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Seismic Load Analysis of a Laboratory Building Using the Equivalent Static Method

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ABSTRACT

Earthquakes caused by tectonic activity are major hazards in Indonesia, requiring structures to be designed to resist seismic loads safely. This study evaluates the seismic performance of a laboratory building based on SNI 1726:2019 using real ground motion data from the 2016 Pidie Jaya earthquake. This study uses actual Pidie Jaya earthquake records to provide a more realistic seismic evaluation of existing buildings in Aceh. This study aims to evaluate the structural safety, stability, and serviceability under seismic loading using the equivalent static analysis method. The equivalent static method was used to analyze the earthquake load, where seismic forces are represented as equivalent horizontal static forces applied at each floor level. The results indicate that the fundamental period of the structure is 0.638 seconds, which remains within the allowable limit, while the base shear forces are 886.60 kN in the X-direction and 856.80 kN in the Y-direction. The difference in base shear between the X and Y directions is caused by slight asymmetries in the structure's mass and stiffness distribution. The maximum roof displacements at an elevation of 12.60 m are 5.381 mm in the X-direction and 5.049 mm in the Y-direction, which are still below the allowable inter-story drift limits of 7.214 mm and 6.938 mm, respectively, and significantly below the overall drift limit of 84 mm. The drift limits of 7.214 mm and 6.938 mm were determined from the allowable inter-story drift ratio of 0.5% according to SNI 1726:2019 for Risk Category II structures.

Keywords: Equivalent Static; Displacement; Earthquake; Structural Performance; Seismic

INTRODUCTION

Earthquakes are natural phenomena that have significant potential to cause infrastructure damage and loss of life, particularly in regions located along the Ring of Fire [1]. Indonesia is considered an earthquake-prone country because it is located at the convergence of three major active tectonic plates: the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. The movement and subduction of these plates generate frequent and often strong seismic activity, particularly in regions such as Aceh. This event occurs due to the sudden release of energy within the Earth's crust, which is generally caused by tectonic activity, such as the movement and interaction between tectonic plates [2]. The released energy propagates in the form of seismic waves, generating ground acceleration that is perceived as shaking at the Earth’s surface [3]. Indonesia, located at the convergence of several active tectonic plates, experiences high seismic activity; therefore, the design of building structures in this region must carefully consider the effects of seismic loading [4], [5]. Earthquake-induced vibrations generate inertial forces within building structures that act in both horizontal and vertical directions, potentially leading to deformation, structural damage, and even collapse if the structure is not properly designed [6], [7].

In the context of building design, particularly for multi-story structures, an analytical approach capable of accurately representing structural response to seismic loading is required. The Laboratory Building of UPTD BPPPL DLHK Aceh is a three-story structure with an approximate height of 17.14 m, serving important functions for environmental testing, research, and development. The function of this laboratory building includes environmental sample analysis, water and soil quality testing, and research activities related to environmental protection. Its safety is important because the building houses sensitive equipment, hazardous chemicals, and specialized personnel; structural damage during an earthquake could lead to not only human casualties but also environmental contamination from spilled materials and loss of critical testing capabilities. The building is designed using a reinforced concrete moment-resisting frame system, which generally provides good resistance against lateral loads. However, considering that the building is located in a seismically active region, a structural performance evaluation under actual earthquake loading, such as the 2016 Pidie Jaya earthquake, is necessary. This specific earthquake was chosen because it represents the most recent significant seismic event near the building location with a magnitude (Mw 6.5) that closely matches the design basis earthquake for the Aceh region, and its recorded ground motion data were available from the Indonesian Agency for Meteorology, Climatology, and Geophysics. This evaluation is essential to ensure that the structure not only satisfies strength requirements but also maintains serviceability performance and guarantees the safety of building users.

Theoretically, structural response to earthquakes is governed by the interaction between the characteristics of seismic loading and the capacity of the structure [8]. When an earthquake occurs, the structure is subjected to vibrations that induce internal forces in the form of axial forces, shear forces, and bending moments [9]. The magnitude of these internal forces is influenced by the structural mass, stiffness, and geometric configuration. Therefore, structural design must satisfy three main criteria: strength, stiffness, and stability [10]. Strength refers to the ability of structural elements to resist applied loads without failure, stiffness relates to the structure's capacity to limit excessive deformations, while stability concerns the ability of the structure to remain in equilibrium without collapse under external disturbances. These three aspects must be satisfied simultaneously to ensure that the structure can perform adequately during and after an earthquake [11].

The materials used in building structures also significantly influence structural performance. Reinforced concrete is the most commonly used material due to its complementary properties, where concrete exhibits high compressive strength, while reinforcing steel provides high tensile strength [6], [12], [13]. In this system, concrete resists compressive stresses induced by bending moments, while steel reinforcement resists the resulting tensile stresses. The interaction between these two materials results in a structural system capable of efficiently distributing applied loads [14]. However, in reinforced concrete design, strength reduction factors must be considered to account for uncertainties in material properties and construction practices, ensuring that the designed structural capacity remains within a safe condition [15].

