COMSERVA
JURNAL PENELITIAN DAN PENGABDIAN MASYARAKAT
Volume 5 No. 7 July 2025 (XXX-XXX)

e-ISSN: 2798-5210
p-ISSN: 2798-5652

Comparison of Reinforced Concrete Structures Using Local Spectral Response Analysis, Indonesian Spectral Design and SNI 1726-2019

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ABSTRACT

In planning earthquake-resistant building structures, especially in areas with a high seismic risk, it is crucial to consider earthquake resilience factors. Maximum ground acceleration and spectral response are seismic parameters used to design buildings in accordance with the provisions of the Indonesian National Standard (SNI) 1726-2019 regarding earthquake-resistant building design. The spectral response values used for the comparison of reinforced concrete structures include the Local Spectral Response calculated using the Probabilistic Seismic Hazard Analysis (PSHA) method with the assistance of EZ-FRISK software, the spectral response value from Spektra Design Indonesia, and SNI 1726:2019. The results of soil classification indicated that the soil layer at the research site was of medium type; therefore, the structural components of the Special Moment Resisting Frame System (SRPMK) were designed accordingly. Building modeling and analysis were conducted using ETABS version 19 software. Based on the results of the PSHA analysis, the Peak Ground Acceleration (PGA) value for the 2500-year earthquake recurrence period for the Local Spectral Response was 0.7233 g, and the spectral response value was 0.8473 g. The comparative analysis of reinforced concrete structures using the Local Spectral Response value revealed that some structural components experienced shear failure, particularly around openings such as stairwells. In contrast, the analysis using the Indonesian Spectral Design and SNI 1726:2019 indicated that the structural components could withstand the shear forces acting on the cross-sections.

Keywords: Earthquake, Spectra Response, PHSA, EZ-FRISK, Structural Planning, Reinforced Concrete, SRPMK, ETABS

INTRODUCTION

Earthquakes are natural disasters that cannot be avoided or predicted precisely in terms of timing and location. Indonesia is classified as a region with high seismic intensity due to its position at the convergence of three major tectonic plates: the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. Previous research indicates that North Sulawesi Province lies within zone 5, one of the most earthquake-prone areas in Indonesia. To anticipate the impacts of future earthquakes, it is essential to obtain information regarding the magnitude of earthquake acceleration within specific recurrence periods.

Earthquake acceleration can be estimated using a probabilistic approach referred to as Probabilistic Seismic Hazard Analysis (PSHA), facilitated by EZ-FRISK software. This analysis yields values of Peak Ground Acceleration (PGA) and local spectral response, which can subsequently be employed in the structural design of buildings. These parameters form the basis for determining building resilience to seismic shocks, enabling construction planning that accounts for risks consistent with local seismic conditions.

Careful planning is critical in designing buildings, especially in seismic zones, to ensure that structural components do not experience catastrophic failure during an earthquake. Buildings intended for high seismic areas should exhibit adequate ductility, allowing them to absorb seismic energy and remain standing after deformation. One effective approach to achieve this seismic resilience is the implementation of the Special Moment Resisting Frame System (*Sistem Rangka Pemikul Momen Khusus*, SRPMK), which is engineered to withstand lateral forces induced by earthquakes.

This study conducts earthquake force analysis by comparing three approaches: spectral response based on local data, Indonesian spectral design, and the SNI 1726:2019 standard. By comparing the spectral response outcomes from these methods, the study evaluates the influence of spectral parameter variations on the rigidity, strength, and stability of the designed reinforced concrete structures. The aim of this comparative analysis is to assess how differences in spectral responses affect structural performance.

The scope of this study is deliberately limited to maintain focus and ensure accuracy. Earthquake data were sourced from the United States Geological Survey (USGS), covering the period from January 1900 to January 2024, with magnitudes greater than 5, depths less than 200 km, and within a 300 km radius of the study site. The data set includes only major earthquakes of tectonic origin. Structurally, the analysis centers on a six-story hotel building with reinforced concrete construction, focusing on the upper structural elements. All structural analyses were performed using ETABS version 19 software, with design references to SNI 1726:2019, SNI 2847:2019, and SNI 1727:2020.

