Numerical Analysis of Bolon as Traditional Batak Toba House During An Earthquake: A Study in Village of Siallagan And Silalahi North Sumatera

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Abstract. There were many two-story building collapsed in The Province of Sumatera during an earthquake. One structure that did not collapse is the Traditional Batak House, which mostly made of wood. Traditional Batak House still stands strong until now even though it was built years before the presence of building code. The layout of the structure, the frame concept and also the earthquake force is calculated using Guideline SNI 7973:2013 for wood construction, and SNI 03-1726-2012 for earthquake structure resistant structure design. The research observed traditional Batak Toba house from two villages, the village of Siallagan and Silalahi which is neighboring village. The houses have different model of timber roof construction and also different height. The structure then analyses with the help of structure software application in seismic condition. One of the outcomes using software computation was natural frequency. The for both house in Village of Siallagan and Silalahi are 12,697 rad/sec and 13,846 rad/sec. while the period of the structure are 0.494 second and 0.454 second. The maximum value of the dynamic response expressed in the shear force of the traditional house for both village is 28,87 kN. The maximum floor displacement for Village of Siallagan is 4.01 cm, and for the Village of Silalahi is 4.14 cm.

1. Introduction
Traditional Batak Toba House Structure mostly made of timber, which known in Batak Language as Rumah Bolon. Exploration on Rumah Bolon has been carried out by PUPR and Development Center in 2013 [1] which concern about the structural and thermal reliability. As we know, wood is a renewable building material, other uses of wood are for fuel in industrial material, wood also use in joinery. The technical requirements for construction use are: strong, hard, large in size and possesses high natural durability. The types of wood for construction are as follows: balau, bangkirai, belangeran, cengal, giam, jati, kapur, Kempas [1]. Rumah Bolon is predicted to meet the technical requirements for construction, even though when it was built, it was believed that there were no wood construction experts at the time of construction.

This Rumah Bolon was built two hundred years ago. Rumah Bolon is a type of stilt house with a height of about 1.75 m, where the columns are made of wood. The building floor is also made of wood. Rumah Bolon has a wooden roof frame with hooks made of bamboo. While the roof is from
palm fiber. The shape of the roof is like a horse's saddle. Usually the lower part of the building is used as a cattle enclosure, such as Buffalo. Nails are not used in the construction of Rumah Bolon.

2. Literature Review
From the history, it was told that the tribe of Batak Toba ethnicity came from the Batak King who lived in the Early Sianjur Valley lived in the sky and landed on the roof. Due to the climate impact of the sun's heat and rain, based on the needs, a residence called jabu is built [1]. The residence is called Rumah Bolon, where the concept is extremely close to the culture and customs of Batak. In Indonesia, the applicable regulations on design specifications for wood construction is SNI 7973: 2013 [3]. For the calculation of the structure, AF & PA / ASCE 16-95 could be referred as well [4].

2.1 Village of Siallagan
To continue the research carried out in [1], the resistance to earthquake forces will be assessed by conducting a re-survey at Rumah Bolon located in the village of Siallagan which is located in the middle of Lake Toba on Samosir Island. The distance from Siallagan Village from Medan is around 230 km by road via Pangururan. Meanwhile, from Parapat, the distance is 166 km, with a ride on a ferry across from Parapat to the village for 40 minutes. Siallagan Village is located in Ambarita Village, Simanindo District, Samosir Regency, North Sumatra Province. Pictures of Rumah Bolon in Village of Siallagan can be seen in Figure 2.

2.2 The Village of Silalahi
The Village of Silalahi is located Dairi Regency, North Sumatra Province. And it located next to Village of Siallagan. The distance from Village of Siallagan is 109 km with a ride on car. The location between the two villages can be seen ini Figure 2, and the pictures of Rumah Bolon in Village of Silalahi can be seen in Figure 2.

Figure 1. Location between Village of Siallagan and Village of Silalahi
Figure 2. *Rumah Bolon* from Village of Siallagan [11] and from Village of Silalahi

2.3 Traditional Batak House Structure

2.3.1. Building Column Plan. The size of *Rumah Bolon* on the ground floor based on the survey is 5 m x 7 m, where the distance between columns varies, such as in the front (top) and behind (bottom) the distance of the column is 60 cm, while the door area is 140 cm. On the left and right side, the column distance is 70 cm and the outer column distance is 77 cm. The number of columns is 38. There are 8 columns which are up to the length that support the construction frame which are located in the middle. While the others (30 columns) only go to the floor. The type of wood used for the column is *Sibagure* wood, a type of iron wood [1].

