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Performance Assessment of Multi-story Building After 24 Years in Service

Taufiq Saidi[1,*], Muttaqin[1], Imam Muzhaffar[2], Bambang Setiawan[3], Juellyan[4,5]

[1] Department of Civil Engineering, Faculty of Engineering, Universitas Syiah Kuala, Aceh, Indonesia;
[2] Student, Department of Civil Engineering, Faculty of Engineering, Universitas Syiah Kuala, Aceh, Indonesia;
[3] Department of Geological Engineering, Faculty of Engineering, Universitas Syiah Kuala, Aceh, Indonesia;
[4] Engineering Doctoral Program, Post Graduate Program, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[5] Awardee, Program Riset Unggulan Universitas Syiah Kuala Percepatan Doktor (PRUU-PD), Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM), Universitas Syiah Kuala, Banda Aceh 23111, Indonesia;
*Corresponding author: taufiq_saidi@usk.ac.id

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Abstract – Any public infrastructure has a set service life limit. In the Indonesian case, the public building has a 50-year design life. This paper presents a performance assessment of a multiple-story building in Aceh-Indonesia. A multi-story Faculty of Engineering Universitas Syiah Kuala building was used in this study. This multi-story building structure has been used for more than 24 years since it was built in 1998. This structure is 29.4 m long, 13 m wide, and 14.4 m tall in geometric terms. This study reveals how this three-story building behaves, including displacement, base shear, and structure performance level per ASCE 41-17 criteria. The processes in this study are broken down into various stages, including pushover analysis and comparing the building's current natural frequency. ETABS software was used to model building structures. According to the study, the building's performance is still more or less similar to the initial plan. Pushover in the X-direction (Push X) is believed to be immediate occupancy (IO), and pushover in the Y-direction (Push Y) is believed to be life safety (LS). The pushover analysis results for Push X suggested that the structure is safe and retains rigidity. Push Y indicated minor damage within the life safety category after a service life of 24 years. This pushover analysis indicated that the structure has reduced its rigidity, making it less able to resist further displacement. Based on the base shear, which experiences a displacement that is significantly greater than the estimate at the original planning stage, it is known that stiffness decreases.

Keywords: pushover, structure performance, microtremor, seismic, period, building code.

Introduction

A structure has been built to be utilized in accordance with applicable standards for a certain amount of lifetime services. However, there are a number of things that can speed up a structural system's descent into degradation along the way. To prevent further harm, any structural damage must be found as soon as possible (Handana *et al.*, 2018), as the building is an essential area where humans conduct any activities. Earthquakes have become one of the triggering elements that accelerate damage to a building, even though it was built with earthquake loads in mind during the planning stage. In high seismicity regions, earthquakes of any magnitude will occur throughout the service time and cause the structure to sustain damage faster than anticipated (Chen *et al.*, 2022). A multi-story building of the Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh-Indonesia, has been in operation since 1998. This structure was constructed with a moment-bearing reinforced concrete frame. This structure stands 14.4 meters tall, 13.4 meters wide, and 29.4 meters long. This structure is characterized as a medium-rise building based on the above geometry (Arieza *et al.*, 2018; Mulyono, 2000). This structure has been in operation for at least 24 years. As Banda Aceh-Indonesia is categorized as a high seismicity region, these building structures' seismic performance must be re-evaluated to identify probable displacements or system failures that could threaten building occupants (Handana *et al.*, 2018). Pushover analysis is a standard method for determining the extent of vulnerability to structural damage. Pushover analysis is a set of incremental

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static analyses used to create a capacity curve for a building. (Kadid & Boumrkik, 2008). The natural period of a building or structure is one of the criteria considered in the pushover analysis. The natural period can be calculated using one of the microtremor measurement methods, specifically the floor spectral ratio (FSR) (Gosar *et al.*, 2010; Hadianfard *et al.*, 2015).