Although numerous studies have explored the relationship between earthquakes and building design, many remain limited in their approaches to calculating earthquake acceleration and applying earthquake-resistant design principles. For example, Pratama et al. (2020) examined the application of PSHA across Indonesian regions and provided PGA estimates for several seismic zones. However, their study concentrated primarily on PGA values without integrating structural design variations based on local spectral responses. Meanwhile, Wulandari (2021) employed a similar methodology but lacked a detailed evaluation of how the three spectral response methods influenced building strength and stability. These studies offer valuable insights but fall short of comprehensively assessing how spectral response variations impact the overall stability of reinforced concrete structures.

The primary objective of this study is to determine the maximum soil acceleration (PGA) and spectral response values for Manado City through the PSHA method, and to design earthquake-resistant building structures using the SRPMK approach. Furthermore, this research aims to compare structural design outcomes based on local spectral response data, national spectral design, and SNI standards, thereby providing a holistic perspective on designing reinforced concrete buildings in seismic-prone regions.

The benefits of this study include the provision of more accurate earthquake acceleration data for the research area, which can assist relevant stakeholders in structural planning. Moreover, the findings are expected to serve as a reference for designing high-rise building structures with enhanced earthquake resistance and to contribute technical knowledge to practitioners and academics involved in structural engineering and disaster risk mitigation.

RESEARCH METHODS

This research was conducted in Manado City with the coordinate point "1.55 N, 124.883333 E", using soil data obtained through the Cone Penetration Test (CPT), provided by experts in the form of N-SPT values. This N-SPT value is then correlated with the shear wave velocity (Vs) to determine the required soil parameters in the EZ-FRISK software. The average shear wave velocity up to a depth of 30 meters from the ground level (Vs30) was used to determine the classification of local soil conditions based on the 2017 Indonesian Earthquake Source and Hazard Map. In addition, earthquake data was obtained from the official website of the United States Geological Survey (USGS) with a time range from January 1908 to January 2024. The parameters taken included magnitudes greater than 5 Mw, depths of less than 200 km, and radius of less than 300 km from the research site. This earthquake data is then processed with ZMAP software through the MATLAB interface and visualized in the form of a seismic map based on predetermined parameters.

The next step is the separation between the main earthquake and the aftershock using the Gardner & Knopoff Declustering method to generate a catalog of major earthquakes. The analysis of the completeness of the data was then carried out to obtain the a-value and b-value parameters using the Mc a and b value estimation features in ZMAP. These parameters are used in modeling the frequency of earthquake events based on the magnitude distribution curve. Earthquake source modeling refers to the tectonic conditions of the Manado region and its surroundings, considering subduction earthquake sources (megathrust), identified active faults, and shallow and deep earthquake sources (background). Earthquake parameters, such as source location, maximum magnitude, fault mechanism, slip-rate, and values of a and b, were taken from official documents and previous studies to describe seismic activity and seismic risk in the study area. The attenuation function is used to describe the relationship between the intensity of ground vibrations, the magnitude of the earthquake, and the distance to the location of the earthquake source, which is strongly influenced by geological conditions and local tectonic structures.

RESULTS AND DISCUSSION

The soil data in this study is secondary data obtained from experts and comes from the results of the Cone Penetration Test (CPT) or commonly known as the soil sondir test. The results of this test were then correlated to obtain the value of the average shear wave velocity (Vs) at the ground level. In this study, the correlation of N-SPT to Vs30 value was carried out using the formula of Seed & Idriss (1981), while the calculation of the average speed of the shear wave used the formula from SNI 1726-2019. From the results of the calculation, the average speed of the shear wave was 182.750 m/second, so that the soil classification according to SNI 1726-2019 is included in the type of medium soil or type D. Meanwhile, earthquake data was obtained from the official website of the USGS (United States Geological Survey) by entering the coordinates of the research location, namely Latitude 1.55 and Longitude 124.883333, as well as the parameter limit of magnitude (Mw) of more than 5, a depth of less than 200 km, and a radius of less than 300 km from the point of location, in the time range from 1908 to January 2024. Because the earthquake catalog from the USGS presents various types of magnitudes such as surface magnitude (Ms), body magnitude (Mb), and magnitude moment (Mw), for the purpose of consistent analysis and in accordance with the standards of updating earthquake maps in Indonesia, all magnitude data is converted into a uniform unit, namely magnitude moment (Mw), so that it can be used in further calculations precisely and accurately.

Separation Results of Major Earthquakes and Aftershocks

The separation between the main earthquake (mainshock) and aftershock (aftershock) is carried out using a method developed by Reasenberg in 1985, with the help of ZMAP software.

