Comparative Study of Internal Force between Dynamic Method and Equivalent Static Methods in Lecture Buildings in Yogyakarta Based on Earthquake Indonesian National Standard (SNI 1726-2019)

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Abstract. Earthquakes are events of the movement of the earth due to the sudden release of energy in the earth which is marked by the breaking of the rock layers in the earth's crust. Indonesia is located in an earthquake-prone area where three tectonic plates meet, namely the Indo-Australian plate, the Eurasian plate and the Pacific plate. Realizing the threat of an earthquake that could occur at any time, the Indonesian government took the initiative to take measures to prevent the risk of damage to infrastructure that could occur due to an earthquake. This paper presents an analysis of the earthquake resistance of a lecture building at an educational institution in the city of Yogyakarta with the equivalent static method and the dynamic response spectrum method. The purpose of this paper is to provide an overview of whether construction projects that have been implemented using SNI 1726-2012 are analyzed and compared with the latest standards, namely SNI 1726-2019, whether the building construction still meets earthquake resistance. The results of the comparative analysis of the equivalent static method and the dynamic response spectrum method show that the building under study does not meet the strength and resistance to earthquakes based on SNI 1726-2019, so it is necessary to strengthen the structure of the building under study.

1. Introduction
Indonesia is the largest archipelagic country in the world with 17,504 islands and an area of marine waters of 5.8 million km² (consisting of a territorial sea area of 0.3 million km², an area of archipelagic waters 2.95 million km², and an area of the Indonesian Exclusive Economic Zone (EEZ) 2.55 million km²) [1]. With the area of Indonesia that spreads from Sabang to Merauke, Indonesia is located in an earthquake-prone area because it is traversed by the meeting point of three tectonic plates which include: the Indo-Australian plate, the Eurasian plate and the Pacific plate. The meeting of the three plates has resulted in Indonesia having a high potential as an earthquake-active country, so the chance for an earthquake to occur is very large. This has an impact on the level of potential and a great risk of damage to existing structures and construction when an earthquake occurs.

An earthquake is an event of movement of the earth due to the sudden release of energy in the earth which is marked by the breaking of the rock layers in the earth's crust. According to Jackson et al, explaining that the characteristics of the earthquake destroy all fault segments, alternately, or one of a series of earthquakes that break out in the same fault area [2]. As a measure to prevent the risk of damage to buildings due to earthquakes, the Indonesian government ratifies standards on earthquake resistance.
planning procedures for buildings starting with SNI 03-1726-1989; then SNI 1726-2002; furthermore, SNI 1726-2012 and updated with SNI 1726-2019. This renewal of earthquake resistant building planning standards is not without reason, considering that Indonesia is in an earthquake-active area and the potential for earthquakes to occur is very high. Furthermore, the Ministry of Public Works and Public Housing (PUPR) released the latest Earthquake Map, namely 2017, where there was an addition of 295 fault points, updating the 2010 Earthquake Map [3].

This shows that planning a building construction requires the implementation of up-to-date standards in accordance with current needs and methodologies, with the aim of minimizing the risk of structural damage and casualties that will occur if an earthquake occurs. Until now, the insights and discipline of implementing earthquake resistance planning standards for the newest building, namely SNI 1726-2019 have not been optimal. There are still projects that refer to SNI 1726-2012. Although the latest standard (SNI 1726-2019) is still relatively new, as construction actors need to be aware of the importance of implementing this latest standard. Most of the building plans in Indonesia currently still use SNI 1726-2012 refers to hazard map 2010, so it is necessary to evaluation of the building planning which has been completed by comparing the resistance of the building in the face of earthquake strength defined in SNI 1726-2019 refers to hazard map 2017. The form of evaluation of the loading and earthquake resistance of a building can be carried out by equivalent static analysis or dynamic response spectrum analysis [4-5].