Pushover analysis

The pushover analysis method is one of the components of performance-based design, which is a method for determining a structural capacity. The analytical results can describe the link between base shear and roof displacement. Pushover analysis (si) can be performed by distributing uniform height and width forces using the mass matrix (M) and the natural vibration period (ϕ_i) (Brozovič & Dolšek, 2014; Kadid & Boumrkik, 2008; Vamvatsikos & Cornell, 2006).

$$s_i = M.\phi_i \quad (1)$$

The pushover analysis method described above has the highest level of consistency in the fundamental pushover analysis (Brozovič & Dolšek, 2014; Fajfar, 2000; Peruš et al., 2013; Vamvatsikos & Cornell, 2006). The above-mentioned relationship between base shear and roof displacement can then be mapped and seen as a structure capacity curve. Furthermore, ASCE 41-17 establishes roof drift ratio restrictions for different levels of structural performance. Table 1 explains the distribution bounds. These restrictions are specified by describing the building's physical damage and liability after the earthquake (ASCE/SEI 41-17, 2017).

Microtremor

Microtremor is a ground vibration induced by natural sources such as wind and long-period sea waves and artificial ones such as transportation action, factory machinery, etc. In microtremors, the horizontal-to-vertical spectral ratio (HVSR) approach is well-known. The HVSR method is used to determine the natural frequency at a location (Kadid & Boumrkik, 2008; Sato et al., 2004). The floor spectral ratio (FSR) approach is recommended for analyzing natural frequencies in buildings. The FSR method is a method for determining natural frequencies and architectural resonances that explain the seismic resistance of buildings (Gosar et al., 2010; Kadid & Boumrkik, 2008).

Table 1. Limitation of the Drift Ratio ASCE 41-17 (ASCE/SEI 41-17, 2017)

Items	Performance Level		
Parameter	IO	LS	CP
Inter-Story Drift	0,5%	1,5%	2,0%

*IO=Immediately Occupancy, LS=Life Safety, CP=Collapse Prevention

Material and Methods

This study focuses on the Administrative Building of the Faculty of Engineering, Universitas Syiah Kuala, Banda Aceh City, Aceh Province, Indonesia. The coordinates for this object are 5.56696810 E and 95.36865890 N. Figure 1a shows the study site, and Figure 1b shows the detailed location of the investigated building. This multi-story building has been under construction since 1998. Therefore, it has a service life of more than 24 years at the time of this evaluation. The geometry of this multi-story building is 29.4 meters in length, 13 meters in width, and 14.4 meters in height. Figure 2 shows the geometry of the model in further detail.

The data utilized in this study are shop drawing data from the as-built drawing of the Faculty of Engineering and spectrum response data from Pusat Studi Gempa Nasional (Indonesia) & Pusat Penelitian dan Pengembangan Perumahan dan Permukiman Indonesia (PUSGEN) 2017. The next piece of information required is the natural frequency measurement data from the building, as obtained by a seismometer.

Table 2 shows the material quality employed in this study. Meanwhile, the floor spectral ratio (FSR) is utilized to determine the natural frequency of buildings. Microtremor data measurements were performed using the Raspberry Shake 3D seismometer (Figure 3a), with nine measurement points divided into three spots on each level, each with a measurement length of 24 hours. The position of each issue is on the core pillar of the structure, with the component at the end of each system and the center point of the design. The results of the analysis will be displayed in the form of a curve with a comparison of frequency and power spectral density, with the peak value of the curve representing the frequency value of a measurement result (Figure 3b).

