BUILDING STRENGTH ANALYSIS BASED ON SNI 1726-2019 AND THE PERFORMANCE OF BUILDING STRUCTURE BASED ON ATC-40 WITH PUSHOVER ANALYSIS METHOD (CASE STUDY : LABORATORY BUILDING OF FAKULTAS KEDOKTERAN UNIMUS SEMARANG)

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Abstract— Changes in the earthquake map due to new faults and earthquake sources have caused changes in the applicable regulations, such as SNI 1726-2012 being updated to SNI 1726-2019 and so on. Analysis of old regulations against the latest regulations is carried out to control building capacity against the latest regulations, and the performance of the building structure is reviewed so that capacity is known. Strength analysis was carried out based on SNI 1726-2019, and performance analysis was carried out using Pushover Analysis, namely nonlinear static analysis based on parameters determined by the Applied Technology Council (ATC-40). The study results obtained the maximum Drift Limit value based on SNI 1726-2019 40 mm. For Inelastic Drift Limit results, for the X direction, a maximum of 20.771 mm and 24.346 mm for the Y direction. This value does not exceed the Drift Limit. The maximum stability coefficient based on SNI 1726-2019 is 0.0909, while the analysis results are 0.07 in the X direction and 0.086 in the Y direction. So, the structure can be said to be satisfactory and safe to use. The value of the Pushover Analysis based on the ATC-40 is Performance Point, namely the X direction, Vt = 17208.775 kN with a displacement of 0.076 m. Y direction, Vt = 15305.699 kN with a displacement of 0.018 m. From these values, it is concluded that the structure is in a state of IO or Immediate Occupancy.

Keywords: Pushover, Nonlinear, SNI 1726-2019, ATC-40, Building Performance.

I. INTRODUCTION

Indonesia is a region that frequently changes its seismic map and the applicable regulatory standards. Just like the previous seismic standard, SNI 1726-2012 has been replaced by the current updated standard, SNI 1726-2019. These changes have been implemented to align regulations with the latest conditions resulting from the emergence of new faults or seismic sources. The seismic map is a prerequisite for determining the earthquake loads used for scientifically justifiable designs (1). In this context, the structures constructed before the new regulations, which were based on the previous standards, need to be analyzed for their suitability according to the newly issued and applicable regulations (6). Performance-based seismic evaluation of buildings is conducted using Pushover Analysis based on ATC-40 to determine the structural performance level of a building. Pushover Analysis is a component of Performance-Based Seismic Evaluation (PBSE) used to assess the performance of a building structure. This performance evaluation is necessary to understand a building's resilience to the loads it experiences and to serve as a reference for strengthening a building structure if it does not comply with the prevailing regulations. In practice, this evaluation commonly employs the ATC-40 standard as the foundation for assessment. (4).

The Medical Laboratory Building of Muhammadiyah University Semarang was constructed in 2018, referencing several regulations in effect. For the reinforced concrete structure, the construction of this building adhered to SNI 2847-2013, the Code for the Structural Design of Concrete Buildings. The seismic resilience planning for this building followed SNI 1726-2012, the Code for Earthquake Resilience Planning of Buildings. Changes in Indonesia's seismic maps and regulations have undoubtedly altered the parameters and values established during the planning phase. Consequently, structural strength analysis was also conducted to assess the performance and strength of the structure due to changes in seismic maps and prevailing regulations.

The new regulations, particularly SNI 1726-2019, which replaced SNI 1726-2013, have replaced the old standards. Through structural analysis, it can be determined whether the building's structural changes in response to the new regulations comply with the current standards and meet the requirements set by the new regulations. Structural strength and performance analysis are performed to ascertain the structural capacity when subjected to internal and earthquake-induced loads. The Pushover analysis generates displacement values that serve as the basis for evaluating the performance of the building structure (7). The Pushover analysis was done to ascertain the structural capacity and map out the performance levels of the structure.

II. RESEARCH METHODS

A strength analysis of the building based on SNI 1726-2019 is carried out to determine the building's compliance with the latest applicable regulations. Pushover Analysis is employed to assess the performance level of the examined building structure. This evaluation is conducted using SNI 1726-2019, which outlines the seismic design procedures for buildings and the Applied Technology Council (ATC)-40 (1). The evaluation utilizes SAP2000 software for structural analysis and the assessment of the performance of the evaluated building structure.

