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# Comparative Study of Stiffness and Strength Behavior of RISHA Type 36 Modular House with and without Isolators

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## ABSTRACT

*The reliability assessment of the isolator model, namely rubber base isolation (RBI), has been carried out using an experimental method by conducting tests in the laboratory and continued with analysis of the test results. The purpose of this study is to conduct a dynamic analysis of the time history of the Rumah Instan Sederhana Sehat (RISHA) type 36 residential building to obtain information on the strength and stiffness behavior of the building due to lateral loads (earthquake loads). The scope of the study is the model studied in this report, namely RISHA type 36 m2. The simulation is a house model without isolators and with isolators installed at the base of the column to the foundation, using four earthquake recordings, namely El Centro, Flores, Pacoima Dam, Bucharest, which are scaled in intensity to Cianjur, namely 0.501g. The general conclusion is that the presence of isolators has an impact on reducing internal forces in columns and beams, thus potentially resulting in a stronger structure when an earthquake occurs, so that non-structural damage such as cracks in the walls can be reduced. However, the weakness of the structural system with isolators is that the lateral deformation due to earthquakes is higher than that of structural systems without isolators, but this is not an obstacle considering that the deformation that occurs is still smaller than the permissible deformation limits based on the SNI 1726:2019 code.*

**Key words**: *isolator, RISHA type 36, strength, stiffness, Cianjur.*

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## INTRODUCTION

The reliability assessment of the rubber-based isolation (RBI) model was conducted using an experimental method by conducting laboratory tests and continued with analysis of the test results. Testing of the test model includes testing a three-dimensional rubber based isolation model against alternating pseudo-dynamic loads. This experimental method is a validation process of the modeling that has been created and planned previously. The test model is a 3D rubber base isolated from used tires with a height of 15 cm and a diameter of 15 cm. This is a modeling of the existing rubber base isolation that will later be installed on the foundations of single-story houses. This rubber base isolation will receive a combination of vertical and horizontal loads. The vertical load is caused by the building's own weight and live load acting on the building, while the horizontal load is caused by wind loads and earthquake loads. The test was conducted to determine the level of reliability and performance of the rubber-based isolation model in terms of strength, stiffness, ductility, and damage patterns (Rakhman et al., 2017; BPPWD, 2019).

The purpose of this study is to conduct a dynamic analysis of the time history of the Rumah Instan Sederhana Sehat (RISHA) type 36 residential building to obtain information on the strength and stiffness behavior of the building due to lateral loads (earthquake loads).

The scope of the study is the model studied in this report, namely RISHA type 36 $m^2$ (DJCK, 2016). The simulation is a house model without isolators and with isolators installed at the base of the column to the foundation, using four earthquake recordings, namely El Centro, Flores, Pacoima Dam, Bucharest, which are scaled in intensity to Cianjur, namely 0.501g (PusGeN, 2022).

## RESEARCH METHODS

### The research methodology

The research methodology used are step one in the form of a literature review, related reference literature, data from previous tests, namely the Rubber Base Isolation spring stiffness model (Setio et al., 2012; Evany and Rajesh, 2012; Rakhman et al., 2017; Patel and Jamani, 2017; BPPPWD, 2019). Step two is three-dimensional structural modeling and conducting three-dimensional structural analysis based on the finite element method theory (Whiteley, 2017; Morita, 2021; CSI, 2023; Pranata, 2026). Lateral load analysis (earthquake) is carried out using RISHA type 36 time history dynamic analysis (Pranata, 2005; Lagaros et al., 2015; Mahmoud et al., 2017; Cimellaro and Marasco, 2018; Arjakoni and Lutfi, 2020; Bartolomeus and Pasaribu, 2024) according to the attached plan. The last step is to study the behavior of the building due to lateral loads and draw conclusions. Figure 1 shows a complete research flowchart.

