Study of bolon house structure as a traditional Batak Toba house on earthquake force

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Abstract. Traditional Batak house is believed to be earthquake-resistant. Hence, the layout of the structure, the frame concept and also the earthquake force is calculated based on SNI 7973: 2013, namely regulations on design specifications for wood construction and SNI 03-1726-2012 regarding earthquake resistance planning procedures for building and non-building structures, especially the natural frequencyω of house, period T of house, floor displacement and shear forces V that occur. The traditional Batak house building was built long before the SNI 7973: 2013 and SNI 03-1726-2012 regulations existed. The traditional Batak Toba house studied was located in the village of Siallagan "Batu Parsidangan, Huta Siallagan". According to mechanical properties of wood, the traditional Batak house has fulfilled the wood specifications based on SNI 7973: 2013 and the structural concepts have met the requirements of SNI 03-1726-2012. Calculation or analysis on the resilience of traditional Batak Toba houses against earthquake forces are carried out using software. It is found that the natural frequency ω is 12.697 rad/sec and period of the structure T is0.494 seconds. The shear forcesthat occurs due to the earthquake force V is 28.87 kN, the maximum floordisplacement from the traditional Batak Toba house is taken from the highest point, which is 4.01 cm.

1. Introduction

Traditional Batak Toba Traditional House Structure is a wooden structure known in Batak Language as *Rumah Bolon*. Research on *Rumah Bolon* has been carried out by the 2013 PUPR Research and Development Center in the literature [1] regarding the structural and thermal reliability.

In general, wood is used in carpentry, buildings (construction), industrial materials and as fuel. 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.

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. 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

The origins of the Batak Toba ethnicity are from the ancestors of the Batak King who lived in the Early Sianjur Valley who is said to have reportedly lived in the sky and landed on the roof. However, with 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. Pictures of *Rumah Bolon* can be seen in Figure 2.

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].

Figure 1. *Rumah Bolon* [2]

2.1.Traditional Batak House Structure

a. 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].

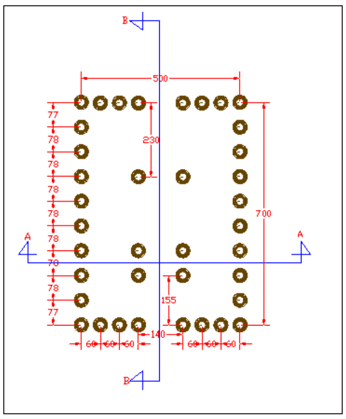

Figure 2. Building’s column plan

The column shape is round. The column height is 1.75 m with a column diameter of 40 cm as seen in Figure 3.

Figure 3. *Rumah Bolon*'s Column

The column is called the *Sopo* pole. Whereas, each columns are connected with wooden blocks. The wooden beams are called *Rassang*. In terms of structure can be seen in Figure 4, a cross section of *Rumah Bolon*.

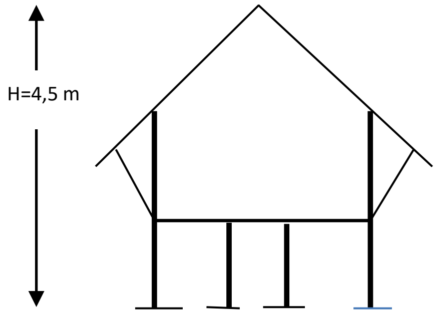

Figure 4. A cross section of *Rumah Bolon*

According to the concept of structural dynamics, it can be approached with the MDOF system with two masses as in Figure 5.

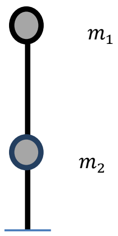

Figure 5. MDOF Concept

Mechanical connections in wood construction can be seen in 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.

In this *Rumah Bolon*, the mechanical connection between the *Sopo* pole and *Rassang* is a pin connection, where the pierced column and incoming beam penetrate the column. It seems like the beam is continuously intact without a connection. Between *rassang* beam and column, wooden pegs are inserted. The connection can be seen in figure 6. 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.