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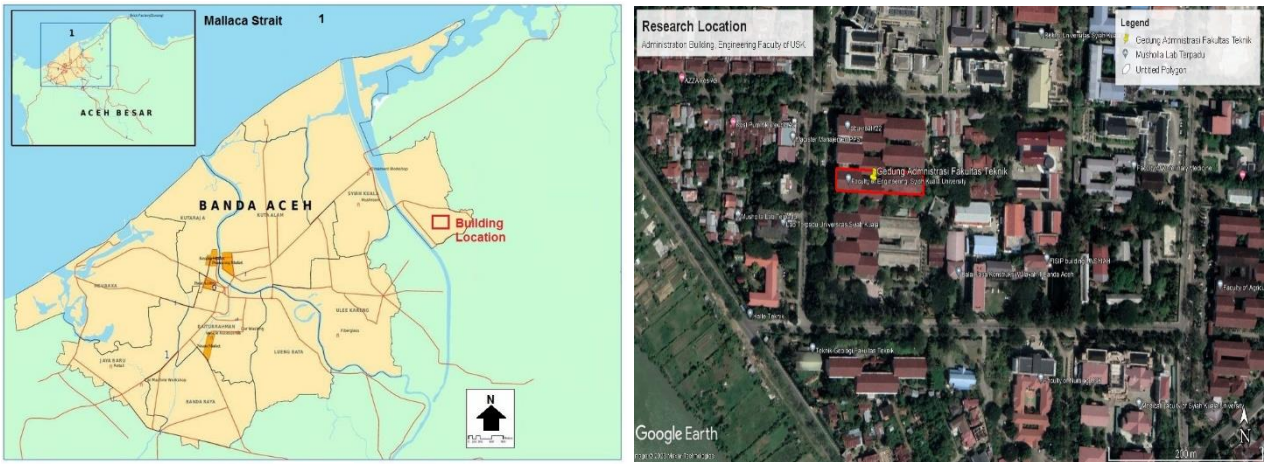
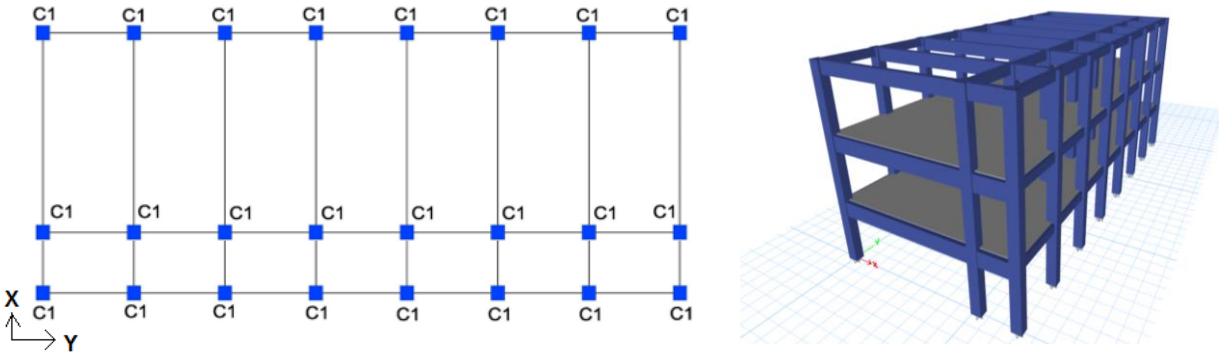


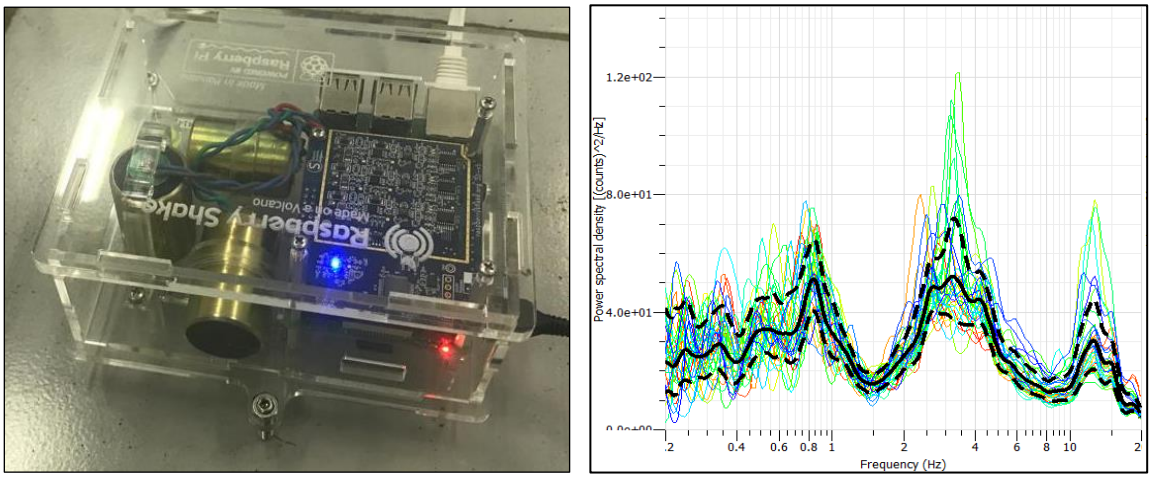
(a) (b)