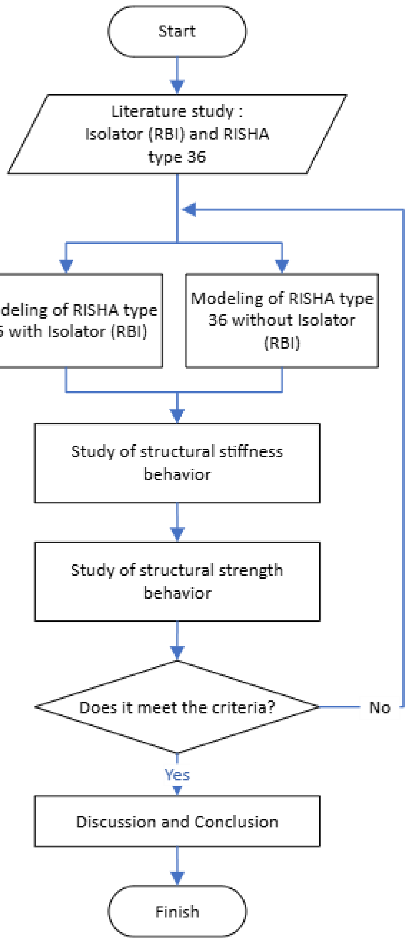


**Figure 1**. Flowchart of research.

## Time History Analysis

Time history dynamic analysis (THA) is a detailed structural analysis method that calculates the step-by-step response of a structure to a specific dynamic loading that changes over time. This method provides the most accurate picture of the structure's dynamic response, such as displacement, velocity, and acceleration over a specified time interval. Dynamic time history analysis is a method for determining the time history of a building's nonlinear dynamic response to ground motion caused by a planned earthquake as input data. The dynamic response at each time interval is calculated using a stepwise integration method.

The mass is concentrated at the connection point of the structural elements. The mass proportional to the gravitational load is W/g, with g = 9.81 m/s². Because the building is classified as regular, a rigid diaphragm model is used, with the mass concentrated at a single nodal point for each floor. The peak ground acceleration (PGA) value used in this report is the highest PGA reference based on historical earthquakes in Cianjur, which is 501 gals or 0.501g (PusGeN, 2022). This data was obtained during a 5.6 Mw earthquake in Cianjur on November 21, 2022 (source: https://id.wikipedia.org/wiki/Gempa_bumi_Cianjur_2022).

## Earthquake Record Data

Then, the four earthquake recordings used for the time history analysis were then scaled in intensity against the PGA. Four earthquake recordings with different characteristics were used to study the stiffness behavior of the building under earthquake (lateral) loads.

Earthquake loads are a function of time, so the response that occurs in a building structure also depends on the loading time. As a result of the Design Earthquake load, the structure will behave inelastically. To obtain the structural response at each time by taking into account nonlinear behavior, a nonlinear inelastic time history analysis is performed with a step-by-step analysis (stepwise integration method). The earthquake loads used are ground acceleration recordings for certain earthquakes. In this case, in the study, we took recordings of the 1940 El Centro earthquake, 1977 Bucharest, 1992 Flores and 1971 Pacoima Dam earthquakes.

The analysis uses earthquakes whose intensity is scaled against the maximum amplitude of ground acceleration Ao on the SNI 1726-2002 spectrum response curve at T = 0. In this case study, the time history analysis uses the Design Earthquake load level with a return period of 500 years. The purpose of the time history analysis is to evaluate whether the performance of the planned structure has been achieved or not, and the discussion includes displacement and drift. In accordance with the Indonesian earthquake code SNI 1726:2019 (NSA, 2019) and the previous code SNI 1726:2002 (NSA, 2002), input earthquake accelerograms must review at least 4 accelerograms from four different earthquakes (see Figure 2, Figure 3, Figure 4, and Figure 5), one of which must be taken as the accelerogram of the El Centro N-S Earthquake. The El Centro

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earthquake is considered a standard, because its accelerogram has a broad frequency, recorded at a moderate distance from the epicenter with a moderate magnitude (not extreme).