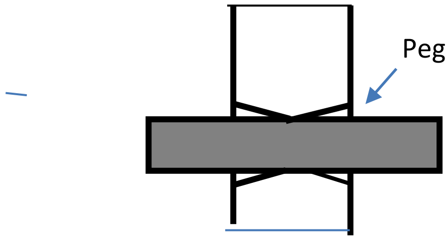

Figure 6. Connection using wooden pegs

b. 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, as seen in figure 2.

Figure 7. Building floor supported by the wooden blocks

Thus, if the building floor is divided into the direction of A in Figure 2, it would be as in the illustration in Figure 8.

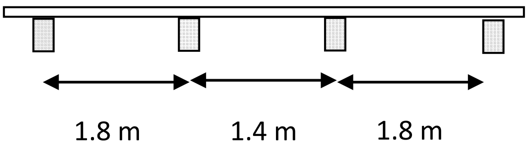

Figure 8. Sketch of the *Rumah Bolon*'s floor

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 body part of the house is equipped with an ornament in the form of *ipon-ipon* as a protection from evil/misfortune.

The concept of the beam/floor structure of *Rumah Bolon* is as follow: the length of the longitudinal beam is 7 m, which consisted of B1 as many as 4 units, with a distance of 1.8 m next to the edge, while in the middle the distance is 1.4 m. Moreover, there are 4 B2 blocks. Thus the floor plate is a wooden floor consisting of four supports with spans of 1.8 m, 1.4 m and 1.8 m. Refer to Figure 9.

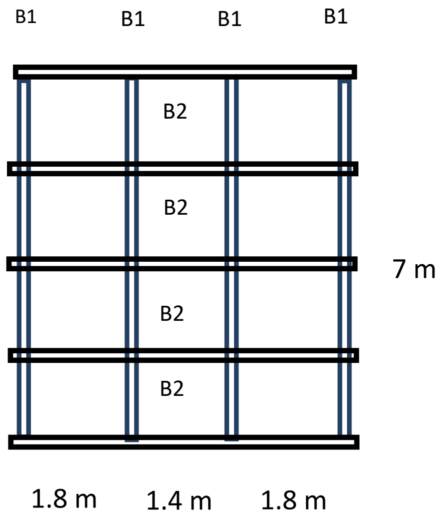

Figure 9. Blocks and *Rumah Bolon*'s Floor

In terms of 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.

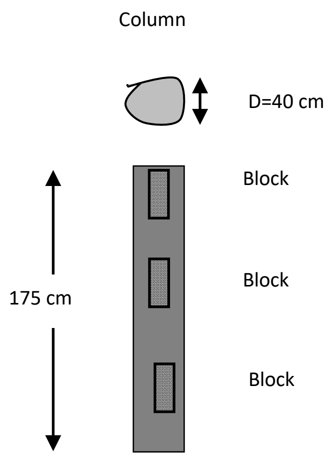

Figure 10. Connection between column and floor block

c. 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.

d. Roof

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.

e. 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 11. 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.

Figure 11. Foundation

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.

2.2.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/cm^2. While the MOR (modulus of rupture) is 352.41 kg/cm^2. Compressive strength parallel to grain is 241 kg/cm^2. Tensile strength paralel to grain is equal to 452.92 kg/cm2, tensile strength perpendicular to grain is 512.3 kg/cm^2. Shear strength parallel to grain is 47.28 kg/cm^2, 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*.

2.3.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].

2.3.1. Single Degree of Freedom

SDOF [6] equation caused by earthquake is as follow:

$$f_I + f_D + f_S = P(t) \tag{1}$$

Whereby f_I: Inertia force, f_D: damping force and f_s: static force. Equation (1) can be written as:

$$m\,\ddot{u} + c\,\dot{u} + \ k\,\dot{u} = P(t) \tag{2}$$

Whereby,

$$p(t) = -m.\ddot{U}_b(t). \tag{3}$$

From the equation (3) $\ddot{U}_g$: 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).