Figure 1. (a) General research location, and (b) detailed location of the investigated building



(a) (b)

Figure 2. (a) plan of the investigated building, and (b) isometric of the investigated building



(a) (b)

Figure 3. (a) Data acquisition using Raspberry Shake 3D, and (b) data analysis

The study is performed by introducing a lateral load whose value is gradually increased proportionally to the structure, causing failure owing to plastic hinges in the column and beam parts. Pushover analysis seeks to

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provide information on a structural capability. This stage employs ETABS v.18 software to construct base shear-displacement performance points, spectrum responses, and demand curves based on SNI 1726 (2019), which is displayed on the program and then generate the performance point where it intersects the capacity curve from the pushover analysis. The performance point is the intersection of the capacity and spectral response curves generated following the pushover analysis. The performance level of the building can then be established after obtaining the building's performance point.

Table 2. The quality of the materials

Items	Material quality value
Concrete quality f" c	28 MPa
Threaded steel quality (BJTS)	U24, U32, dan U39
Young modulus of concrete	200000 MPa
Young modulus of steel	24870,1 MPa
Specific gravity of reinforced concrete	2400 kg/m^3
Specific gravity of steel	7850 kg/m^3
Specific gravity of concrete	2200 kg/m^3

Results

Based on the initial planning, the outcomes of this study are pushover curves in the x and y directions, followed by pushover curves in the x and y directions after 24 years of service. The pushover load is a thrust load that is applied to the building's center of mass. The load is involved at joint 23 of the Administration Building, Faculty of Engineering, Universitas Syiah Kuala, in the x and y directions. The pushover analysis findings in the x-direction are shown in Table 3 and Figure 4a, while the pushover analysis results in the y-direction are shown in Table 4 and Figure 4b. While Table 5 and Figure 5a show the pushover analysis results in the x-direction after 24 years of service, Table 6 and Figure 5b provide the y-direction results after 24 years of service.

Table 3. The results of the x-direction pushover analysis based on the initial planning

Step	Displacement mm	Base Shear kN
0	0	0
1	18,033	4282,059
2	51,19	9741,3025
3	64,921	11255,3826
4	87,959	12808,3402
5	88,017	12810,7337
6	88,406	12834,3671
7	88,459	12836,3653
8	100,35	13427,6147
9	100,38	13427,5279
10	100,494	13433,7278
11	130,07	14675,3776
12	136,77	14935,1947
13	136,771	14927,0587
14	137,509	14655,6715

Table 4. The results of the y-direction pushover analysis based on the initial planning

Step	Displacement Mm	Base Shear kN
0	0	0
1	28,8	3574,9771
2	29,428	3652,8747
3	59,696	6740,0814
4	64,233	7115,8515
5	64,236	7116,2023
6	65,368	7203,644
7	65,372	7183,1209
8	65,382	7180,7861

The following step is to compute building performance during the original planning stage and after a 24-year service period. Table 7 displays the computation results. Figure 6 depicts a comparison of building performance results based on the original planning stage and after a 24-year service period for the x direction. Meanwhile, Figure 7 depicts the results of building performance comparisons in the y direction

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Table 5. Result of x-direction pushover analysis after 24 years of service life

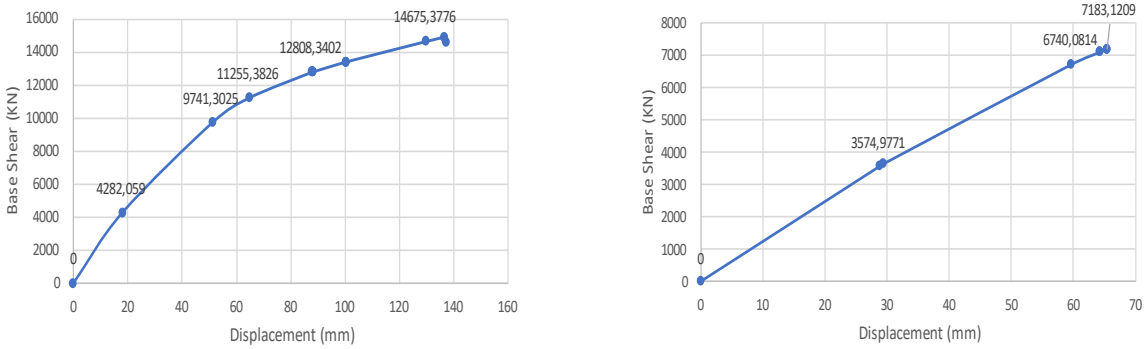
Step	Displacement	Base Shear
	mm	kN
0	0	0
1	28,8	4124,7584
2	29,868	4277,7852
3	59,124	7649,3412
4	59,943	7728,5323
5	60,338	7747,5038
6	60,338	7747,5039