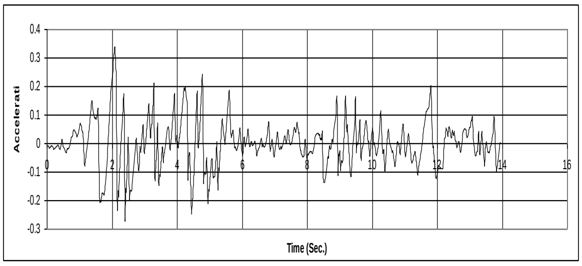



**Figure 2**. El Centro 1940 accelerogram record (Pranata, 2005).

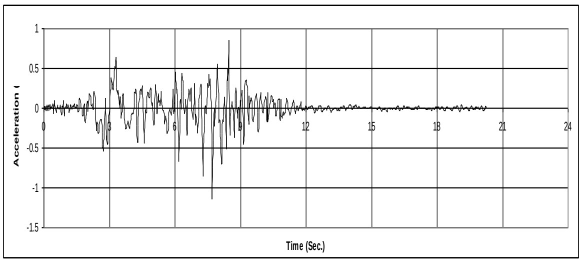



**Figure 3**. Pacoima Dam 1971 accelerogram record (Pranata, 2005).

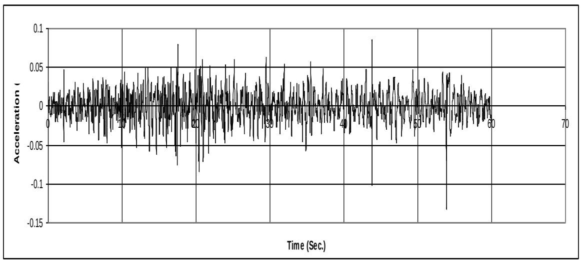



**Figure 4**. Flores 1992 accelerogram record (Pranata, 2005).

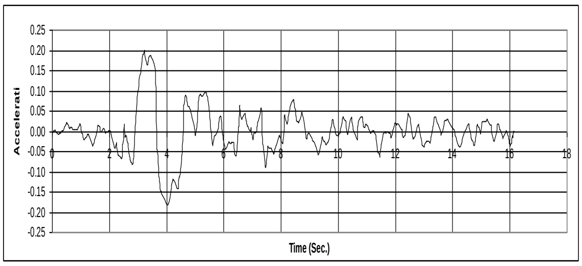



**Figure 5**. Bucharest 1977 accelerogram record (Pranata, 2005).

## Isolator

Base isolation is a technology to support earthquake-resistant buildings by placing isolators above the foundation and below the building's superstructure. This system aims to reduce ground movement impacting the building, thereby reducing earthquake energy and allowing the building to shift horizontally, thereby reducing potential damage, particularly to structural components.

The rubber base isolation used in this study was made from Camel Shore 70 rubber tires fitted with spiral steel springs (Rakhman et al., 2017. A prototype of isolator, namely rubber base isolation (RBI) is shown in Figure 6. The stiffness property model is taken from the results of cyclic experimental testing (Rakhman et al., 2017), which is then idealized into an envelope curve model as shown in Figure 7. The data is then used to model nonlinear spring elements in the 3D structural model of the building.