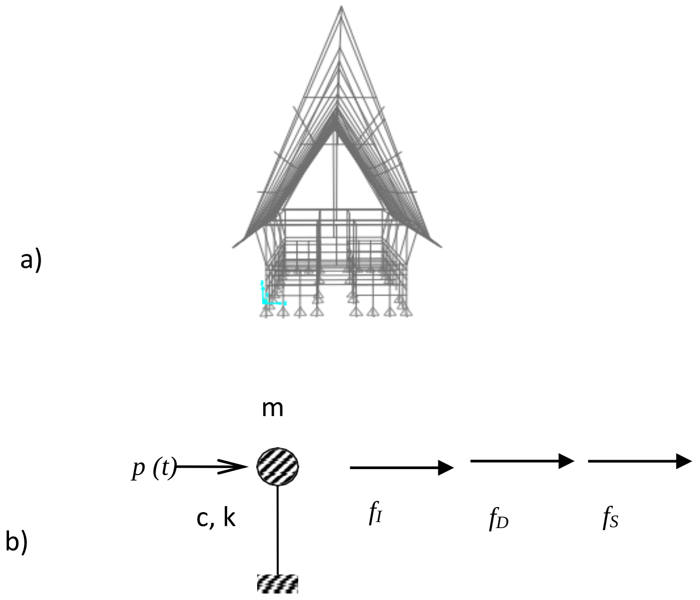

Figure 12. Generalized Mass modeled as SDOF

With the response spectrum method, then this applies:

$$\ddot{u}_{max} = S_a \tag{4}$$

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

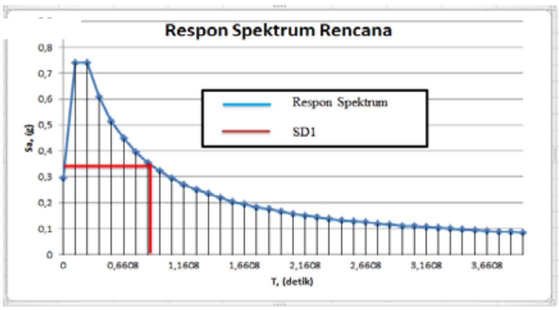

Figure 13. Earthquake Response Spectrum

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

$$\omega = \sqrt{\frac{m}{k}} \tag{5}$$

2.3.2 Multi Degree of Freedom

The equation for the dynamic structure in the MDOF system with a dynamic force is

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

For free vibration equation (6)become to:

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

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

Thus the value of ω is called the natural frequency.

$$\text{Whereby: } \{\omega\} = \begin{Bmatrix} \omega_1 \\ \omega_2 \\ \cdot\cdot \\ \omega_n \end{Bmatrix} \qquad (8)$$

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

$$tot\ H_{E,i} = m_{e,i} S_{ai} \qquad (9)$$

$H_{e,i}$: shear force from the earthquake based on mode
S_{ai} : spectrum response based on figure 12

Whereby:

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

$m_{e,i}$: generalized mass forsingle degree mass from other mass, see also figure 12 .

Hence the earthquake force [7,8]

$$H = \lambda_{ij}\ \epsilon_i\ m\ S_a \qquad (11)$$

$$\lambda_{ij} = \frac{m_j \phi_{ij}}{\sum m_j \phi_{ij}} \qquad (12)$$

$$\epsilon_i = \frac{m_{e,i}}{m} \qquad (13)$$

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.

2.4. Structural Loading

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 living load on the floor of a residential house is planned to carry a living load of 200 kg/m^2, while 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. Because this study is only to determine the effect of earthquake loads that occur on each model, the combination of loads used is as follow:

- 1,2D ± 1,0E + 0,5L
- 0,9D ± 1,0 E

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. The results of the survey were modeled on SketchUp and CAD.

The research flow can be seen in figure 14.