One of the key parameters in evaluating structural performance under seismic loading is displacement and inter-story drift [16]. Displacement represents the total structural displacement induced by seismic loading, whereas inter-story drift describes the relative displacement between two consecutive floors. This drift value is particularly important as it is directly related to the potential level of damage in both structural and non-structural elements [17]. If the drift is excessive, it may lead to wall cracking, damage to partitions, and even structural instability [18]. Therefore, design standards such as SNI 1726:2019 specify the maximum allowable drift limits to ensure occupant comfort and structural safety.

In addition, base shear is a key parameter in seismic analysis that represents the total lateral force acting at the base of the structure. Engineers need to calculate base shear because it is the total horizontal force that the foundation system must resist during an earthquake. It serves as the primary input for designing the size and reinforcement of columns, shear walls, and foundations, ensuring that the building has sufficient strength to withstand seismic shaking without collapsing. The magnitude of this force is determined by the building weight and seismic response spectrum parameters, and it is then distributed to each floor in proportion to its mass and height [19]. This force distribution generates internal forces within structural elements, which are subsequently used to evaluate their capacity. Accurate calculation of base shear is essential, as it serves as the fundamental basis for the overall structural analysis [20].

In this study, structural analysis is conducted using the equivalent static method, which represents earthquake effects as static horizontal forces acting at the center of mass of each floor. This method is selected due to its relative simplicity and suitability for low- to mid-rise buildings with regular configurations. To obtain more accurate analytical results, the structural modeling is carried out using structural analysis software such as ETABS, which is based on the finite element method. With the aid of this software, the structural response under various load combinations can be comprehensively evaluated, including internal force distribution, displacement, and inter-story drift.

Based on the foregoing description, the main problem addressed in this study is how the structural performance of the Laboratory Building of UPTD BPPPL DLHK Aceh responds to seismic loading, particularly the 2016 Pidie Jaya earthquake, and whether the structure satisfies the applicable safety standards. The building utilizes a Special Moment Resisting Frame (SMRF) system with a response modification factor (R) of 8.0, as later specified in the methodology. This factor is mentioned here to provide early clarity on the seismic design parameters. In addition, it is necessary to determine the magnitude of the resulting deformations and the distribution of internal forces in the structural elements as indicators of the overall structural performance.

The objective of this study is to evaluate the structural response of the building to seismic loading using the equivalent static method. Specifically, this research aims to determine the base shear force, analyze displacement and inter-story drift, and evaluate the internal forces acting on structural elements such as columns and beams. In addition, this study also seeks to assess whether the building structure complies with the requirements of SNI 1726:2019.

The findings of this study are expected to provide comprehensive information regarding the seismic resistance level of the building structure and to serve as a reference for the evaluation of existing buildings in earthquake-prone areas. Furthermore, this research is intended to enhance understanding of the application of the equivalent static method in structural analysis, as well as the use of structural analysis software in building design and planning.

The expected outcome of this study is to obtain a clear understanding of the structural performance of the building in response to seismic loading, including the values of base shear, displacement, and inter-story drift. In addition, it is expected that the safety level of the structure can be determined based on strength and serviceability criteria, allowing a conclusion to be drawn as to whether the building is safe for use and compliant with the applicable design standards.

MATERIALS AND METHODS

This study is conducted through a series of systematically structured, well-planned, and continuous stages, with the aim of ensuring that each analytical process produces accurate, reliable, and highly valid results that can be scientifically justified in accordance with established research methodology principles.

Research Approach and Type of Study

This study is a computational-based analytical research aimed at evaluating the structural performance of a building under seismic loading. The approach used is structural analysis employing the equivalent static method, which represents earthquake effects as static lateral forces acting at the center of mass of each floor. This method is selected due to its suitability for low- to mid-rise buildings with relatively regular structural configurations.

The analysis process is carried out using ETABS software, which is based on the finite element method. The use of this software enables three-dimensional structural modeling and allows the structural response to various load combinations to be analyzed more accurately and efficiently

Data Collection

The data used in this study consist of primary and secondary data. Primary data were obtained through field surveys, including measurements of structural element dimensions and identification of the existing building conditions. In addition, material properties data, such as concrete compressive strength, were obtained through testing or available technical information in the field.

Meanwhile, secondary data were obtained from design documents and relevant institutions, such as as-built drawings, technical specifications, and structural audit reports. These secondary data were used as the basis for structural modeling and the determination of analysis parameters. The combination of primary and secondary data is expected to produce a structural model that closely represents the actual field conditions.

Location and Research Object

The object of this study is the Laboratory Building of the Regional Technical Implementation Unit of the Environmental Testing, Research, and Development Center under the Environmental and Forestry Agency of Aceh. The building is located at Gampong Tibang, Syiah Kuala District, Banda Aceh City.

In general, the building is a three-story structure with a height of approximately 17.14 meters, functioning as an environmental testing and research laboratory. The structural system uses a reinforced concrete special moment-resisting frame designed to resist both gravity loads and lateral loads induced by earthquakes. The soil conditions at the study location are classified as soft soil (Site Class E), which has a significant influence on the structural response to seismic loading.