Table 6. Result of y-direction pushover analysis after 24 years of service life

Step	Displacement	Base Shear
	mm	kN
0	0	0
1	28,8	2156,1931
2	47,42	3550,206
3	76,682	5515,2872
4	83,584	5876,5902

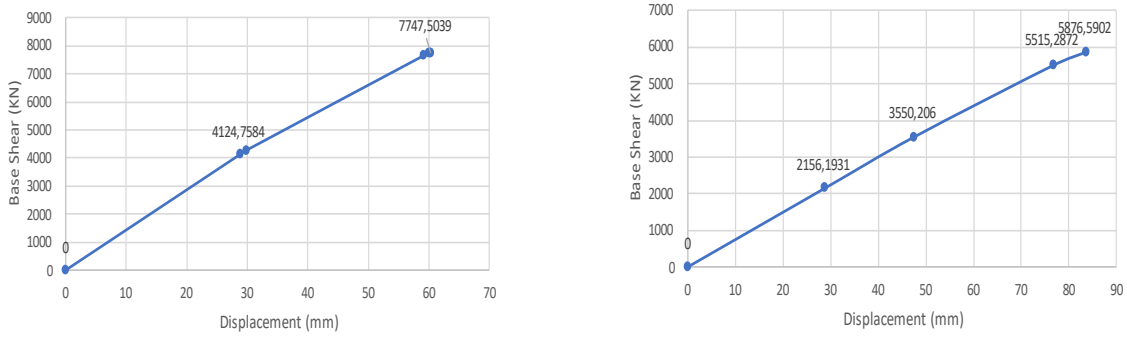
.**Table 7.** Building performance level

Step	Total Drift (%)	
	x-direction	y-direction
Initial planning	0,44	0,69
After 24 years service life	0,58	1,09



(a) (b)

Figure 4. Pushover curve based on the initial planning (a) x-direction, (b) y-direction



(a) (b)

Figure 5. Pushover curve after 24 years service life (a) x-direction, (b) y-direction

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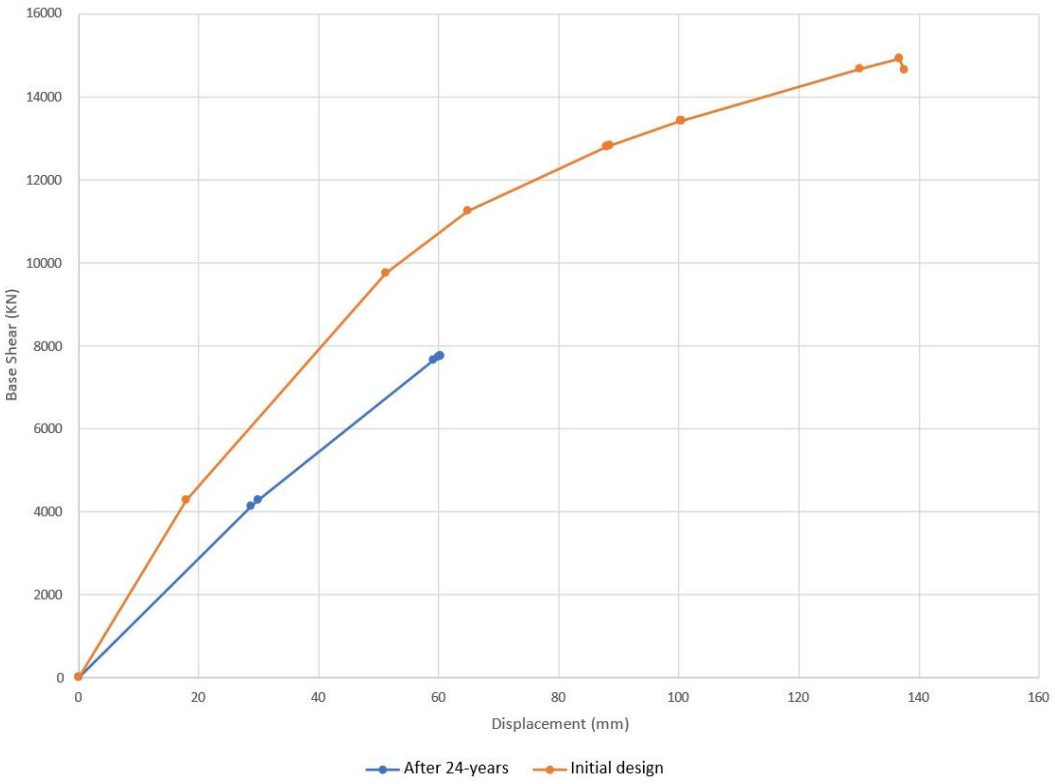

