Strengthening capacity study of reinforced concrete school building structure in Banda Aceh toward earthquakes and tsunami hazards

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Abstract. Banda Aceh City was a high level areas of the earthquake and tsunami damage that occurred in 2004. Building damage prevention can be done by planning earthquake-resistant school building structures. The rebuilding needs to be reviewed for its capacity structure because of the high risk building location of earthquake and tsunami hazards. This study aims to determine the behavior and capacity of the school building structure using the earthquake and tsunami scenario in 2004 in Banda Aceh. Capacity analysis by column enlargement of the existing building is one of the research variables. Earthquake load refers to data from the Sumatera-Andaman earthquake on December 26, 2004 and tsunami load refers to FEMA P646. Two typical school buildings were taken from data recapitulation of 100 buildings survey, namely SDN 48 and SDN 8, which represented the overall typical school building in Banda Aceh. This study uses the pushover analysis method on the SAP2000 software. Based on the capacity curve, the value of displacement in the x-y directions in the existing building are greater than the column variation building at SDN 48 and SDN 8. While the shear force value in the existing building are smaller than the column variation building. This shows that with the addition of column dimensions, the cross-sectional area gets bigger and affects the capacity of the building structure.

1 Introduction

Earthquake and tsunami are natural disasters that can cause casualties and buildings damage. Real evidence of this disaster could be seen in 2004, an earthquake measuring 9.3 SR that once rocked Banda Aceh City and was followed by a tsunami wave. The estimated impact of the 2004 earthquake and tsunami was that as many as 45,000 students and 1,870 teachers died, as well as damage to 2,065 educational facilities [2]. School buildings, especially elementary schools, are educational facilities that have a high priority index because they accommodate many of the burdens of life such as students and teachers. Prevention of damage to buildings caused by the earthquake and tsunami can be pursued by planning school building structures that meet the criteria for earthquake-resistant buildings, so that they can be used as temporary shelters in disaster emergency situations. The damage level to buildings is influenced by the strength and intensity of the earthquake, the configuration of the building structure, the stiffness and strength of the building structure, and the quality of building materials. Buildings that suffered light and moderate damage only needed repairs to certain parts, while buildings that suffered heavy damage and total damage required overall repairs to rebuilding. School buildings located in areas affected by the earthquake and tsunami need to be reviewed for their capacity to withstand earthquake and tsunami loads. This is related to efforts to minimize the potential damage caused by the earthquake and tsunami. This study uses earthquake and tsunami loading with earthquake and tsunami scenario in 2004. Capacity analysis by adding column dimensions from the existing building is one of the research variables. This variable will be simulated using parametric studies. The selection of research objects was carried out based on typical building criteria in the form of a top view of the building, number of floors, and building materials, as well as observe the condition of the building and the vulnerabilities found during the field survey. The results of data recapitulation on 100 school buildings and obtained two typical school buildings, namely SD Negeri 48 and SD Negeri 8 which represent the overall typical building in Banda Aceh City. The results of this study were obtained of displacement values, shear forces, and interstory drift to see the behavior of the building structure. The results of the capacity curve obtained from the pushover analysis are evaluated to obtain a comparison of the structural capacity values for the existing building and the column variation building. The capacity curve is converted into a capacity spectrum.

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curve that can determine the level of damage to the building. The probability value for the level of building damage is determined using and the developed seismic and tsunami fragility curve, so it can be seen the level of damage that occurs to the building. So that with the addition of column dimensions it can be used as an effort to strengthen the capacity of the building structure. The limitation of the problem in this study is that the research location is in Banda Aceh area, the planning does not take into account the lower structure of the building, and the analysis of earthquake and tsunami loading is carried out separately.

2 Literature review

2.1 Earthquake

Earthquakes are defined as natural vibrations that occur at certain locations and are unsustainable. Earthquakes are usually caused by sudden movements of the earth’s crust (plates). The sudden movement occurs because of a source of force as the cause, both from nature and from human assistance (artificial earthquakes) [11].

2.2 Tsunami

Tsunami waves cannot be seen when they are far in the middle of the ocean, but once they reach shallow areas the waves will move quickly. The energy generated by a tsunami is constant with respect to the function of altitude and its continuation [10].