**Figure 6**. Prototype of isolator (Rakhman et al., 2017).

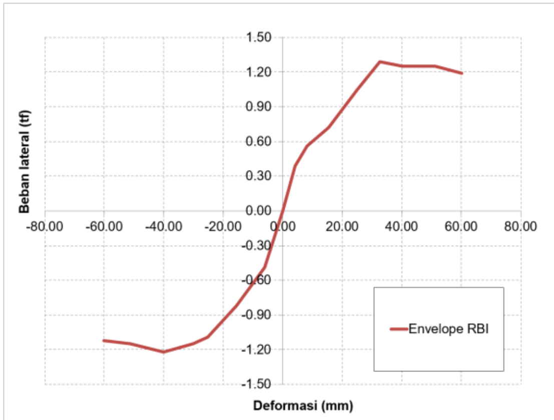



**Figure 7**. Load and deformation (envelope) curve of isolator (Rakhman et al., 2017).

## RESULTS AND DISCUSSION

Figure 8 shows the floor plan of a type 36 house. The complete structural modeling results are shown in Figure 9.a for the RISHA type 36 with a conventional system, where the module rests on a foundation. In this structural model, the structure is modeled with conventional placement. The roof structure in this modeling is modeled as a gravity load, namely resting on the elevation of the ring beam according to the placement conditions of the roof truss structure.

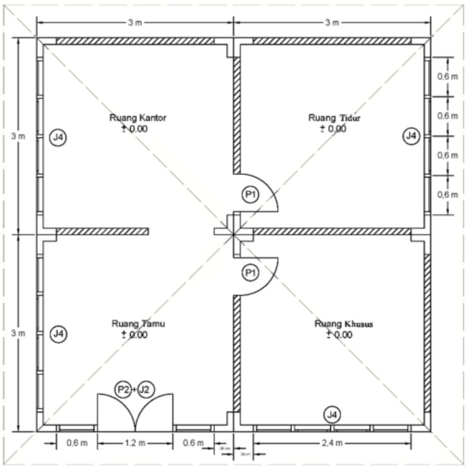
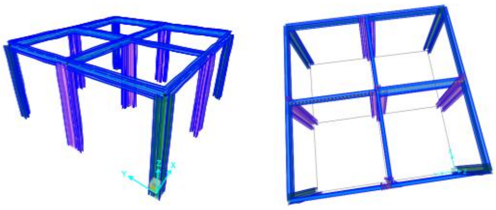
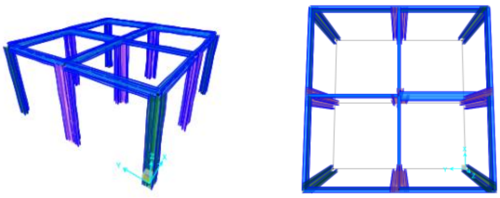



**Figure 8**. Floor plan of RISHA type 36 (Mudawarisman et al., 2020).



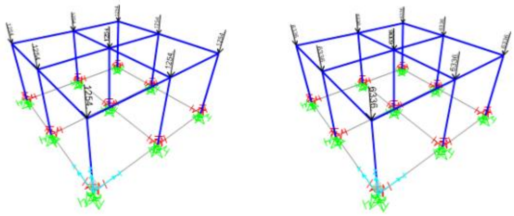
a. Schematic of RISHA type 36 model without isolator.



b. Schematic of RISHA type 36 model with isolator.

**Figure 9**. Modeling of RISHA type 36.

Figure 9.b shows a RISHA type 36 with nine main columns resting on rubber base isolation (RBI). Similar to the conventionally placed structural model, the RBI structural model also models the weight of the roof structure as a gravity load (NSA, 2020). In this structural analysis. Figure 10 shows the roof structure load modeling.



a. Dead load. b. Live load.

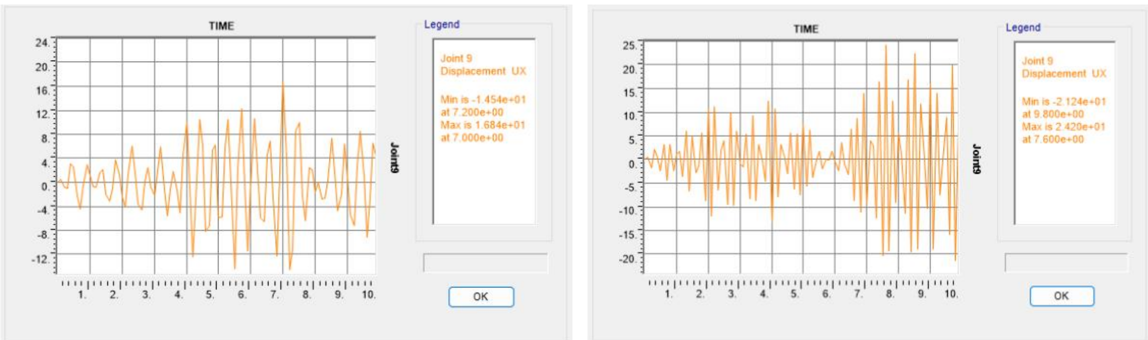
**Figure 10**. Modeling of roof construction as a gravity loads.