Building Data and Characteristics

The technical data of the building used in this study include geometric dimensions, material properties, and the structural system. The main structural system consists of columns, beams, floor slabs, and ground beams constructed from reinforced concrete. The concrete used has a compressive strength of 23 MPa (K-275), while the reinforcing steel consists of mild steel bars with a yield strength of 240 MPa and deformed (ribbed) steel bars with a yield strength of 320 MPa. The following section presents the material properties adopted in this study:

- Concrete Strength Grade : $f'c = 23$ MPa (K275)
- Concrete Elastic Modulus : $4700\sqrt{f'c} = 22540$ Mpa
- Unit Weight of Reinforced Concrete : 2400 kg/m^3
- Steel Strength Grade : $fy = 420$ MPa, $f_u = 545$ MPa (BjTS 420B)
  $fy = 280$ MPa, $f_u = 405$ MPa (BjTP 280)
- Steel Elastic Modulus : 200.000 MPa
- Unit Weight of Steel : 7850 kg/m^3

Thus, beams and columns utilize deformed bars with fy = 420 MPa for longitudinal reinforcement, while mild steel with fy = 280 MPa is used for transverse reinforcement. The building is classified as Risk Category II, with an importance factor of 1.0 in accordance with the applicable design standards. The structural system adopted is a Special Moment Resisting Frame (SMRF), which is designed to provide high ductility and enable effective dissipation of seismic energy. The seismic parameters used in the analysis are based on site-specific conditions, including the design spectral acceleration values and the assigned seismic design category.

Structural Modeling

The structural modeling was carried out in three dimensions using ETABS software. The initial stage involved generating the building grid, which represents the coordinate system and geometric dimensions of the structure. This grid was developed based on design drawings and field measurement data. Subsequently, material properties were defined, including concrete and reinforcing steel, by specifying parameters such as compressive strength, modulus of elasticity, and unit weight. The structural elements were then modeled, where columns and beams were represented using frame sections, while floor slabs were modeled as shell elements with the assumption of a rigid diaphragm.

The cross-sectional dimensions of the structural elements were determined based on existing data, where variations in column and beam sizes were adjusted to reflect actual field conditions. After all elements were modeled, a comprehensive model verification was conducted to ensure there were no errors in connectivity or element definitions. The resulting structural model is presented in Figure 1.

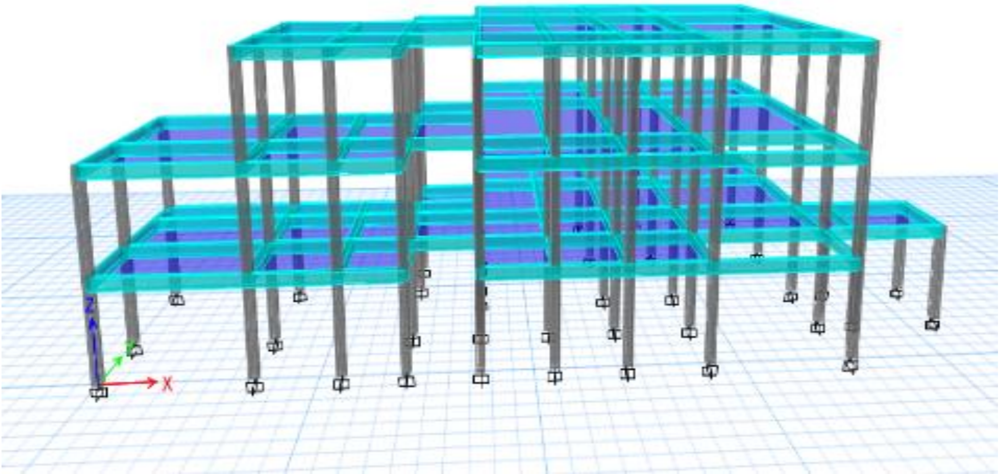

Figure 1. Three-Dimensional Structural Model of the UPTD BPPPL DLHK Aceh Laboratory Building Using ETABS

Determination of Supports and Boundary Conditions

In the structural model, the support conditions were defined as fixed supports at the base of the columns, representing the connection between the superstructure and the foundation. The building actually uses a pile foundation system (concrete piles) which transfers loads to deeper competent soil layers. However, assuming fixed supports is a common conservative simplification in equivalent static analysis for buildings with pile foundations, as piles provide significant rotational restraint. This assumption was adopted to simplify the analysis by considering the foundation to have sufficient stiffness, such that no significant displacement or rotation occurs.

This boundary condition is critical, as it significantly influences the distribution of internal forces as well as the overall structural deformation. Therefore, the selection of support conditions must be carefully aligned with the actual field conditions.

Structural Loading

The loading applied in the analysis includes dead load, live load, and seismic load. The dead load consists of the self-weight of the structure as well as non-structural components, which are automatically calculated by the software using specified load factors. The live load is assigned based on the building's function as a laboratory, while the seismic load is determined using the equivalent static method.

The seismic load was modeled as lateral forces acting in the horizontal directions (X and Y), with magnitudes determined based on the response spectrum parameters. In this study, the seismic input data were derived from the Pidie Jaya earthquake record, representing actual seismic conditions in the Aceh region.