1.1 Purpose of the study
a) To find out the internal force of the dynamic method and equivalent static method in buildings based on SNI 1726-2019.
b) To compare the results of internal force between the dynamic method and equivalent static method in buildings based on SNI 1726-2019.

2. Literature Review
This comparative study refers to the Indonesian National Standard, namely SNI 1726-2019 [6] concerning Earthquake Resistance Planning Procedures for Building and Non-Building Structures. In this paper, the loading structure consists of two types, namely i) gravity load (dead load and live load) and ii) lateral load (earthquake load).

2.1. Gravity load
Gravity load include all tributary dead loads and live loads. Dead load is the load of all building construction materials that are installed and static including walls, floors, roofs, ceilings, stairs, permanent partition walls, architectural and structural components and equipment installed in the building. Meanwhile live loads are loads caused by users of buildings or other structures that do not include construction loads and environmental loads, such as wind loads, rain loads, earthquake loads and flood loads [15]. Then calculation of the gravity load combination structure refers to PPIUG 1983 & PPURG 1987 and and the latest standards namely SNI 2847-2013 [7]. Dead load and live load function as loads distributed on the building towards the foundation.

2.2. Lateral load
Each structure shall be analyzed for the effect of a static lateral force that is applied independently in each of the two orthogonal directions [15]. Lateral load is a load that has a horizontal direction. It consists of various types of loads such as wind loads, earthquake loads, soil pressure on the wall, etc [16]. Furthermore, the main effect from a seismic load on structures is the lateral load induced by the earthquake [17]. Therefore, this research focuses on earthquake loads which are analyzed by the equivalent static method and the response spectrum refers to SNI 1726-2019 [6].

2.2.1 Equivalent static analysis refers to SNI 1726-2019
Equivalent static analysis is divided into three stages, including (1) Seismic base shear, (2) Calculation of seismic response coefficients, and (3) Distribution of vertical earthquake force.
In seismic base shear stage, V in the direction specified must correspond to the following equation:

\[ V = Cs \cdot W \]

where: Cs is coefficient of seismic response and W is effective seismic weight/load.

In calculation of seismic response coefficients stage, Cs must be determined by the following equation:

\[ Cs = \frac{S_{DS}}{R \cdot I_e} \]

where: SDS is the acceleration parameter of the design response spectrum over a short period, R is response modification factor, and Ie is earthquake factor.

In distribution of vertical earthquake force stage, Fx (kN) at all levels must be determined from the equation following:

\[ Fx = C_{vx} \cdot V \]

and

\[ C_{vx} = \frac{W_i \cdot h_x^k}{W_i \cdot h_x^k} \]

where:
- \( C_{vx} \) = vertical distribution factor
- \( V \) = total design lateral force or shear at the base of the structure (kN)
- \( W_i \) & \( W_x \) = the total effective seismic weight portion of the structure (W) which is placed or subjected to level \( i \) or \( x \)
- \( h_i \) & \( h_x \) = height from base to level \( i \) or \( x \) (m)
- \( k \) = the exponent corresponding to the period of the structure with the following values:
  - for structures with \( T \leq 0.5 \) second, \( k = 1 \)
  - for structures with \( T \geq 2.5 \) second, \( k = 2 \)
  - for structures with \( 0.5 < T < 2.5 \) second, \( k = 2 \) or determined by linear interpolation between 1 and 2

2.2.2 *Response spectrum analysis refers to SNI 1726-2019 (Dynamic method)*

Response Spectrum analysis design according to SNI 1726-2019 [6] consist of seven stages, including:

(1) Observing the location of the building which is going to be evaluated,
(2) Determining SPT value and classification of soil type,
(3) Determining the acceleration parameters of the maximum earthquake response by considering the risk targeted MCE_R (Maximum Considered Earthquake, Risk Targeted) for short periods of 0.2 seconds (S_2) and 1.0 seconds (S_1),
(4) Carrying out the amplification factor of the response parameters of the ground surface acceleration spectrum for short periods (Fa) and 1 second period (Fv),
(5) Determining the acceleration spectral response parameter for short period and 1 second period (S_MS and S_M1),
(6) Determining the parameters of the design acceleration spectrum response (S_DS and S_D1), and
(7) Making a graph response to images with the provisions that have been examined SNI 1726-2019.