2.3 Earthquake resistant building structure

Earthquake resistant buildings are defined as buildings that are able to withstand the design earthquake loads without experiencing excessive damage or not collapsing due to the earthquake [12].

2.4 Structure behaviour

2.4.1 Displacement

The degrees of freedom are the degrees of independence needed to express the position of a degree’s system at any time. If a reviewed point experiences a displacement of X, Y, and Z direction, then the system has three degrees of freedom. This happens because the point in question can move freely in three directions [1].

2.4.2 Inter-story drift

The inter-story drift is the horizontal displacement at the top of the reviewed level relative to the bottom [1]. The determination of inter-story drift can be seen in Fig. 1.

2.4.3 Base shear force

Base shear force is the total design shear or lateral force that occurs at the base level [1]. The basic seismic shear force (V) in the specified direction is determined by Eq. (1-2):

\[ V = C_s W \]  
\[ C_s = \frac{S_{SD} \cdot R \cdot \epsilon}{I} \]  

2.5 Pushover analysis

Pushover analysis is a linear and nonlinear two or three dimensional static analysis method, where the influence of the design earthquake on the building structure is considered as static loads that capture the center of mass of each floor, whose value is gradually increased until it exceeds the loading, which causes the plastic hinge in the building structure, then with a further increase in load undergoes a large elastoplastic deformation until it reaches a condition on the verge of collapse [9].

2.6 Seismic fragility curve

Seismic fragility curve is a curve that shows the possibility of damage to a structure when it receives an earthquake load with a certain intensity. This curve becomes very important in assessing or evaluating the seismic performance of a structure because it displays the level of seismic fragility as a possible damage based on earthquake loads that exceed the design load on the performance or limit state of a particular structure [15]. Due to a statistical program, the probability values that form the fragility curve will be obtained as shown in Fig. 2.
The degrees of freedom are the degrees of independence of the system at a time. If a point in the system experiences a displacement, all other points in the system can move freely in three directions [1].

Earthquakes are defined as natural vibrations that occur due to the sudden movement of the Earth's crust (plates). The sudden movement occurs because of a source of force as the cause, both from nature and from human assistance (artificial earthquakes) [11].

2.2 Tsunami

Tsunami fragility is defined as the structural damage probability or fatality ratio with particular regard to the hydrodynamic features of tsunami inundation flow, such as inundation depth, current velocity and hydrodynamic force. In principle, the development of tsunami fragility requires that tsunami hazard information and damage data should be used synergistically [7]. The tsunami fragility curve can be seen in Fig. 3 and the level of damage is in Table 2 [13].

3 Research methods

3.1 Object of research

The object of research in this study is a typical two-story school building in Banda Aceh City with reinforced concrete construction. The determination of the building type is carried out by recapitulating survey data from 100 school buildings and taking two typical buildings that dominate the structural design of the building.

3.2 Research data

The types of data needed in this study are:

1. Primary data is data obtained directly from the results of filling out data forms through field surveys on school buildings in Banda Aceh City in the form of data on the dimensions of building structural elements.
2. Secondary data is supporting data and a reference for the implementation of the primary survey. This data is obtained from relevant agencies in a ready-to-use form.
3. The literature used is SNI-1726-2019, SNI-03-1727-2020, Map of Sources and Earthquake Hazards in Indonesia, as well as books related to research.
3.3 Data collection technique

Research data collection was carried out by means of a field survey. Surveys are used to collect building structure data and building vulnerability factors by looking directly at the condition of the building. Structural data collection was carried out randomly on 100 school buildings in Banda Aceh using a rapid assessment survey, so that the distribution of surveyed school buildings was achieved for each sub-district in Banda Aceh.

3.3.1 Building technical data

Typical details of building structures for various building forms in Banda Aceh are as shown in Table 3 [5].

| Materials          | Typical Beam | Typical Column | Typical Joint |
|--------------------|--------------|----------------|--------------|
| Pre-2012 Concrete, $f_c = 21.5$ Mpa | $3Φ16$ top | $3Φ16$ top | No stirrups |
| Long. steel, $f = 400$ Mpa | $3Φ16$ bottom | $3Φ16$ bottom | No stirrups |
| Long. steel, $f = 240$ Mpa | $Φ10@150$ mm stirrups | $Φ10@200$ mm stirrups | |
| Post-2012 Concrete, $f_c = 24$ Mpa | $3Φ16$ top | $3Φ16$ top | No stirrups |
| Long. steel, $f = 400$ Mpa | $3Φ16$ bottom | $3Φ16$ bottom | No stirrups |
| Long. steel, $f = 240$ Mpa | $Φ10@150$ mm stirrups | $Φ10@100$ mm stirrups | |

3.3.2 Earthquake data

The Earthquake data used is recorded earthquake data that occurred in Sumatra – Andaman fault on December 26th, 2004 obtained from United States Geological Survey (USGS).