Load Combinations

To obtain the most critical loading condition, load combinations were applied in accordance with the provisions of SNI 1726:2019. These combinations account for various possible interactions among dead load, live load, and seismic load, resulting in ultimate load cases used for evaluating the structural capacity.

These load combinations are essential in the analysis, as they define the most critical conditions that the structure must be capable of resisting without experiencing failure.

Equivalent Static Analysis

The equivalent static analysis was performed by converting the dynamic seismic load into equivalent horizontal static forces acting at each floor level of the building. These forces were then distributed along the height of the structure based on the weight and elevation of each story.

The seismic parameters adopted in the analysis include the design spectral acceleration values, the seismic response modification factor, and the building importance factor. In addition, the soft soil conditions at the study site were also taken into account in evaluating the structural response to seismic loading.

Earthquake Data and Seismic Parameters

The seismic data used in this study were obtained from accelerogram records provided by the relevant authorities. The seismic parameters considered include the spectral acceleration values at short periods and at a one-second period, the structural response reduction factor, and the assigned seismic design category.

The use of actual seismic data is expected to provide more realistic analysis results in representing the structural response to real earthquake conditions. In this study, accelerogram records obtained from BMKG Aceh were utilized, representing ground acceleration data induced by seismic events. The site soil conditions used in the analysis are presented as follows:

- Building Location : Tibang – Banda Aceh City
- Coordinates : N5º 58’31.434”E95º 34’94.195”
- Subsoil Condition : Soft Soil
- Seismic Design Category : E
- I (Seismic Importance Factor) : 1,0
- R (Seismic Response Reduction Factor) : 8
- SS (g) : 1,525
- S1 (g) : 0,60
- SD1 (g) : 0,80
- SDS (g) : 0,8014

Analysis and Evaluation Stages

The analysis procedure commenced with structural modeling, followed by the application of loading conditions, and subsequently performing the analysis using the software. The results were then evaluated based on key structural performance parameters, including base shear, displacement, inter-story drift, and internal forces within the structural elements.

The evaluation results were compared with the provisions specified in SNI 1726:2019 to determine whether the structure satisfies both strength and serviceability requirements. Accordingly, the level of safety and overall structural performance of the building under seismic loading can be assessed.

RESULTS AND DISCUSSION

The results presented in this study are derived from a series of systematic processes, including structural planning, modeling, and analysis, conducted in accordance with established principles and relevant theoretical frameworks. The calculated outcomes serve not only as quantitative data but also as the primary basis for interpreting and discussing the research problems addressed in this study. Accordingly, the analysis results play a crucial role in explaining the relationship between theoretical concepts and the actual structural conditions, while providing a comprehensive understanding of the structural performance in response to applied loads. Furthermore, these results are utilized to evaluate the level of compliance between the design and the applicable standards, as well as to identify potential weaknesses or critical aspects that require further attention in order to enhance the overall reliability and safety of the structure.

Structural Design Evaluation

A. Modal Analysis and Mass Participation

Modal analysis is a crucial step in understanding the dynamic characteristics of a structure, particularly in determining the contribution of each vibration mode to the overall structural response [21]. Based on the analysis results, the effective modal mass participation in both the X and Y directions reached 100%. This value significantly exceeds the minimum requirement of 90% as specified in SNI 1726:2019.

This condition indicates that the structural model is capable of capturing the majority of the dynamic response of the structure under seismic loading. In other words, the number of modes considered is sufficient to adequately represent the overall structural behavior. This is particularly important, as insufficient mass participation may lead to inaccuracies in estimating the seismic forces acting on the structure [22].

When compared with previous studies on low- to mid-rise reinforced concrete buildings, the modal mass participation values are generally found to exceed 90% [23]. Therefore, achieving 100% modal mass participation in this study indicates that the structural model is of high quality and can be considered reliable.

B. Lumped Mass of the Structure

The structural mass is a key parameter in seismic analysis, as it is directly related to the inertia forces generated due to ground acceleration. Based on the calculation results, the lumped mass is 9,043 $kg \cdot s^2/cm$, derived from the total structural weight of 8,862.33 kN.

An accurate mass distribution significantly influences the analysis results, particularly in determining the magnitude of base shear and the distribution of lateral forces at each story. Errors in mass estimation may lead to underestimation or overestimation of seismic forces, which can ultimately affect structural safety. Therefore, the results of this study indicate that the mass modeling has been carried out consistently and in accordance with the actual building conditions [24].

C. Fundamental Natural Period

The natural vibration period is an important indicator in assessing the structural stiffness. Based on the analysis results, the fundamental period is 0.4557 seconds (obtained from the ETABS modal analysis using the eigenvector method), which is still below the maximum allowable limit of 0.6380 seconds as specified in SNI 1726:2019 for the building's height and soil conditions.

This relatively short period indicates that the structure has a high level of stiffness. Stiffer structures tend to exhibit shorter natural periods, which generally result in higher seismic forces but smaller deformations.

