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EVALUATION OF SEISMIC PERFORMANCE OF HOSPITAL BUILDING USING PUSHOVER ANALYSIS BASED ON ATC-40

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Abstract — Hospitals are crucial healthcare facilities that play a significant role in improving the health level of people in Aceh. The Cut Nyak Dien Meulaboh Aceh Regional Referral Hospital is located in an area with a high earthquake intensity, making earthquake-resistant building aspects indispensable. The hospital was designed in 2016, but changes were made to its structural elements during construction. The aim of this study was to establish the performance level criteria for the hospital building structures that underwent design changes in practice. The research revealed that the structure could exhibit nonlinear behaviour, as shown by the distribution of plastic hinges that started with the yielding of the beam, followed by yielding of the column. This aligns with the planning concept of strong weak beam earthquake-resistant column (SCWB). The pushover analysis results demonstrated that the performance point displacement in the x-direction was 0.052 m with a base shear of 20090.204 KN and the displacement in the y-direction was 0.058 m with a base shear of 19832.572 KN. With a maximum story drift value based on ATC-40 during an earthquake in the x and y directions of D > 0.01, the structure falls under the category of Immediate Occupancy.

Keywords: Hospital, nonlinear, performance point, plastic joint, pushover analysis

1.0 INTRODUCTION

Earthquake-resistant building design is very important for buildings located in areas with high earthquake intensity such as Indonesia. In Indonesia, buildings located in earthquake-prone areas are required to comply with applicable national standards. [1] According to SNI 1726-2019 regulations, all buildings must be designed with an earthquake-resistant concept to enhance the safety of building users.

Shear walls are useful to increase the stiffness and strength of building structures. They are very stiff and are able to reduce drift. They are also cheaper to construct. Therefore, it can be said that shear walls are cost-effective ways to reduce deformation. [2][3]

Planning for earthquake-resistant building structures is necessary to ensure the safety of occupants, minimise damage to building structures and avoid casualties in an earthquake. An earthquake-resistant building structure must have sufficient strength, rigidity, and stability to prevent the building from collapsing. [4] Nonlinear dynamic analysis is a theoretically the correct approach for this purpose. [5][6]

The study provided a single degree of freedom (SDOF) system response in pushover analysis. [7][8] Performance Based Seismic Design (PBSD) is a design concept that aims to predict the performance of a building in the event of an earthquake. In this case, it is possible for the structure to reach a gradual failure limit, so that the correlation between structural performance and structural damage can be identified. The pattern of accumulation of damage to the structure as a whole is expected to occur long before the failure of structure. [9] In practice, performance-based structural analysis is highly appropriate for earthquake loading in real cases. [10] It is highly recommended for structural analysis [11] because of the ease of doing the analysis [12].

The pushover analysis method is a part of PBSD. It is a design concept that offers to evaluate the performance of building structures when an earthquake occurs so that the capacity of a structural element can be evaluated against the risk of building damage. [13]

Pushover analysis is a static analysis procedure that uses a simplified nonlinear analysis approach to estimate inelastic deformation in structural systems, in which the effect of earthquake loads is represented in the form of monotonic lateral loads, gradually applied until a certain inelastic deformation target is reached. [9] This analysis procedure aims to determine the inelastic deformation of the structural components, the effect of force distribution on each increase in the lateral load, the collapse of the structure as well as the expected lateral displacement targets. The current study used the ATC 40 version in its pushover analysis.

2.0 METHODS

2.1 Conceptual Research Process

In Figure 1. shows the process of research.