3.3.3 Tsunami data

The tsunami data needed to calculate the tsunami load [4] is the depth of the tsunami flow in 2004 [6] and the difference in the elevation of the building subgrade to the water level [14].

3.4 Building structure modeling

The reviewed structure in this study is the entire structure of the school building. The structural modeled using SAP2000 software as a space frame.

The data entered are detail building data, the quality of the materials used, the dimensions of the building, and the loading. The modeling structure of each school building is done with two variations of the column in the same way.

3.5 Loading

Loads that are inputted in the SAP2000 program are dead loads, live loads, earthquake loads, tsunami loads, and combined loads.

1. Combined earthquake loading
   \[ U_1 = 1.4D \]
   \[ U_2 = 1.2D + 1.6L \]
   \[ U_3 = 1.38D + 1L + 0.39Q_{Ex} + 1.3Q_{Ey} \]
   \[ U_4 = 1.38D + 1L + 0.39Q_{Ex} - 1.3Q_{Ey} \]
   \[ U_5 = 1.38D + 1L - 0.39Q_{Ex} - 1.3Q_{Ey} \]
   \[ U_6 = 1.38D + 1L - 0.39Q_{Ex} + 1.3Q_{Ey} \]
   \[ U_7 = 1.38D + 1L + 1.3Q_{Ex} + 0.39Q_{Ey} \]
   \[ U_8 = 1.38D + 1L + 1.3Q_{Ex} - 0.39Q_{Ey} \]
   \[ U_9 = 1.38D + 1L - 1.3Q_{Ex} - 0.39Q_{Ey} \]
   \[ U_{10} = 1.38D + 1L - 1.3Q_{Ex} + 0.39Q_{Ey} \]
   \[ U_{11} = 1.08D + 0.39Q_{Ex} + 1.3Q_{Ey} \]
   \[ U_{12} = 1.08D + 0.39Q_{Ex} - 1.3Q_{Ey} \]
   \[ U_{13} = 1.08D - 0.39Q_{Ex} - 1.3Q_{Ey} \]
   \[ U_{14} = 1.08D - 0.39Q_{Ex} + 1.3Q_{Ey} \]
   \[ U_{15} = 1.08D + 1.3Q_{Ex} - 0.39Q_{Ey} \]
   \[ U_{16} = 1.08D + 1.3Q_{Ex} + 0.39Q_{Ey} \]
   \[ U_{17} = 1.08D - 1.3Q_{Ex} - 0.39Q_{Ey} \]
   \[ U_{18} = 1.08D - 1.3Q_{Ex} + 0.39Q_{Ey} \]

2. Combined tsunami loading
   \[ U_{19} = 1.2D + 1.0T_s + 1.0L_{REF} + 0.25L \]
   \[ U_{20} = 0.9D + 1.0T_s \]

3.6 Pushover analysis

Pushover analysis is done by loading in stages, the lateral loading carried out represents the earthquake force on each floor. The lateral loading direction is carried out in direction of the main axis building. Lateral loading uses the displacement-controlled concept, which the loading process is increased gradually until the displacement target is achieved.

3.7 Tsunami loading

The tsunami load used is hydrostatic force, hydrodynamic force, and debris impact force. These forces are calculated with a flow depth of 7 meters. The hydrostatic force is input as distributed load, pyramidal shaped along the flooded column. The hydrodynamic force is input as distributed load along the flooded
building is done with two variations of the column in the and the loading. The modeling structure of each school of the materials used, the dimensions of the building, structure of the school building. The structural modeled in this study is the entire school buildings was achieved for each sub-district in assessment survey, so that the distribution of surveyed 100 school buildings in Banda Aceh using a rapid Research data collection was carried out randomly on looking directly at the condition of the building. The reviewed data for the inter-story drift that occurs for the two typical buildings. The same method is also carried out on the column variation building for the two typical buildings. While for the tsunami load, the results from SAP2000 are seen for the inter-story drift that occurred. The result of this research is the comparison of the capacity structure that occurs between the existing and column variation building.

