Analysis of earthquake structure on a traditional wooden house of Mandailing

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Abstract. Most regions in Indonesia have the potential for earthquakes, including Mandailing. Traditional wooden house of Mandailing was established without the expertise of an engineer and architect. The aim of the study was to identify the wooden structures against seismicity to obtain an efficient and contextual wood construction for earthquakes. Therefore, it is important to observe and analyse the structure of buildings through seismic approaches and alternative solutions to the sustainability of construction. The research method was an experimental using SAP2000 simulations. It was to identify the performance of columns and beams as the main structures that require reinforcement and experience friction. The data analysis showed that the building had a mass of 355.484 kN with a static shear force of 150.0142 kN and a dynamic shear force of 693.274 kN, while the vibrating period of the Mandailing traditional wooden houses structure had a T = 0.94267 seconds value. In other words, the SAP2000 modelling results illustrate that the displacement which occurs in buildings with an earthquake scale factor of 10 is still within the safety limits. Thus, the buildings are flexible to earthquake movements, and damages in the buildings can be minimized.

1. Introduction

Mandailing is an administrative area in Mandailing Natal District, North Sumatera, Indonesia. North Sumatera has various ethnicities whose cultural results are still maintained today. Traditional wooden houses are one of the existing cultural results, which can be found particularly in Sibanggor Julu Village, Mandailing Natal District. However, these traditional wooden houses are currently in poor conditions. Moreover, these houses are slowly extinct by economic, cultural, and technological developments. Many houses were damaged because they were not repaired, and the repairs did not use local craft techniques but conventional technology. As a result, material knowledge and craftsman skills in the village were extinct. Efforts can be made by conducting inspections and diagnoses on the quality of existing wood and analysing building structures against the earthquakes. It is based on the fact that Sibanggor Julu Village is prone to earthquakes [1].

Sibanggor Julu Village is located at Puncak Sorik Marapi Sub-district, Mandailing Natal District. The location of the village is at the foot of the Sorik Marapi volcano. Mandailing Natal District is included in the Panyabungan graben physiographic unit, which is part of the Sumatera Fault System [2]. The geological conditions of Mandailing are complex with permocarbon to resen rock types. The
characteristics of soil in Sibanggor Village are hard rocky soil, and the rocks were obtained from the lava of volcanic eruptions decades ago. Thus, this village is indicated to be close to the epicentre of the earthquake, especially the earthquake caused by volcanic eruptions.

Earthquakes can damage the human environment or buildings; one of which is determined by the distance of the hypocentre or epicentre [3]. In addition, the soil type, earthquake duration, and building design also determine the damage. The earthquake activity around the Sorik Marapi mountain area was dominated by a distant tectonic earthquake type [4]. The earthquake energy and the building loads highly affect the physical building during the earthquake. Besides, environmental factors also determine the effect of earthquakes on buildings. The similarity of earthquake magnitude in different regions will have a different impact on the building. Building damage due to the earthquake depends on the strength of the earthquake source and the wave of energy transmitted to the location of the building.

In ensuring the response of the traditional Mandailing wooden house buildings to earthquakes, an analysis was required. The analysis was conducted to observe the base shear force and displacement due to dead loads and live loads acting on the structures caused by earthquake forces and structural loads. The method used was SAP2000 modelling with spectrum response parameters. The structure response to the earthquake is strongly influenced by the building’s shape. Regular, simple, and symmetrical buildings will be better against earthquakes than irregular buildings [5]. Therefore, it is necessary to consider the size, structure, and construction system, and the selection of the right materials to reduce the lateral load of the earthquake.

2. Methodology
The data were obtained from various literature sources and tests in the field. Data collected were simulated in modelling using SAP2000 Ultimate version 14, AutoCAD 2013, Microsoft Word 2010, and Microsoft Excel 2010 programs. The modelling results were described in quantitative descriptive based on the calculation results of the spectrum response of dead loads and live loads working on buildings. Load parameters were assessed from the earthquake force in the Mandailing region. The measurement results were analysed by entering the spectrum response coefficients of Mandailing Natal Districts with specifications of rock soil types and functions of residential buildings.

3. Data and literature

3.1. Traditional wooden house of Mandailing
The specifications of traditional wooden houses in Mandailing are stilt houses with wooden construction systems. The house was built with simple or non-engineered construction technology, which means that the building was designed by little or no interference from engineers and architects. The structural system is a wooden frame structure that stands on a stone base without a joint system.