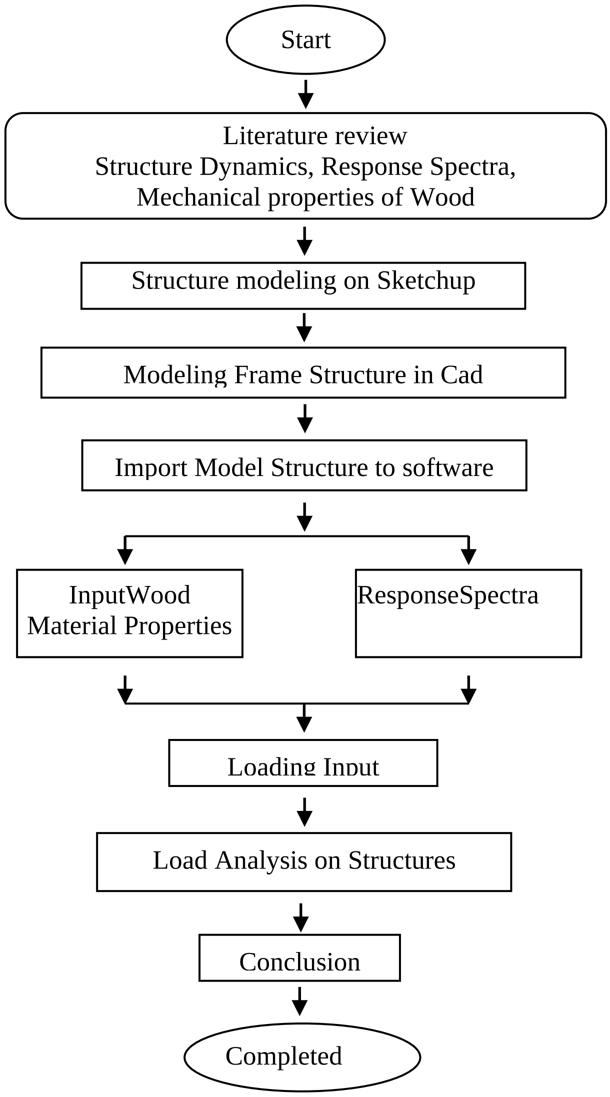

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Figure 14. Analysis Diagram

4. RESULT 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].

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

$$T_a = C_t h_n^x \qquad (14)$$

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

$T_a = 0.0488 \times 5^{0,75}$
Result
$T_a =$ *0.163172 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

Mode	Period (T) Seconds	Eigenvalue rad^2/sec^2
1	0.494841	161.22
2	0.441546	202.49
3	0.286556	480.77
4	0.247337	645.33
5	0.195576	1032.1
6	0.17101	1349.9
7	0.15645	1612.9
8	0.145857	1855.7
9	0.145851	1855.8
10	0.145850	1855.9

4.3. Natural Frequency Structure

A vibrating will caused isolation at the natural frequency ω_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,

$$T = \frac{2\pi}{\omega} \qquad (15)$$

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

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

From calculation results, the natural frequency *(ω_n)* structure for the 10 modes are presented in the following table.

Table 2. Natural Frequency*(ω_n)* of the Structure

Mode	Natural Frequency (ω_n) (rad/sec)	Eigenvalue rad^2/sec^2
1	12.697	161.22
2	14.23	202.49
3	21.93	480.77
4	25.403	645.33
5	32.127	1032.1
6	36.742	1349.9
7	40.161	1612.9
8	43.078	1855.7

9	43.080	1855.8
10	43.082	1855.9

There are difference between empirical calculation and software. The natural frequency with equation (14) was 38.48 rad/sec, so using dynamic analysis the natural frequency was12.697 rad/sec.