![Building's column plan](image)

**Figure 3.** Building’s column plan [14]

The column shape is round. The column height is 1.75 m with a column diameter of 40 cm as seen in Figure 4.

![The column of Rumah Bolon in both village](image)

**Figure 4.** The column of *Rumah Bolon* in both village

The structure support by pillars which is called the *Sopo* pole. To connect the columns, wooden blocks are used. This house also has wooden beams support called *Rassang*. A cross section of *Rumah Bolon* structure can be seen in Figure 5.
According to the concept of structural dynamics, it can be approached with the MDOF system with two masses as in Figure 5. To connect the wood each other, we use mechanical connection which refer to SNI 7973: 2013 [3], article 10.1.1.1 technical design of connections could use bolts, key screws, split rings, sliding plates, bolts, wood screws, pins, nails, nail pins, wooden rivet.

Connection between beam (Rassang) and column (Sopo pole) in Rumah Bolon construction use a pin connection, where the perforated column and incoming beam drilling the column. The whole beam looks continuously stack without a connection. Between rassang beam and column, wooden pegs are inserted. The connection can be seen in figure 7. Wooden pegs are taken from hardwood and inserted by hitting it until the post is fully inserted. It can be categorized as a rigid connection.

2.3.2. Building Floor. The building floor consists of wood supported by wooden blocks. The side beam that supports the floor can be seen in Figure 7. The beam that supports the floor has four beams, two in the corner and two in the middle, the four beams are stretched. Distance from the edge beam to the middle beam is 1.20 m while in the middle it is 1.40 m.

The building floor is categorized as the body of the house which in Batak mythology is called the middle world, the middle world symbolizes the place of human activities such as cooking, sleeping and socializing. The Batak Toba house has, therefore, three distinct zones. The lower zone beneath the
house among the piles is a working area and often used as a pen for animals. The floor area, the zone above this, is the actual home of the extended family, accessed by a ladder or stairs. The interior of the house has no division and is therefore one long, dimly lit hall. At night, cloths are drawn down to separate the sleeping areas between each family. While the highest storey or the attic is the most important part of the building where family heirlooms and ancestral shrines are placed. In accordance with building plans, Rumah Bolon has symmetrical plans, and is qualified and suitable as a building in an area prone to earthquake. The type of beam connection that supports the floor can be seen in Figure 10. The column is made of wood with a diameter of about 40 cm. The column height is around 175 cm. After looking at the columns and beams, it is certain that the column is safe against bending. If an earthquake occurs the column is also quite strong because there are blocks of three parallel units.

![Figure 9](image1.png)

**Figure 9.** connection between column and floor block

2.3.3. Wall. The wall material at Rumah Bolon was from wood. However, in other Rumah Bolon, bamboo is also used. The walls of the Batak Toba house is tilted to enable ventilation. The sloping straps are called retract ropes, made of palm fiber or rattan. These straps form a pattern like a lizard that has 2 heads opposite each other, meaning that the lizard is said to be the guardian of the house, and 2 opposing heads symbolize all occupants of the house have the same role and mutual respect.

2.3.4. Roof in The Village of Siallagan. The Rumah Bolon roof is inspired from the basic idea of a buffalo back, its curved shape adds to its aerodynamic value against strong lake winds. The roof is made of palm fiber, an ingredient that is easily obtained in the local area. Batak people consider the roof as something sacred, so it is used to store heirlooms. The roof can be seen in Figure 10.

![Figure 10](image2.png)

**Figure 10.** The roof shape of Rumah Bolon in Village of Siallagan [2]

2.3.5. Roof in The Village of Silalahi. Similar with the structure of Rumah Bolon in the Village of Siallagan, the roof is also inspired from the basic idea of a buffalo back. The roof shape curved out, while the Village of Silalahi The roof can be seen in Figure 11.
2.3.6. Foundation. The foundation of the traditional Batak Toba house is categorized as isolated footing or umpak foundation. The wood column is supported by the pedestal foundation. Laying columns on the foundation can be categorized joints, see figure 12. There is nothing particular regarding the connections between columns and foundations, it is just installed on the ground and relies on shear force between stone and wood.