In the stage of determining the parameters of the acceleration spectrum response, S_MS and S_M1 can be determined by the following equation:

\[ S_{MS} = Fa \times S_s \]

and

\[ S_{M1} = Fv \times S_1 \]

where: \( S_{MS} \) is the acceleration spectral response parameter for short period, \( Fa \) is the site coefficient for a short period is 0.2 seconds, \( S_s \) is the acceleration spectral response parameters of the MCER earthquake are mapped for a short period, \( S_{M1} \) is the acceleration spectral response parameter for period of 1 second, \( Fv \) is the site coefficients for a long period at a period of 1 second, and \( S_1 \) is the acceleration spectral response parameters of the MCER earthquake are mapped for a period of 1.0 second.
In the stage of determining the parameters of the acceleration spectrum response, $S_{MS}$ and $S_{M1}$ can be determined by the following equation:

$$S_{DS} = \frac{2}{3} \times S_{MS}$$

and

$$S_{D1} = \frac{2}{3} \times S_{M1}$$

where: $S_{DS}$ is parameters of the design acceleration spectrum response for short period and $S_{D1}$ is parameters of the design acceleration spectrum response for period of 1 second.

After determining the parameters of the design acceleration spectrum response, then it continues at the last stage by making a graph response to images with the provisions that have been examined SNI 1726-2019 as in Figure 1 below.

![Figure 1. Graph of response spectra in SNI 1726-2019](image)

Period provisions are explained further as follows: (1) For periods which are smaller than $T_0$, the following equation use $S_a = S_{DS} (0.4 + 0.6 T/T_0)$, (2) For periods which are greater than or equal to $T_0$ and smaller than or equal to $T_S$, the response spectrum of the design is $S_a = S_{DS}$, (3) For periods which are greater than $T_S$, but smaller than or equal to $T_L$, the spectral response of the design acceleration, $S_a$, is taken equation $S_a = S_{D1}/T$, (4) For periods greater than $T_L$, the spectral response of the design acceleration, $S_a$, is taken based on Equation $S_a = (S_{D1} \times T_L)/ T^2$, (5) For the value of $T$ is obtained by calculating the fundamental period of the structure ($T$) based on this equation: $T_a = C_t \times h_X$ (where $h_X$ is the height of the structure (m) above the base to the highest level of the structure, $C_t$ and $x$ are obtained from the table specified by SNI 1726-2019), (6) For the values of $T_0$ and $T_S$ can be obtained from the equation: $T_0 = 0.2 \times S_{DS}/S_{DS}$ (where $T_S = S_{D1}/S_{DS}$), (7) For $T_L$ values are obtained from Figure 20 about SNI 1726-2019, (8) In determining the risk category of buildings and earthquake priority factors, it is found that the lecture building is categorized as IV and the earthquake priority factor is 1.50; and (9) Determination of seismic design categories is based on the seismic design category of the acceleration response parameters in the short and 1 second periods.

2.2.3 Internal force

Internal force is the force that holds the propagation force in the construction to achieve balance. Axial and shear forces, and moments are categorized as the internal force [8-9]. Factored moment ($M_u$), ultimate shear strength ($V_u$), and factored axial force ($N_u$) are the result of internal force.
3. Method
This research method is a comparative study of internal force between dynamic and static methods equivalent to buildings based on SNI 1726-2019. Comparative analysis of SRPMK (Special moment bearer frame system) reinforced concrete structure design with seismic design category D according to SNI 1726-2019 and SNI 03-2847-2019. The 3-storey building model was analyzed using the SAP2000 program. Furthermore, Figure 2 below shows the research method used in this study.

```
Start
↓
Existing Data Structure Analysis
↓
Structure Modeling with SAP2000
↓
Structural Loading Modeling:
  - Equivalent Static Load
  - Dynamic (Response Spectrum)
↓
Structure Analysis:
  - Internal force of structural elements
↓
Comparison of Internal Force Analysis Results:
  - Equivalent Static Method
  - Dynamic method (Response Spectrum)
↓
Conclusion
↓
Finish
```

