Are vertical evacuation buildings in Banda Aceh meeting the building standards?

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Abstract. The tsunami vertical evacuation buildings in Banda Aceh were built after tsunami in 2004. The buildings were intended as one of the mitigation strategies for the community that live in the tsunami prone zone area. The buildings should be designed as a robust structure that can resist the earthquake and tsunami impact. Previously, there were no national standard for the design of tsunami resistant structure. The state of damage buildings that had been considered was only based on the result of an earthquake impact, which include the ground shaking, soil failures, and surface fault ruptures. As the Standard in Indonesia did not cover the tsunami load, it is important to review the capability of the existing vertical evacuation in Banda Aceh. The study is aimed to explore the capability of the existing tsunami evacuation buildings as the vertical evacuation in Banda Aceh. The observation includes the tsunami load assessment of the buildings based on the existing standard that had been used internationally. The existing vertical evacuation buildings in this study is analysed for the performance based on the International standard (The Federal Emergency Management Agency FEMA P646 2012) for tsunami loading impact and the earthquake performance was based on the national standard (SNI 1726 – 2012). The model of the building structure was generated using software structural anaysis, i.e. SAP2000. The earthquake simulation was based on the 2004 earthquake scenario that input as the dynamic loading. The tsunami loading was analysed using the static analyse. The data of tsunami characteristic such as tsunami inundation and speed were using the data from the existing data and research. The results show that the building needs to be strengthening, as it will suffer the large inter-story displacement in the first and second floors.

1. Introduction
One of the mitigation strategies to reduce the risk in tsunami prone zone is building tsunami vertical evacuation center. It is become an important strategy for reducing the tsunami risk for the flat area where the natural evacuation such as hills and other existing buildings, are not available. This strategy had been applied in Banda Aceh, post tsunami in 2004. The topography of Banda Aceh city is flat. In 2004, the casualties of the tsunami disaster were mostly from this city and Aceh Besar district, especially form Meuraxa sub-district. Four evacuation buildings were built in this sub-district. One of the buildings is also intended as the office for the Tsunami and Disaster Research Center, Universitas Syiah Kuala Banda Aceh, Indonesia. These buildings had been built before Indonesian released the new code for the earthquake resistant design, SNI 1726 – 2012 [1]. The difference between the updated standard with the previous standard was the different earthquake map. Since the tsunami vertical evacuation buildings in Meuraxa, Banda Aceh Indonesia was built before 2012, then it is assumed that the standard that been used was SNI
1726-2002 [2]. As the buildings is intended as the evacuation center which need to be resistant from the earthquake load, the performance of the buildings should be checked using the recent standard.

Tsunami load is assumed not included in the design. It is because there were no standard of tsunami resistant structures in the Indonesian standard. It is then important to review the capability of the existing vertical evacuation in Banda Aceh. The tsunami loading on buildings standard have been developed, i.e. Guideline for Tsunami evacuation buildings from Cabinet Office government of Japan [3], The Federal Emergency Management Agency (FEMA) P646 [4], and ASCE/Structural Engineering Institute 7 standards committee Tsunami loads and effects chapter [5]. Some researchers had also studied the tsunami loads and effects on designing buildings intensively, namely: Yeh, et. al. [6], Heintz and Mahoney [7], Fukuyama et. al [3], and Chock [5]. To sum up the tsunami loads that need to be considered for Tsunami vertical evacuation and other offshore buildings were hydrostatic load, hydrodynamic load, buoyant, impulsive load, and debris impact. This paper is going to explore the capability of the existing tsunami evacuation buildings as the vertical evacuation in Banda Aceh based on the new earthquake resistant structures (SNI 1726 2012) and the tsunami loads based on the inundation and runup modeling from the existing study [8]. The vertical evacuation building in Lambung, Meuraxa district was observed by modeling the structure using structural analysis software SAP2000. The building is assumed to have similar design from the other two buildings that built as a reinforced concrete with the open structures (frame with very minimal wall infill).

2. Methodology

2.1 Buildings assessment and modeling

To start modeling the building using structural analysis, the buildings properties were assessed. The building and frame dimensions were measured and sketched. The data and dimension of vertical evacuation buildings in Lambung based on the observations were listed here:

1. The location coordinate of the building is : (5o33’17.06”U) , (95o17’33.36”T)
2. Year of Construction : 2006
3. Number of Floors : 3 stories
4. Height of 1st story : 6 meter
5. Height of 2nd dan 3rd : 4 meter
6. Construction type : Reinforced Concrete (RC)
7. Structural dimensions:

Columns : circular column with diameter 700 mm and 500 mm, rectangular beams with 600 x 400 mm and 300 x 200 mm. The buildings data then input into a sketch for SAP2000 analysis. The model of the structures is provided in Figure 1.
As could be seen from the figure and data collection, the building meet the category of tsunami evacuation buildings for its type of construction, i.e. reinforced concrete structures frame and the buildings have mainly open structures with minimal wall infill. Fraser [9] observed that the structures of tsunami vertical evacuation with reinforced concrete frames could support the tsunami load effectively for a certain height of tsunami inundation. The design of tsunami vertical evacuation is intended to have an open space for allowing the tsunami flood could pass through the buildings without adding more pressure on the building [10]. The dead load and live load were then input based on the building information. The reference for the live load was the SNI 1727:2013.

