District, Sukabumi Regency, West Java. The area of this research review is 1350 m2 with a population of 31,308 people. The Pelabuhan Ratu Village area is an area consisting of residential houses, markets, offices, schools, and is a coastal tourist area so that there are several lodging places.

This research uses secondary data obtained from related agencies and relevant studies such as research from National Disaster Management Agency (Badan Nasional Penanggulanan Bencana, BNPB) and Tanioka, et al. (2011). The data collection technique in this research uses data collection methods in the form of statistical data sets, this method is to collect data by using datasets from previous research, such as geographical data sourced from google earth, road network data obtained from DEMNAS, data on the speed of people during evacuation which refers to publications from the Badan Nasional Penanggulangan Bencana (2013) and inundation map data [12].

a. Evacuation Route Design
Based on the book Planning a Temporary Tsunami Evacuation Site of the National Disaster Management Agency (2013), tsunami evacuation route planning is analyzed based on the speed of the weakest people when evacuating. By paying attention to the time of arrival of the tsunami and the magnitude of the weakest person's speed, it can be predicted the distance that can be traveled to the location of the temporary evacuation site (TES) and the best evacuation route to a location that is safe from tsunami inundation. The speed value of weak people walking set by BNPB is 3.22 km/h.

Table 1. Walking Ability (Weak)

Tsunami Estimated Time of Arrival	Pace of People Walk (Weak)	Travel Distance to TES	Maximum Distance between 2 TES Locations
2 hours	3.22 km/hours	6.44 km	12.87 km
30 minutes	3.22 km/hours	1.61 km	3.22 km
15 minutes	3.22 km/hours	804.5 m	1.61 km

To determine the efficient distance in evacuation, the following equation is used:

$$S = v \text{ x } t \quad (1)$$

Where:
S= Minimum evacuation distance (m)
v= Speed during evacuation (m/min)
t= Time needed in evacuation (minutes)

b. Escape Building Design

TES planning begins with determining the height of the TES, calculating the working load and determining the initial dimensions for structural components such as beams, columns, and plates. Planning continued with modeling in the SAP 2000 application to determine the structural response to the working load and find out the number of reinforcements needed in each component of the structure. The regulations used as the basis for the design are SNI 1726:2019, SNI 2847:2019, SNI 1727:2020, Indonesian Loading Regulations for Buildings (1987), and BNPB Tsunami Temporary Evacuation Site Planning Guidelines (TES).

1. Determination of Temporary Evacuation Site Height (TES)

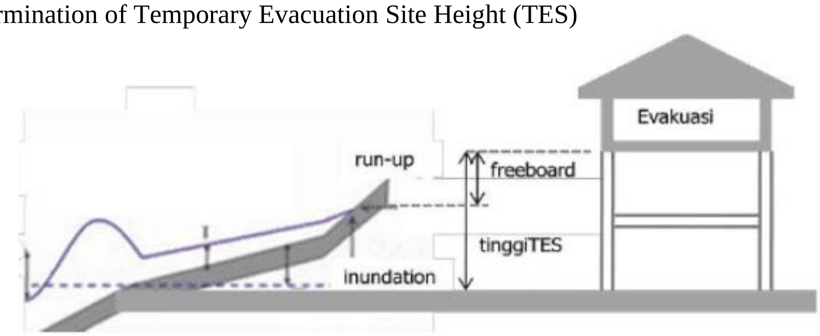


Fig. 2. Height of Escape Building

The calculation of altitude in TES planning is based on Guidelines 2 of the BNPB Tsunami Temporary Evacuation Site Planning (TES) with provisions based on the inundation height and freeboard height. With the equation used as follows:

$$T = Ti + Freeboard \quad (2)$$

Where:
Freeboard = 3 + 30%Ti
T = TES height from ground level (m)
Ti = height of inundation of tsunami wave (m)

2. Combination of Loading on Structures

Based on SNI 1727:2020 and SNI 1726:2019, the combination of loading used in the calculation is as follows:

1. 1,4 D
2. 1,2 D + 1,6 L + 0,5 (L_r atau R)
3. 1,2 D + 1,6 (L_r atau R) + (L atau 0,5 W)
4. 1,2 D + 1,0 W + L + 0,5 ($L_{r\ atau\ R}$)
5. 1,2 D $\pm$ 1 E + L

Where:

D = Dead load (kN)
L = Burden of living (kN)
R = Rain load (kN)
W = Wind load (kN)
Lr = Roof live load (kN)
E = Earthquake load (kN)

3. Structural Analysis

Earthquake load analysis using spectrum response analysis based on the provisions of SNI 1726:2019, the data needed for spectrum response analysis based on SNI 1726:2019 are as follows:

3.1 Determination of earthquake acceleration parameters

The parameters of earthquake acceleration in short periods and 1-second periods can be calculated based on **Figures 15 and 16** in SNI 1726:2019.

3.2 Determination of Spectral Response Parameters

The spectral response parameters in short periods and periods of 1 second can be calculated using the following equation:

$$S_{MS} = F_a \times S_s \quad (3)$$

$$S_{M1} = F_v \times S_1 \quad (4)$$

Where the site coefficient values can be seen in tables 6 and 7 of SNI 1726:2019 based on the type of site class and earthquake acceleration parameters.

3.3 Design Spectral Acceleration Parameters

The spectral acceleration parameters of the design can be calculated on the basis of equations 5 and 6 as follows:

$$S_{DS} = \frac{2}{3} S_{MS} \quad (5)$$

$$S_{D1} = \frac{2}{3} S_{M1} \quad (6)$$

4. Beam Design

The calculation of the minimum height and width of the beam is as follows:

H min $= \frac{L}{18,5} \text{x} (0,4 + \frac{fy}{700})$

B min $= \frac{2}{3} \text{x}$ H min

The minimum reinforcement area requirements of the beam must meet the requirements under SNI 2847:2019 as follows:

$$As_{min} = \frac{1,4}{fy} b_w d \quad (7)$$

5. Column Design

   The dimensions of the column to be planned are cylindrical columns with calculations based on SNI 2847:2019. The equation used is as follows:

   $$Ag = \frac{Pu}{0,25\ x\ f'c}$$

   Information:

   Ag = Total cross-sectional area of the column (mm2)

   Pu = Axial load acting on the structure (kN)

   f'c = Compresive strength for design (MPa)

3 Results and Discussion

a. Inundation

   Based on inundation modeling using the M8.5 earthquake scenario, the maximum inundation distance in the territory of Pelabuhan Ratu Village can reach a distance of up to 800 m with a height of up to 10 meters [12]. With this height and distance, it is certain that the Pelabuhan Ratu Village area will sink in the event of a tsunami disaster. The inundation map in the Pelabuhan Ratu Area is shown in **Figure 3**.

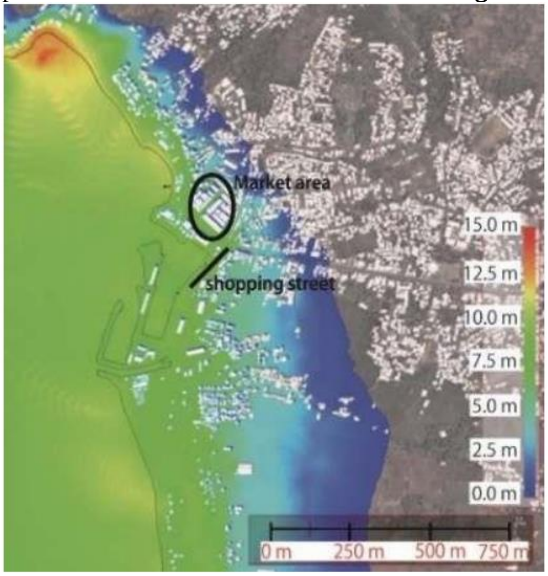


Fig. 3. Inundation Modelling of Pelabuhan Ratu Village [12].

b. Pelabuhann Ratu Village Tsunami Evacuation Route

Designing a tsunami evacuation route map requires data such as inundation distance, regional topography, and road network map for the Pelabuhan Ratu Village area. The determination of evacuation routes is reviewed based on the inundation distance, topographic map of the territory, road dimensions, and travel time in the evacuation. Pelabuhan Ratu Village Tsunami Evacuation Route