**Figure 2.** Research flowchart

4. Result and Discussion
4.1. Structure data
The technical data used in the analysis are as follows: (1) Building location in Yogyakarta City, (2) Type of building is lecture building, (3) Construction of the building is reinforced concrete, (4) Structure system is Special moment bearer frame system (SRPMK), (5) Soil type is medium soil (SD), (6) value of N-SPT is 21, (7) Land area of building is 12 x 45 m, (8) Building height is 13.95 m and (9) The number of floor is 3 floors/storey building.

Material quality specifications consist of column and beam concrete with quality f_c 'is 25 Mpa, slab concrete quality and Tie beam f_c is 25 Mpa, quality of reinforcing steel use D16 and D22, column size C1 is 400 x 700 mm, column size C2 is 400 x 400 mm, size of beam B1 is 350 x 700 mm, size of beam B2 is 300 x 400 mm, plate thickness is 120 mm, and seismic design category (KDS) is D (SRPMK / Special moment bearer frame system).
4.2. Earthquake analysis refers to SNI 1726-2019
SAP2000 software to analyze the structure to analyze the structure of the lecture building. The primary structures studied are the main column (C1) and beam (B1 and B2). The part under review is the longest transverse side which is ranked evenly distributed. The following image is a review of the lecture building analysis.

Figure 3. Sketch of lecture building in Yogyakarta City

Figure 4. Modeling 2D in software for analyzing the structure

4.3. Earthquake analysis based on SNI 1726-2019
The earthquake analysis step includes 13 stages, including (1) Determination of Class and Site Coefficient, (2) Design Spectral Acceleration Parameters (SDs & SD1), (3) Period of Fundamental Structure (T), (4) Response Spectrum Diagram, (5) Risk Category, (6) Earthquake Priority Factor (Ie), (7) Seismic Design Category (Cs), (8) Structure System, (9) Period Fundamental Approach (Ta), (10) Seismic Response Coefficient (Cs), (11) Seismic Weight (W), (12) Basic Seismic Style (V) and (13) Horizontal Distribution of Earthquake Force (Fx).
4.4. Analysis of response spectrum diagram

Through earthquake analysis based on SNI 1726-2019 above, the values used to make the spectrum response diagram in Table 1 and 2 are obtained.

Table 1. The parameter of acceleration of spectrum response earthquake is based on SNI 1726-2019

| Parameter | SNI 1726-2019 |
|-----------|---------------|
| Ss        | 0.75          |
| S1        | 0.3           |
| Fa        | 1.2           |
| Fv        | 2.0           |
| SMS       | 0.9           |
| SM1       | 0.6           |

Table 2. The value used to make response spectrum graph based on SNI 1726-2019

| Value                  | SNI 1726-2019 |
|------------------------|---------------|
| S_DS                   | 0.6           |
| S_D1                   | 0.4           |
| T0                     | 0.13          |
| T_s                    | 0.67          |
| Ta                     | 0.5           |
| T                       | 0.5           |
| Sa = S_DS (0.4 + 0.6 x(T/T0)) | 1.625 |
| Sa = S_DS               | 0.6           |
| Sa = S_D1/T            | 32            |
| T_L                    | 20            |

The spectrum response graphs based on SNI 1726-2019 with values above, are represented in Figures 6 bellow.