Technically, the size of the house follows a pattern of 6.00 x 6.00 m with a stilt height of ± 80 cm and a building height of 6.31 m. The building has a square form made using lightweight local materials. The shape and specifications of the building can be seen in figure 1 below.
Figure 1. Specification of traditional Mandailing wooden house according to local terms.

The data used in SAP2000 program calculation are explained in table 1.

Table 1. The data input in SAP2000 program.

| Location of building | Mandailing Natal District |
|----------------------|--------------------------|
| Building construction| wooden frame             |
| Structure system     | other structures         |
| Type of soil         | rocky soil               |
| Material specification| MoE of structural wood 13969.40 MPa |
|                      | MoE of wood wall board 12432.70 MPa |
|                      | MoE of wood floor board 12432.70 MPa |
| Structure dimensions | roof sheating (fibre) 1.52 gr/cm³ |
|                      | post footing R = 76 – 32 cm, T = 6.5 – 24 cm |
|                      | stump 9 x 9 x 60 cm      |
|                      | bearer 9 x 3 cm          |
|                      | sill plate 6 x 3 cm      |
|                      | floor joist Ø7 cm        |
|                      | floor sheating 2 x 20 cm |
|                      | bottom plate 10 x 4 cm   |
|                      | stud 6 x 4 cm            |
|                      | ridge beam 10 x 10 cm    |
|                      | cornice Ø8 cm            |
|                      | hip rafter Ø8 cm         |
|                      | hanging beam Ø8 cm       |
|                      | purlin 2 x 8 cm          |
3.2. Response spectrum analysis

The response spectrum is a spectrum presented in the form of a graph or plot between periods of vibrating structures (T), opponents of maximum responses based on certain attenuation and earthquake ratios. Maximum responses can be maximum spectral displacement (SD), spectral velocity (SV) or spectral acceleration (SA), and a single degree of freedom (SDOF) mass structure [6]. Acceleration spectrum will be related to the maximum shear forces acting on the base of the structure.

As one of the dynamic analysis methods, the response spectrum is often used in building planning that receives earthquake loads. Several things must be fulfilled to use the response spectrum as a method of seismic load analysis. One of the requirements is the base shear force.

In using the scale factor, design values or parameters including the intersection of the floor level, support force, and the force of individual structural elements for each variety of responses have to be calculated and divided by the quantity $R / I_e$ [7]. $R$-value is a modification factor of response, and $I_e$ is a factor of excellence.

The seismic load used in the analysis was taken from the response spectrum of the Mandailing Natal District by entering data on the type of rocky soil and residential buildings. The data were issued by the Indonesian Spectra, which can be seen in figure 2.

![Figure 2. Earthquake Zonation Spectra Design Lat: 0.8613683813001359, Long: 99.5633548746141 Mandailing Natal District [8].](image)

3.3. SAP2000 program

SAP2000 is known as a program or method used to analyse and design tools, or structural modelling, which has been used by engineers for more than 30 years ago. This program is the result of research and development by a team from the University of California led by Prof. Edward L. Wilson, which is text-based (DOS) and launched in 1970. SAP2000 has graphical-based graphics modelling and
operates in Windows systems. Graphical-based systems allow the process of modelling, checking, and displaying results is done interactively on the screen [9].

This program provides several design features, which can produce wind, wave, bridge and seismic loads based on international standards. The SAP2000 analysis technique allows for analysis of high deformations, Eigen and Ritz analysis based on non-linear case rigidity, catenary cable analysis, non-linear material analysis with fibre hinges, multi-layered non-linear shell elements, buckling analysis, progressive collapse analysis, energy method for drift control, speed-dependent reducer, base insulator, supporting plasticity, and non-linear segmental construction analysis. SAP2000 is the easiest and most productive solution for structural analysis and design needs.

To facilitate modelling, SAP2000 has provided several variations of templates (ready-to-use models) of a typical structure. To make the structure model, the user modifies it as needed so that the modelling and analysis process becomes faster. SAP2000 has been integrated to provide analysis and design process. After the analysis is complete and the correct results are obtained, the design can be done to obtain profile dimensions or steel/wood reinforcement. Re-analysis and redesign can be performed easily by using SAP2000.

The structure model in SAP2000 can be idealized within diverse elements, including joint (points), frames (rods), shell (plates) to solid elements as the actualization elements. For example, beams and columns in multi-story buildings are modelled as frame elements, bridge plates or shear walls acts as shells, weir bodies are divided into small pieces of solid elements, and others.