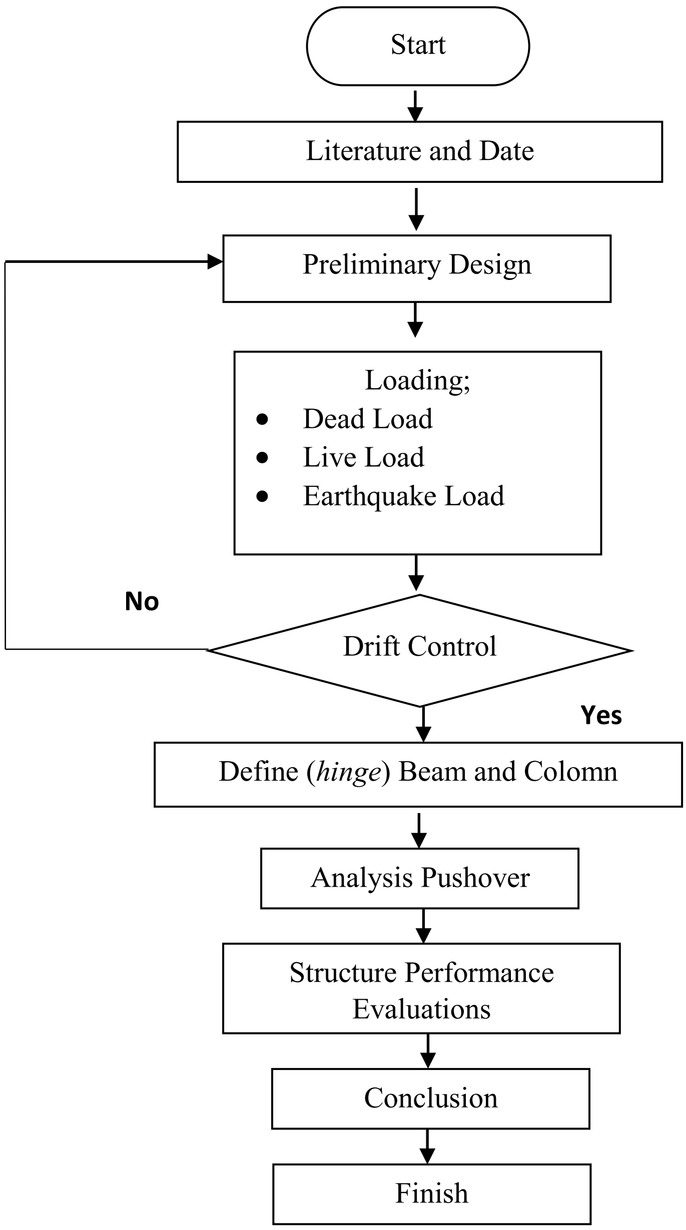

Figure 1 Flow chart

2.2 Research Types and Concepts

This study evaluated the resilience of earthquake-resistant buildings in accordance with SNI 1726-2019 for the 3-floor Cut Nyak Dhien Meulaboh Hospital Building located in Aceh, to determine the yield behavior of plastic joints. The level of structural performance was re-evaluated using the pushover method based on ATC-40.

2.3 Building Load

In structural analysis using the ETABS software, various types of loads can be incorporated into the model, including dead loads, additional dead loads, live loads, seismic loads (linear static), and seismic loads (nonlinear static) pushover. Seismic loads can be applied using the equivalent static earthquake method based on SNI 1726-2019 and SNI 1727-2020.

Based on ATC-40, the structural capacity of a building after an earthquake is categorized into four post-earthquake categories: Immediate Occupation (IO), Damage Control (DC), Life Safety (LS), and Structural Stability (SS). The selection of the post-earthquake category depends on the building's condition and the severity of damage.

To calculate the structural capacity of a building, the force-deformation behaviour of plastic hinges needs to be considered. These plastic hinges are labeled as A, B, C, D, and E in Figure 2. The behaviour of plastic hinges is crucial in determining the building's overall performance and its ability to withstand seismic loads.

ATC-40 provides guidelines for assessing a building's post-earthquake condition, determining the post-earthquake category, and evaluating the structural capacity based on the behaviour of plastic hinges. The assessment includes a visual inspection of the building's structural elements, such as beams, columns, and walls, to identify damages that may affect the building's overall performance.

After the assessment, the analysed building is classified into one of the four post-earthquake categories based on its structural condition. The LS category is the minimum level of performance required for occupied buildings, while the SS category represents the highest level of performance required for critical structures, such as hospitals and emergency response centers.

