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Calculation Of Earthquake Resistant Structure Of Medical Center Building Rumah Sakit Umum Daerah (RSUD) Soedarso Pontianak Using Pushover Analysis

*Tansetiadi Sutiono[1], Gatot Setya Budi[1], and Herwani[1]

[1]Department of Civil Engineering, University of Tanjungpura, Pontianak
*tansetiadi16@student.untan.ac.id

Abstract

Hospitals are essential in providing health services and must withstand the forces that may occur, even due to an earthquake. RSUD Soedarso is a hospital in Pontianak City that has been around for a long time. However, because it is already quite old, various problems must be addressed. The step taken by the government is to build a new building, namely the Medical Centre and Inpatient Building.

The purpose of writing this final project is to evaluate the performance of the earthquake-resistant structure of the Soedarso Hospital Medical Centre building using the pushover analysis method. This method analyses the inelastic behaviour of the system due to the earthquake, where the result is a curve of the relationship between the shear force and the displacement of the roof that occurs. The guidelines for pushover rules used are based on the provisions of ATC-40 and FEMA 356. Further research was carried out on the dilation between the Medical Centre Building and the IRNA Building.

The results are that both buildings are still in elastic condition when the performance point is reached. Based on ATC-40 and FEMA 356, the building is classified as in the Immediate Occupancy (IO) performance level, regarding drift ratio and from plastic hinges that occur in column and beam elements. Then the dilatation that arises due to pushover is smaller than the design dilation of 150 mm. Both buildings are protected from potential collisions, which is a relief.

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1. Introduction

Indonesia is geographically located in a potentially earthquake-prone area. Based on earthquake studies by the National Centre for Earthquake Studies (PUSGEN), Pontianak is one of the new earthquake zones in SNI (Rahmanto et al., 2023), therefore when planning buildings, including in Pontianak, it is essential to build a system that can withstand earthquakes, so that earthquake force parameters must be taken into account so that precautions can be taken to prevent significant losses.

The hospital building is one of the buildings that must resist earthquakes (Hooda & Goyal, 2021). Thus, important considering that hospitals are only allowed to experience minor damage, must not reach collapse, and must remain safely standing so that the function of health services can run as it should.

Rumah Sakit Umum Daerah (RSUD Soedarso is a hospital that located in Pontianak City, West Kalimantan Province. In order to improve health services, the government built a Medical Center building and an Inpatient building. Both buildings have 6 floors with a total height of 26,075 m and have dilatations in the walkways. The buildings were designed based on Indonesian National Standard (SNI) 1726 – 2012 about Procedures for Planning Earthquake Resistance for Building and Non-Building Structures.

Because of the importance of hospital structure, the author will analyse the earthquake resistance of the Medical Centre and Inpatient buildings. One of the analyses that can be used is the Nonlinear Pushover analysis with the Performance-Based Earthquake Engineering (PBEE) concept (Budi, 2011; Bianchi et al., 2019). Pushover analysis is an analytical procedure that utilizes a static thrust load which is enlarged gradually until the target displacement of the structure is reached or the system begins to show a pattern of critical failure—then followed by an evaluation of the performance of the design so that the conditions and resistance to earthquakes that may occur can be identified (Mahlisani, 2017; Handana & Karolina, 2018; Zebua & Kuspiadi, 2022).

The goals of this study are: (1) to generate pushover curves of the building structure; (2) to analyze the performance level when the performance point is reached; (3) to analyse the yield scheme (plastic hinge distribution) that occurs due to the influence of earthquake loads; (4) to analysing the collisions that might occur in the dilatation of both buildings.

2. Materials and Methods

2.1 Theoretical Frame Work

According to SNI 1726-2012, hospital buildings are classified as buildings with risk category IV and must have a strength of 1.5 times compared to buildings in general. Earthquake analysis was carried out based on SNI 1726 – 2012 to analyse the structure of the Soedarso building according to the conditions that have been built. The suitability referred to is the type of Seismic Design Category, Earthquake Force Resisting System, and other parameters. This is to avoid differences in the dimensions of the structural elements. In addition, it will also affect the value of the load and deformation that occurs, thus allowing the difference in determining the performance of the building.

The structure is reinforced concrete with an Ordinary Moment-Bearing Frame System built on soft soil (Gazetas, 2015). This study is limited to analysing only the upper construction of the building and not analysing the performance of stairs and lifts after experiencing an earthquake. The structural analysis is carried out with the help of SAP 2000, a software program integrated with pushover regulations. The expected result of this analysis is that the relationship between the shear force and displacement that occur is still at the performance level of Immediate Occupancy. At this level, the building can still function safely after the earthquake.