This result is consistent with the characteristics of reinforced concrete buildings employing a Special Moment Resisting Frame (SMRF) system, which generally exhibit high stiffness. Previous studies have also indicated that structures with shorter natural periods tend to demonstrate better deformation performance; however, attention must be given to the potential increase in internal forces that may occur [25].

Base Shear

Base shear is a key parameter in equivalent static seismic analysis, representing the total lateral force acting at the base of the structure. Based on the ETABS analysis results, the base shear values are 886.60 kN in the X direction and 856.80 kN in the Y direction. Meanwhile, the manual calculation yields a value of 886.23 kN.

The very small difference between the numerical analysis results and the theoretical calculations indicates that the adopted model satisfies force equilibrium principles and demonstrates consistency in computation. This also suggests that the input parameters, such as structural mass, response factors, and seismic coefficients, have been properly defined [26].

When compared with previous studies, the close agreement between the numerical and manual base shear values indicates that the structure has been designed using an appropriate approach. In many cases, significant deviations between these methods may suggest errors in modeling or loading assumptions. Furthermore, the obtained base shear values also satisfy the minimum requirements specified in SNI 1726:2019, indicating that the structure has adequate capacity to resist lateral forces induced by seismic loading [22].

The analysis results indicate that all major structural parameters satisfy the requirements of SNI 1726:2019. This demonstrates that the structure has adequate capacity to resist the design seismic loads. The appropriate base shear values, controlled natural period, and high mass participation further indicate that the structure has been properly designed and modeled [22].

In the context of previous studies, structures that satisfy all these parameters are generally categorized as having at least an Immediate Occupancy (IO) performance level, where the building remains functional after an earthquake without significant damage [27].

Structural Lateral Displacement

Lateral displacement is a parameter used to evaluate the global deformation of a structure due to seismic loading. The analysis results indicate that the maximum displacement occurs at the roof level, with values of 5.318 mm in the X direction and 5.049 mm in the Y direction. For further details, refer to Table 1 and Figure 2 below.

Table 1. Maximum Displacement Values

Story	**Elevation (m)**	**X-Dir (mm)**	**Y-Dir (mm)**
Roof Slab	12.6	5.318	5.049
Floor-3	8.4	4.006	3.788
Floor-2	4.2	1.927	1.747
Floor-1	0	0	0

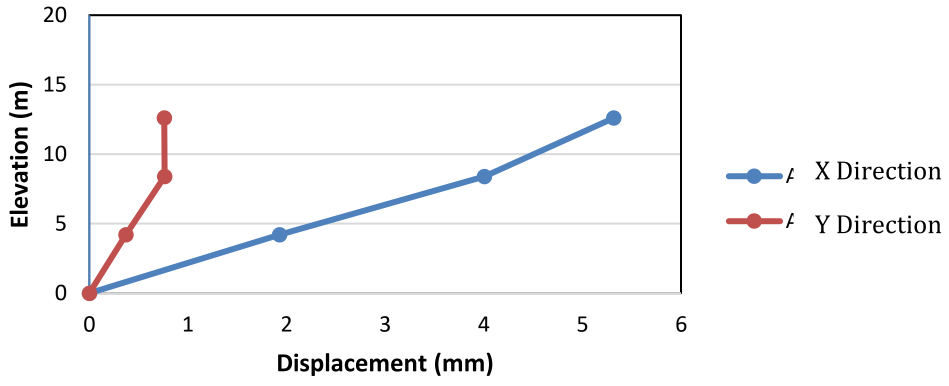

Figure 2. Displacement Response Due to the Pidie Jaya Earthquake

The displacement distribution pattern, which gradually increases from the lower floors to the upper floors, indicates normal structural behavior consistent with structural mechanics theory. This suggests that the structure is still operating within the elastic range, where the relationship between load and deformation remains linear. It is important to note that the present analysis assumes linear elastic material behavior throughout the structure. While this assumption is appropriate for the equivalent static method and for serviceability-level evaluations, it constitutes a limitation because real reinforced concrete buildings exhibit nonlinear behavior (e.g., cracking, yielding) under strong earthquake ground motions. Therefore, the computed displacements represent elastic estimates, and actual deformations under a design-level earthquake may be larger.

However, differences in displacement values between the X and Y directions are observed. This may be attributed to variations in structural stiffness in both directions, resulting from differences in structural element dimensions as well as mass distribution. Previous studies have shown that such displacement imbalances are often associated with torsional effects, which may increase the risk of localized structural damage [26].

Although the displacement and story drift values indicate safe conditions, structural evaluation cannot be based solely on deformation criteria. In many studies, structural failure is more frequently triggered by insufficient strength capacity rather than exceeding deformation limits [28]. Therefore, it is essential to ensure that, in addition to satisfying serviceability criteria, the structure also possesses adequate strength capacity to resist the internal forces that develop under loading conditions [29].

Inter-story Drift

Inter-story drift is an important parameter in evaluating structural performance, particularly in relation to occupant comfort and non-structural damage. Based on the analysis results, the maximum drift values were found to be 11.433 mm in the X direction and 11.224 mm in the Y direction at the third-floor level. These results are clearly presented in Table 2 and Figure 3 below.