If you look at the condition of the wood associated with the foundation, it looks durable and still has not been eaten by termites. This is due to the groundwater in this area is quite deep, so the wood column remains durable.

2.4 Mechanical Properties
Traditional Batak Toba houses are built with materials found in nature, such as wood, palm fiber, and stone. The wood used is like hau resse, zior, pokki, suren wood (hau ingul), and others. The survey was conducted to find the mechanical properties of wood, for example the type of wood used, the size of wood, and the properties of wood. At Rumah Bolon, the type of wood with the local name boking-boking, in Java is called kayu tengguli while the scientific name is called Cassia fistula [1]. MOE (Modulus of elasticity) of wood is 37,915 kg/cm². While the MOR (modulus of rupture) is 352.41 kg/cm². Compressive strength parallel to grain is 241 kg/cm². Tensile strength parallel to grain is equal to 452.92 kg/cm², tensile strength perpendicular to grain is 512.3 kg/cm². Shear strength parallel to grain is 47.28 kg/cm², shear strength perpendicular to grain is 57.64 kg/cm². Hardness: radial 267.50 kg, tangential 286.33 kg. Specific gravity 0.788. [1] Mechanical properties will be used to calculate the structure of Rumah Bolon.
2.5 Earthquake Force
In calculating earthquake forces, the modal analysis will be used, also called spectral respons method. While the earthquake respons spectra is using the Indonesian Earthquake Response Spectra issued by puskim.pu.go.id, 2011 [5].

2.5.1. Single Degree of Freedom. SDOF [6] equation caused by earthquake is as follow:

\[ f_t + f_D + f_S = P(t) \]  
\[ (1) \]

Whereby \( f_t \) : Inertia force, \( f_D \) : damping force and \( f_S \) : static force. Equation (1) can be written as:

\[ m \ddot{u} + c \dot{u} + k u = P(t) \]  
\[ (2) \]

Whereby,

\[ p(t) = -m \ddot{u}_b(t). \]  
\[ (3) \]

From the equation (3) \( \ddot{u}_b \) : earthquake force, \( m \) : mass, \( c \) : damping coefficient, \( k \) : stiffness, \( \ddot{u} \) : acceleration, \( \dot{u} \) : velocity dan \( u \) : displacement. In a single generalized mass model Rumah Bolon in figure 12 a) could be modelled as in figure 12 b).

![Diagram](image)

Figure 13. generalized Mass modeled as SDOF With the response spectrum method

then equation (4) applies,
\[ \ddot{u}_{\text{max}} = S_a \] (4)

\( S_a \): is a large response spectrum based on period \((T)\) structure. Response spectrum can be used in figure 13.

**Figure 14. Earthquake Response Spectrum**

The natural frequency equation for the SDOF system, with the period of structure is

\[ \omega = \sqrt{\frac{m}{k}} \] (5)

2.5.2 **Multi Degree of Freedom.** The equation for the dynamic structure in the MDOF system with a dynamic force is

\[ [M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = [P(t)] \] (6)

For free vibration equation (6) become to:

\[ ([K] - \omega^2[M])\{a\} = 0 \] (7)

Whereby \( a \) is the *eigen vector* and \( \{a\} \neq 0 \)

Thus the value of \( \omega \) is called the natural frequency.

Whereby: \( \{\omega\} = \left\{ \begin{array}{c} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_n \end{array} \right\} \) (8)

From equation (8) the period of each mode is obtained. The number of modes depends on the mass. With several periods the earthquake force [7] and [8] is as stated below

\[ t o t H_{E,\ell} = m_{e,\ell} S_{a\ell} \] (9)

\( H_{E,\ell} \): shear force from the earthquake based on mode

\( S_{a\ell} \): spectrum response based on figure 12

Whereby:

\[ m_{e,\ell} = \frac{\left[ \sum_{j=1}^{n} m_j \phi_{ij} \right]^2}{\sum_{j=1}^{n} m_j \phi_{ij}^2} \] (10)

\( m_{e,\ell} \): generalized mass for single degree mass from other mass, see also figure 12. Hence the earthquake force [7,8]
If the mass is two, then there are two periods and the earthquake force can be calculated from mode 1 and mode 2 and then added together.