## Time-history Dynamic Analysis

Time-history dynamic analysis (THA) is a detailed structural analysis method that calculates the step-by-step response of a structure to a specific dynamic load that changes over time. This method provides the most accurate depiction of the structure's dynamic response, such as displacement, velocity, and acceleration over a specified time interval.

The analysis results, namely the lateral deformation of the building in the x-direction due to the earthquake load, are presented in full in Table 1. Considering that the configuration of the RISHA type 36 house is symmetrical along both the building's main axes, namely the x-axis and the y-axis, this analysis report simulates one of the main directions, namely the x-axis. Figures 11, 12, 13, and 14 shows the results of lateral deformation of RISHA type 36 due to earthquake load.

The results of the structural analysis, namely the building deformation due to the planned earthquake load, namely the dynamic earthquake load time history, show that the installation of RBI has an impact on increasing lateral deformation. In general, both RISHA type 36 buildings without RBI and RISHA type 36 with RBI, the lateral deformation that occurs is lower than the limit of SNI 1729:2019 (NSA, 2019), namely 0.025h.




(a). RISHA type 36 without isolator. (b). RISHA type 36 with isolator.

**Figure 11**. Lateral eformation lateral due to Flores earthquake load (unit: mm).

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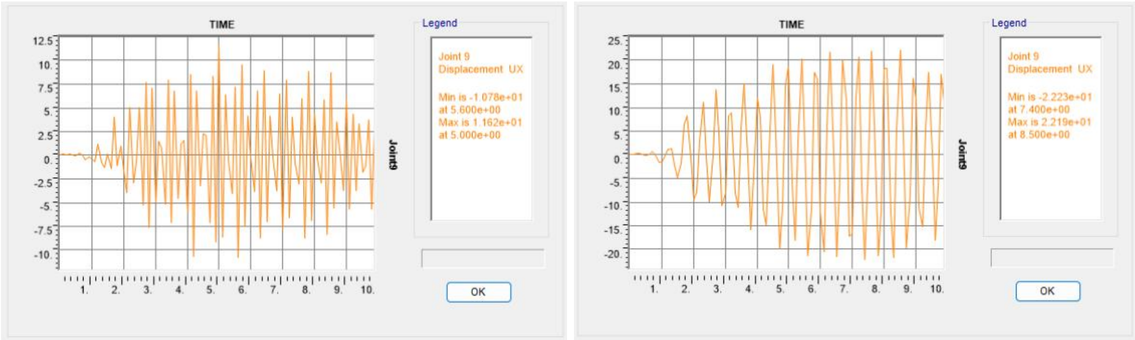
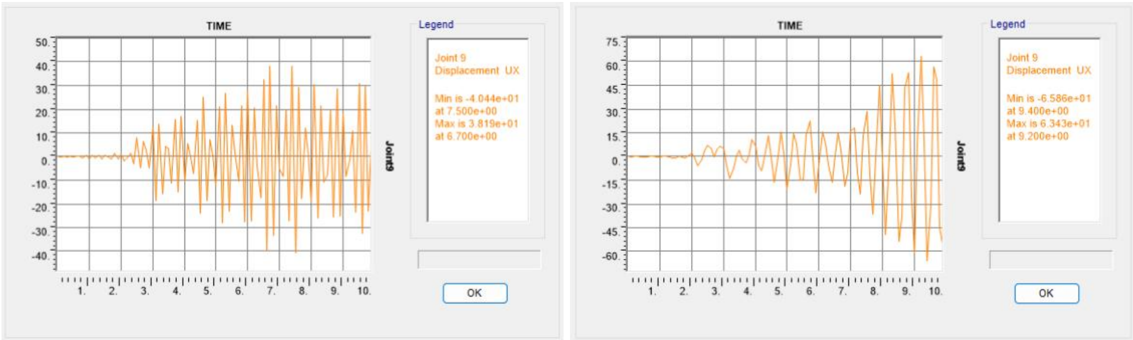