Table 2. Maximum Story Drift Values

Story	**Elevation (m)**	**X-Dir (mm)**	**Y-Dir (mm)**	**Drift Limit (mm)**	**Description**
Roof Slab	12,6	7,214	6,938	84,000	OK
Floor-3	8,4	11,433	11,224	84,000	OK
Floor-2	4.2	10,601	9,608	84,000	OK
Floor-1	0	0.000	0.000	0.000	OK

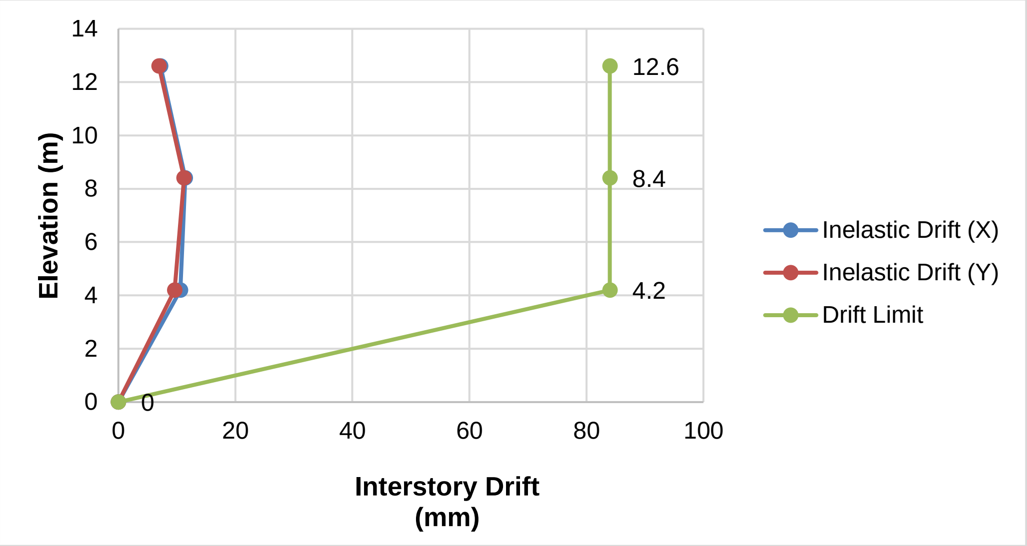

Figure 3. Inter-story Drift Graph

These values are well below the allowable limit of 84 mm, indicating that the structure possesses adequate lateral stiffness. The relatively uniform distribution of inter-story drift also suggests that there is no significant concentration of deformation at any particular floor level.

When compared with previous studies, structures with small story drift values generally demonstrate good seismic performance, particularly in reducing the risk of damage to non-structural elements such as partition walls and other architectural components [30].

The results of this study indicate that the structure exhibits good performance in resisting seismic loads. However, several aspects still require attention, such as potential structural asymmetry and stiffness distribution, which may lead to torsional effects [31]. Moreover, the equivalent static analysis method has limitations in capturing complex dynamic responses of structures. Therefore, for future studies, it is recommended to employ dynamic analysis methods such as response spectrum analysis or time history analysis to obtain more comprehensive and accurate results.

Overall, the analysis results indicate that the UPTD BPPPL DLHK Aceh Laboratory Building demonstrates good structural performance under seismic loading. All evaluated parameters fall within the allowable limits, indicating that the structure is safe and complies with the applicable design standards. However, further evaluation is still required to enhance the structural reliability in resisting higher-intensity seismic events.

CONCLUSION

Based on the analysis and discussion presented, it can be concluded that the structural performance of the UPTD BPPPL DLHK Aceh Laboratory Building under seismic loading using the equivalent static method shows satisfactory results and complies with the applicable design provisions. This is evidenced by the effective modal mass participation exceeding the minimum requirement, the natural vibration period falling within the allowable range, and the base shear values showing good agreement between numerical analysis and theoretical calculations. In addition, the obtained displacement and interstory drift values remain below the allowable limits specified in SNI 1726:2019, indicating that, in terms of deformation, the structure can be considered safe and meets serviceability criteria.

On the other hand, although all analysis parameters indicate that the structure is in a safe condition, this study also highlights the importance of a comprehensive evaluation of structural performance aspects, both in terms of strength and serviceability. The variation in response between directions and the potential irregularity in stiffness distribution suggest that further analyses, such as dynamic analysis, should be considered to obtain a more accurate representation of structural behavior. Based on the findings, the following specific recommendations are provided to the building owner:

1) Routine visual inspections should be conducted annually, focusing on beam-column joints and non-structural elements such as partition walls, where minor drift concentrations were observed.
2) Installation of low-cost accelerometers or seismometers is recommended to monitor real-time building response during future seismic events, which would help validate the analytical model and refine performance assessments.
3) Although retrofitting is not required at present, it is advised to reassess the structure if a higher-intensity earthquake (Mw > 7.0) occurs nearby or if any signs of distress (e.g., cracking, settlement) become evident, in which case a detailed dynamic analysis should be performed to evaluate potential nonlinear behavior.