4. Results and discussions

Modelling with SAP2000 produced 280 connections, which were semi-rigid joint systems with an assumption value of rigid factor of 0.5. The loading data used in the modelling was dead loads consisting of structural loads and live loads with a coefficient value for a house according to SNI (the National Standardization of Indonesia), which was 200 kg/m² [10]. On the other hand, the maximum seismic loads used an earthquake scale factor of 10. By entering this data, the SAP2000 modelling produced a graphical structure as shown in figure 3.

Then, the response spectrum analysis process was carried out by using the SAP2000 program, and the output displayed was the response of structural parameters in the form of base shear and displacement presented and summarized in table 2 and figure 3.
4.1. Displacement

The traditional wooden houses of Mandailing are simple structures with one-story stilt house construction. The determination of inter-floor displacement should not exceed the level of permits inter-floor [7]. SNI 1726-2012 explains that the inter-floor displacement of permits for all other structures has inter-floor displacement permits for earthquake risk category I or II, which is 0.020 h_{xs} [7], where h_{xs} is the height of the building which is 0.020 x 6 = 12 cm.

Based on the calculation of SAP2000 analysis, the highest part of the traditional wooden house of Mandailing obtained a displacement at the connection point 110 with 0.1162817 m or 11.62817 cm. Table 2 describes the height of the main structure, which illustrates that the highest point of displacement was at 305 elevations, namely the beam joint and overhang roof. Figure 4 illustrates the displacement that occurred in buildings that were analysed through the SAP2000 program. The maximum value obtained from these calculations shows that the displacement occurred in construction did not expose significant building collapse. It means that the displacement was still within the safety limits.

**Figure 3.** Structural modelling of the traditional wooden house of Mandailing using the SAP2000 program.

**Table 2.** The output value of the displacement in structural elevation.

| Elevation (cm) | Displacement (cm) |
|---------------|-------------------|
|               | x                 | y                 |
| 60            | 7.21496           | 6.85187           |
| 275           | 7.5684            | 8.38664           |
| 305           | 8.32035           | 11.62817          |
| 458           | 7.8066            | 8.03506           |
| 612           | 7.43806           | 7.56591           |
4.2. Base Shear

Parameters from the previous calculations and seismic coefficients (Cs) were required to obtain a more accurate base shear force (V). Measurement of shear force value due to earthquake loads depends on the structure vibrating period value (Tc).

The structure vibrating period values from the analysis obtained Tc = 0.94267 seconds in mode 1, whereas the seismic coefficient (Cs) value was determined from the equation (1).

\[ Cs = \left( \frac{S1}{R} \right) = \left( \frac{0.633}{1.5} \right) = 0.422 \]  

(1)

Based on the SAP2000 calculation, the structure weight (W) = 355.484 kN was obtained, and the static shear force was the equation (2).

\[ (V_s) = W \times Cs = 355.484 \times 0.422 = 150.0142 \text{ kN} \]  

(2)

The final value of the dynamic response of the building structure to nominal earthquake load due to the effect of the earthquake plan in a specific direction should not be less than 80\% of the variance response value or mode 1. If the dynamic response of a building structure is expressed in the base shear force V, the requirements can be formulated according to the following equation (3).

\[ V > 0.8V_{\text{static}} \]  

(3)

If the static value V was 150.0142 kN, the analysis with the SAP2000 program showed the base shear value in mode 1 of 693.274 kN, then:

\[ 693.274 \text{ kN} > 0.8 \times 150.0142 \text{ kN} \]  

(4)

\[ 693.274 \text{ kN} > 120.0113 \text{ kN} \]  

(5)

Based on these calculations, the building had a mass of 355.484 kN with a static shear force of 150.0142 kN and a dynamic shear force of 693.274 kN. This means that the SAP2000 modelling...
results illustrate that the displacement occurred in buildings with an earthquake scale factor of 10 was still within the safety limits. In other words, the building was responsive to earthquakes.

5. Conclusions
Based on the analysis results of the calculation of displacement and base shear force values in the SAP2000 modelling, the structure and construction of a traditional wooden house of Mandailing were within the limits of safe and responsive to an earthquake. The structure and construction of buildings have fulfilled the requirements in planning earthquake-resistant buildings. The base shear force obtained from the analysis V was 124.84 kN. Moreover, the vibrating period of the traditional Mandailing wooden houses structure had a $T = 0.94267$ seconds value, which indicated that the building was safe from earthquakes.

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