Structural analysis of traditional Batak Karo house against earthquake

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Abstract. The Karo traditional house studied was \textit{gerga sepulu dua jabu} in Lingga village. The structure is modelled into frames and 3D models. Structural irregularity will be analyzed and spectral response analysis were carried out with SAP 2000. Earthquake resistance is determined based on period, base shear force, friction between rock with piles, story drift and appearance analysis. Horizontally the Batak Karo traditional house is regular but vertically has an irregularity that is mass irregularity, vertical geometry, discontinuity in the direction of holding horizontal force. From the SAP 2000 analysis, a period of 0.107993 seconds was obtained, a basic shear of 94.884 kN, a friction force between the rock with piles a 94.884 kN, story drift of 8.068 mm. Column axial force 152,755 kN, beam bending moment 16,372 kNm and beam shear force 47,982 kN. The upper limit of the period is 0.4676 seconds, dynamic shear force of 80.561 kN, rock friction with 368.55 kN, and 37 mm deviation. Column compressive force 1864.01 kN, beam bending moment 36,277 kNm, and beam shear force 380,725 kN. Based on that, it can be concluded that the Karo traditional house is safe from earthquakes.

1. Introduction

Karo Regency is an earthquake-prone area because it is located near a large Sumatran fault which often experiences movement and volcanic activity of Sinabung Mountain. On January 16, 2017, a 5.6 magnitude earthquake centered on Sibolangit caused a lot of damage in Karo regency. Seven houses were severely damaged, while 70 houses, 3 schools and 1 mosque were slightly damaged. All damage happened to the concrete house, but the traditional Karo Batak house made of wood was not damaged. This is very impressive because the Karo Batak traditional house was built ± 160 years ago. This is consistent with the assumption that wooden houses are safer than wooden houses in resisting earthquake forces [1].

Bhagavathula (2014) conducted a study of Batak Toba traditional houses analyzed as SDOF by reviewing the fundamental period of the structure, the natural frequency of the structure, the basic shear force and displacement [2]. Visually the Toba and Karo Batak houses have the same structure, but the dimensions of the Batak Karo traditional house structure are much greater. The number of columns (poles) used is less with a longer distance so that the burden carried by the column will be greater. In addition, the type of house that was analyzed, that is, \textit{gerga sepulu dua jabu}, was found sloop on the side pillar of the house. Many people are not aware of the structure of the Batak Karo traditional house, so it is necessary to study the structure of the house and its resistance to earthquake. This structure will be analyzed as MDOF with parameters of earthquake resistance, namely the period of the structure, the basic shear force, the friction force of the pile with the foundation stone, the intersection between floors, and the analysis of the cross section of the structure. Batak Karo traditional house can be seen in Figure 1.
2. Research method
The research begins with an initial survey in Lingga village, Karo district on traditional houses *gerga sepulu dua jabu*. Interviews were conducted to obtain information about traditional houses and measurements for obtain the dimensions of the structure. The structure will be modeled as a 3D model (SketchUp) to determine the concept of 3D structure and frame (AutoCAD) for analysis. The model is imported into SAP 2000 v20 and analyzed by response spectra. The results of this analysis will be compared against the structural strength.

2.1 Loading
The relationship of period with the acceleration response spectra can be seen in Table 1.

| Period, T (s) | Parameter of Acceleration Design Response Spectrum, Sa (g) |
|--------------|----------------------------------------------------------|
| 0            | 0,241                                                    |
| 0,133        | 0,602                                                    |
| 0,663        | 0,602                                                    |
| 0,75         | 0,532                                                    |
| 1            | 0,399                                                    |
| 1,5          | 0,266                                                    |
| 2            | 0,200                                                    |
| 2,5          | 0,160                                                    |
| 3            | 0,133                                                    |
| 3,5          | 0,114                                                    |
| 4            | 0,100                                                    |
| 4,5          | 0,089                                                    |
| 5            | 0,080                                                    |
This relationship can be described in figure 3.

![Figure 3. Parameter of design response spectrum](image)

3. Result and discussion

3.1 Centre of mass and stiffness

The location of the center of mass and center of stiffness can be seen in Table 2.

| Floor | Mass (Ton) | Mass Centre (m) | Stiffness Centre (m) |
|-------|------------|-----------------|----------------------|
|       |            | x    | y    | x    | y    |
| ALL   | 60.18      | 6.65 | 8.175| 6.65 | 8.175|
| 1     | 23.24      | 6.65 | 8.175| 6.65 | 8.175|
| 2     | 36.94      | 6.65 | 8.175| 6.65 | 8.175|

The center of mass and center of stiffness are at the same coordinates, so there is no eccentricity in the structure so that no torsion occurs in the structure.