4 Results and discussion

4.1 Survey data recapitulation results
The recapitulation data was conducted to determine the object of research which is a typical school building in Banda Aceh. From the recapitulation results, an infographic is made to show the criteria for school buildings that dominate in Banda Aceh which can be seen in Fig. 6.
8 Banda Aceh located in Meuraxa District. The technical data for the school buildings of SD Negeri 48 and SD Negeri 8 Banda Aceh can be seen in Table 4.

Table 4. Characteristics and building position

| Criteria          | SD Negeri 48 | SD Negeri 8 |
|-------------------|--------------|-------------|
| Place Coordinates | Longitude 95.2898; Latitude 5.5586 | Longitude 95.31060; Latitude 5.56041 |
| Construction Year | 2015         | 2016        |
| Number of stories | Two-story    | Two-story   |
| Height per story  | 3.5 meters   | 3.5 meters  |
| Materials         | Reinforced Concrete (RC) | Reinforced Concrete (RC) |
| Frame system      | Space Frame  | Space Frame |

4.2 Number of variety analysis results

Based on the analysis results on SAP2000, it shows that the modal load participation value of the existing and column variation building in the SDN 48 and SDN 8 has met the provisions of the SNI 03 – 1726 – 2019 limit (in Table 5), which the effective mass participation factor for UX and UY is a minimum of 90%.

Table 5. Results of analysis of fundamental vibration time of structure

| Building                  | Period Ta izin (Sec) | Description |
|---------------------------|----------------------|-------------|
| SDN 48 (Existing Building)| 0.2274               |             |
| SDN 48 (Column Variation Building)| 0.1728 |             |
| SDN 8 (Existing Building) | 0.2209               |             |
| SDN 8 (Column Variation Building)| 0.16054 |             |

4.3 Result of analysis of fundamental period of structure

Based on the analysis results on SAP2000, it shows that the natural period of the existing and column variation building in the SDN 48 and SDN 8 has met the provisions of the SNI 03 – 1726 – 2019 (in Table 6.) with natural period limit of 0.3759 seconds.

Table 6. Results of analysis of fundamental vibration time of structure

| Building                  | Period Ta izin (Sec) | Description |
|---------------------------|----------------------|-------------|
| SDN 48 (Existing Building)| 0.2274               |             |
| SDN 48 (Column Variation Building)| 0.1728 |             |
| SDN 8 (Existing Building) | 0.2209               |             |
| SDN 8 (Column Variation Building)| 0.16054 |             |

4.4 Displacement analysis results

The maximum displacement due to the combination of x-y direction earthquake loads for existing and column variations buildings and can be seen in Table 7.

Table 7. Maximum displacement result of SDN 48

| Building                  | Comb. Displacement Max. (m) | Joint Displacement Max. (m) |
|---------------------------|-----------------------------|----------------------------|
| SDN 48 (Existing Building)| U4 49 0.1198               | U4 50 0.0850               |
| SDN 48 (Column Variation Building)| U6 56 0.0839 | U6 56 0.0622 |

Table 7. Maximum Displacement Result of SDN 8

| Building                  | Comb. Displacement Max. (m) | Joint Displacement Max. (m) |
|---------------------------|-----------------------------|----------------------------|
| SDN 8 (Existing Building) | U16 101 0.0763             | U7 93 0.0686               |
| SDN 8 (Column Variation Building)| U14 101 0.0371 | U14 102 0.0268 |

4.5 Shear force analysis results

The basic shear force (Vt) ≥ V, where the calculation of the basic shear force value for each building is as follows (eq. 1):

$$S_{DS} = 0.9 \text{ g}$$
$$S_1 = 0.75 \text{ g}$$
$$L_e = 1.5$$
$$R = 8$$

The coefficient of Cs must be determined by:

$$C_s = \frac{S_{DS}}{R} = \frac{0.9}{8} = 0.075$$
For structures located in areas where $S_1 \geq 0.6$ g, the $C_s$ must be not less than:

$$C_s = \frac{0.5 \times S_1}{2} = \frac{0.5 \times 0.75}{2} = 0.0703$$

So, the value of $C_s$ used for this analysis is 0.0703.