2.2 Research Location

The research objects are the Medical Centre Building and Inpatient Building of Rumah Sakit Umum Daerah (RSUD) Soedarso, Kota Pontianak.

2.3 Data

The data used for the calculation of this study are (a) reinforced concrete structure with six levels and a total height of 26,075 m; (b) medical centre building with a length of 59,5, a width of 27,5 m, 1st-floor height is 3,675 m, 2nd and 6th-floor height is 4,9 m, and 3rd - 5th-floor height is 4,2 m; (c) inpatient building with a length of 52 m, width of 18 m, 1st-floor height is 4,375 m, 2nd - 5th-floor height are 4,2 m, and 6th-floor height are 4,9 m; (d) material specifications: concrete quality (fc') of 25 MPa; (e) reinforcement steel quality (fy) of 390 MPa. In detail, the dimensions of the structure element and the building plans are shown in Table 1.

Table 1. Dimensions of Structure Element

Structure Element	Explanation
Beam	B1 (300×700), B2 (250×600), B2 (250×600)A, B3 (200×400), B4 (150×300), B5 (300×1400), B6 (300×820)
Column	K1 (600×600), K2 (550×550), K3 (400×400), K4 (650×650), KK (425×425), KP (200×200)
Plate	Thick = 120 mm

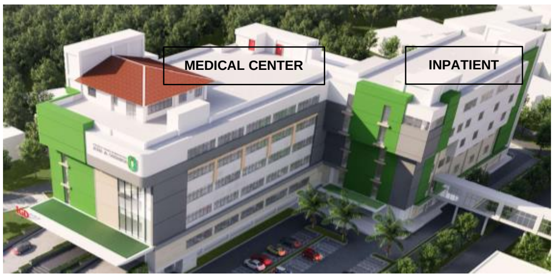

Fig. 1 3D Design

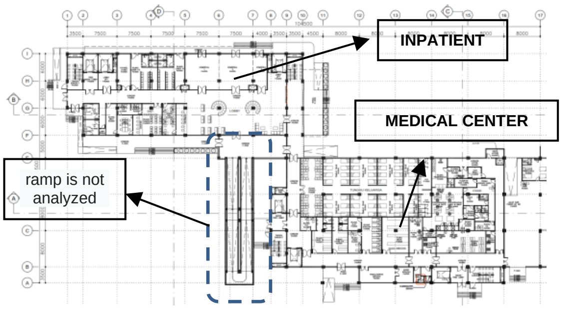

Fig. 2 1st Floor Plan

Fig. 3 2nd Floor Plan

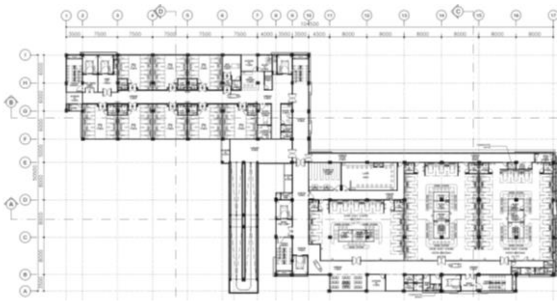

Fig. 4 3th Floor Plan

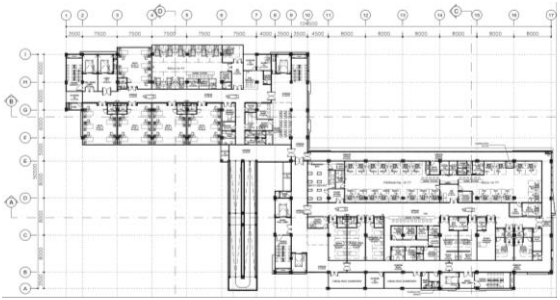

Fig. 5 4th Floor Plan

Fig. 6 5th Floor Plan

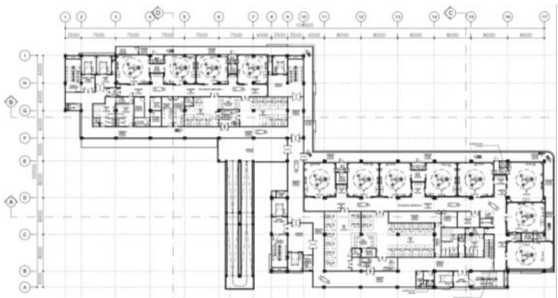

Fig. 7 6th Floor Plan

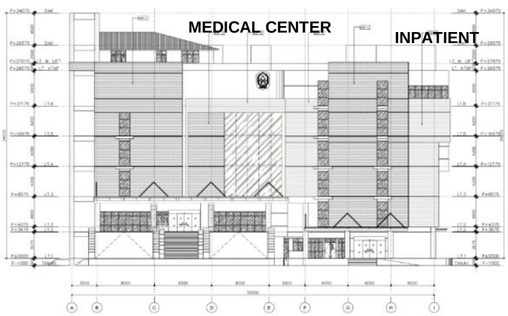

Fig. 8 Front View

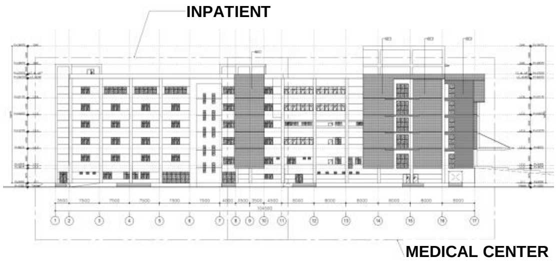

Fig. 9 Left Side View

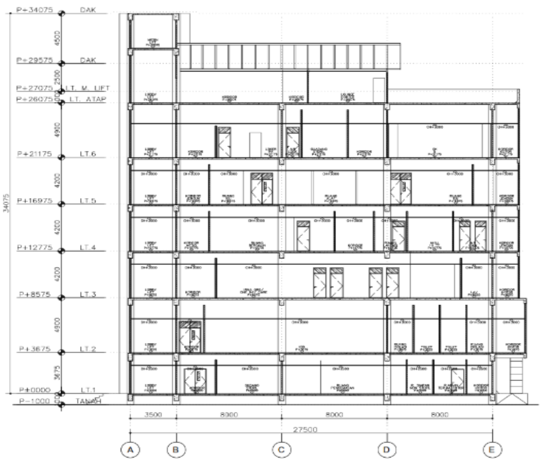

Fig. 10 Cross Section of Medical Centre

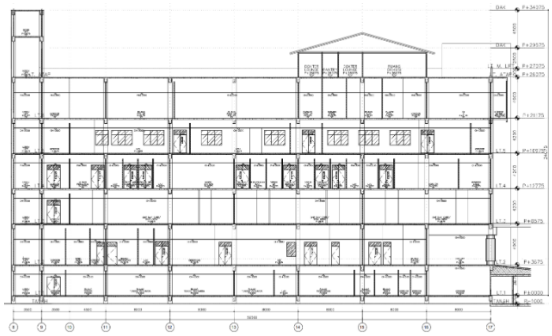

Fig. 11 Long Section of Medical Centre