Fig. 4. Topographic Maps and Inundation Modeling

According to the technical manual for designing the structure of the tsunami temporary evacuation site (TES), the time needed for evacuation is 15 minutes after the tsunami warning alarm that sounds a maximum of 5 minutes after the earthquake. The ability of weak people to run during evacuation is 3.22 km/h [1]. So that the speed and time become a reference to get the minimum evacuation distance. There is a potential for residents of the coastal areas of the queen harbour to remain concerned with valuables and the use of private vehicles that will cause bottlenecks, assuming a 2-minutes reduction in emergency time to magnify the potential safety of residents around the coast.

The following is a calculation of evacuation mileage based on the speed at which weak people walk. The speed of a weak person walking is changed from km/h to m/min:

$$\frac{3{,}22 \times 1000\, m}{60\, menit} = 53{,}33\, m/menit$$

Determining evacuation mileage according to equation 1

$s = v \times t = 53{,}33 \times 13 = 693$ m

The safe distance of tsunami inundation in Pelabuhan Ratu Village Area is 800 m [12]. Meanwhile, according to calculations, the ability of weak people to run within a period of 13 minutes the evacuation mileage that can be reached is 693 m. Based on calculations and inundation maps, a scenario is made with 3 evacuation routes that have passed the safe inundation limit as shown in **Figures 3 and 4.**

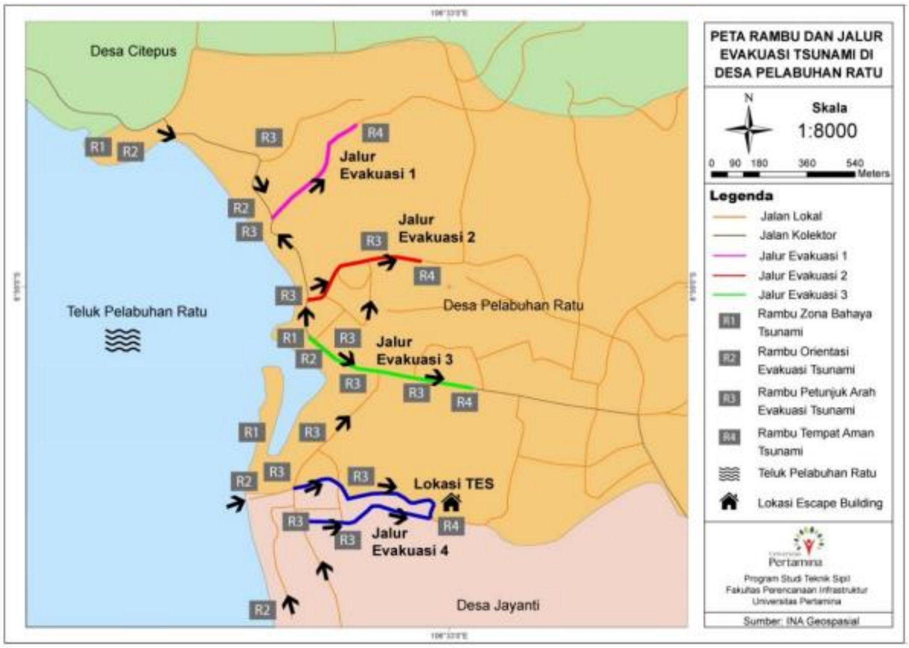


Fig. 5. Evacuation Maps and Signs

a) Route 1

Route 1 is in the upper coastal area and includes Cipatu Buran Road. Lane 1 is a type of secondary local road that has a road width of ± 5.3 m with road conditions around dense residential areas. The inundation coverage in the area of line 1 has a length of ±238 m with an average road slope of 7.1°, so the path to the recommended safe place is 453 m long with an estimated travel time of 8 minutes 49 seconds.

b) Route 2

Line 2 is in the central coastal area and includes Jalan Sirgalih and Jalan Nasional 3. Line 2 is a type of secondary local road that has a road width of ± 5.7 m with road conditions in the form of small shophouses, settlements, and there is a type B terminal±.