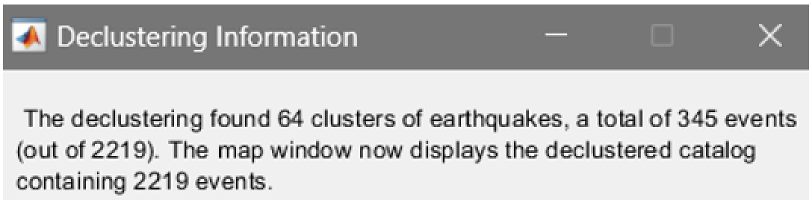


Figure 1. ***Declustering Results***
(Source: ZMAP Output, 2024)

The results *of the declustering* obtained were 345 aftershocks out of a total of 2219 earthquakes so that the main earthquake became 1874 earthquake points.

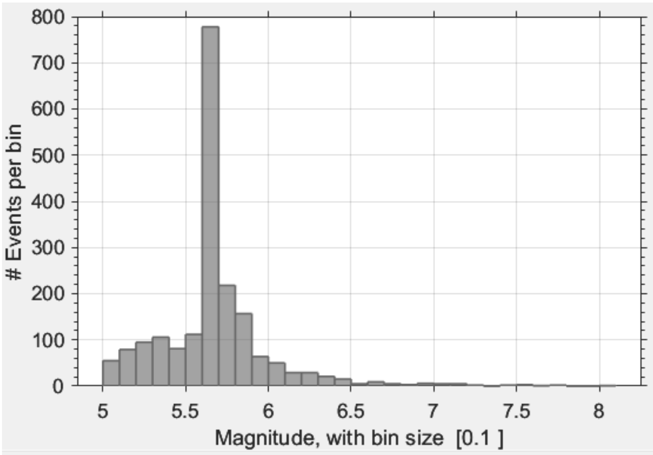


Figure 2. Histogram Magnitude
(Source: ZMAP Output, 2024)

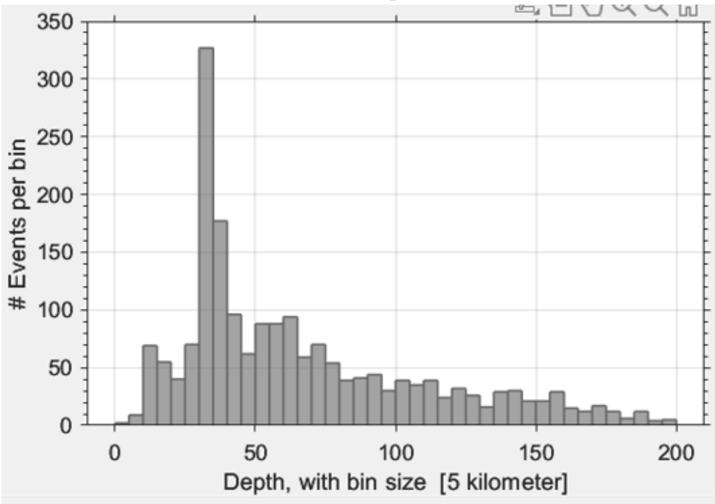


Figure 3. Depth Histogram
(Source: ZMAP Output, 2024)

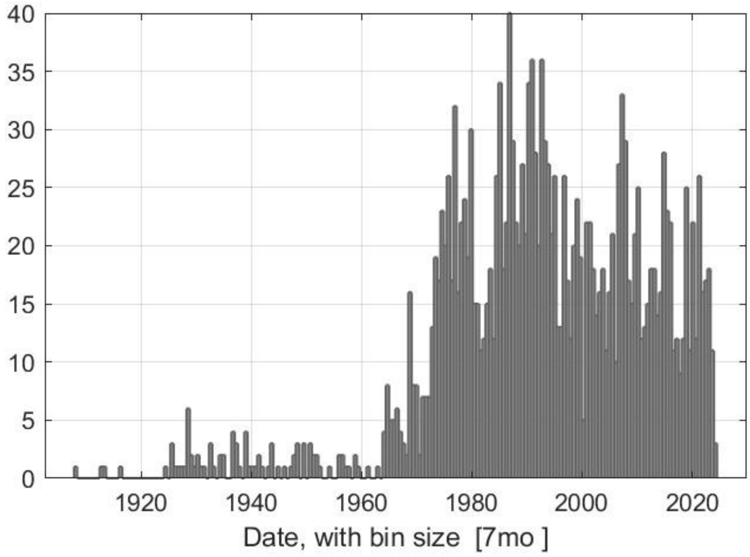
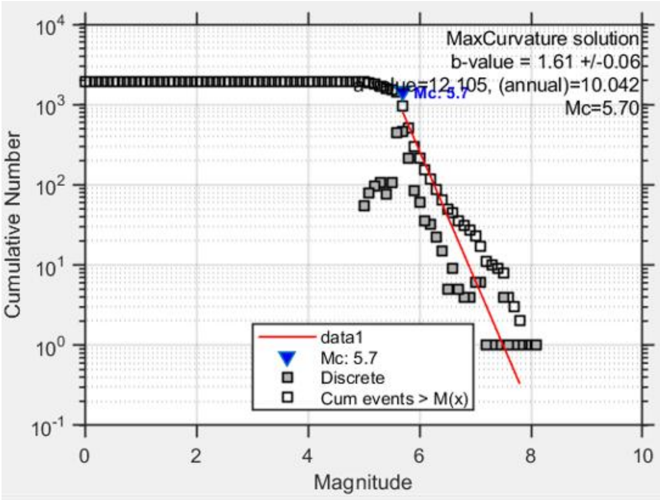