Figure 5. SNI 1726-2019 response spectrum graph
4.5. Analysis of equivalent static method

- Calculating the seismic response coefficient (Cs)

| Cs Minimum < Cs < Cs Maximum |
|------------------------------|
| $0.044 \cdot SDs \cdot Ie < \frac{SDs}{Ie} < \frac{SD1}{T_s \cdot Ie}$ |

Then use $Cs = 0.113$

- Seismic weight of the structure (W)

| Number | Component | Notation | Load (kN/m) |
|--------|-----------|----------|-------------|
| 1      | Dead load of 1st floor | WDL 1 | 28.83 (kN/m) |
| 2      | Dead load of 2nd floor | WDL 2 | 28.83 (kN/m) |
| 3      | Dead load of 3rd floor | WDL 3 | 32.14 (kN/m) |
| 4      | Dead load of roof | WDL R | 55.54 (kN/m) |
| 5      | Live load of 1st floor | WLL 1 | 30.20 (kN/m) |
| 6      | Live load of 2nd floor | WLL 2 | 25.88 (kN/m) |
| 7      | Live load of 3rd floor | WLL 3 | 25.88 (kN/m) |
| 8      | Live load of roof | WLL R | 2.88 (kN/m) |

Total dead load $WDL = 145.34$ (kN/m)
Total live load $WLL = 84.83$ (kN/m)
Total static load on $As E$ $W = 230.16$ (kN/m)

- Seismic Shear (V)

$V = Cs \cdot W_{4.5m}$

$V = 0.113 \cdot 230.16$ kN

$V = 26.01$ kN

- Horizontal Distribution of Seismic Forces (Fx)

Value of $k = 1$

| Floor | wi (kg) | hi (m) | wi . hi^k | Vx | Fi (kN) |
|--------|---------|--------|------------|----|--------|
| 3rd floor | 116.43 | 13.95 | 1624.22 | 26.01 | 18.12 |
| 2nd floor | 54.71 | 8.4 | 459.53 | 26.01 | 5.13 |
| 1st floor | 59.03 | 4.2 | 247.91 | 26.01 | 2.77 |

$\sum W = 230.16$

The combination of loading uses SNI 2847-2013.

Load combination = 1,2 D + 1 L + 1 Q

After obtaining static loading, response spectrum diagrams and equivalent static values based on SNI 1726-2019, then the structure analysis using software will then obtain a table of structural analysis results showing the magnitude of the force in the structure under study. The comparison of the results of the structural analysis includes the value of the axial force (Pu), ultimate shear strength (Vu), and the factored moment (Mu) on each structural element, presented in the Table 3 below.
The form of his needs to withstand earthquake forces based on SNI 1726-2019 guidelines. Therefore, the building requires structural strengthening as a measure to prevent structural damage caused by earthquakes. This needs to be done, considering the lecture building is public services needed by the community. The form of structural strengthening that can be done in the building is to increase the ability of the compressive strength of the concrete (concrete coating) and shortening the span using a column injector.

Furthermore, Indonesia is in an earthquake-prone area geographically so that it has the potential to cause casualties due to the disaster, research of [12] regarding earthquake mapping in all earthquake-prone areas in Indonesia, was able to produce earthquake hazard maps in 2010 and 2017 which can be used for earthquake-resistant building planning. Therefore, it is hoped that the development of earthquake-prone maps and guidelines for earthquake-resistant building structure planning will always experience the latest changes or additional forces acting on these structures so as to allow the building to remain standing and not collapse (minimizing structural damage due to earthquakes) with reference to the latest findings from earthquake-prone maps [8][13][14].