3.2 Horizontal irregularity

The eccentricity of the structure towards the x and y sums is 0 so that neither torsion nor excessive torsion occurs. In the structure, there was no diaphragmatic discontinuity or discontinuity in the lateral force trajectory. The vertical lateral force resisting element is also parallel to the orthogonal axis of the earthquake force bearing system. Then it can be concluded that there is no horizontal irregularity that occurs.

3.3 Vertical irregularity

The comparison of stiffness on the 1st floor and 2nd, can be seen in Table 3.
Table 3. The stiffness of each story on the x and y direction

| Floor | $K_x$ (EI/m³) | $K_y$ (EI/m³) |
|-------|---------------|---------------|
| 1     | 95.75         | 35.98         |
| 2     | 19.54         | 19.54         |

Comparison 1st floor to 2nd floor (%)

490 184.1351

The ratio of the x direction stiffness was 490% and the y direction was 184.13%. Since the stiffness of the 1st floor in the y direction is greater than 70% (soft) and 60% (excessively soft) the stiffness of the 2nd floor, it is categorized as a regular building (not soft and not excessively soft). Because the stiffness of the 1st floor is greater than that of the 2nd floor, there is no discontinuity in the soft level irregularity.

In the structure there is a vertical geometric irregularity, namely the difference between the lateral force retaining elements where on the 1st floor there are bracing and the walls on the 2nd floor. There was also a discontinuity in the direction of the plane of the vertical lateral force resistance element, where the roof column did not rest on the column, resulting in load eccentricity.

Table 4. Vertical irregularity

| No | Vertical Irregularity | Analysis Result |
|----|-----------------------|-----------------|
| 1  | Mass irregularity     | Exist           |
| 2  | Excessive soft and soft stiffness irregularity | Un exist |
| 3  | Vertical geometric irregularity | Exist |
| 4  | Irregular discontinuity of direction of vertical force bearing elements | Exist |
| 5  | The irregularity of the strong lateral level and the strong lateral level is excessive | Un exist |

3.4 Earthquake performance

3.4.1 Structural fundamental period

The structure period that occurs can be seen in Table 5.

Table 5. Period results from the analysis of SAP 2000

| Mode | Period, $T$ (s) | Mode | Period, $T$ (s) |
|------|----------------|------|----------------|
| 1    | 0.107993       | 7    | 0.060596       |
| 2    | 0.104025       | 8    | 0.047705       |
| 3    | 0.0939         | 9    | 0.047231       |
| 4    | 0.079755       | 10   | 0.046475       |
| 5    | 0.077008       | 11   | 0.045638       |
| 6    | 0.076921       | 12   | 0.044773       |

It can be seen that the period of structure analysis results is smaller than the fundamental period and the limit on the period so it can be concluded that the period of the Batak Karo traditional house is safe.
3.4.2 Base shear force
Based on SNI 1726: 2012, the dynamic shear forces that occur must be ≥ 85% of the static shear forces that occur.

| Load | Type of Load | Global FX (kN) | Global FY (kN) |
|------|--------------|----------------|----------------|
| RSx  | Dynamic      | 87,766         | 0.183          |
| RSy  | Dynamic      | 0.183          | 90,264         |
| EQy  | Static       | -5,829 x 10^{-15} | -94,884        |
| EQx  | Static       | -94,884        | -5,945 x 10^{-14} |
| ENVE-LOPE | Combination | -94,884 | -94,884 |

The amount of dynamic shear is greater than 85% of the static shear force (80.651), so the structure is safe against basic shear forces.

3.4.3 The friction force between the column and the foundation stone
The shear force that occurs is 94,884 kN, will be held back by the static friction on the relationship between the stone and the pile. The effective weight of the structure (W) of the Karo traditional house is 966,388 kN. Then the normal force (N) that occurs is 966,388 kN. The static friction (fs) at the meeting point of the pile and the foundation stone is: \( f_s = \mu_s N = 0.4 \times 966,388 \text{ kN} = 386,55 \text{ kN} \)
Because the shear force (F) is smaller than the static friction force, the Batak Karo traditional house does not experience a shift.