Figure 4. Time Histogram
(Source: ZMAP Output, 2024)

Results of Analysis of Completeness of Earthquake Data

Analysis of the completeness of earthquake data was carried out to determine the value of parameter a and parameter b (*a-b value*) through ZMAP. The following are the results of the analysis of *a-b value* through ZMAP.



Gambar 5. Frequency-Magnitude Distribution
(Source: ZMAP Output, 2024)

The results of the analysis obtained at the research location for parameter a (*a-value*) were 12.1 and parameter b value (*b-value*) was 1.61. A large *a-value* indicates that the seismic activity in the research loci is quite high. For the range of *b-value* values is usually 0.5 to 2, where the smaller the b value means the number of earthquakes with a smaller magnitude will be more. On the other hand, if the value of b tends to be large, then the number of earthquakes with a smaller magnitude will be smaller.

EZ-FRIZK Analysis Results

The following are the results obtained from the data that have been entered to obtain the Peak Ground Acceleration (PGA) value.

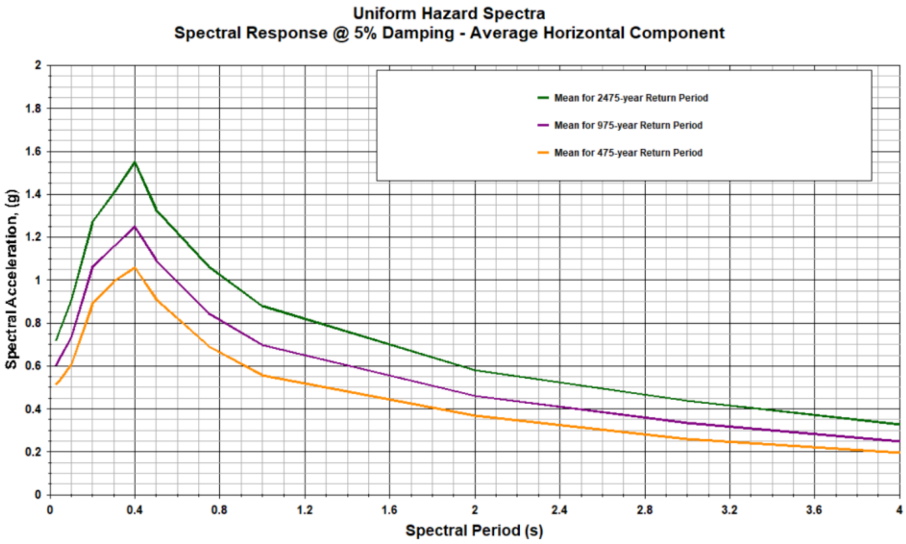


Figure 6. UHS Graph for 500, 1000 and 2500 Year Earthquake Repetition Periods
(Source: EZ-FRISK Output, 2024)

From the UHS graph in the image above, the value of the peak acceleration in the bedrock or *Peak Ground Acceleration* (PGA) for the 500, 1000 and 2500 year re-enactments are as follows:

Table 1. PGA Value Local Spectrum Response

Birthday Period (Birthday)	PGA (g)
500	0.5181
1000	0.6046
2500	0.7233

(Source: EZ-FRISK Output, 2024)