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The research was conducted through a literature review, where relevant materials related to the conducted study were analyzed. Subsequently, data collection was carried out, involving gathering structural planning data, including working drawings and Specifications. Next, loads are calculated based on each room's functions following SNI 1727:2020, while for lateral seismic loads, SNI 1726-2019 is applied. Before the analysis, the structure is modeled using an application, and the loads are input according to the calculations from the preceding steps. The analysis is conducted using the SAP2000 application, with output values calculated using SAP2000 and correlated with SNI 1726-2019 standards using Microsoft Excel. Pushover analysis is conducted after defining the Push X and Push Y loads and the Gravity loads. Before the analysis, plastic hinges are defined on beam and column elements with a definition of 5% and 95% of the length of the building's structural columns and beams. Once the plastic hinge definitions are established, the structural model is run. This running process generates graphs and Performance Points in both the X and Y directions. These values are calculated using Microsoft Excel following the specified guidelines. After conducting the analysis and calculations based on SNI 1726-2019 and the Pushover Analysis following ATC-40, conclusions are drawn from the research, and recommendations are provided for potential future studies.

III. RESULTS AND DISCUSSION

A. Loading of Building Structures

The dead and live loadings of the building structure are carried out according to SNI 1727-2020. These loadings are determined through calculations and calculations that align with the needs and functions of each respective room. In addition to these loadings, seismic loading is performed based on SNI 1726-2019, which is inputted into the building structure's modeling and automatically analyzed using the SAP2000 application.

B. Building Structure Modeling

The building structure modeling is carried out separately for both the roof and portal structures. In this case, the Joint reaction values of the roof structure will be inputted into the portal structure as Dead Load. Below is the roof structure modeling (figure 1).

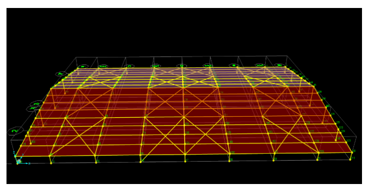


Figure 1. Roof structure modeling

The above modeling employs pinned joints, and loadings are inputted in accordance with SNI 1727-2020. After the Running Analysis, the Joint reaction values obtained from the analysis are incorporated into the main structure as Dead Load. Below is the primary portal model of the building structure (figure 2).

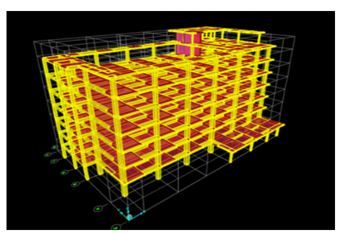


Figure 2. Building portal structure modeling

The foundation of the portal structure is considered to be rigid. After the modeling and inputting of loadings, the subsequent analysis is conducted.

C. Structural Analysis of Buildings Based on SNI 1726-2019

From the structural modeling, an analysis based on SNI 1726-2019 was conducted, yielding the following analysis results,

- Modal Participating Mass Ratios

  The participation mass modal required in SNI 1726-2019 is 100%. Here are the results of the structural mass participation modal analysis (table 1).

TABLE 1. MODAL PARTICIPATING MASS RATIOS

Step	Period	UX	UY	UZ	SumUX	SumUY
1	1,576	0,3	0,097	0	0,297	0,097
2	1,303	0,4	0,12	0	0,699	0,217
3	0,997	0,01	0,502	0	0,705	0,72
4	0,503	0,03	0,015	0	0,737	0,734
5	0,41	0,07	0,012	0	0,805	0,746
6	0,356	0,04	0	0	0,847	0,746
7	0,335	0	0,081	0	0,847	0,827
8	0,296	0,02	0,001	0	0,869	0,828
9	0,293	0	0	0,041	0,869	0,828
10	0,286	0	0,002	0,003	0,871	0,83
11	0,262	0,01	0,005	0	0,877	0,834
12	0,255	0	0,052	0,003	0,878	0,887
13	0,252	0	0,017	0,01	0,879	0,903
14	0,229	0	0	0	0,88	0,903
15	0,209	0	0,001	0,001	0,88	0,905
16	0,181	0,04	0,001	0	0,919	0,906
17	0,176	0,01	0,014	0,001	0,926	0,92
18	0,169	0,01	0,002	0	0,937	0,922
19	0,139	0	0,035	0	0,94	0,957
20	0,116	0,03	0,002	0,001	0,966	0,959
21	0,095	0	0,024	0,001	0,966	0,983
22	0,087	0,02	0	0,002	0,985	0,983
23	0,063	0	0,014	0,001	0,988	0,997
24	0,06	0,01	0,002	0	1	1

- Seismic Base Shear Force

  In SNI 1726-2019, it is required that Vstatic < Vdynamic. Here are the results of the calculation for seismic base shear force (table 2).