2.2 Earthquake Loading

The earthquake loading on buildings were developed using the recorded waveform from the Sumatera – Andaman waveform on 26 December 2004 PSI station, the waveform then calibrate into response spectrum using application (DADiSP/SE 6.7). The response spectrum was input into SAP2000 as load with the scale factor = g x I/R, with g = gravitational acceleration (9.81 m/s²), I is the earthquake main factor, which is 1.5 as the building risk categorized number IV (the important building), and R is the earthquake reduction factor equal to 8. The scale factor is equal to 1.84.

2.3 Tsunami Loading

The tsunami loading on buildings was consisting of hydrostatic forces, Hydrodynamic forces, impulsive load, debris impact and debris resistant force. Those loads were calculated by using the equations that list in the following table:

| Type of Forces       | Tsunami consideration                                                                 | Formula                                      |
|----------------------|---------------------------------------------------------------------------------------|----------------------------------------------|
| Hydrostatic          | Forces of the water mass on one side of the structures which had different elevation than the other side | $F_h = p_c A_w = \frac{1}{2} \rho_s g b h_{\text{max}}^2$ |
| Hydrodynamic         | Tsunami load for the wave that pass the building structures                            | $F_d = \frac{1}{2} \rho_s C_d B (h u^2)_{\text{max}}$ |
| Impulsive force      | The force that occur due to the impact of the wave front on building structures        | $F_s = 1.5F_d$                                |
| Debris Impact force  | The force from the impact of the debris that brought by the tsunami wave              | $F_i = 1.3u_{\text{max}} \sqrt{km_d (1 + c)}$ |
| Debris resistant force| The accumulation of debris that had been stacked on the structure surfaces            | $F_{dm} = \frac{1}{2} \rho_s C_d B_d (h u^2)_{\text{max}}$ |
The formula explanation:

\[ p_c = \text{Hydrostatic pressure} \]
\[ A_w = \text{The wet area of the walls} \]
\[ \rho_s = \text{The tsunami water mass (including the tsunami sendiment mass) (1100 kg/m}^3\) \]
\[ g = \text{Gravitational acceleration (9.81 m/s}^2\) \]
\[ b = \text{The width of the walls} \]
\[ h_{max} = \text{The height of the maximum tsunami inundation from the floor} \]
\[ C_d = \text{dragging coefficient} \]
\[ B = \text{the area of structures on normal direction of the tsunami wave} \]
\[ h = \text{flow depth} \]
\[ u = \text{the run up on the location of the structures} \]
\[ U_{max} = \text{the maximum run up that brought the debris to the location} \]
\[ M = \text{debris mass} \]
\[ K = \text{debris stiffness} \]
\[ C = \text{hydrodynamic mass coefficient} \]
\[ B_d = \text{width/area of debris surfaces} \]

The hydrostatic force was input as the load per meter with pyramid shape along the column part in the water. The hydrodynamic, impulsive and debris resistant loads were described as an equivalent load per meter along the wet columns. The debris impact was input as the point load in the column. The different elevation of the soil surface for the surrounding area of the building location was described in Figure 2. The data of the tsunami inundation, the design run up and height of the wave was taken from the existing study of Syamsidik et al [8]. The results of the tsunami wave depth from the study of Syamsidik et al [8] for the Ulelheu surrounding were ranged from 6 (six) to 10 (ten) meter height. That study had been validated to the tsunami inundation data from NOOA and tsunami pole in the city. The simulation was based on the 9.5 Mw earthquakes. The evacuation building was located in 500 m from the shoreline. Based on the simulation data of [8], the tsunami data for the location was summarized as the following:

The tsunami data for the location could be summarized as the following:

The run up height (R) = 8 meter
Building Elevation (z) = 0.9 meter
Flow depth = 7.0 meter
Gravitation acceleration = 9.81 m/det2

Weight volume of the tsunami run up (qs) = 1100 kg/m3
Cd = 2

The run up height in the location for 2004 tsunami scenario was 8 m while the height of the first story was 6 m. The required minimum heights for the evacuation buildings is considered as run-up elevations increased by 30% and add another 3 m [5]. Thus the minimum height for Lambung area would at least 13.4 m for the occupied area of the refugee. In other words, the two-floor levels of the building were not capable as the refugee area in the simulation of the 2004 tsunami. The
hydrodynamic forces were assumed to work on columns, as the structure of the buildings on the first floor was an opening structure without infill wall. The tsunami hydrodynamic force on the column was 67.11 kN/m². The debris impact was assumed as lumber or wood log as the location of the buildings were not far from the shorelines area with less residential area in front the buildings. The forces that act on the column would be 500672.5 N.