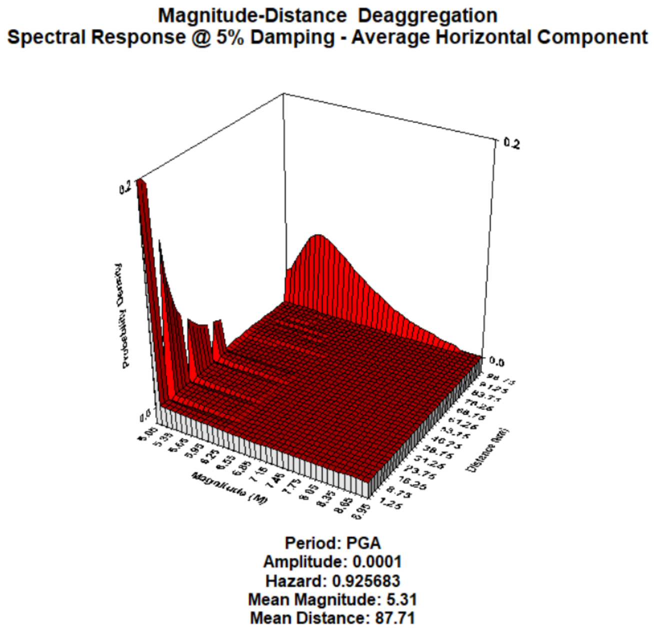


Figure 7. Magnitude – Distance Deaggregation Graph
(Source: EZ-FRISK Output, 2024)

The results of the disaggregation analysis in the study area showed that the earthquake with a magnitude of 5.31 and a distance of 87.71 km was the most significant and had the potential to affect the research location.

Comparison of Spectral Response Results

Table 2. Comparison of PGA, SS and S1 Scores

Source	Parameter-Parameter		
	PGA (g)	SS	S1
SNI 1726-2019	0,4 – 0,5	1,0 – 1,2	0,4 – 0,5
Spektra Indonesia Design	0,4726	1,0329	0,4592
Local Spectrum Response	0,7233	1,2710	0,8786

(Source: Research Results, 2024)

Table 3. Comparison of T vs Sa Values

T (s)	Sa (g)		
	SNI 1726-2019	Spektra Indonesia Design	Local Spectrum Response
0	0,30	0,30	0,34
0,2350	0,75	0,75	0,85
1,1752	0,75	0,75	0,85
1,5	0,56	0,56	0,66
1,75	0,44	0,45	0,57

2	0,37	0,38	0,50
2,25	0,32	0,32	0,44
2,5	0,28	0,28	0,40
2,75	0,25	0,25	0,36
3	0,22	0,23	0,33
3,25	0,20	0,20	0,31
3,5	0,19	0,19	0,28
3,75	0,17	0,17	0,27
4	0,16	0,16	0,25
4,25	0,15	0,15	0,23
4,5	0,14	0,14	0,22
4,75	0,13	0,13	0,21
5	0,12	0,13	0,20
5,25	0,12	0,12	0,19
5,5	0,11	0,11	0,18
5,75	0,11	0,11	0,17
6	0,10	0,10	0,17
6,25	0,10	0,10	0,16
6,5	0,09	0,09	0,15
6,75	0,09	0,09	0,15
7	0,09	0,09	0,14
7,25	0,08	0,08	0,14
7,5	0,08	0,08	0,13
7,75	0,08	0,08	0,13
8	0,07	0,08	0,12
8,25	0,07	0,07	0,12
8,5	0,07	0,07	0,12
8,75	0,07	0,07	0,11
9	0,07	0,07	0,11
9,25	0,06	0,06	0,11
9,5	0,06	0,06	0,10
9,75	0,06	0,06	0,10
10	0,06	0,06	0,10

(Source: Research Results, 2024)