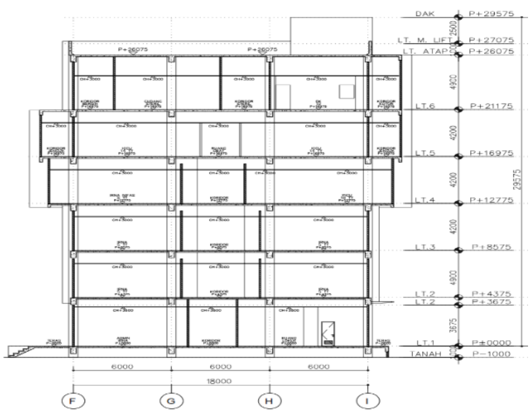

Fig. 12 Cross Section of Inpatient

Fig. 13 Long Section of Inpatient

2.4 Analysis Method

This study starts by collecting data from related parties, such as building planning data, dimensions, quality, loading, and other data, and then modelling the structure in the SAP 2000 application according to the existing data. Gravity loads, both dead and live loads, are included in the building model. Loading analysis is carried out to determine the value of the structure's seismic weight.

Then proceed with lateral loading in the form of static earthquake loads obtained by multiplying the seismic coefficient and the structure's weight. Static earthquakes are applied in 2 directions, the x and y directions which work on the centre of mass of each floor. The x and y earthquakes were analysed separately for their effects on buildings. This static earthquake force will be used later for modelling pushover earthquakes.

Spectral response is also used by the spectral acceleration values determined from SNI 1726-2012. The spectral acceleration value is obtained from a spectra design application developed by the Indonesian government called RSA Puskim 2010. From this application, it can be seen the spectral value and period for the location being analysed.

After that, the study continued with the nonlinear stages, where the load used is nonlinear. First, the structure is loaded by the planned gravity load, then continued with the application of lateral static loads gradually to achieve a specific displacement target. The control point used is the centre of mass on the top floor of the building. The target is expected not to surpass the Life Safety (LS) condition, which has a maximum displacement of 0,02 of the total building height.