c) Route 3

Line 3 covers Jalan Pelita – Cipatugaran and Jalan Silawangi. Line 3 is a type of secondary collector road that has a road width of ± 7.3 m with road conditions around shopping centers, restaurants, and shops. The inundation coverage in the area of line 3 has a length of ±383 m, so the path to the recommended safe place is 456 m long with an estimated travel time of 11 minutes 19 seconds. In addition, because the inundation coverage on line 3 is longer than lines 1 and 2, a temporary evacuation site is also recommended in the form of a BJB Bank building. The building is able to accommodate about 400 people.

c. Temporary Evacuation Site Design

For the southern coastal area of Pelabuhan Ratu Village which is around line 3, a temporary evacuation site is needed. Line 4 is a type of secondary local road that has a road width of ± 5.04 m with road conditions surrounded by dense residential areas. The construction of a temporary evacuation site was caused because the area is an area with an inundation height of 10 meters and a distance of 800 meters, so it is not possible to plan an evacuation route because the distance is too far to go to the safe zone.

The temporary evacuation point has an evacuation distance of 607.15 m with an estimated distance of 11 minutes 38 seconds. The temporary evacuation site consists of 3 floors with a roof floor equipped with a helipad having the following specifications:

Building area 1800 m2
Building Material = Reinforced concrete
Concrete Quality = f'c 30 Mpa
Steel Quality = BJTP24 and BJTD40

1. TES Height Calculation

   Based on **Figure 3**, at the planning point of TES the inundation height reaches 2.5 meters. So, the calculation of the height of TES from the ground level is as follows:

   $T = 2.5 + (3 + 30\% \ x \ 2{,}5)$

   $T = 6.25 \ meter$

2. Thus, the minimum height of TES is 6.25 meters. To facilitate the construction process and other calculations, a TES height of 6.5 meters from the ground level is used Structural Analysis Using Earthquake Response Spectrum

   Earthquake response spectrum is calculated with equation 3 to equation 6 with the following data and calculation results [7]:

   Location : Pelabuhan Ratu Village, Sukabumi Regency
   Coordinates : -6.991576, 106.545679
   Site Classification : Medium Soil (SD)

   S_s = 2,5 g
   S_1 = 1 g
   S_{MS} = 2,5 g
   S_{M1} = 1,7 g
   S_{DS} = 1,667 g
   S_{D1} = 1,133 g
   T_L = 20 Second

   The following is the graph of the spectrum response of Pelabuhan Ratu Village

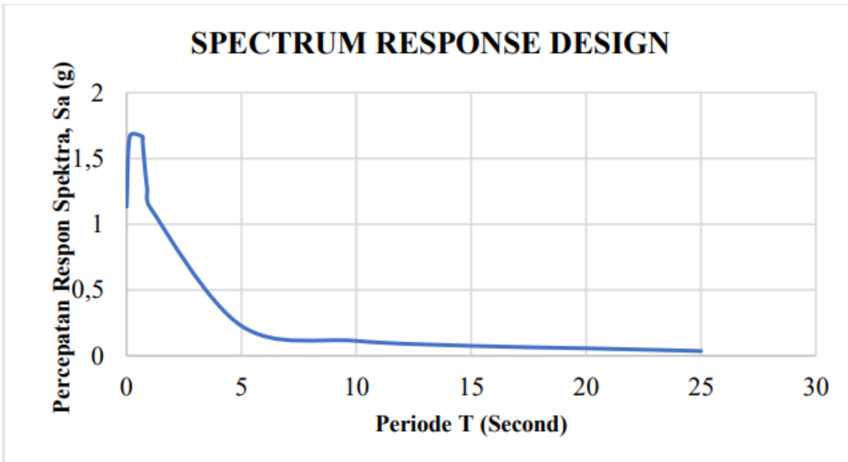


Fig. 6. Spectrum Response Design

3. Beam Design
   Based on the calculation of the preliminary design of the beam, the dimensions of the beam used are as follows:
   1. Main Beam 1: 450 x 650 mm
   2. Main Beam 2: 700 x 750 mm

   After conducting an analysis using the SAP200 auxiliary program, it was found that the area of the necessary reinforcement would be used to determine the number of reinforcements used in the planning. Longitudinal reinforcement uses a diameter of 25 mm and bending reinforcement uses a diameter of 12 mm.