Figure 6. Comparison of the building capacity curve in the x-direction

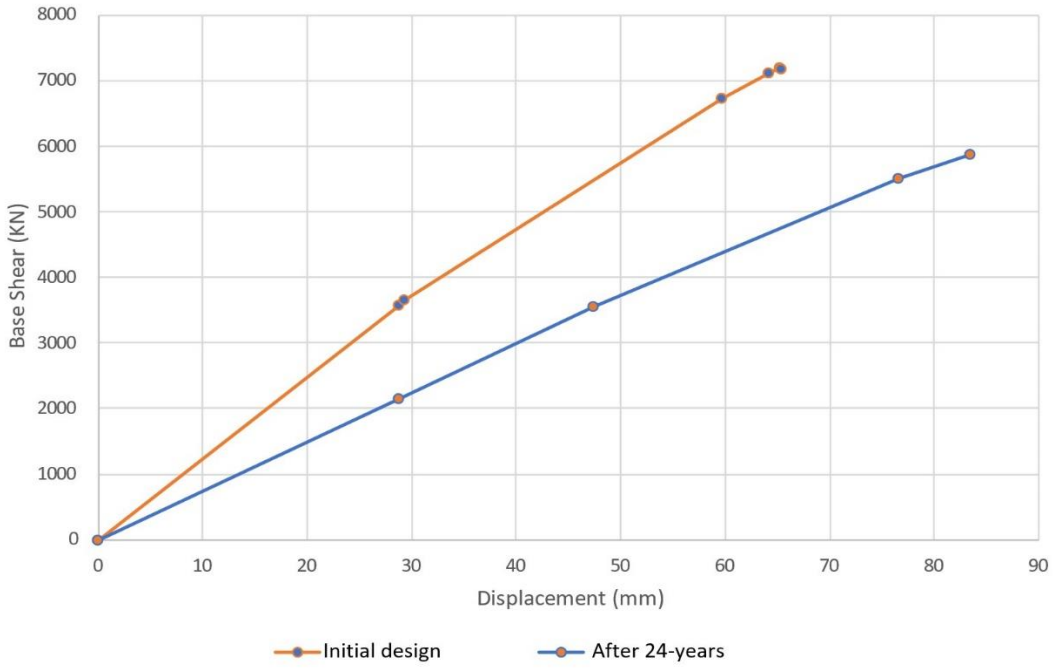

Figure 7. Comparison of the building capacity curve in the y-direction

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Discussion

The results of microtremor studies show that the natural frequency of buildings ranges from 0.38 Hz to 3.8 Hz on average. The natural period value of a building, according to SNI 1726 of 2019, is the building period value taken at the center of the building's mass. According to the results of microtremor measurements, the measurement on the 2nd level in the middle is the one closest to the building's center of mass. As a result, at that position, the average natural frequency of the building is 1.377 Hz. The needed value in pushover analysis is the natural period value of the building. As a result, the resulting frequency value is transformed into a period value until the building's natural period value reaches 0.73 s. The pushover analysis in the x direction at the start of the plan yielded the maximum base shear value at step 12 with a magnitude of 14935.195 kN and displacement of 136.77 mm (Table 3).