Table 8. Basic shear force calculation

| Building   | $V_{yvar}$ | $0.85 V_{yvar}$ |
|------------|------------|-----------------|
| SDN 48 (Existing Building) | 0.0703 (75780,93) | 0.85 (5337,399) |
| SDN 48 (Column Variation Building) | 0.0703 (93420,93) | 0.85 (6567,491) |
| SDN 8 (Existing Building) | 0.0703 (210328,67) | 0.85 (14786,106) |
| SDN 8 (Column Variation Building) | 0.0703 (247960,67) | 0.85 (17431,635) |

Table 9. Base shear force results

| Building               | $V$      | Base Shear ($V_i$) | $V_{yx}$ | $V_{ys}$ | $V_i > V$ |
|------------------------|----------|--------------------|----------|----------|-----------|
| SDN 48 (Existing Building) | 4528,29 | 6031,03            | 255,52   |          | ✓         |
| SDN 48 (Column Variation Building) | 5,582,37 | 28689,31           | 8601,34  |          | ✓         |
| SDN 8 (Existing Building) | 12568,19 | 316131,16          | 235916,26 |          | ✓         |
| SDN 8 (Column Variation Building) | 14816,89 | 377150,87          | 292761,01 |          | ✓         |

Based on the Table 9, the value of the basic y-direction shear force for the existing SDN 48 building is not greater than the value of the allowable shear force. So that this value does not meet the provisions of SNI 1726-2019. After the column variation, the result of the basic shear force obtained is greater than the value of the allowable shear force. While the basic shear force for the existing building and the column variation building at SDN 8 has met the requirements because the resulting value is greater than the allowable shear force value.

4.6 The result of the analysis inter-story drift with earthquake load

Berdasarkan SNI 1726:2019, the value of the inter-story drift must be less than 0.01 or 1% times the height of the building before the floor level under review for risk category IV buildings. The results of the calculation of the deviation between levels in the x and y directions due to the earthquake can be seen in Table 4.8 and Table 4.9.

Table 10. Inter-story drift with earthquake load x-direction

| Building               | Story Displacement x-direction | Inter-story Drift | Inter-story Drift Ratio | Description |
|------------------------|-------------------------------|-------------------|-------------------------|-------------|
|                       | $m$                            | $m$               | $m$                     | Description |
| SDN 48 (Existing Building) | 2 0,1149                      | 0,0572            | 0,035                   | ✓           |
| (Existing Building)    | 1 0,0577                      | 0,0344            | 0,035                   | ✓           |
| SDN 48 (Column Variation Building) | 2 0,0678                     | 0,0252            | 0,035                   | ✓           |
| (Column Variation Building) | 1 0,0427                     | 0,0427            | 0,035                   | ✓           |
| SDN 8 (Existing Building) | 2 0,0657                      | 0,0337            | 0,035                   | ✓           |
| (Column Variation Building) | 1 0,0320                    | 0,0320            | 0,035                   | ✓           |

Table 11. Inter-story drift with earthquake load y-direction

| Building               | Story Displacement y-direction | Inter-story Drift | Inter-story Drift Ratio | Description |
|------------------------|-------------------------------|-------------------|-------------------------|-------------|
|                       | $m$                            | $m$               | $m$                     | Description |
| SDN 48 (Existing Building) | 2 0,0838                      | 0,0163            | 0,035                   | ✓           |
| (Existing Building)    | 1 0,0675                      | 0,0675            | 0,035                   | ✓           |
| SDN 48 (Column Variation Building) | 2 0,0522                    | 0,0244            | 0,035                   | ✓           |
| (Column Variation Building) | 1 0,0278                    | 0,0278            | 0,035                   | ✓           |
| SDN 8 (Existing Building) | 2 0,0871                      | 0,0352            | 0,035                   | ✓           |
| (Column Variation Building) | 1 0,0519                    | 0,0519            | 0,035                   | ✓           |
| SDN 8 (Column Variation Building) | 2 0,0265                   | 0,0126            | 0,035                   | ✓           |
| (Column Variation Building) | 1 0,0139                    | 0,0139            | 0,035                   | ✓           |