2.6 Structural Roof Loading

In order to build a good, strong roof, it is necessary to take into account the forces which act on a roof. These forces are called loads and can be divided into Live load and Dead load. The most dangerous load in most locations is the wind load. Strong winds or storms can cause great damage to a roof if it is not well made and securely fixed to the building. It should be noted that the suction forces are much higher at roof overhangs, ridges, eaves, verges and other protruding edges and corners. These must be counteracted by fixing the roof structure and covering firmly in these areas. Moreover, if a building has large openings, or in the case of an open shed, the wind forces are further increased.

The load reviewed in the traditional Batak Toba house is its own heavy load, dead load and earthquake load. Dead load is a load originating from the building’s own weight which is calculated using the density of wood material, the wood used is teak wood which has a specific gravity of 0.788. The dynamic load is in the form of a spectrum response plan from http://puskim.pu.go.id [5] for the Samosir area with the site class. This study determine the effect of earthquake loads that occur on the house, loads used is as follow:

- Dead Load, contain of: Weight of the roofing; weight of the purlin; weight of the joist; weight of the rafters
- Live Load
- Wind Load

The combination used in this calculation are:
- $1.2D \pm 1.0L + 1.6W$
- $0.9D \pm 1.6W$

3. Research Method

The research method applied is a method of data collection and analysis using software. Data collection is carried out by survey, interviews, and literature studies. The survey was conducted in Siallagan village, Samosir district and in Silalahi Village, Dairi Regency. The results of the survey were modeled on SketchUp and CAD. The research flow can be seen in figure 15.
4. Results and Discussion

4.1. Structure Modelling
The traditional Batak Toba house structure consists of several parts, such as columns, roof truss, and wooden blocks. The structural system has a rod configuration, where the joints or joint points are jointly modeled as semi-rigid. The connection in this modeling is made semi rigid from the End (Length) Offsets command by assuming the value of rigid-zone factor of 0.4. For the pedestal, it is more suitable to be modeled with a Pendulum Friction support system where the support between wood and stone has a gap or distance using the Friction Isolator type, but to simplify the completion of this final task, it is assumed that the traditional Batak Toba pedestal is a joint.

4.2. Fundamental Period of a Structure
Fundamental period of a structure cannot exceed the coefficient for the upper limit in the calculated period (Cu) and the fundamental period of approach, Ta, which is determined according to SNI 1726-2012 article 7.8.2.1 [9], [10]. Structural calculation in the village of Siallagan has been accomplished previously [14]. This section explain the result of calculation in the village of Silalahi.

Fundamental period of a structure, $T_a$, in seconds, has to be determined from the equation:

$$ T_a = C_t h_n^x $$  \hspace{1cm} (14)

Whereby: $h_n$ : Height of structure (m) \hspace{0.5cm} C_t \hspace{0.5cm} dan $x$ : coefficient from table 15 (SNI 1726-2012) [3]

$$ T_a = 0.0488 \times 5^{0.75} $$

Result

$$ T_a = 0.163172 \text{ seconds} $$
Calculations using dynamic systems (eigenvalue analysis) produce a period of structure vibration for the 10 modes presented in the following table.

### Table 1. Period (T) of Rumah Bolon in Village Silalahi

| Mode | Period (T) Seconds | Eigenvalue rad$^2$/sec$^2$ |
|------|--------------------|---------------------------|
| 1    | 0.45380            | 191.7                     |
| 2    | 0.44079            | 203.19                    |
| 3    | 0.32417            | 375.67                    |
| 4    | 0.29498            | 453.7                     |
| 5    | 0.25082            | 627.55                    |
| 6    | 0.22076            | 810.05                    |
| 7    | 0.21558            | 849.43                    |
| 8    | 0.19180            | 1073.1                    |
| 9    | 0.18353            | 1172.1                    |
| 10   | 0.16913            | 1380.1                    |

### 4.3. Natural Frequency Structure

A vibrating will caused isolation at the natural frequency $\omega_n$ which is the property of the system. Single Degree of Freedom (SDOF) differential equation involves three main properties of a structure, namely, mass, stiffness, and damping. Period of structure,

$$T = \frac{2\pi}{\omega} \tag{15}$$

By inputting $T_a$ value = 0.16 seconds to the equation (15) hence the result is as follow:

$$\omega = \frac{6.28}{0.16} = 38.48 \text{ rad/sec}$$

From calculation results, the natural frequency ($\omega_n$) structure for the 10 modes are presented in the following table.