Before running the pushover analysis, it is necessary to define the hinge properties and determine the location of the plastic hinges in the building structure. The purpose is to find out the shape of the structure's inability to withstand pushover forces. Running the pushover analysis on SAP 2000, then evaluating the result to get the building performance. Check whether the performance of the building is satisfactory (in Immediate Occupancy condition) or not with a drift ratio of 1%.

The SAP 2000 can help evaluate the collapse schematic of buildings by looking at structural elements that experience plastic hinges. In the last step, the dilatation between the two buildings can be analysed by checking the distance.

In summary, the analysis method can be seen in the following flowchart:

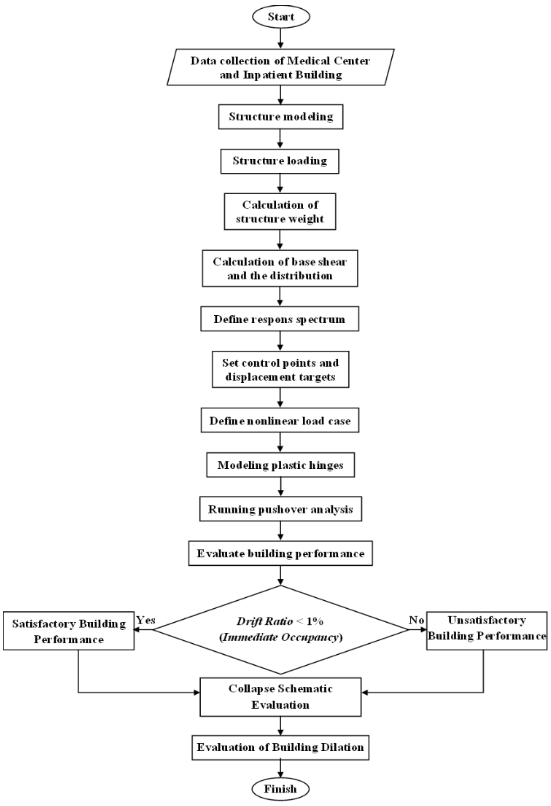

Fig. 14 Flowchart of The Study

3. Result and Discussion

3.1 Calculation of Gravity Load

The gravity load used to determine the seismic weight of the building is the dead load due to the structure itself, and the additional dead load is the superimposed dead load.

Table 2. Seismic Weight of the Medical Centre Building

Floor	Dead Load (kN)	Super Imposed Dead Load (kN)	Total Load (kN)
Rooftop	14.306,70	4.891,86	19.198,56
6th Floor	11.006,64	9.192,12	20.198,76
5th Floor	10.782,99	7.477,02	18.260,01
4th Floor	10.843,75	8.786,10	19.629,85
3rd Floor	10.912,50	7.163,13	18.075,63
2nd Floor	10.661,12	8.965,06	19.626,18
Total Building Weight			114.988,99

Table 3. Seismic Weight of the Inpatient Building

Floor	Dead Load (kN)	Super Imposed Dead Load (kN)	Total Load (kN)
Rooftop	9.554,15	2.176,66	11.730,81
6th Floor	7.525,50	6.440,53	13.966,03
5th Floor	7.437,67	5.727,13	13.164,81
4th Floor	7.057,95	5.242,94	12.300,89
3rd Floor	6.493,74	4.884,33	11.378,06
2nd Floor	6.624,43	4.814,87	11.439,29
Total Building Weight			73.979,89

3.2 Calculation of Lateral Load

The lateral load used is the static earthquake load and the earthquake response spectrum, which refers to SNI 1726-2012 and uses the following seismic parameters:

Table 4. Seismic Parameters

Parameter	Description
Risk Category	IV
Priority Factor (I_e)	1,5
Acceleration Spectral	Ss = 0,017 S1 = 0,022
Site Class	Soft soil (SE)
Site Class Coefficient	Fa = 2,5 Fv = 3,5
Response Spectral	SDs = 0,028 SD1 = 0,051
Lateral System	Regular Moment Resisting Frame System
Response Modification Coefficient (R)	3
System Overpower Factor (Ω_0)	3
Deflection Magnification Factor (C_d)	2,5
Structure Max Period	1,491
Seismic Response Coefficient (C_s)	0,0142

Base Shear

The base shear force (V) simplifies vibrations due to earthquakes at the base of a building.