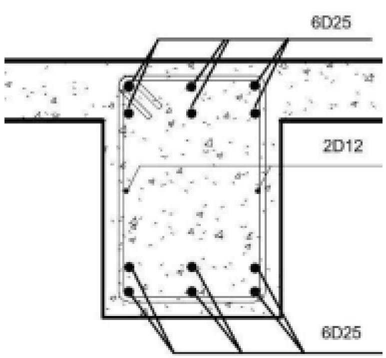


Fig. 7. Quarter Area of Main Beam 1

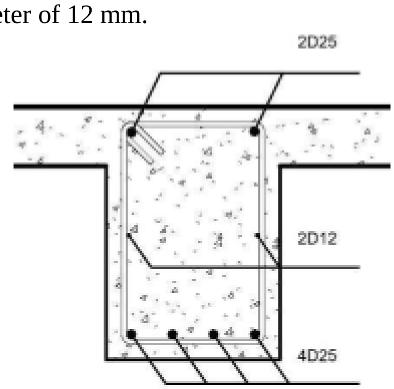
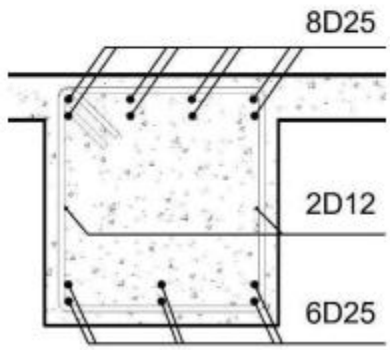


Fig. 8. Half Area of Main Beam 1



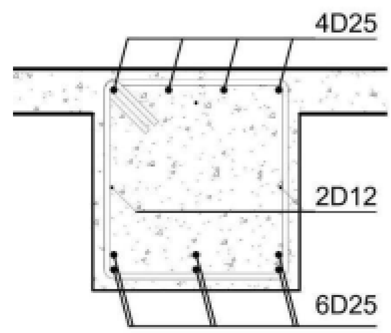
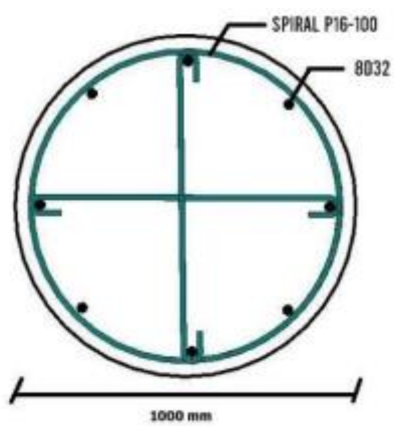


Fig. 9. Quarter Area of Main Beam 1 **Fig. 10.** Half Area of Main Beam 2

4. Column Design
   After preliminary design is done in the column. Thus, the dimensions of the columns used are cylindrical columns with a diameter of 1000 mm and 11000 mm. From the calculation results, the reinforcement used in column 1 was obtained, namely the main reinforcement 8D32 and the bending reinforcement D16-100. In column 2, the main reinforcement used is 15D32 and bending reinforcement D16-150.



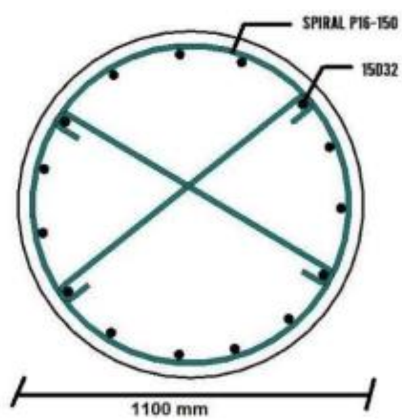


Fig. 11. Column 1 **Fig. 12.** Column 2

The capacity and area of the temporary evacuation site that has been taken into account can then be used to determine the design of the building cementation evacuation site planning guidelines (TES) [2]. The design of the building that has been planned is as follows.