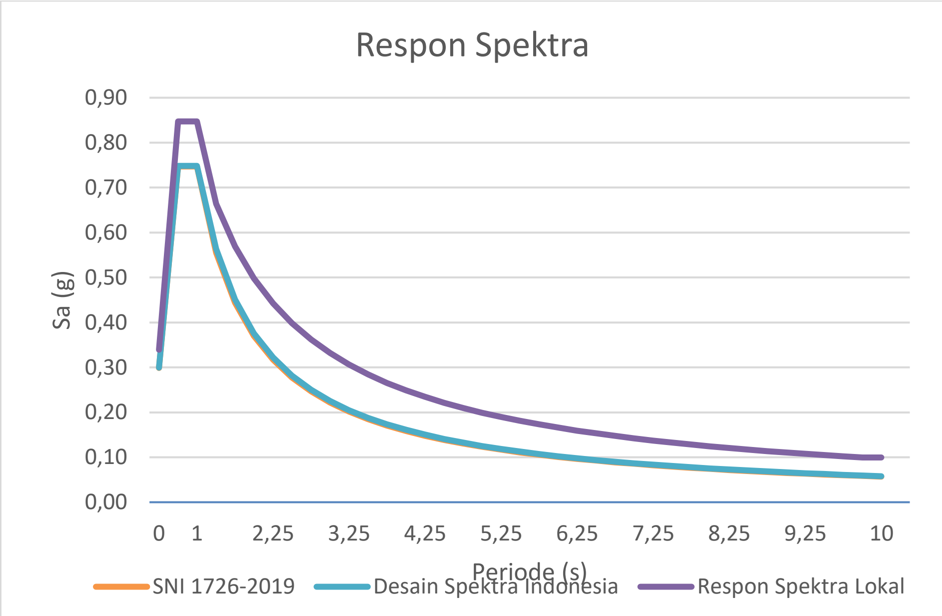


Figure 8. Results Comparison Chart Spektra Answers
(Source: Research Results, 2024)

Based on the results of the comparison of the table and the spectral response graph above, it can be seen that the value of the spectral response results from the Indonesian Spectral Design and SNI 1726-2019 almost has the same value, so for the modeling of reinforced concrete structure buildings, only one modeling will be used to represent the results of the two spectral responses, in addition to building modeling for the Local Spectral Response.

Control of Horizontal Structure Irregularities

Based on SNI 1726-2019 article 7.3.2.1 for horizontal irregularities consists of several types, which must be controlled against several types:

Torque Irregularities and Excess Torque Irregularities

Torque irregularity control can be checked based on the following conditions:

$\delta_{max} \leq 1{,}2\delta_{avg}$ → No torque irregularities

$1{,}2\delta_{avg} < \delta_{max} \leq 1{,}4\delta_{avg}$ → Torque irregularities (1a)

$\delta_{max} \leq 1{,}4\delta_{avg}$ → Excess torque irregularities (1b)

Inspection Results for Building Design Using Local Spectral Response:

1) The direction of X experiences a torque irregularity of 1.a at all levels, where the ratio (maximum deviation/average deviation) exceeds 1.2 and is less than 1.4.
2) The Y direction does not experience torque irregularities at all levels, as the ratio (maximum deviation/average deviation) is the largest, which is 1.190 < 1.2.

Furthermore, the consequences of irregularities will be applied according to the requirements in the planning guidelines. The following are the repair steps:

1) The unexpected torque moment (Mta) of each level should be calculated using the torque magnification factor.

$$Ax = \left(\frac{\delta max}{1{,}2\delta avg}\right)^2$$

2) The direction X, the factor of torque magnification is multiplied by the moment of unexpected torque at each level by taking into account an eccentricity of 5% x (L perpendicular to the direction of the working earthquake force). The next one is analyzed using *ETAS* software.

The Y direction does not experience torque magnification, so it is assumed that the torque magnification factor at all levels is taken, 1.

Inner Angle Irregularities

An irregularity of the inner angle is defined if the two projections of the structure plan of the inner angle are greater than 15 percent of the dimensions of the structure plan in the specified direction, such parameters can be seen in the building plan that has been shown earlier. Irregularities exist when: Py > 0.15 Ly and Px > 0.15 Lx.

Inspection Results: The building has an irregularity of the inner corner.

Structures that experience deep angle irregularities can be done for the safety of the structure with the following steps:

1) The design force based on static procedures is increased by 25% for diagfrage joints with vertical elements and with collector elements, and for collector elements and their joints, including joints to vertical elements, of seismic force holding systems. (Regulated in the ETAB Software).
2) Using a more rigorous analysis model or procedure according to the requirements for the selection of Structure Analysis. (The Analysis Procedure has been carried out based on the Earthquake Seismic Design Category "D" which is allowed based on planning guidelines, namely using Variety Response Spectrum Analysis).