- Base Shear of Medical Center Building

$Vx = Vy = Cs.\ W$

$= 0,0142.\ 114988,987$

= 1629,01 kN

- Base Shear of Inpatient Building

$V_x = V_y = C_s.\ W$

$= 0{,}0142.\ 73979{,}89$

$= 1048{,}05$ kN

The base shear force is then distributed to each level of the building to become a lateral static earthquake load Fx, which acts on the center of mass of the i^{th} floor.

$$F_x = C_{vx} V$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

Description:

C_{vx} = vertical distribution factor

V = base shear (kN)

w_i and w_x = part of total seismic weight of the building (kN)

h_i and h_x = height from the base to a certain level (m)

k = exponential of the structure period

Following are the results of the distribution of seismic force analysis on buildings:

Table 5. Seismic Force Distribution of the Medical Center Building

Floor	h_x (m)	h_x^k (m)	C_{vx}	F_x (kN)
Rooftop	26,075	131,179	0,35	570,37
6th Floor	21,175	96,089	0,27	439,57
5th Floor	16,975	69,039	0,18	285,51
4th Floor	12,775	45,132	0,12	200,64
3rd Floor	8,575	24,865	0,06	101,79
2nd Floor	3,675	7,003	0,02	31,13
	Total		1	1.629,01

Table 6. Seismic Force Distribution of the Inpatient Building

Floor	h_x (m)	h_x^k (m)	C_{vx}	F_x (kN)
Rooftop	26,075	131,179	0,33	340,89
6th Floor	21,175	96,089	0,28	297,29
5th Floor	16,975	69,039	0,19	201,34
4th Floor	12,775	45,132	0,12	122,98
3rd Floor	8,575	24,865	0,06	62,67
2nd Floor	3,675	7,003	0,02	22,33
	Total		1	1.629,01

Response Spectrum

Spectrum response needs to be used for pushover calculation purposes. The spectrum response value will be obtained by entering the location, soil type, and building coordinates on RSA Puskim. Soedarso is located in Pontianak City, built on soft soil, and has longitude coordinates 109.363336° and latitude coordinates -0.064306°. Thus the response spectrum will be obtained as below.

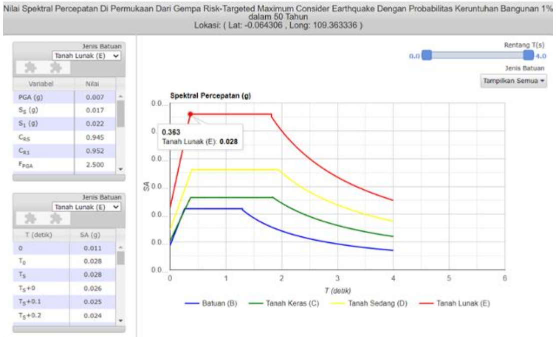

Fig. 15 Response Spectrum of Soedarso Building

3.3 Performance-Based Earthquake Engineering

Performance-based earthquake-resistant planning has been introduced in the development of earthquake-resistant building designs, namely Performance-Based Earthquake Engineering (PBEE), a combination of resistance and service aspects. The PBEE concept can be used to design new buildings (Performance-Based Seismic Design) or evaluate existing buildings (Performance-Based Seismic Evaluation).

This concept takes structural displacement as its approach. It emphasizes the performance of the structure (performance level) when an earthquake response occurs, where the structure may be damaged or even collapse. The story of structural performance can be determined by looking at the level of damage to the system when it is hit by an earthquake with a specific return period. Therefore the level of structural performance will always be related to the cost of repairs to the building.

Performance Evaluation with Nonlinear Pushover Static Analysis

Pushover analysis is a nonlinear static analysis that models the effect of the design earthquake as a static load at the center of mass of each story, the value of which is gradually increased until the structure experiences the first yielding (plastic hinge), which is then followed by sharing significant elastoplastic changes and reaching a condition collapse threshold. This procedure will describe the elements that experience yielding and inelastic deformation along with the addition of the modeled load. The result of this analysis is the values of the shear force (base shear), which will be used to describe the shape of the lateral displacement of the load (demand) given.

Plastic Hinge

A plastic hinge is a form of the inability of structural elements (beams and columns) to withstand internal forces. Pin modeling defines non-linear force-displacement behavior or rotational moments that can be located at several different places along a span of a beam or column. The joint model is rigid and does not affect the linear behavior of the members. Joints are assumed to be located at each end of the beam and column elements.