4.7 Capacity curve evaluation results

The capacity curve is nonlinear due to an increase in load which makes the structural elements of the building change from an elastic condition to a plastic condition.
Based on the fig. 8, the value of displacement in the x and y directions in the existing building is greater than the column variation building at SDN 48 and SDN 8. While the shear force value in the existing building is smaller than the column variation building. This is influenced by the addition of column dimensions which results in a larger cross-sectional area. Overall, these results indicate that the existing buildings and column variations in both schools are more flexible and prone to shifts in the x-direction.

4.8 Capacity spectrum results

The capacity spectrum curve aims to obtain the value of the median spectral acceleration parameter. Furthermore, on the capacity spectrum curve, the position of each damage limit is determined. Determination of the position of each damage limit on the capacity spectrum curve based on research [3].
4.8 Capacity spectrum results influenced by the addition of column dimensions which smaller than the column variation building. This is the column variation building at SDN 48 and SDN 8. Based on the Fig. 8, the value of displacement in the x direction in the existing building is greater than Fig. 7.

Furthermore, on the capacity spectrum curve, the shifts in the x-direction. Determination of the position of each damage limit on the capacity spectrum curve based on research [3]. The 13th AIWEST-DR 2021

4.8.1 The results of the evaluation of the developed seismic fragility curve

The required data is taken from the results of spectra response of PUSKIM (Pusat Penelitian dan Pengembangan Pemukiman). The seismic fragility curve used for this evaluation is the curve in the Gentile, et al (2019).

1. Calculation of $S_b$ SDN 48 building
   \[ T_s = 0.679154 \text{ sec} \]
   \[ T_0 = 0.135983 \text{ sec} \]
   \[ T_s = 0.679916 \text{ sec} \]
   \[ T_L = 14.000000 \text{ sec} \]
   \[ S_{db} = 1.000124 \text{ g} \]

Since $T \geq T_0$ or $T \leq T_s$, then $S_d = S_{db}$, $S_b = 1.000124 \text{ g}$.

Data $S_a$ is inputted into the online graph-reader application and generates probability values as shown in Fig. 13.

### Table 13. $S_d$ and $S_a$ values for each type of structural damage at SDN 8 building

| Building          | Damage state | $S_d$ ($m$) | $S_{a,ds}$ ($g$) |
|-------------------|--------------|-------------|------------------|
| SDN 8 (Existing Building) | Slight      | 0.0110      | 1.3015 1.1303   |
|                   | Moderate     | 0.0165      | 1.5869 1.4464   |
|                   | Complete     | 0.0414      | 2.0706 1.4914   |
| SDN 8 (Column Variation Building) | Slight      | 0.0089      | 1.5053 1.1404   |
|                   | Moderate     | 0.0134      | 1.8053 1.4762   |
|                   | Complete     | 0.0343      | 2.1113 1.6638   |

### Table 12. $S_d$ and $S_a$ values for each type of structural damage at SDN 48 building

| Building          | Damage state | $S_d$ ($m$) | $S_{a,ds}$ ($g$) |
|-------------------|--------------|-------------|------------------|
| SDN 48 (Existing Building) | Slight      | 0.0140      | 1.3808 1.4681   |
|                   | Moderate     | 0.0210      | 1.6613 1.7666   |
|                   | Complete     | 0.0393      | 2.0545 2.1640   |
| SDN 48 (Column Variation Building) | Slight      | 0.0091      | 1.2440 1.1834   |
|                   | Moderate     | 0.0135      | 1.5511 1.6225   |
|                   | Complete     | 0.0321      | 2.1898 2.4099   |
|                   | Complete     | 0.0537      | 2.7677 3.0089   |

### Fig. 13. Identification of the probability of the seismic fragility curve in the x and y directions of SDN 48 building

2. Calculation of $S_b$ SDN 8 building
   \[ T = 0.3759 \text{ sec} \]
   \[ T_0 = 0.135983 \text{ sec} \]
   \[ T_s = 0.679916 \text{ sec} \]
   \[ T_L = 14.000000 \text{ sec} \]
   \[ S_{db} = 1.000124 \text{ g} \]

Data $S_a$ is inputted into the online graph-reader application and generates probability values as shown in Fig. 13.
Since $T \geq T_0$ or $T \leq T_s$, then $S_a = S_{ds}$, $S_a = 1001245$ g. Data $S_a$ is inputted into the online graph-reader application and generates probability values as shown in Fig. 14.