TABLE 2. SEISMIC BASIC SHEAR FORCE CALCULATION RESULTS

BASE SHEAR	DYNAMIC (KN)	STATIC (KN)	(VD > 100%VS)	(VD/VS)	SCALE FACTOR (FS)
X - DIRECTION	2668,696	7181,178	DOES NOT MEET THE REQUIREMENTS	0,372	2,691
Y- DIRECTION	3505,012	7181,178	DOES NOT MEET THE REQUIREMENTS	0,488	2,0488

Since it does not meet the requirement of Vstatic < Vdynamic, scaling of forces is performed and a re-calculation is conducted. Below is the table 3 of results for the scaling of seismic base shear force.

TABLE 3. RESULTS OF SCALING SEISMIC BASE SHEAR FORCE

Base Shear	Dynamic (VD) (kN)	Static (Vs) (kN)	Scale Factor (VS/VD)	Control (VD > 100%Vs)
X - Direction	8806,698	7181,178	1,23	Meets the requirements.
Y- Direction	8762,529	7181,178	1,22	Meets the requirements.

From the table above, the value of VDynamic is greater than 100% * VStatic. Therefore, the structure has fulfilled the requirements of SNI 1726-2019. Based on these results, further analysis is conducted on the structure following SNI 1726-2019.

- Story Drift

  The structural analysis of the building has yielded calculation results regarding inter-story drifts, as shown in the table 4.

TABLE 4. RESULTS OF STORY DRIFT ANALYSIS

Story	*Displacement*		*Elastic Drift*		*h*	*Inelastic Drift*		*Drift Limit*	*Cek*
	δe_X	δe_Y	δe_X	δe_Y		Δ_X	Δ_Y		
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	
8	41,5	46,8	5,7	6,6	3500	20,8	24,3	35	OK
7	35,8	40,1	5	5,7	4000	18,2	21	40	OK
6	30,9	34,4	5,5	6,5	4000	20,3	23,8	40	OK

5	25,3	27,9	6	6,7	4000	22,1	24,6	40	OK
4	19,3	21,2	6,3	6,8	4000	23,2	25,1	40	OK
3	13	14,4	5,9	6,3	4000	21,7	23,1	40	OK
2	7,1	8,1	4,8	5,3	4000	17,6	19,4	40	OK
1	2,3	2,8	2,3	2,8	4000	8,5	10,3	40	OK

The table 4 shows that the structure has met the requirements as the analysis results for inter-story drift do not exceed the Drift Limit value. Thus, it can be concluded that the structure is safe. For further clarity, refer to the following figure 3.

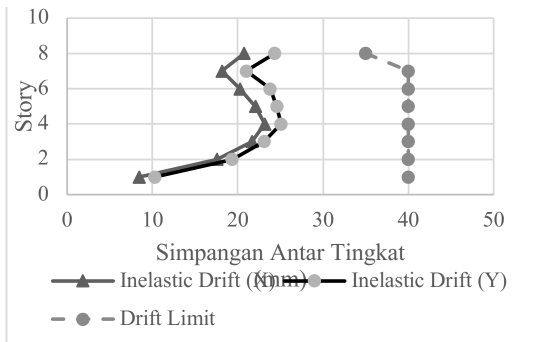


Figure 3. Story Drift Graph

From the graph above, it can be observed that the Inelastic Drift values do not exceed the Drift Limit value. This is attributed to the fact that the rigidity of the building's structure has met the stipulated criteria, thereby leading to deflections that are in accordance with the prevailing regulations.