The structural capacity of the analysed building is then evaluated based on the plastic hinge behaviour and the post-earthquake category. The evaluation considers various factors, such as the expected seismic demand, the available ductility capacity, and the overall performance of the building under seismic loads. Based on this evaluation, recommendations are made for retrofitting or repairing the building to improve its seismic performance and ensure the safety of occupants.

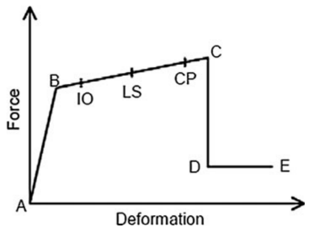

Figure 2 Force-deformation relationship of typical plastic hinge

2.4 Combination Loading

The study used live load, dead load, and seismic load (linear static).

1. U = 1.4 D
2. U = 1.2 D + 1.6 L
3. U = 1.2 D ± 1.0 E + 0.5 L
4. U = 0.9 D ± 1.0 E

3.0 RESEARCH METHODS

3.1 Building Data and Structure

Below is data from the structure of the analysed building.

f_c'	=	21 MPa
f_y	=	400 MPa
Beam dimension	=	40x70 cm, 25x40 cm, 30x50 cm, 20x40 cm.
Coloum dimension	=	50x50 cm, 60x60 cm.
Shearwall thickness	=	25 cm
Structure Type	=	Special Moment Resisting Frame (SMRF)
Building function	=	Hospital

The following buildings are analysed in Figure 3.

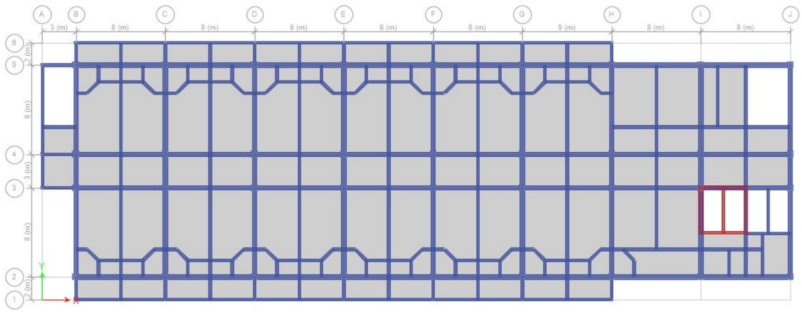

Figure 3 Top View the Building

Table 1 depicts the displacement values for the x and y directions. Different displacement responses were found in both directions. The highest displacement values were 17.00 mm in the x direction and 21.00 mm in the y direction.

Table 1 Displacement in the x-x and y-y direction

Story	H(mm)	δex	δey
i	ii	iii	iv
3	4500	17,00	21,00
2	5000	13,00	15,00
1	3500	4,00	5,00

3.2 Drift Analysis

The results of calculating the displacement between floors based on SNI 1729: 2019 indicate that, in the design of earthquake-resistant buildings, it is essential to have control over the performance of structural boundaries in the analysed building. The control of drift between floors covers both x and y directions.

$$\delta_S = \frac{C_d \, x \, \delta_{se}}{I} \tag{1}$$

Where :

δ_{se} =displacement on the x^{th} floor

C_d =magnification factor per

I =priority factor

Δ =Displacement

$\Delta_1 = \delta_{S2} - \delta_{S1}$

$\Delta_a = 0.010h_x$

The drift analysis shows that all floors met the permitted acceptance criteria. The largest displacement between floors was 22.00 mm which did not exceed the required threshold value of 34.64 mm. The results can be seen in Table 2.