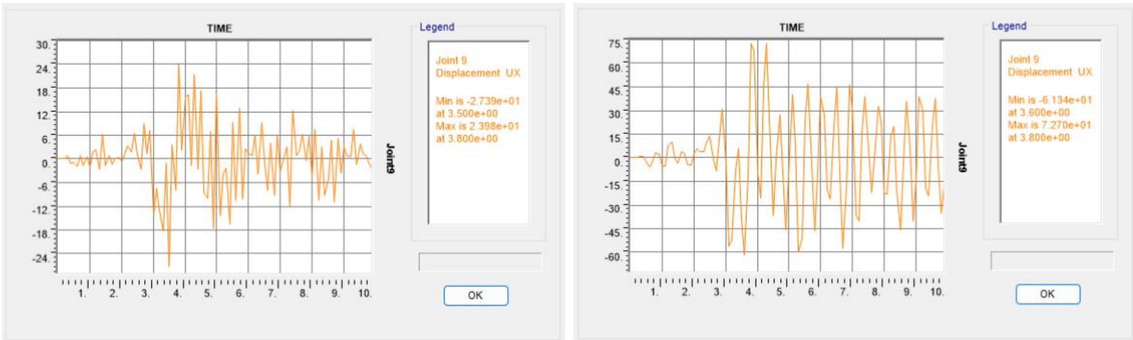

(a). RISHA type 36 without isolator. (b). RISHA type 36 with isolator.

**Figure 12**. Lateral eformation lateral due to El Centro earthquake load (unit: mm).




(a). RISHA type 36 without isolator. (b). RISHA type 36 with isolator.

**Figure 13**. Lateral eformation lateral due to Pacoima Dam earthquake load (unit: mm).




(a). RISHA type 36 without isolator. (b). RISHA type 36 with isolator.

**Figure 14**. Lateral deformation lateral due to Bucharest earthquake load (unit: mm).

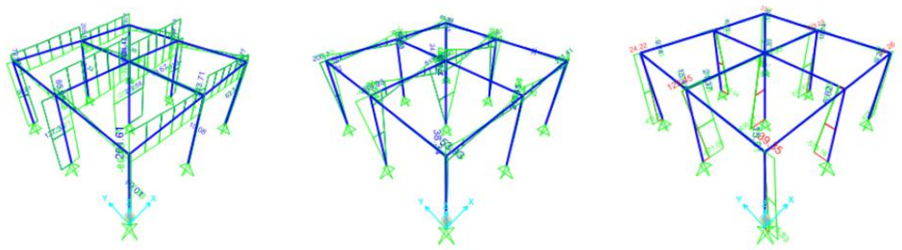
Next, Figures 15 and 16 displays the internal forces, namely the shear force and bending moment diagrams in the beam, as well as the axial force diagram in the column. The complete results of the internal force readings are shown in Tables 2, 3, 4, and 5.

The complete analysis results are presented in Tables 2 and 3 for both of columns L and T. In general, the internal forces, namely axial forces, shear forces, and bending moments that occur in the interior columns of the RISHA type 36 building with RBI are lower than those of the RISHA type 36 without RBI. These results indicate that RBI acts as a damper, thus reducing lateral forces entering the building's structural system.

Furthermore, Tables 4 and 5 show the results of the internal forces in the beams (elevation +3.0 m). The same trend also occurs in the beams, where the axial forces, shear forces, and bending moments of the RISHA type 36 house with RBI are lower than those of the RISHA type 36 without RBI.