Therefore, this study not only provides an overview of the safety level of the existing structure but also serves as a basis for engineering decision-making aimed at improving structural reliability against future seismic loads.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Bunyamin Bunyamin: Conceptualization, Methodology, Supervision. **Gusti Mistra:** Data Curation, Writing-Original Draft Preparation. **Azzaki Mubarak:** Visualization, Investigation, Software, Validation. **Muhajjir Muhajjir:** Writing-Reviewing and Editing.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

REFERENCES

[1] N. Lathifah, I. Idroes, M. Hady, B. Bunyamin, and H. Pramanda, “Seismic Performance Analysis of Buildings Strengthened with X-Bracing Systems under Dynamic Earthquake Loads,” *Disaster Civ. Eng. Archit.*, vol. 2, no. 2, pp. 159–172, 2025, doi: 10.70028/dcea.v2i2.64.

[2] I. Wally, H. J. Wattimanela, and Y. A. Lesnussa, “Analysis of Earthquake Activity Level in Several Districts in The Province of Aceh with Using the Guttenberg-Richter Method Approach,” in *AIP Conference Proceedings*, 2023, vol. 2588, no. 1, p. 50017. doi: 10.1063/5.0112463.

[3] H. J. Wattimanela, N. T. Puspito, and H. Batkunde, “Simeulue Earthquake Activity Analysis Using the MLE Method,” *Indones. J. Geogr.*, vol. 57, no. 1, pp. 42–51, 2025, doi: 10.22146/ijg.91332.

[4] N. A. Pambudi, “Geothermal power generation in Indonesia, a country within the ring of fire: Current status, future development and policy,” *Renew. Sustain. Energy Rev.*, vol. 81, pp. 2893–2901, 2018, doi: 10.1016/j.rser.2017.06.096.

[5] M. Masum and M. Ali Akbar, “The Pacific Ring of Fire is Working as a Home Country of Geothermal Resources in the World,” in *IOP Conference Series: Earth and Environmental Science*, 2019, vol. 249, no. 1, p. 12020. doi: 10.1088/1755-1315/249/1/012020.

[6] B. Bunyamin, M. Silviana, and L. Lindawati, “Influence of precast concrete joints on the ductility of beam elements,” in *Journal of Physics: Conference Series*, 2021, vol. 1882, no. 1, p. 12032. doi: 10.1088/1742-6596/1882/1/012032.

[7] M. Hasan, T. Saidi, M. Afifuddin, and B. Setiawan, “The assessment and strengthening proposal of building structure after the Pidie Jaya earthquake in December 2016,” *J. King Saud Univ. - Eng. Sci.*, vol. 35, no. 1, pp. 12–23, 2023, doi: 10.1016/j.jksues.2021.02.007.

[8] P. Zakian and A. Kaveh, “Seismic design optimization of engineering structures: a comprehensive review,” *Acta Mech.*, vol. 234, no. 4, pp. 1305–1330, 2023, doi: 10.1007/s00707-022-03470-6.

[9] R. Pang, B. Xu, Y. Zhou, and L. Song, “Seismic time-history response and system reliability analysis of slopes considering uncertainty of multi-parameters and earthquake excitations,” *Comput. Geotech.*, vol. 136, p. 104245, 2021, doi: 10.1016/j.compgeo.2021.104245.

[10] T. S. Sprague, “Evaluating Structures: Understanding Strength, Stiffness, Suitability, and Stability,” in *Design-Tech: Building Science for Architects*, Routledge, 2025, pp. 204–231.

[11] L. Aditya and G. Tamizharasi, “Probabilistic approach for correlating stiffness and strength irregularities in RC buildings under earthquake shaking,” in *Structures*, 2025, vol. 77, p. 109024. doi: 10.1016/j.istruc.2025.109024.

[12] M. Hasan, T. Saidi, D. Sarana, and Bunyamin, “The strength of hollow concrete block walls, reinforced hollow concrete block beams, and columns,” *J. King Saud Univ. - Eng. Sci.*, vol. 34, no. 8, pp. 523–535, 2022, doi: 10.1016/j.jksues.2021.01.008.

[13] Bunyamin, “Comparison of deflection of hollow block concrete blocks with normal reinforced concrete beam,” in *AIP Conference Proceedings*, 2019, vol. 2059, no. 1, p. 20039. doi: 10.1063/1.5085982.

[14] A. K. H. Kwan, J. C. M. Ho, and H. J. Pam, “Flexural strength and ductility of reinforced concrete beams,” *Proc. Inst. Civ. Eng. Struct. Build.*, vol. 152, no. 4, pp. 361–369, 2002, doi: 10.1680/stbu.2002.152.4.361.

[15] N. Attarchian, R. Aghamohammadi, and K. Nasrollahzadeh, “Reliability-Based Calibration of Strength-Reduction Factors for Flexural Design of FRP-RC Beams Under Various Load Combinations,” *J. Compos. Sci.*, vol. 9, no. 4, p. 154, 2025, doi: 10.3390/jcs9040154.