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:

$$V = C_s W \tag{16}$$

Whereby,
C_s: Seismic response coefficient
W: effective seismic weight

The earthquake force coefficient is as follow:

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_e}\right)} \tag{17}$$

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

$$C_s = \frac{S_{D1}}{T\left(\frac{R}{I_e}\right)} \tag{18}$$

$$C_s = 0.044\ S_{DS} I_e \geq 0{,}01 \tag{19}$$

The value of the vibrating period of the structure from the calculation of analysis is obtained, Tc = 0.49 seconds, Mode 1 Table 1. While the period of vibration structure from the calculation of SNI 1726-2012 [9], Ta = 0.16 seconds.
Tc = 0.49 seconds > Ta = 0.16seconds, hence Ta can use the multiplier coefficient value, Cu.
From the previous calculations obtained values from SD1 = 0.341g, the values of Cu = 1.4 (ASCE7) [10].

Ta.Cu = (0.16) . (1.4) = 0.22848 seconds.Whereby the Ta.Cu value <Tc, therefore the period value used to determine the seismic coefficient value, Cs is T = 0.228 seconds.
The value of the seismic coefficient Cs, determined from equation (16),whereby$S_{DS}$is taken from Figure 13 and$I_e = 1$

$$C_s min = 0.044\ S_{DS} I_e = 0.044x0{,}74x1 = 0.03256$$

The value of the seismic coefficient Cs from equation (17),whereby$S_{DS} = 0.74$and$R = 1.5$. While$I = 1$

$$C_s = \frac{S_{DS}}{R/_I} = \frac{0.74}{1.5/1} = 0.493$$

Meanwhile, the seismic coefficient value is based on equation (18) with value $S_{D1}$from Figure 12.

$$C_s max = \frac{S_{D1}}{T\left(\frac{R}{I}\right)} = \frac{0.341}{0.228\left(\frac{1.5}{1}\right)} = 0.99$$

So, the value of Cs determine the equivalent static shear force is:

$$Cs_{(min)} < Cs < Cs_{(max)}$$
$$0.032 < 0.493 < 0.99$$

The value of Cs used is 0.493 because it meets the requirement at the interval between $Cs_{(min)}$ and $Cs_{(max)}$.
Then the nominal of static shear force is equivalent to (V), that is V = Cs. W. From the program analysis, the total weight of the building obtained W = 58.522 kN, then, V = Cs. W = 0.49333 x 58.522 kN = 28.87 kN.
The final value of the structural response of the building to the earthquake loading nominal due to the influence of the Planned Earthquake in a certain direction, should not be taken less than 80% of the first variety response value. If the dynamic response of a building structure is expressed in nominal base shear force V, then the requirement can be expressed according to the following equation:

$$V > 0.8\ V_{static} \tag{20}$$

Where the static V value is 28.87 kN, from the calculation of analysis with a computer program the value of the base shear from mode 1 is obtained at 52.821 kN, then:

$$52{,}821 \text{ kN} > 0.8 * 28.87$$
$$52{,}821 \text{ kN} > 23{,} 096 \text{ kN}$$

Thus the earthquake force that occurs isV =52,821 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 two-story structure. Determination of displacement between floors should not exceed the level of clearance between floors (Δ_a) (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 $0.020h_{xs}$. Whereby$h_{xs}$is the building height.

$$0.020 \text{ (5 m)} = 0.1 \text{ m} = 10 \text{ cm}$$

From the calculation by using the computer program, the highest displacement part of the traditional Batak Toba building is obtained, which is at the top is 4.01 cm.

5. CONCLUSION

Based on the results of the analysis conducted by the author, the results obtained with conclusions are as follows:

1. The structure of the traditional Batak Toba house is proven to be an earthquake resistant building structure because it fulfills the requirements in earthquake resistant structures plan.
2. The natural frequency $\omega$of Building is 12.697 rad/sec (first mode).
3. The period T of traditional Batak Toba house structure from *mode 1* has a value of T = 0.494 seconds.
4. The base shear V force obtained from the calculation of the analysis, V = 52,821 kN
5. The maximum floor displacement is 4.01 cm.

Acknowledgement

This research was carried out with the help of University of Sumatera Utara, in Talenta research in 2019.

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