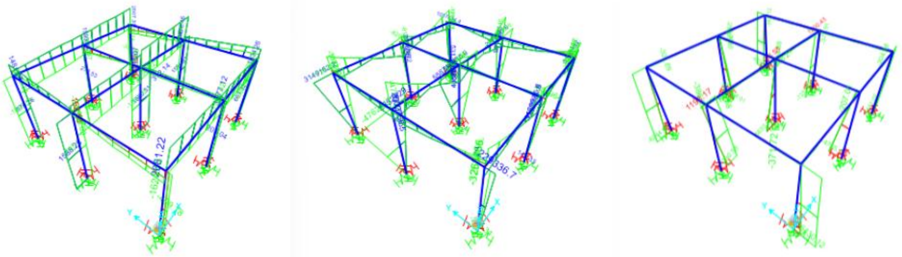
**Table 1**. Lateral deformation due to earthquake load and the permitted limit.

| Earthquake load | RISHA without isolator: Deformation (mm) | RISHA with isolator: Deformation (mm) | Permitted limit (mm) |
|---|---|---|---|
| Flores | 16.80 | 24.20 | 75.00 |
| El Centro | 11.62 | 22.23 | 75.00 |
| Pacoima Dam | 38.10 | 63.43 | 75.00 |
| Bucharest | 27.20 | 72.70 | 75.00 |



(a). Shear forces. (b). Bending moments. (c). Axial forces.

**Figure 15**. Internal forces of column and beam elements of RISHA type 36 with isolator (unit: kN and m).



(a). Shear forces. (b). Bending moments. (c). Axial forces.

**Figure 16**. Internal forces of column and beam elements of RISHA type 36 with isolator (unit: kN and m).

**Table 2**. Internal forces of column T.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 221.12 | 140.46 | -36.48 |
| Shear forces (kN) | 40.18 | 30.67 | -23.67 |
| Bending Moments (kN.m) | 120.37 | 91.94 | -23.62 |

**Table 3**. Internal forces of column L.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 198.99 | 177.36 | -10.87 |
| Shear forces (kN) | 37.43 | 34.67 | -7.37 |
| Bending Moments (kN.m) | 118.87 | 103.96 | -12.54 |

**Table 4**. Internal forces of interior beam.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 12.72 | 8.08 | -36.48 |
| Shear forces (kN) | 82.84 | 55.69 | -32.77 |
| Bending Moments (kN.m) | 126.77 | 91.76 | -27.62 |

**Table 5**. Internal forces of exterior beam.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 18.76 | 9.15 | -51.23 |
| Shear forces (kN) | 90.11 | 60.08 | -33.33 |
| Bending Moments (kN.m) | 149.22 | 91.14 | -38.92 |

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### Flores Earthquake Recording with Modified 0.501g Intensity Scale

The Flores earthquake recording has similar characteristics to the Cianjur earthquake recording (PusGeN, 2022; PusGeN, 2021). Therefore, the use of this earthquake recording, with its intensity scale using the 0.501g reference data, is expected to provide an overview of the behavior of the RISHA Type 36 building with Rubber-Based Isolation (RBI) under earthquake simulations. Tables 6, 7, 8, and 9 specifically display the internal forces occurring in the columns and beams due to the design earthquake load, namely the Flores earthquake scaled to 0.501g (peak acceleration).