![Identification of the probability of the seismic fragility curve in the x and y directions of SDN 8 building.](image)

**Fig. 14.** Identification of the probability of the seismic fragility curve in the x and y directions of SDN 8 building.

### 4.9 Structural reinforcement evaluation results

Based on the results of the evaluation of the existing fragility curve, it shows that the buildings of SDN 48 and SDN 8 will experience slight and moderate conditions so that it can be recommended to carry out structural reinforcement. After adding 15% column dimensions, Table 4.9 shows the results of the structural capacity by connecting the values of displacement and base reaction and in Table 14 shows the largest displacement results for the x and y directions.

**Table 14.** Result of displacement direction X and direction Y

| Building | Column dimension | Column dimension enlargement | Displacement x-direction | Displacement y-direction |
|----------|------------------|-----------------------------|--------------------------|--------------------------|
|          | cm               | %                           | m                        | m                        |
| SDN 48   | 30 x 30          | 0%                          | 0,1198                   | 0,0839                   |
|          | 40 x 40          | 15%                         | 0,0850                   | 0,0622                   |
| SDN 8    | 30 x 30; 30 x 40 | 0%                          | 0,0763                   | 0,0371                   |
|          | 40 x 40; 40 x 50 | 15%                         | 0,0686                   | 0,0268                   |

Based on the Table 14, in the SDN 48 building, the displacement value that occurred after adding the column dimensions were reduced by 29% for the x direction and decreased by 26% for the y direction. Meanwhile, in SDN 8 building, the displacement value that occurs after adding the column dimensions is reduced by 10% for the x direction and 28% for the y direction. This shows that with the addition of column dimensions, the building structure becomes more rigid because the displacement results are getting smaller.

### 4.10 Tsunami load analysis results

FEMA P646 only explains how to calculate the tsunami load on the building, so that for checking, SNI 1726:2019 is used as a control for inter-story drift.

**Table 15** Tsunami force calculation results

| Force                | Results |
|----------------------|---------|
| Hydrostatic force    | 793138,5 N 1057518 N |
| Hydrodynamic force   | 20848,2 N 20508,3 N |
| Debris impact force  | - 62584,1 N |

The results of the inter-story drift of the combined tsunami load (Table 15) that occurred can be seen in Table 16 and Table 17.

**Table 16** Inter-story drift with tsunami load X-direction

| Building                | Story | Displacement x-direction | Inter-story Drift | Inter-story Drift Ratio | Description |
|-------------------------|-------|---------------------------|-------------------|-------------------------|-------------|
|                         | m     | m                         | m                 |                         |             |
| SDN 48 (Existing Building) | 2     | 0,0145                    | 0,0013            | 0,035                   | ✓           |
|                         | 1     | 0,0132                    | 0,0132            | 0,035                   | ✓           |
| SDN 48 (Column Variation Building) | 2     | 0,0044                    | 0,0009            | 0,035                   | ✓           |
|                         | 1     | 0,0035                    | 0,0035            | 0,035                   | ✓           |
| SDN 8 (Existing Building)  | 2     | 0,0020                    | 0,0004            | 0,035                   | ✓           |
|                         | 1     | 0,0016                    | 0,0016            | 0,035                   | ✓           |
| SDN 8 (Column Variation Building) | 2     | 0,0020                    | 0,0004            | 0,035                   | ✓           |
|                         | 1     | 0,0015                    | 0,0015            | 0,035                   | ✓           |

Based on Table 16, the result of the inter-story drift in the x-direction at SDN 48 and SDN 8 is smaller than the inter-story drift permit, so that it meets the provisions of SNI 1726-2019.