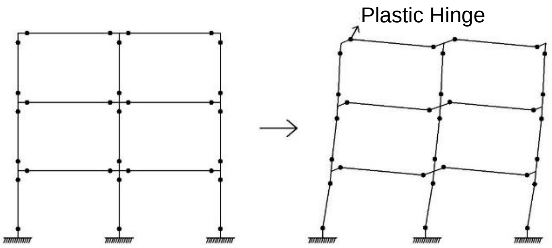

Fig. 16 Plastic Hinge in Beams and Columns

Several commonly used performance-based evaluation rules exist, namely ATC-40 and FEMA 356.

a. Capacity Spectrum Method (ATC-40)

In the ATC-40 method, structural performance is determined by the capacity spectrum method. The capacity spectrum method plots the demand response spectrum and capacity curve in a format between acceleration spectral vs displacement spectral, or called the Acceleration-Displacement Response Spectra (ADRS) format. The capacity curve is obtained from the pushover analysis results, where this curve displays the relationship between the base shear force "V" and the roof displacement "Δroof." The capacity curve describes the strength of the structure, which depends on the deformation capacity of each structural component.

The ADRS graph has an intersection point between the capacity and demand spectrum, referred to as the performance point. Information obtained from the performance point is about the building period and effective damping due to changes in structural stiffness after plastic hinges occur.

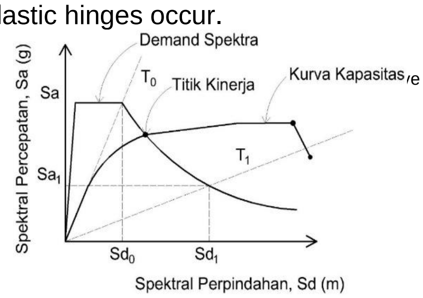

Fig. 17 Structural Performance Point based on ATC-40

At the performance point, the lateral deformation must be checked against the deformation limit at various performance levels.

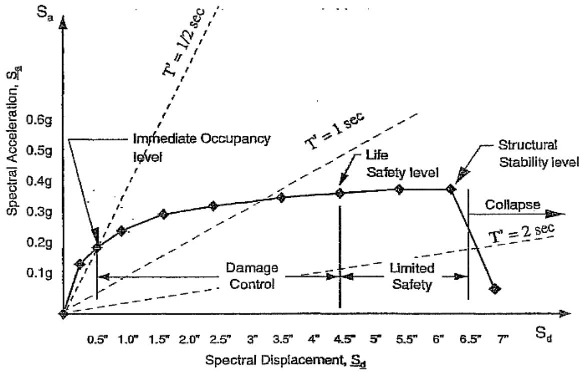

Fig. 18 Performance Criteria Based on ATC-40

Table 7. Performance Criteria Based on ATC-40

Performance Level	Explanation
Immediate Occupancy (IO)	The building is safe during an earthquake, the risk of loss of life and structural failure is insignificant, the building is not significantly damaged, and can be used again immediately.
Damage Control (DO)	It is a transition between Immediate Occupancy and Life Safety. The building is still able to withstand the earthquake that occurred, the risk of human casualties is very small.
Life Safety (LS)	Buildings are damaged but are not allowed to collapse causing human casualties (the risk of fatalities is very low). After an earthquake occurs, the building can function again after repairs to structural and non-structural components.
Structural Stability (SS)	Post-earthquake structures were damaged to the point of total or partial collapse. Gravity load bearing structural components are still working even though the overall stability is on the verge of collapse.

Table 8. Drift Limitation on Structure Performance Level (ATC-40)

Drift Limits Between Floors	*Immediate Occupancy*	*Damage Control*	*Life Safety*	*Structural Stability*
Maximum Total Drift	0,01	0,01-0,02	0,02	0,33 Vi/Pi
Maximum Nonelastic Drift	0,005	0,005-0,015	No Limit	No Limit

b. Displacement Coefficient Method (FEMA 356)

The FEMA 356 displacement coefficient method is an approximation method that provides a direct numerical calculation of the maximum global displacement of a structure. The solution is carried out by modifying the elastic response of the Single Degree of Freedom (SDOF) system equivalent to the coefficient factors Co, C1, C2, and C3 so that the maximum global displacement (elastic and inelastic) is obtained which is called the displacement target (δT).

Based on FEMA 356, the performance of building structures during an earthquake is divided into several categories.