### Table 2. Natural Frequency ($\omega_n$) of the Structure in Village Silalahi

| Mode | Natural Frequency ($\omega_n$) (rad/sec) | Eigenvalue rad$^2$/sec$^2$ |
|------|------------------------------------------|-----------------------------|
| 1    | 13.846                                   | 191.7                       |
| 2    | 14.254                                   | 203.19                      |
| 3    | 19.382                                   | 375.67                      |
| 4    | 21.3                                     | 453.7                       |
| 5    | 25.051                                   | 627.55                      |
| 6    | 28.461                                   | 810.05                      |
| 7    | 29.145                                   | 849.43                      |
| 8    | 32.7599                                  | 1073.1                      |
| 9    | 34.236                                   | 1172.1                      |
| 10   | 37.15                                    | 1380.1                      |
There are differences between empirical calculation and software. The natural frequency with equation (14) was 38.48 rad/sec, so using dynamic analysis the natural frequency was 12.697 rad/sec. [14]

### 4.4 Base Shear Force Nominal, V (Base Shear)
In order to calculate the nominal of base shear force, V (base shear), according to the direction in SNI 1726-2012 article 7.8.1 [9].

The shear force formula is:

\[ V = C_s W \]  \hspace{1cm} (16)

Whereby,

- \( C_s \): Seismic response coefficient
- \( W \): effective seismic weight

The earthquake force coefficient is as follows:

\[ C_s = \frac{S_{DS}}{R} \]  \hspace{1cm} (17)

\( S_{DS} \): Spectrum acceleration parameters in short periods, \( R \): response modification factor, \( I_e \): primacy factor of the earthquake

\[ C_s = \frac{S_{DI}}{R \left( \frac{T}{T_e} \right)} \]  \hspace{1cm} (18)

\[ C_s = 0.044 \times S_{DS} I_e \geq 0.01 \]  \hspace{1cm} (19)

The value of the vibrating period of the structure from the calculation of analysis is obtained, \( T_e = 0.454 \) seconds, Mode 1 Table 1. From the calculation of analysis with a computer program the value of the base shear from mode 1, the earthquake force that occurs is \( V = 119,388 \) kN.

### 4.5 Displacement in the Structure of Traditional Batak House

The traditional Batak Toba house in this study was categorized as a simple structure with a two-story structure. Determination of displacement between floors should not exceed the level of clearance between floors \( \Delta \) (SNI 1726-2012, article 7.12.1). In SNI 1726-2012, it is explained that the inter-floor deviation of permits for all other structures (Table 16 SNI 1726-2012) has permissible intersections of permits for earthquake risk categories I or II are \( 0.020h \). Whereby \( h \) is the building height.

\[ 0.020 \times (8.22 \text{ m}) = 0.1644 \text{ m} = 16.44 \text{ cm} \]

From the calculation by using the computer program, the highest displacement part of the traditional Batak Toba building in Village of Silalahi is obtained, which is at the top is 5.14 cm.

### 5. CONCLUSION AND SUGGESTION

#### 5.1 Conclusion

Traditional Batak House has its characteristic shape, and it is similar with other traditional house construction from different tribes on the different geographical sites [13]. But they also indicate a common thread between traditional houses scattered in archipelago to the Asia Pacific region and even Europe.
Based on the results of the analysis conducted by the author, the results obtained with conclusions are as follows:

1. The difference between Traditional Batak house in the village of Sillalahi and Siallagan is lies in the shape of their roof and their height.

2. The structure of the traditional Batak Toba house is in the Village of Siallagan are proven to be an earthquake resistant building structure [14], and the village of Silalahi are also, because it fulfills the requirements in earthquake resistant structures plan.

3. First mode occurred and gives a 12, Rad/sec value of the natural frequency $\omega$ for Village of Silalahi and $\omega$ for Siallagan [14]

4. The period T of traditional Batak Toba house structure from mode 1 has a value of $T = 0.494$ seconds for Village of Siallagan and $T = 0.454$ for Village of Silalahi.

5. The base shear $V$ force obtained from the calculation of the analysis, $V = 52,821$ kN for Village of Siallagan, and $V=119,39$ kN for Village of Silalahi.

6. Since the building in Village of Silalahi is higher than the building in Village of Siallagan, maximum displacement also bigger. They are 5,14 cm and 4,01 cm

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