- P-Δ Effect

The P-Δ Effect is calculated to analyze the structural stability due to the influence of secondary moments resulting from axial forces and inter-story drifts. Below are the results of the P-Δ Effect calculation on the building structure (table 5)

TABLE 5. RESULTS OF P-Δ EFFECT CALCULATION

Story	Inelastic Drift		Story Forces			h	Stability Coefficient		P-Delta Limit	Structural Stability Limit, θ_{max}
	Δ_X (mm)	Δ_Y (mm)	P (kN)	V_x (kN)	V_y (kN)	(mm)	θX	θY		
8	20,8	24,3	718	129	151	3500	0,01	0,009	0,1	0,091
7	18,2	21	6618	646	447	4000	0,01	0,021	0,1	0,091
6	20,3	23,8	33112	1104	975	4000	0,04	0,055	0,1	0,091
5	22,1	24,6	33112	1104	975	4000	0,05	0,057	0,1	0,091
4	23,2	25,1	46800	1143	968	4000	0,06	0,083	0,1	0,091
3	21,7	23,1	60949	1346	1121	4000	0,07	0,086	0,1	0,091
2	17,6	19,4	75676	1298	1231	4000	0,07	0,081	0,1	0,091
1	8,5	10,3	91747	1450	1693	4000	0,04	0,038	0,1	0,091

From the table above, it can be concluded that the building structure has met the requirements as the stability coefficient values do not exceed the structural stability limit. Therefore, the structure is safe and compliant with SNI 1726-2019. This information from the table can be illustrated using the following graph,

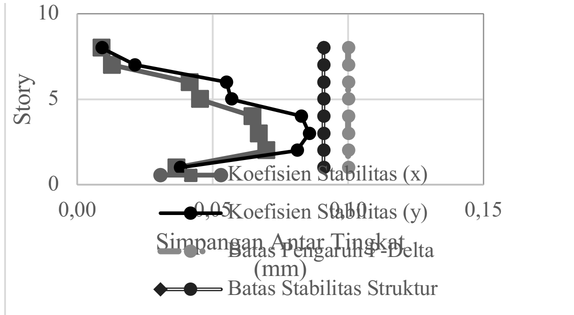


Figure 4. P-Δ Effect Graph

The graph above shows that the stability coefficient values do not exceed the limit of the P-Δ Effect influence and the structural stability limit. Hence, the structure can be deemed safe and compliant with SNI 1726-2019 requirements.

D. *Structural Performance Analysis Based on ATC-40*

Nonlinear static pushover analysis or Pushover Analysis is conducted using SAP2000. Below are the results of the analysis that have been carried out in figure 5 to 6.

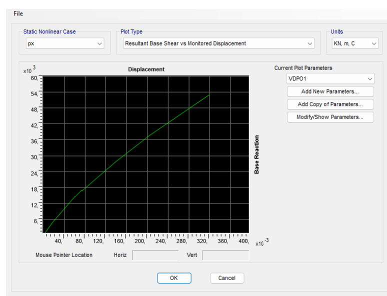


Figure 5. Capacity Curve Graph - X Direction SAP2000 Output

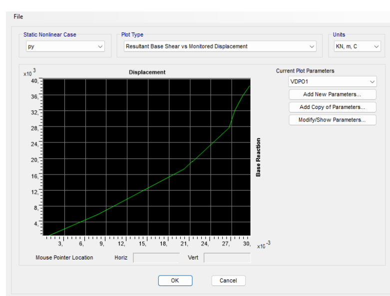


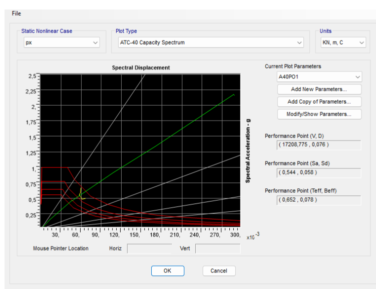
Figure 6. Capacity Curve Graph - Y Direction SAP2000 Output

The image above shows the output results of the push forces that generate the capacity curve (table 6).