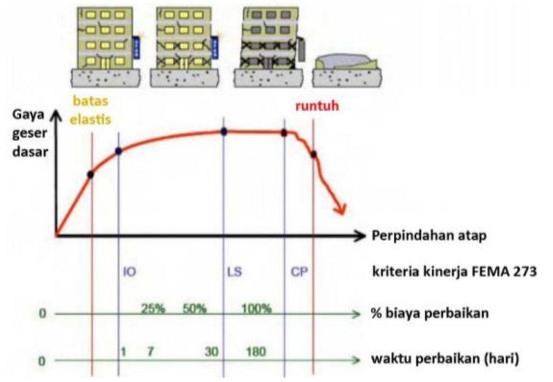

Fig. 19 Performance Criteria Based on FEMA 356

Table 9. Performance Criteria Based on FEMA 356

Performance Level	Explanation
Operational	The building has no significant damage to structural or non-structural components. Specifically, no permanent displacement of the building characterizes this, most structures can maintain their strength and rigidity with few cracks, and all critical systems in the building can operate normally.
Immediate Ocupancy (IO)	The building has no significant damage to the structural components. The strength and stiffness of the building are still almost the same as before the earthquake hit the structure. Non-structural components, equipment and building contents are generally safe, but operationally they cannot work due to mechanical failure or lack of utilities.
Life Safety (LS)	In this category, it means that the post-earthquake building experienced some damage to the structural components and reduced strength and stiffness. The structure still has enough strength to carry the loads that occur on the verge of collapse. Non-structural components are still there but cannot function and can be reused if repairs have been carried out.
Collapse Prevention (CP)	The condition which is the limit of the ability of the structure where the structural and non-structural have suffered severe damage, but the structure remains standing and almost collapses, the structure is no longer able to withstand lateral forces.

Table 10. Drift Limitation on Structural Performance Level (FEMA 356)

Structural Performance Level	Drift (%)	Description
Immediate Occupancy	1	Transient
Life Safety	2	Life Safety
	1	Transient
Collapse Prevention	4	Transient/ Permanent

3.4 Pushover Analysis Results of The Medical Center Building

a. Performance Evaluation with ATC-40

Drift Ratio of Push X

In the X direction capacity spectrum curve, the performance point value is obtained under shear force conditions 3407,543 kN with a displacement of 50,187 mm.

- Maximum total drift

$$= \frac{Dt}{Htotal} = \frac{50{,}187}{26075} = 0{,}00192 < 0{,}01$$

then included in **Immediate Occupancy**

- Maximum in-elastic drift

$$= \frac{Dt - D1}{Htotal} = \frac{50{,}187 - 47{,}539}{26075} = 0{,}0001 < 0{,}005$$

then included in **Immediate Occupancy**

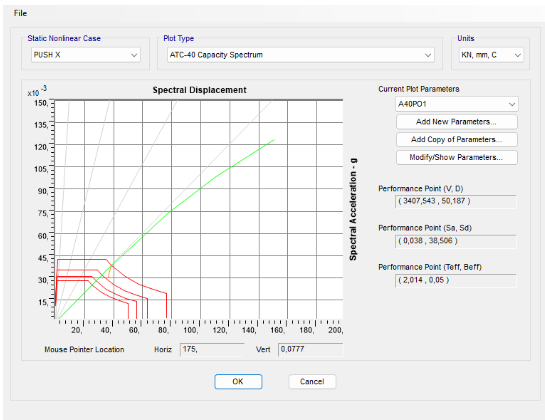

Fig. 20 Performance Point of Medical Center Building in X Direction (ATC-40)

Drift Ratio of Push Y

The performance point value is obtained under shear force conditions around 2749,650 kN in the Y direction capacity spectrum curve with 57,575 mm of displacement.

- Maximum total drift

$$= \frac{Dt}{Htotal} = \frac{57{,}575}{26075} = 0{,}00221 < 0{,}01$$

then included in **Immediate Occupancy**

- Maximum in-elastic drift

$$= \frac{Dt - D1}{Htotal} = \frac{57{,}575 - 42{,}877}{26075} = 0{,}0006 < 0{,}005$$

then included in **Immediate Occupancy**

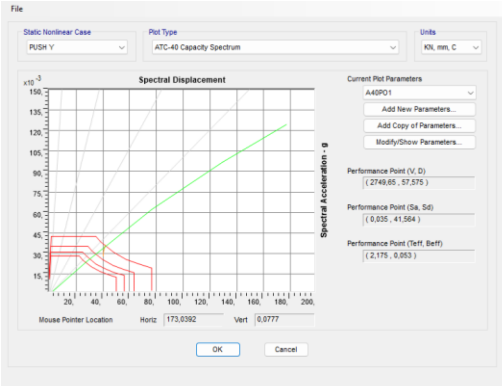

Fig. 21 Performance Point of Medical Center Building in Y Direction (ATC-40)

b. Performance Evaluation with FEMA 356

Drift Ratio of Push X

- Displacement Target (δ_T)