Table 2 Control Drift Analysis Earthquake Loads in the x-y directions

`	h	Displacement		Elastic Drift		Elastic Drift		Drift Limit	Cek
		δe x	δe y	δe x	δe y	Δ_x	Δ_x		
3	4500	17,00	21,00	4,00	6,00	14,67	22,00	34,62	Ok
2	5000	13,00	15,00	9,00	10,00	33,00	36,67	38,46	Ok
1	3500	4,00	5,00	4,00	5,00	14,67	18,33	26,92	Ok

4.0 RESEARCH RESULTS AND DISCUSSION

In line with the pushover analysis, the modelled structure was pushed to its ultimate limit. A thrust load pattern of 9 steps in the x-x direction and 11 steps in the y-y direction was applied to the structure until the structure experienced a yield limit and started to exhibit inelastic deformation. It can be seen that the failure in the x-x direction started from steps 3 to 9 with the CP position and for the y-y direction started from steps 2 to 11 with the CP position. Figure 4 shows that graph of capacity curve.

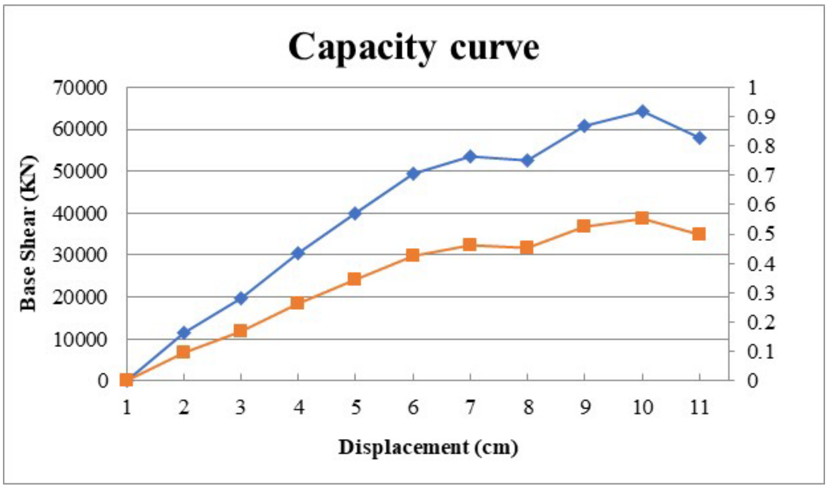

Figure 4 Capacity curve in x and y directions

Table 3 Monitored displacement x-x

Step.	Displ.	Base Force	(A-B)	(B-C)	(C-D)	(>E)	(A-IO)	(IO-LS)	(LS-CP)	(>CP)	Total
	mm	kN									
0	0,0	0,0	3636	0	0	0	3636	0	0	0	3636
1	-23,6	11435,0	3636	0	0	0	3636	0	0	0	3636
2	-40,7	19736,3	3634	2	0	0	3636	0	0	0	3636
3	-65,3	30303,1	3532	104	0	0	3632	0	0	4	3636
4	-90,6	39940,4	3506	130	0	0	3626	2	2	6	3636
5	-116,1	49372,1	3372	262	2	0	3604	24	0	8	3636
6	-127,9	53471,1	3312	322	2	0	3558	68	2	8	3636
7	-127,9	52624,0	3312	322	0	2	3558	68	2	8	3636
8	-152,8	60874,2	3186	448	0	2	3528	88	8	12	3636
9	-163,8	64247,1	3156	478	0	2	3520	88	16	12	3636

Table 4 Monitored displacement y-y

Step.	Displ.	Base Force	(A-B)	(B-C)	(C-D)	(>E)	(A-IO)	(IO-LS)	Total
	mm	kN							
0	0,0	0,0	3636	0	3636	0	0	0	3636
1	-23,6	4794,8	3636	0	3636	0	0	0	3636
2	-37,1	7537,0	3634	2	3636	0	0	0	3636
3	-62,1	12310,3	3586	50	3634	0	0	2	3636
4	-87,0	15639,7	3500	136	3630	0	0	6	3636
5	-105,3	17348,5	3454	182	3626	2	0	8	3636
6	-105,3	17347,8	3452	184	3626	2	0	8	3636
7	-105,5	17369,2	3450	186	3626	0	2	8	3636
8	-105,5	17368,5	3450	186	3626	0	2	8	3636
9	-105,6	17376,2	3448	188	3626	0	2	8	3636
10	-105,6	17377,1	3448	188	3626	0	2	8	3636
11	-105,7	17388,4	3448	188	3626	0	2	8	3636

The results of the analysis showed that there were displacements in the x-x direction of 163.8 mm and in the y-y direction of 105.7 mm. The calculation to determine the performance level of the structure based on ATC-40 is as shown in Table 5.