TABLE 6. ROOF DISPLACEMENT VS. BASE FORCE

Step	Displacement X (m)	BaseForce X (kN)	Displacement Y (m)	BaseForce Y (KN)
0	0	0	0	0
1	0,0171	4694,82	0,0078	5923,19
2	0,0599	14422,4	0,0201	17381
3	0,0611	14531,17	0,0214	19240,49
4	0,0738	16890,58	0,0214	19224,22
5	0,0738	16910,41	0,0266	27761,82
6	0,0738	16905,64	0,0274	32093,87
7	0,0738	16913,02	0,0285	35796,86
8	0,0743	16845,63	0,0295	38287,67
9	0,0743	16774,35		
10	0,1379	27569,21		
11	0,2043	37574,79		
12	0,3168	52737,62		
13	0,3175	52845,55		
14	0,3185	52767,34		
15	0,3199	52927,72		

From the table above, the values of the static nonlinear push forces are obtained. After obtaining the capacity curve from the pushover analysis, the structural performance is determined from the Performance Point obtained from the intersection between the Capacity Curve and the Demand Spectrum. Performance assessment is conducted following the ATC-40 procedure (figure 7 to 8).



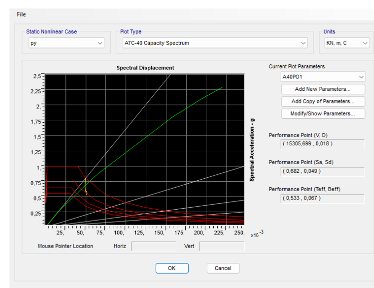


Figure 7. Pushover Analysis Results Graph Based on ATC-40 - X Direction

Figure 8. Pushover Analysis Results Graph Based on ATC-40 - *Y* Direction

From the graph above, the Performance Point value is obtained, and the results of the analysis are presented in the table 7.

TABLE 7. PERFORMANCE POINT

Force	Base Shear (kN)	Performance Point					
		Vt (kN)	δt (m)	Sa	Sd	T eff	β eff
Push X	7160,207	17208,8	0,076	0,544	0,058	0,652	0,078
Push Y	7160,207	15305,7	0,018	0,682	0,049	0,533	0,067

From the table above, calculations are conducted to determine the performance using the following formula,

- Pushover Analysis - X Direction

$$Maximum\ Total\ Drift = \frac{Dt}{Htotal}$$

$$= \frac{0,076}{31,5}$$
= 0,0024127

According to the ATC-40 table, 0.0024127 < 0.01. Based on this value, the structure falls under the Immediate Occupancy (IO) category.

$$Maximum\ Inelastic\ Drift = \frac{(Dt-D1)}{Htotal} = \frac{(0,076-0,017061)}{31,5}$$
= 0,00187

According to the ATC-40 table, 0.00187 < 0.005. Based on this value, the structure falls under the Immediate Occupancy (IO) category.

- Pushover Analysis - X Direction

$$Maximum\ Total\ Drift = \frac{Dt}{Htotal} = \frac{0,018}{31,5}$$
= 0,00057

According to the ATC-40 table, 0.0024127 < 0.01. Based on this value, the structure falls under the Immediate Occupancy (IO) category.

$$Maximum\ Inelastic\ Drift = \frac{(Dt-D1)}{Htotal} = \frac{(0,018-0,007807)}{31,5}$$
= 0,00032

According to the ATC-40 table, 0.00187 < 0.005. Based on this value, the structure falls under the Immediate Occupancy (IO) category.

IV. CONCLUSION

In the implementation of the analysis based on SNI 1726-2019 and Pushover Analysis based on ATC-40, the obtained results for the Drift Limit based on the SNI 1726-2019 analysis have a maximum value of 40 mm. For the inelastic drift limit, the maximum values obtained are 20.771 mm in the X direction and 24.346 mm in the Y direction, which do not exceed the drift limit. The maximum stability coefficient value obtained from the analysis according to SNI 1726-2019 is 0.0909, while the stability coefficient values obtained from the analysis are 0.07 for the X direction and 0.086 for the Y direction, indicating compliance.

The values obtained from the Pushover Analysis based on ATC-40 are as follows: The Performance Point values are Vt = 17208.775 kN with a displacement of 0.076 m in the X direction and Vt = 15305.699 kN with a displacement of 0.018 m in the Y direction. Based on these values, an analysis is carried out, concluding that the structure is in an Immediate Occupancy (IO) state. This means the structure experiences slight damage, and the structural elements, including lateral and vertical force-resisting systems, do not suffer damage. As a result, the structure can function as intended before the earthquake without requiring repair or strengthening.

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