Based on FEMA P-646 the tsunami load combination would be:

\[
\begin{align*}
U &= 1.2D + 1.0TS + 1.0 \text{LREF} + 0.25L \\
U &= 0.9D + 1.0TS
\end{align*}
\]

Where:

\[
\begin{align*}
U &= \text{The ultimate load;} \\
D &= \text{Dead load;} \\
L &= \text{Live load;} \\
TS &= \text{Tsunami load,} \\
\text{LREF} &= \text{Live load for the protected area}
\end{align*}
\]

3. Results and Discussion

3.1 Earthquake load assessment

Based on the result of the dynamic response spectrum for the vertical evacuation buildings in Lambung, Banda Aceh using SAP2000, shows that the natural period of building was about 0.2670. The period of the fundamental structures (T) based on SNI-1726 2012 [1] for the building that have less than 12 stories and all of the moment resisting structures made of reinforced concrete structures was taken as Ta = 0.1 N, where N is referred to the number of stories. The period of the building for further calculation was the building natural period (T), which was equal to 0.2670. The modal load participation ratio from the dynamic percent of building-analysis using SAP2000 was not less than 90%, i.e 98.8%. This percentage was in agreement with the requirement of participation mass effective factor, which should be minimum as 90%. The masses and weight of the building is 17371.239 KN. Thus, the horizontal earthquake load (V) was equal to 3419.96 KN.

The base shear of the building due to earthquake load from SAP2000 was less than 0.85 of the base shear from the total weight multiply by the seismic coefficient. This is not in agreement with the national standard of Indonesia (SNI 1726 :2012), then the base shear of SAP2000 results need to enlarged by a scale factor for X and Y direction. The final results of the building base shear due to the simulated earthquake is listed in the Table 2

| Output | Case | X direction | Y direction |
|--------|------|-------------|-------------|
| Text   | N    | N           |
| Quake x| 2996859.99 | 241766.79  |
| Quake Y| 2912015.09  | 33858479.5 |

3.2 Tsunami loading analysis

The tsunami loading was simulated as the static loads in SAP 2000. It was assumed as the two dimensional load models to the buildings. The tsunami loadings based on FEMA P646 in this simulation was limited to the hydrodynamic loading and debris impact loadings. This is due to the structures of the tsunami evacuation buildings is an open structures. The loadings were calculated using the formula that had been listed in the Table 1. The results shows that the hydrodynamic loading was around 67.11 kN/m² and the debris loading that described as the wooden log was around 500672.5 kN.

3.3 Inter-story displacement due to Earthquake and Tsunami load

The analysis of the structures performance due to the impact of the earthquake and the tsunami loadings was observed in the inter-story displacement of the buildings. Figure 3 describes the inter
story the displacement and inter-story displacement of the building due to the X, Y direction of earthquake load and the static load of the calculated tsunami loadings. Overall the inter-story displacement due to earthquake was still satisfying as it is relatively lower than the allowable inter-story displacement. However, the inter-story displacement that occurs due to tsunami load for the evacuation buildings was relatively high than the allowable inter-story displacement. Thus, the building was suggested to have strengthened columns to increase the displacement capacity. The tsunami load that worked mainly in the first story could result in the additional displacement for the columns in that level. The significant inter-story displacement due to the two loads could be seen in the following graph.

![Inter-story displacement due to earthquake and tsunami](image)

**Figure 3.** Inter-story displacement due to earthquake and tsunami

The flow depth was 7 m on the area, with the design run up was assumed to be 8 m. Then the occupancies area will be at least in the third floor of the buildings. This simulation should be considered for re-calculating the safe area for refugee to occupy. As the building is four stories building, thus the most reliable area to be considered as the evacuation area would be the fourth floor.

### 4. Conclusion

Overall the building is considered safe for the 2004 earthquake scenario based on SNI 1726-2012, however the buildings would suffer the large displacement due to tsunami loadings on the first floor and the second floor. Thus, it is important to strengthen the buildings for resisting the large deformation due the lateral impact of the tsunami wave. The available area to be occupied for the 2004 tsunami scenario would be the fourth floor, thus it will need to estimate the effective number of people that could be evacuated in the buildings.

### Acknowledgments

The simulation and modeling was part of the H-Index Research Project funded by Universitas Syiah Kuala, Banda Aceh, Indonesia.

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