**Table 6**. Internal forces of column T.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 146.76 | 94.63 | -35.52 |
| Shear forces (kN) | 10.29 | 5.71 | -44.51 |
| Bending Moments (kN.m) | 30.86 | 17.13 | -44.49 |

**Table 7**. Internal forces of interior beam L.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 138.09 | 137.32 | -0.56 |
| Shear forces (kN) | 9.61 | 8.90 | -7.39 |
| Bending Moments (kN.m) | 28.81 | 26.73 | -7.22 |

**Table 8**. Internal forces of interior beam.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 3.19 | 5.49 | -21.94 |
| Shear forces (kN) | 21.89 | 11.89 | -45.68 |
| Bending Moments (kN.m) | 32.99 | 17.39 | -47.29 |

**Table 9**. Internal forces of exterior beam.

| Internal forces (maximum) | RISHA type 36 without isolator | RISHA type 36 with isolator | %-relatif difference |
|---|---|---|---|
| Axial forces (kN) | 4.53 | 2.84 | -37.31 |
| Shear forces (kN) | 22.45 | 15.91 | -29.13 |
| Bending Moments (kN.m) | 36.48 | 23.86 | -34.59 |

The complete analysis results are presented in Tables 6, 7, 8, and 9 for columns and beams. In general, the internal forces, namely axial force, shear force, and bending moment, occurring in RISHA type 36 columns with RBI are lower than those in RISHA type 36 without RBI. These results indicate that RBI acts as a damper, thereby reducing lateral forces entering the building's structural system.

### Discussion

The axial compressive internal forces occurring in RISHA type 36 building structures with RBI are generally lower than the RBI's compressive capacity, which is 31.5 tons or 315 kN (Rakhman, et al., 2017). Therefore, the RBI's compressive capacity can accommodate the axial compressive forces occurring in each column.

The following discussion can be drawn from the structural analysis results in this report: The structural analysis results, namely the building deformation due to the planned earthquake load, namely the dynamic earthquake load time history, show that the installation of RBI increases lateral deformation. RISHA without RBI is stiffer than RISHA with RBI. However, in general, both RISHA type 36 buildings without RBI and RISHA type 36 with RBI experienced lateral deformation lower than the SNI 1729:2019 (NSA, 2019) limit of 0.025h.

The results of the examination of internal forces in the columns indicate that in general, the internal forces, namely axial force, shear force, and bending moment, occurring in the RISHA type 36 columns without RBI are higher than those in RISHA type 36 with RBI. These results indicate that RBI acts as a damper, thereby reducing the lateral forces entering the building's structural system.

The results of the examination of internal forces in the beam (elevation +3.0m), namely shear force and bending moment, showed that in general, the RISHA type 36 house without RBI was higher than the RISHA type 36 without RBI. The reduction of internal forces in the beam was generally relatively lower than the reduction of internal forces in the column. The use of four earthquake recordings with different characteristics provided a diverse trend in building stiffness behavior, thus justifying the study of building stiffness due to the design earthquake load, namely earthquake recordings scaled by intensity to the peak ground acceleration according to the Cianjur location review (0.501g). The PGA data of 0.501g were obtained when a 5.6 Mw earthquake occurred in Cianjur.

The Flores earthquake recordings have characteristics closest to those of the Cianjur earthquake recordings. Therefore, the use of these earthquake recordings, with an intensity scale of 0.501g, is expected to provide an overview of the behavior of the RISHA type 36 building with Rubber-Based Isolation (RBI) in earthquake simulations. The performance evaluation of the RISHA building with RBI type 36 yielded a performance level of 96.38 kN for shear force and 25,862 mm for deformation, or a drift of 0.008. These results indicate the building's performance level falls within the Damage Control performance category. These criteria can provide an overview of post-disaster mitigation, specifically non-structural component repair methods. The building experienced significant non-structural damage, such as cracks in the walls, but remains habitable and operable because there was no damage to the structural components (beams and columns). Non-structural damage can then be repaired.

## CONCLUSION

The general conclusion is that the presence of isolators has an impact on reducing internal forces in columns and beams, thus potentially resulting in a stronger structure when an earthquake occurs, so that non-structural damage such as cracks in the walls can be reduced. However, the weakness of the structural system with isolators is that the lateral deformation due to earthquakes is higher than that of structural systems without isolators, but this is not an obstacle considering that the deformation that occurs is still smaller than the permissible deformation limits based on the SNI 1726:2019 code.

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