### Table 3. Comparison of internal force between response spectrum method and equivalent static method based on SNI 1726-2019

| Element | Axial Forces (Pu) | Ultimate shear strength (Vu) | Factored moment (Mu) |
|---------|-------------------|------------------------------|----------------------|
|         | Response spectrum | Equivalent static            | Response spectrum   | Equivalent static |
| Element 1 | 358.81            | 322.58                       | 20.45                | 16.72              | 48.84            | 37.6            |
| Element 2 | 225               | 216.2                        | 21.69                | 18.08              | 49.69            | 38.07           |
| Element 3 | 86.45             | 71.12                        | 21.96                | 20.26              | 62.86            | 57.76           |
| Element 4 | 1017.08           | 995.77                       | 111.65               | 101.95             | 266.56           | 246.8           |
| Element 5 | 565.77            | 546.65                       | 199.46               | 163.94             | 454.87           | 393.09          |
| Element 6 | 70.14             | 59.71                        | 42.24                | 34.49              | 118.14           | 109.33          |
| Element 7 | 849.41            | 796.13                       | 109.69               | 99.7               | 252.41           | 215.38          |
| Element 8 | 482.33            | 475.27                       | 190.63               | 155.28             | 442.20           | 416.24          |
| Element 9 | 99.79             | 89.26                        | 40.28                | 30.35              | 117.22           | 94.36           |
| Element 10 | 0                 | 0                             | 144.38               | 114.46             | 126.12           | 119.17          |
| Element 11 | 0                 | 0                             | 166.82               | 132.68             | 154.54           | 135.75          |
| Element 12 | 0                 | 0                             | 34.25                | 22.57              | 59.03            | 44.41           |
| Element 13 | 0                 | 0                             | 340.9                | 306.99             | 591.48           | 541.31          |
| Element 14 | 0                 | 0                             | 360.57               | 323.15             | 594.21           | 540.6           |
| Element 15 | 0                 | 0                             | 282.97               | 234.93             | 550.06           | 528.61          |

From table 3 above it can be concluded from the comparison of the axial force factor (Pu), ultimate shear strength (Vu), and factor moment (Mu), that the internal force value based on SNI 1726-2019 shows that the value of the analysis result of the response spectrum method is greater than the value the results of the analysis of the equivalent static method. According to [10] states that there is no significant difference between dynamic response spectrum analysis and equivalent static analysis. However, the significant difference between the two structural analysis methods indicates that the building is less able to withstand earthquake forces based on SNI 1726-2019 guidelines. Therefore, the building requires structural strengthening as a measure to prevent structural damage caused by earthquakes. This needs to be done, considering the lecture building is public services needed by the community. The form of structural strengthening that can be done in the building is to increase the ability of the compressive strength of the concrete (concrete coating) and shortening the span using a column injector [11].
5. Conclusion
The conclusion that can be drawn from the discussion are as follows:

a) Internal forces of the dynamic method (response spectrum analysis) based on the results of the above analysis shows that the largest axial forces (Pu) is in element 4 at 1017.088, then the largest ultimate shear strength (Vu) is in element 14 at 360.57 and the largest factored moment (Mu) the is in element 14 at 594.21.

b) Internal forces of the equivalent static method based on the results of the above analysis shows that the largest axial forces (Pu) is in element 4 at 995.77, then the largest ultimate shear strength (Vu) is in element 14 at 323.15 and the largest factored moment (Mu) the is in element 13 at 541.31.

c) Comparison result of internal forces between the dynamic method and equivalent static method based on Table 3 above shows that there is difference in the results of the analysis of earthquake resistance structures based on earthquake hazard maps guided by SNI 1726-2019, where the internal force in the dynamic response spectrum method is greater than the internal force in the equivalent static method. For example, value of axial force (Pu) in response spectrum is 1017.08 and axial force in equivalent static method is 995.77.

d) Therefore, has an effect on the inadequate resilience of the building structure, so that structural strengthening of the building is required. This structural strengthening is intended to anticipate structural damage and failure due to earthquakes, so that casualties, property and objects can be minimized.

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Acknowledgements

I am very grateful to Mr Slamet Widodo for his time, energy and support throughout the project process, and for his construction comments during the process of this paper. I also thank to LPDP for giving me the opportunity to study and fund my postgraduate studies. I do not forget to thank the various parties who have helped and in this research.