[16] A. A. Mansor, A. S. Mohammed, and W. D. Salman, “Effect of longitudinal steel reinforcement ratio on deflection and ductility in reinforced concrete beams,” in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 888, no. 1, p. 12008. doi: 10.1088/1757-899X/888/1/012008.

[17] M. G. Guler and K. Guler, “The Effect of Story Drifts in Determining the Earthquake Performance of High-Rise Buildings,” *Buildings*, vol. 14, no. 12, p. 3830, 2024, doi: 10.3390/buildings14123830.

[18] J. Shan, Y. Zhang, and H. Zhang, “Interstory drift estimation by fusing acceleration and computer vision measurements with experiment validation,” *Mech. Syst. Signal Process.*, vol. 223, p. 111891, 2025, doi: 10.1016/j.ymssp.2024.111891.

[19] D. P. N. Kontoni and A. A. Farghaly, “Enhancing the earthquake resistance of RC and steel high-rise buildings by bracings, shear walls and TMDs considering SSI,” *Asian J. Civ. Eng.*, vol. 24, no. 7, pp. 2595–2608, 2023, doi: 10.1007/s42107-023-00666-6.

[20] Y. C. Assidiq and I. Bali, “Study of Base Shear and Inter-Story Drift due to Earthquake Forces on a Ten-Story Building Structure in Surakarta,” *Presunive Civ. Eng. J.*, vol. 3, no. 1, p. 1, 2025, doi: 10.33021/pcej.v3i1.5627.

[21] C. Hickey, R. Kannan, D. Grant, S. Hendry, and K. Hiçyılmaz, “Solving the Conundrum of Recovering Sufficient Participating Mass for Complex Structures,” *World Conf. Earthq. Eng. Proc.*, vol. 2024, 2024.

[22] N. Eka Saputra and Y. A. Priastiwi, “Comparative Study Of Dynamic Earthquake Analysis With Spectral Design And Time History Methods,” *J. Indones. Sos. Teknol.*, vol. 4, no. 8, pp. 1223–1234, 2023, doi: 10.59141/jist.v4i8.700.

[23] M. Chennit, A. Ahmed-Chaouch, M. Saidani, and A. Bourzam, “Periods and Mode Shapes for Uniform Shear Wall Buildings: Importance of Selecting the Appropriate Dynamic Behavior,” *Int. J. Struct. Stab. Dyn.*, vol. 22, no. 11, p. 2250114, 2022, doi: 10.1142/S0219455422501140.

[24] F. Valenzuela-Beltrán *et al.*, “Effect of the Distribution of Mass and Structural Member Discretization on the Seismic Response of Steel Buildings,” *Appl. Sci.*, vol. 12, no. 1, p. 433, 2022, doi: 10.3390/app12010433.

[25] K. Fujii, “Seismic response of reinforced concrete moment-resisting frame with steel damper columns under earthquake sequences: evaluation using extended critical pseudo-multi impulse analysis,” *Front. Built Environ.*, vol. 11,

p. 1561534, 2025, doi: 10.3389/fbuil.2025.1561534.

[26] A. Souhaibou and L. zhi Li, “A comparative study on the lateral displacement of a multi-story RC building under wind and earthquake load actions using base shear method and ETABS software,” *Mater. Today Proc.*, 2023, doi: 10.1016/j.matpr.2023.04.287.

[27] Z. Tonyali, A. Kiral, M. Ergun, and R. Garcia, “Seismic resilience of existing RC dual-system buildings during the 2023 Kahramanmaraş earthquakes: a case study,” *J. Asian Archit. Build. Eng.*, pp. 1–26, 2025, doi: 10.1080/13467581.2025.2564110.

[28] A. Chatzidaki, D. Vamvatsikos, and E. Hernández-Montes, “Performance-based versus conventional seismic design: comparative assessment on a 4-story RC moment frame,” *Bull. Earthq. Eng.*, vol. 22, no. 6, pp. 3031–3053, 2024, doi: 10.1007/s10518-024-01871-7.

[29] C. Xie, X. Wang, G. Vasdravellis, and W. Liang, “Displacement profile for direct-displacement based seismic design of dual frame-wall resilient system,” *J. Constr. Steel Res.*, vol. 214, p. 108495, 2024, doi: 10.1016/j.jcsr.2024.108495.

[30] C. Dönmez *et al.*, “Lessons From The 2023 SE Türkiye EQS: A Study On Damaged RC Buildings Considering The Hassan Index LESSONS FROM THE 2023 SOUTHEAST TÜRKIYE EARTHQUAKES: A STUDY ON DAMAGED RC BUILDINGS CONSIDERING THE HASSAN INDEX,” 2024. [Online]. Available: https://www.researchgate.net/publication/380606550

[31] S. P. Akshara, M. A. Akbar, T. M. M. Pillai, R. Pasunuti, and R. Sabhadiya, “Using an appropriate rotation-based criterion to account for torsional irregularity in reinforced concrete buildings,” *Earthq. Struct.*, vol. 26, no. 5, pp. 349–361, 2024, doi: 10.12989/eas.2024.26.5.349.