Irregularities Discontinuity

Irregularities of discontinuity can be checked against the plan of the building to be planned. Based on the building plan that has been included earlier, the openings can be calculated as follows:

Building Floor Area = 826 m2
Cut/Open Area = 125.6 m2

The floor plan of the building has a floor area of 826 m2 and has an open area of 125.6 m2 or has an opening percentage of 15.2% < 50% of the floor area, so that the planning plan is not categorized as having irregularities in the discontinuity structure.

Irregularity of Crosswise Shift Against the Plane

An irregularity of the transverse shift to the plane exists if there is a discontinuity in the lateral force resistance trajectory (Column/Shearwall) such as the transverse shift of the plane of the vertical element, based on irregularity no 4.

control results of irregular types; where for the vertical plane (column) on each floor based on the building plan there is no transverse shift to the plane as in the picture because the column is continuous upwards, so that the building does not experience/is safe from irregular transverse shifts to the plane.

Nonparallel System Irregularities

For irregularities, this usually occurs in buildings that have lateral force retaining elements that are not parallel or symmetrical to the orthogonal axes or are placed asymmetrically or are not placed at the centers of the building's mass that function as a building stiffener (the portal column is not parallel to the *shearwall*).

control results of irregular types; In the planned building there is no Shear Wall, and for the vertical retaining of each level of the building, i.e. the Columns have structural elements that are located symmetrically from left to right / against the main and continuous axis on each level, so that the building does not experience or is safe from the irregularities of the nonparallel system.

Control of Vertical Structure Irregularities

Irregularity of Soft Level Rigidity and Excess Soft Level Rigidity

1) Soft Level Stiffness irregularity (1a) is defined as if there is a level where the lateral stiffness is less than 70% of the lateral stiffness of the level above it or less than 80% of the average stiffness of three levels above it.
2) Excess Soft Stiffness (1b) is defined as a level where the lateral stiffness is less than 60% of the lateral stiffness of the above level or less than 70% of the average stiffness of three levels above it. Where the calculation is carried out as follows:

Stiffness Levels (K_x) $= \frac{K_x}{K_{x(n+1)}}$

Average Level Stiffness ($\overline{K_x}$) $= \frac{K_{xn}}{K_{x(n+1)}+K_{x(n+2)}+K_{x(n+3)}/3}$

Based on the results of the inspection, the building does not have any soft stiffness irregularities (1a) or excess soft stiffness (1b).

Severe Irregularities (Mass)

Based on SNI 1726:2019 Article 7.3.3.1, Weight Irregularity (Mass) is defined as exists if the effective mass at any level is more than 150% of the effective time of the nearby level. The roof is lighter than the floor below so there is no need to review. Based on the results of the check the building is safe against heavy irregularities (mass), because the effective mass result of a level is smaller than 150% of the effective mass of the nearby level.

Vertical Geometry Irregularities

Based on SNI 1726:2019 Article 7.3.3.1 concerning Vertical Geometry Irregularities, it is defined if the horizontal dimension of the seismic force bearing system at any level is more than 130% of the horizontal dimension of the seismic force bearing system of the nearby level.

Structural irregularity control results:

1) Based on the planning of the planned column dimensions for each floor, which is the same, where a column of 60 cm x 60 cm is used, continuously on each floor so that the ratio of column dimensions is 100% < 130%, not exceeding the specified limit.
2) So the planned structure does not experience vertical geometry irregularities.

Discontinuity of Plane Direction in Vertical Lateral Force Retaining Element Irregularity

Based on SNI 1726:2019 Article 7.3.3.1 is defined as if the shift in the direction of the plane of the lateral force bearing element is greater than the length of that element or there is a reduction in the stiffness of the bearing element at the level below it.

Structural irregularity control results; In the planning of this building the vertical elements (in this case columns) are in continuous design from the ground floor to the upper floor and do not have an offset to a certain extent. So, the building does not have this irregularity.

Discontinuity in Strong Lateral Degree Irregularities and Excessive Degree Lateral Strength

Based on SNI 1726:2019 concerning Irregularities in Weak Levels and Excessive Weak Levels due to Discontinuity in Lateral Strength Levels.

1) A discontinuity in the lateral strength of the level (5a) is defined as exists if the lateral strength of a level is less than 80% of the lateral strength of the level above it. The lateral strength of the level is the total strength of all the seismic bearing elements that share the level shear in the direction under review.

2) Irregularity Excessive Weak Levels Due to Discontinuity in Lateral Strength Level (5b) is defined as exists if the lateral strength of a level is less than 65% of the lateral strength of the level above it. The lateral strength of the level is the total strength of all the seismic bearing elements that share the level shear in the direction under review.