3.4.4 Storey deviation
Storey deviation may not exceed the maximum limit according to the type of structure, namely all other structures.
\[
\Delta_{x_{max}} = 0.020 h_{xx} = 0.02(1.85) = 0.037 \text{ m} = 37 \text{ mm}
\]
The deviation between floors that occurs in the column of the Batak Karo traditional house is:

| No | Joint Name | Deviation each floor, \( \Delta_x \) (mm) | Check \( \Delta_x \) against limit \( \Delta_{x_{max}} \) |
|----|------------|----------------------------------|----------------------------------|
|    |            | 1st Floor | 2nd Floor | x | y | x | y |
| 1  | KA1        | KB1       | -6.067     | -5.154 | Safe | Safe |
| 2  | KA2        | KB2       | -6.677     | -8.146 | Safe | Safe |
| 3  | KA3        | KB3       | -6.334     | -8.154 | Safe | Safe |
| 4  | KA4        | KB4       | -5.195     | -5.167 | Safe | Safe |
| 5  | KA5        | KB5       | -3.873     | -5.461 | Safe | Safe |
| 6  | KA6        |           |           | - | - | - | - |
| 7  | KA7        |           |           | - | - | - | - |
| 8  | KA8        | KB8       | -3.782     | -5.357 | Safe | Safe |
| 9  | KA9        | KB9       | -3.889     | -5.488 | Safe | Safe |
| 10 | KA10       |           |           | - | - | - | - |
| 11 | KA11       |           |           | - | - | - | - |
The maximum amount of deviation between floors that occurs in the structure is in column KA14 (6,687 mm) for the x direction and column 15 (8,068 mm) for the y direction. The amount of deviation that occurs does not exceed the maximum deviation limit so that it can be concluded that the structure of the Batak Karo traditional house is safe against earthquake forces.

3.5 Analysis of structure
3.5.1 Column
Cross-section and material data:
  
| Shape     | Diameter: 35 cm |
|-----------|-----------------|
| E: 108000 kg/cm² = 10594.8 Mpa; Fc: 15.6 Mpa |

The maximum column axial load (\(P_u\)) in the structure occurs in column 21 of 152.755 kN.

\[
P' = F_c' \times A_g = 19,384 \times 96162.5 = 1864013.9 \text{ N} = 152,755 \text{ kN}
\]

\(P_u < P'\), so that the column is safe against axial forces.

3.5.2 Beam
The maximum reaction rate that occurs in the structure can be seen in the following table:

| Table 8. Maximum beam reaction |
|-------------------------------|
| Direction | Beam Label | M Maximum, \(M_u\) (kNm) | Maximum Shear Force, \(V_u\) (kN) |
|-----------|------------|---------------------------|-------------------------------|
| x         | 550        | 16,372                    | 47,982                        |
| y         | 92         | -7,951                    | 7,046                         |

So the beam is safe against bending moments and shear forces. The maximum reaction that occurs in the Batak Karo traditional house gerga sepulu dua jabu when an earthquake occurs, it can be seen in Table 9.
Table 9. Maximum reaction to the Batak Karo traditional house

| No | Parameter                                      | Maximum Reaction | Maximum Limit                      | Safety |
|----|-----------------------------------------------|------------------|------------------------------------|--------|
| 1  | Period \((T)\)                                | 0.107993 sec     | 0.4676 sec                         | Safe   |
| 2  | Static base shear \((V_{\text{static}})\)     | 94,884 kN        | \(V_{\text{dynamic}}\) (90,624 kN) | Safe   |
|    | Dynamic base shear \((V_{\text{dynamic}})\)  | 90,624 kN        | > 80% \(V_{\text{static}}\), (80,561 kN) | Safe   |
| 3  | Friction force between pile and foundation stone \((F)\) | 94,884 kN        | 368,55 kN                         | Safe   |
| 4  | Storey Deviation                              | 0.835 mm         | 37 mm                             | Safe   |
| 5  | Column compressive force \((P)\)              | 152,755 kN       | 1864,01 kN                        | Safe   |
| 6  | The bending moment of the beam \((M)\)        | 16,372 kNm       | 36,277 kNm                        | Safe   |
| 7  | Beam shear \((V)\)                            | 47,982 kN        | 380,725 kN                        | Safe   |

From table 9 it can be seen that the maximum reaction that occurs is smaller than the maximum limit, so it can be said that the Batak Karo traditional house is safe against earthquakes.

4. Conclusion
The conclusion that can be taken from this research that the traditional Batak Karo house has a symmetrical shape where the center of stiffness and center of mass are in the same coordinates. The traditional Batak Karo house is regular horizontally but has vertical irregularity, namely mass irregularity, vertical geometric irregularity and discontinuity of direction of horizontal force retaining elements.

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