**Table 17** Inter-story drift with tsunami load Y-direction

| Building                | Story | Displacement y-direction | Inter-story Drift | Inter-story Drift Ratio | Description |
|-------------------------|-------|---------------------------|-------------------|-------------------------|-------------|
|                         | (m)   | (m)                       | (m)               |                         |             |
| SDN 48 (Existing Building) | 2     | 0,0671                    | 0,0172            | 0,035                   | ✓           |
|                         | 1     | 0,0499                    | 0,0499            | 0,035                   | ✗           |
| SDN 48                 | 2     | 0,0201                    | 0,0077            | 0,035                   | ✓           |
|                         | 1     | 0,0124                    | 0,0124            | 0,035                   | ✓           |
Based on Table 17, the variation of the column buildings in the two schools, the result of the inter-story drift in the y direction is smaller than the inter-story drift permit, so that it meets the provisions of SNI 1726-2019. While the results for the existing 1st floor buildings of SDN 48 and SDN 8 are greater than the inter-story drift permit. This is because the tsunami inundation reached 7 meters on the 2nd floor.

4.11 Comparison of inter-story drift between earthquake and tsunami load

Based on the results of the inter-story drift in Sections 4.6 and 4.10, a graph of the ratio of the inter-story drift to earthquake and tsunami loads can be seen in Fig. 15 and Fig. 16.

Fig. 15. The inter-story drift in the x-y directions of SDN 48

Fig. 16. The inter-story drift in the x-y directions of SDN 8

The results of the inter-story drift due to earthquake and tsunami loads in the column variations of SDN 48 and SDN 8 have met the provisions of SNI 1726-2019 because the inter-story drift is not greater than the inter-story drift permit. This shows that the addition of column dimensions affects the stiffness and behavior of the building structure, so that the building can withstand earthquake and tsunami loads.

4.12 Evaluation results of the developed tsunami fragility curve

The tsunami fragility curve used for this evaluation is the curve in the study of Syamsidik, et al (2020). The data required is the height of the tsunami inundation, which is 7 m for the buildings of SDN 48 and SDN 8. The height data is inputted into the online graph-reader application and produces a probability value as shown in Fig. 17.

Fig. 17. Identify the probability of the developed tsunami fragility curve

The Fig.17 explains the relationship between tsunami inundation height and the probability value of the damage level to buildings. The inputted tsunami inundation height modeling that it was identified that there was no intersection between the inundation height line and the damage level. These results indicate that the probability value of the complete damage building that occurs for the SDN 48 and SDN 8 buildings is 100%. However, if viewed from the structural behavior, namely the inter-story drift of the tsunami load, the column variation buildings for the two schools were able to withstand the tsunami load. Therefore, for tsunami loading, it is necessary to re-analyze the fragility curve that adjusts to the building structure.
5 Conclusions and suggestions

5.1 Conclusions

1. Based on the earthquake and tsunami scenario in 2004, the existing buildings of SDN 48 and SDN 8 do not meet the structural boundary criteria of SNI 1726-2019. After being simulated with the addition of column dimensions, the results obtained for both buildings have met these criteria. This shows that the addition of column dimensions affects the behavior of the building structure.

2. The shear force value for the existing SDN 48 building do not meet the basic shear force requirements in SNI 1726-2019. The value obtained is very small compared to the shear force acting due to the earthquake. This is due to the small cross-sectional area of the column.

3. The inter-story drift value due to earthquake loads for the existing buildings of SDN 48 and SDN 8 have not met the provisions of SNI 1726:2019. So that the two existing buildings are recommended for structural strengthening efforts.

4. The inter-story drift value due to the tsunami load for the existing buildings of SDN 48 and SDN 8 have not met the provisions of SNI 1726:2019. This is because the tsunami inundation reached 7 meters on the 2nd floor.

5. Based on the displacement value, after the addition of the column dimensions by 15%, for the SDN 48 building, the displacement that occurs is reduced by 29% for the x direction and reduced by 26% for the y direction. While the SDN 8 building, the displacement that occurs after adding the column dimensions is reduced by 10% for the x direction and 28% for the y direction.

5.2 Suggestions

1. Using different structural modeling with different types of school buildings, such as the building shape, the height and width of the building, the number of story, or building materials.

2. Perform earthquake modeling with variations of other earthquake sources for earthquake load calculations in order to obtain different spectral response values.

3. Evaluating seismic performance by using a variety of structural reinforcement methods by reviewing other structural parts.

4. Analyze and evaluation of seismic and tsunami fragility curves according to data on school building structures.

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