In contrast, the study findings achieved the maximum base shear value in the 6th step with a magnitude of 7747.5039 kN and a displacement of 60.338 mm after a service duration of 24 years (Table 5). Furthermore, the pushover analysis findings in the y direction obtained the greatest base shear value at step 7 with a magnitude of 7183.121 kN and a displacement of 65.372 mm at the start of the plan (Table 4). In contrast, the study findings yielded the greatest base shear value acquired at the fourth stage with a magnitude of 5876.5902 kN and a displacement of 20.221 mm after a service duration of 24 years (Table 6).

The building's performance level can be calculated using the findings of the pushover analysis. The x-direction inter-story drift for the building at the outset of planning was 0.44 percent, as shown in Table 7. Based on ASCE 41-17, this number is less than the stated threshold of 0.5 percent (see Table 1) and has an immediate occupancy (IO) service performance level, which means that the structure is safe to live in and retains the strength and rigidity of the design before to the earthquake. While the results for buildings with a service life of 24 years after the inter-story drift results in the x direction were 0.58 percent, it has a life safety (LS) service performance level that states that post-earthquake damage includes structural damage but retains limits to initial partial or total collapse based on ASCE 41-17.

At the outset of the planning process, the building's inter-story drift in the y direction was 0.69 percent. It has a level of service life safety (LS) performance based on ASCE 41-17, which implies that post-earthquake damage includes structural component damage but has a limit to the initial partial or entire collapse. While the results for buildings in service after 24 years of inter-story drift results in the y direction were 1.09 percent, it has a life safety (LS) service performance level, which states that post-earthquake damage includes structural damage but retains limits to initial partial or total collapse.

A pushover curve in the x direction is produced by comparing the pushover analysis of the Administration Building of the Faculty of Engineering, Universitas Syiah Kuala, according to the initial plan and after a service time of 24 years, as shown in Figure 6. The graph shows a decrease in the building's ability to absorb pushing loads, which the building could initially withstand up to a displacement of 137,509 mm. After 24 years of operation, the structure can only resist a displacement of 83,584 mm. So, during the course of 24 years, the building's capacity to absorb displacement owing to thrust loads in the x direction has dropped by 53.925 mm or 5.4 cm. On the same base shear, it can also be observed that the displacement of the building after a service life of 24 years is greater than the displacement of the building according to the initial plan. This is due to the concrete's decreasing rigidity over time.

A pushover curve in the y direction is produced by comparing the pushover analysis of the Administration Building of the Faculty of Engineering, Universitas Syiah Kuala, according to the initial plan and after a service time of 24 years, as shown in Figure 7. According to the initial plan, the graph shows that the building can tolerate a displacement of 65.382 mm after 24 years, and the construction can withstand a displacement of 83.584 mm after 24 years. On the same base shear, it can also be observed that the displacement of the building after a service life of 24 years is greater than the displacement of the building according to the initial plan. This is due to the concrete's decreasing rigidity over time.

Conclusions

The following conclusions can be drawn based on the results of examining the performance of the administrative building structure of Universitas Syiah Kuala's Faculty of Engineering against earthquake load. The structural performance level in the initial planning for the x direction is immediate occupancy (IO), while life safety is included for the y direction. Meanwhile, the structure's performance level after a service life of 24 years for the x and y directions is included in life safety (LS). The x-direction pushover analysis results suggest

that the building's ability to withstand thrust loads has decreased. The building could tolerate a displacement of up to 137.509 mm during the initial planning stage, but after 24 years of operation, it could only endure a displacement of roughly 83.584 mm. So, after 24 years, the building's capacity to withstand displacement due to thrust loads in the x direction has diminished by 53.925 mm. At the early planning stage, the results of the pushover study in the y direction, the building's ability to bear thrust loads. After a 24-year service life, the building could tolerate displacements of up to 83.584 mm. Based on the base shear, the displacement of the building after 24 years of operation is more than the displacement during the planning stage. Prolonged displacements are caused by a deterioration in the structure's rigidity over time.

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