Structural irregularity control results:

1) For the X Direction, based on the smallest Lateral Strength is 105.31% > 80%, safe against the minimum required limit of both irregularities (5a) and (5b).
2) For Direction Y, based on the smallest Lateral Strength is 105.21% > 80%, safe to the required minimum limit of both irregularities (5a) and (5b).
3) The building does not have an irregular lateral strength level (5a) or excessive lateral strength (5b).

Structural Fundamental Period Control

The Fundamental Period of the Structure (T) shall not exceed the result coefficient for the upper limit of the calculated period (Cu) and the fundamental period of the approach (Ta)

Mass Participation Control

Based on SNI 1726:2019 Article 7.9.1.1, the analysis must include a sufficient amount of variety to obtain the participation of the combined mass of 100% of the structural mass. In the analysis, it is permissible to consider at least 96 modes to ensure that the mass of the compiled mode is at least 90 % of the actual mass in each orthogonal horizontal direction related to the response analyzed by the model.

Nominal Base Shear Force Control

Based on SNI 1726:2019 Article 7.9.1.4, if the combination response to the basic shear force of the variety-analysis (Vt) is less than 100% of the shear force (V) calculated by the equivalent static method, then the force must be multiplied by V/Vt, where V is the equivalent static base shear force and Vt is the basic shear force obtained from the results of the variety-combination analysis. The final value of the dynamic response of the building structure to nominal earthquake load due to the influence of the planned earthquake in a certain direction should not be taken less than 100% of the first variety response value.

Inter-Floor Deviation Control

For seismic design category D, the deviation between design levels (Δ) must not exceed the deviation between permit levels, Δa/ρ, for all levels where Δa is taken 0.020 hsx according to the structure type and the building risk category i.e. risk category II. Since the structure has a torque irregularity of 1.a and is at KDS "D", the redundancy factor (ρ) must be 1.3. The following is the data used:

Deviation Between Permit Levels (Δa) = 0.025h
Redundancy factor (ρ) = 1.3
Story Inelastic Drift Permission (Δmax) = Δa/ρ = 0.025/1.3 = 0.0192 h
Deflection Enlargement Factor (Cd) = 5.5
Earthquake Priority Factor (ie) = 1.00

Control Displacement

Based on SNI 2847:2019 Article 9.5.3.1. For *displacement*, the deviation of the structure (Δ) must not exceed L/240 where L is the total height of the structure.

P- (P-Delta)Δ Influence Control

The influence of P-Delta on the shear and moment of level, the force and moment of the resulting structural elements and the deviation between the floors of the level arising from this influence are not required to be taken into account if the stability coefficient (θ) is equal to or less than 0.10.

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d}$$

The coefficient of stability (θ) must not exceed θ the max specified as follows:

$$\theta_{maks} = \frac{0.50}{\beta . C_d}$$

M. Comparison of Reinforced Concrete Structure Planning Results Using Local Spectral Response, Indonesian Spectral Design and SNI 1726-2019

Based on the results of planning using ETABS software, it can be seen in the image below, namely the results of the planning of reinforced concrete structures using the spectral response value of the Indonesian Spectral Design or SNI 1726-2019 and the Local Spectral Response, there are differences mainly in the failure of shear in the area around the opening (stairs).

The difference in the form of 3 dimensions of the building that there is no shear failure in the design of reinforced concrete structures uses the spectral response value from Spektra Design Indonesia. This is inversely proportional to the design of reinforced concrete structures using the spectral response value in the Local Spectral Response because there is a shear failure on the entire floor of the building but only in the area around the opening (stairs).

CONCLUSION

The comparison of reinforced concrete structures designed using Local Spectral Response, Indonesian Spectral Design, and SNI 1726-2019 reveals that the Local Spectral Response for the research site exhibits a notably higher maximum ground acceleration (Peak Ground Acceleration, PGA) value of 0.7233 g for a 2500-year recurrence period, compared to 0.4–0.5 g from SNI 1726-2019 and 0.4726 g from Spektra Indonesia Design. This represents a 53.05% increase in PGA relative to the national standards. Consequently, some structural elements, particularly around openings such as stairways, experience shear failure under the higher accelerations predicted by the Local Spectral Response. For future research, it is recommended to explore advanced reinforcement detailing and alternative structural systems to improve shear capacity and overall seismic resilience in regions where local spectral demands significantly exceed national standard values.

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