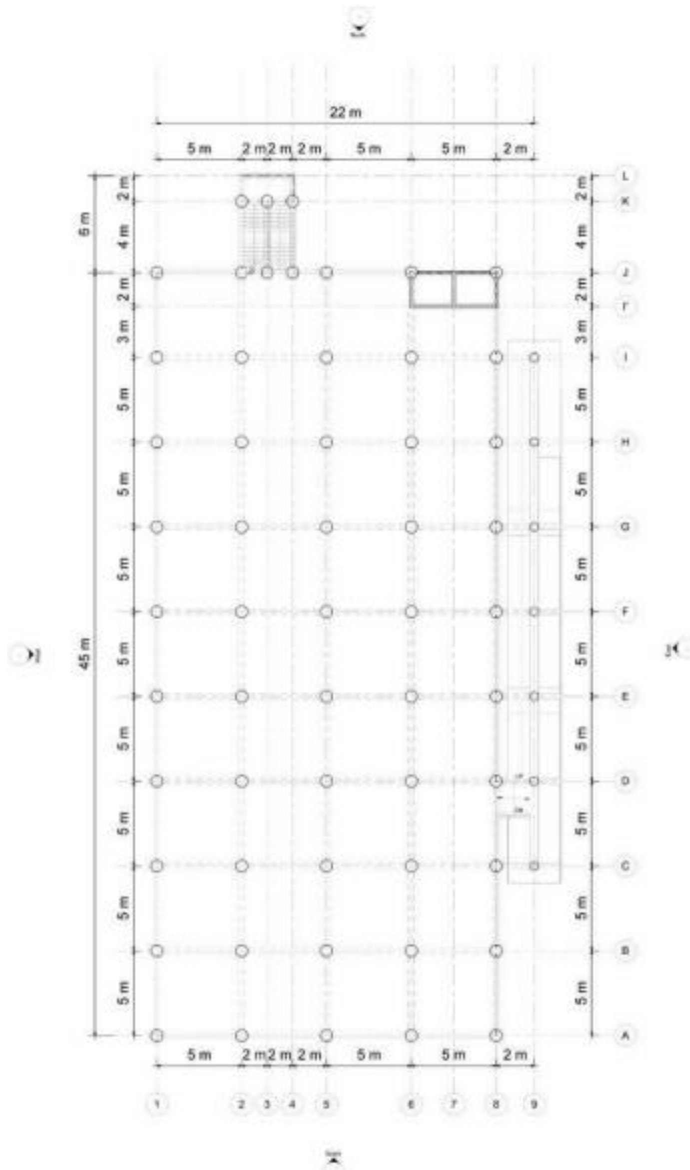


Fig. 13. Building Plan

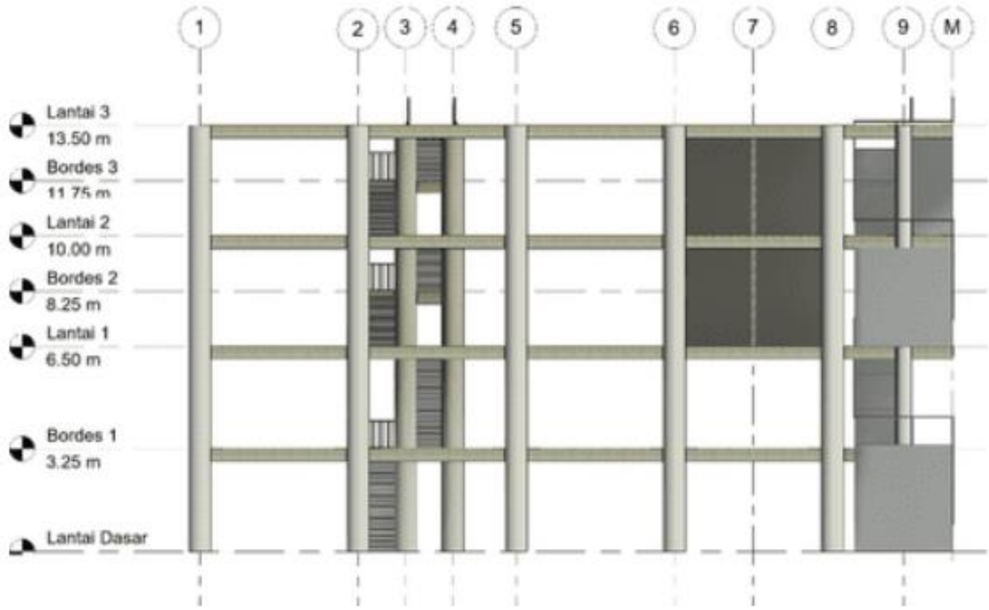


Fig. 14. Front View

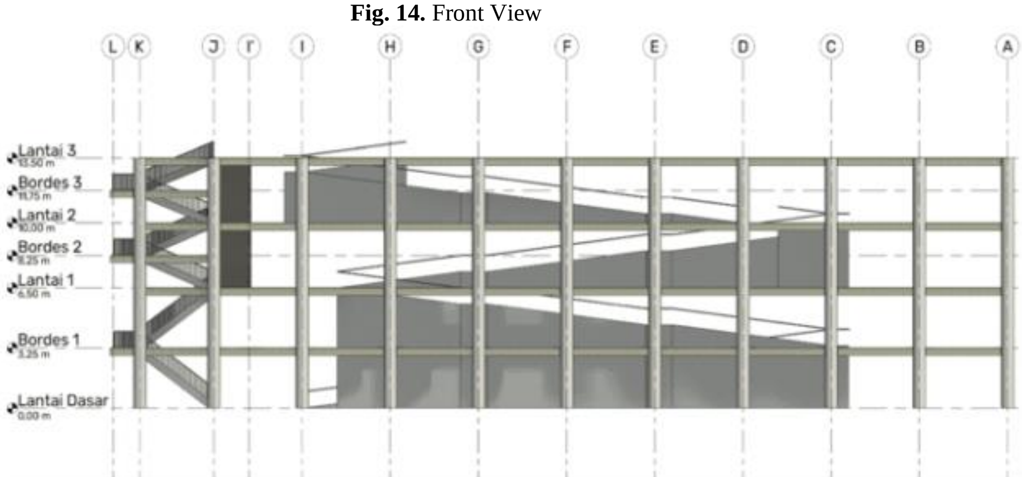


Fig. 15. Side View

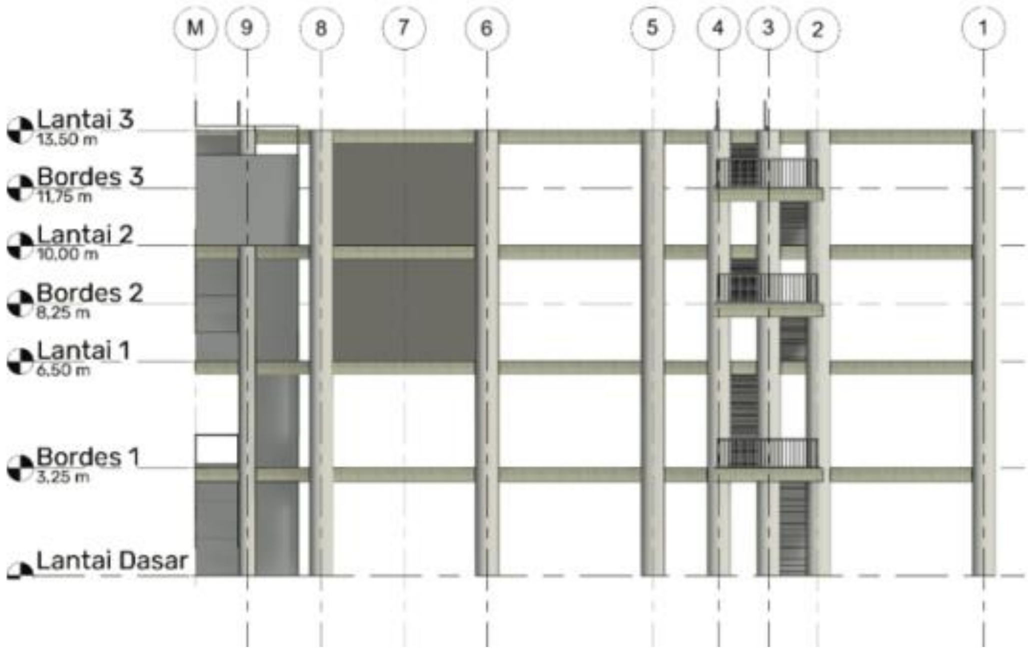


Fig. 16. Back View

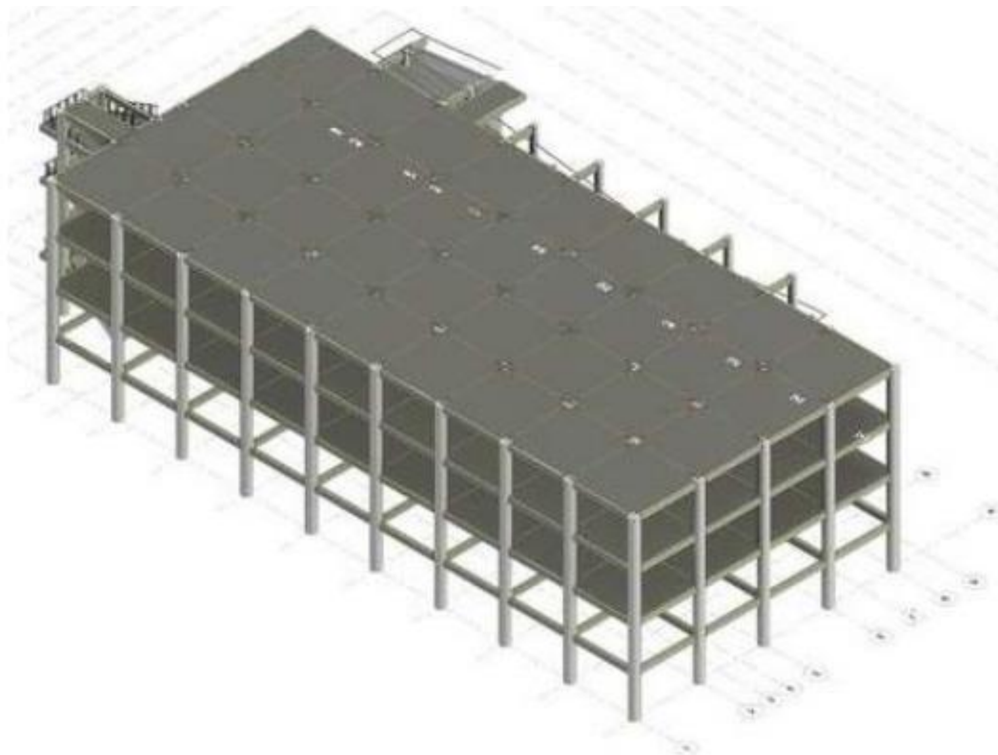


Fig. 17. 3D Design of Escape Building

4 Conclusion

Based on the results of the research that has been done, several conclusions can be obtained. Inundation modeling using the M8.5 earthquake scenario, shows that the maximum inundation distance in the Pelabuhan Ratu Village area can reach distance of up to 825 m with a height of up to 10 meters [12]. On the topographic map and inundation modeling, it is shown that the three evacuation planning routes have passed the inundation zone and the distance of the evacuation route does not exceed the calculated evacuation distance of 693 m so that the three routes are safe to use for evacuation routes. For the lower coastal area, an escape building is needed as an evacuation site because the inundation zone is too wide with a depth of up to 10 m, it is not possible to plan an evacuation route. For the lower coastal areas, a temporary evacuation site is needed as an evacuation site because the inundation zone is too wide with a depth of up to 10 m. Evacuation building design uses BNPB's evacuation building design guidelines which are adjusted to the 1987 PPURG loading regulations guidelines, SNI 2847-2019 structural concrete requirements, and SNI earthquake resistant building design.

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