Table 5 Results of Structure Performance Level according to ATC-40

Direction	Parameter	Result ATC-40
Arah x-x	Displacement. Δ (mm)	163,8190
	Drift Actual (Δ/ T tot)	0,0126
	Performance level	Immediate Occupancy (IO)
Arah y-y	Displacement. Δ (mm)	105,7410
	Drift Actual (Δ/ T tot)	0,0081
	Performance level	Immediate Occupancy (IO)

According to the ATC-40 rules, the performance level of the structure in the x-x and y-y directions in in the Immediate Occupancy (IO) category, where the possible damages caused by earthquakes are limited to non-structural elements and the risk of structural failure and loss of life is low. The building is easy to repair because the stiffness of the building is the same prior to the earthquake.

5.0 PLASTIC JOINT MECHANISM

The plastic hinges formed from the results of pushover analysis in the x-x and y-y directions showed different yield patterns. The distribution scheme of plastic hinges can be seen in Figures 5 and 6 which show that the structure behaved according to the concept of earthquake-resistant buildings, namely strong columns – weak beams.

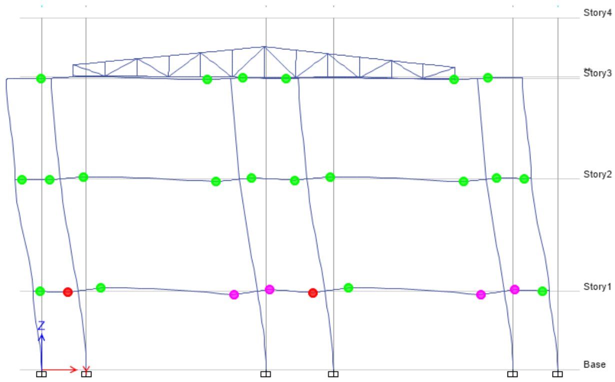

Figure 5 Plastic hinge yield in the x-x direction

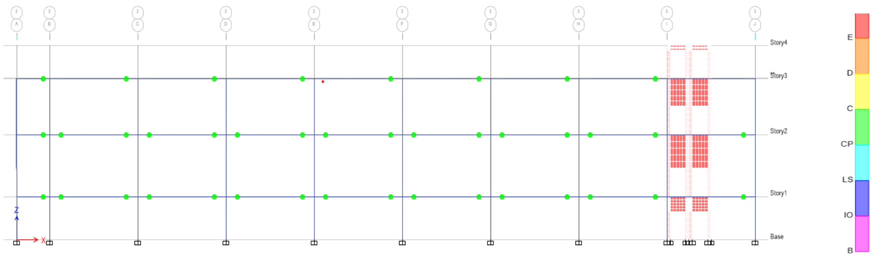

Figure 6 Plastic hinge yield in the y-y direction

Figures 5 and 6 show that yielding occured from steps 4 to 9 in the x-x direction and from steps 5 to 11 in the y-y direction, where several beams entered the IO - CP category.

6.0 CONCLUSION

The study concluded that the hospital building meets the floor displacement requirements allowed according to SNI 1726: 2019 where Δ x-x = 14.67 mm and Δ y-y = 22.00 mm have not exceeded the displacement threshold of a = 34.62mm. The results of the pushover analysis showed that the plastic hinge yield mechanism met the requirements of earthquake-resistant buildings where melting started in the beam and was followed by the column, fulfilling the weak beam – strong column principle. The results of the analysis of the ATC-40 version showed that the structural performance were at the level of 0.0126 in the x direction and 0.0081 in the y direction. It means that the building is in the Immediate Occupancy (IO) category, where earthquake damages are limited to non-structural elements and the risk of structural failure and loss of life is low. The building is also easy to repair because the stiffness of the building is the same prior to the earthquake. Overall, these findings showed that the building is highly safe.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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