  $= C_0C_1C_2C_3S_a\frac{Te2}{4\pi 2}g$

  $= 1{,}2815.1.1.1.0{,}0383.\frac{2{,}00182}{4\pi 2}.9806{,}65$

  = 48,882 mm

- Maximum total drift

  $= \frac{\mathrm{Dt}}{\mathrm{Htotal}} = \frac{48{,}882}{26075} \times 100\%$

  = 0,187 % < 1%

  then included in **Immediate Occupancy**

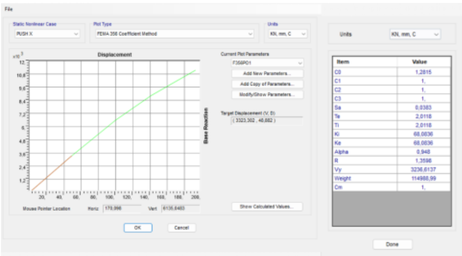

Fig. 22 Perfomance Point of Medical Center Building in X Direction (FEMA 356)

Drift Ratio of Push Y

- Displacement Target (δ_T)

  $= C_0C_1C_2C_3S_a\frac{Te2}{4\pi 2}g$

  $= 1{,}1229.1.1.1.0{,}0357.\frac{2{,}15712}{4\pi 2}.9806{,}65$

  = 46,714 mm

- Maximum total drift

  $= \frac{\mathrm{Dt}}{\mathrm{Htotal}} = \frac{46{,}714}{26075} \times 100\%$

  = 0,179 % < 1%

  then included in **Immediate Occupancy**

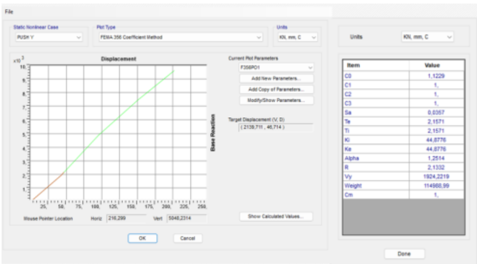

Fig. 22 Performance Point of Medical Center Building in Y Direction (FEMA 356)

Table 11. Performance Evaluation Recap of Medical Center Building

	PUSH X		PUSH Y	
	ATC-40	**FEMA 356**	**ATC-40**	**FEMA 356**
Base Force (kN)	3407,543	3323,302	2749,650	2139,711
Displacement (mm)	50,187	48,882	57,575	46,714
Maximum Total Drift	0,00192	0,00187	0,00221	0,00179
Performance Level	IO	IO	IO	IO

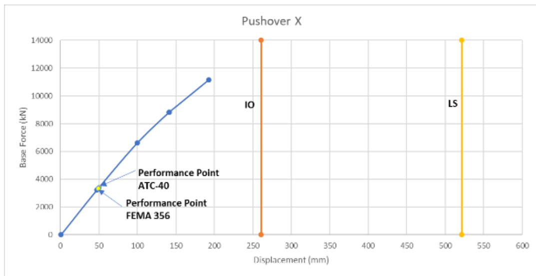

Fig. 23 Pushover of Medical Center Building in X Direction

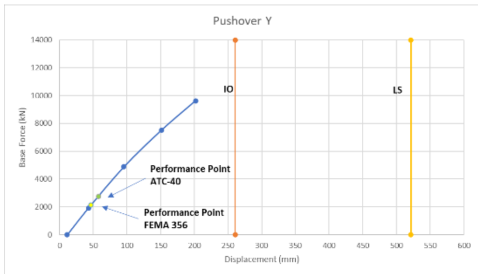

Fig. 24 Pushover of Medical Center Building in Y Direction

Checking the Value of the Earthquake Force Resisting System Factor

After the pushover analysis had been completed, then continued by checking the earthquake force resisting factor R, Ω, and Cd.

Table 12. Force and Displacement Recap of Medical Centre Building

Ket.	***Push* X**	***Push* Y**
Ve (kN)	3.258,021	3.258,021
Vm (kN)	3.323,302	2.139,711
∆m (mm)	48,882	46,714
Vy (kN)	3.236,614	1.924,222
∆y (mm)	47,539	42,877
Vd (kN)	1.629,011	1.629,011
∆d (mm)	24,353	38,032

X Direction

R = 3258,021 / 1629,011 = 2

Ω = 3323,302 / 1629,011 = 2,040

Cd = 48,882 / 24,353 = 2,007

Y Direction

R = 3258,021 / 1629,011 = 2

Ω = 2139,711 / 1629,011 = 1,314

Cd = 46,714 / 38,032 = 1,228

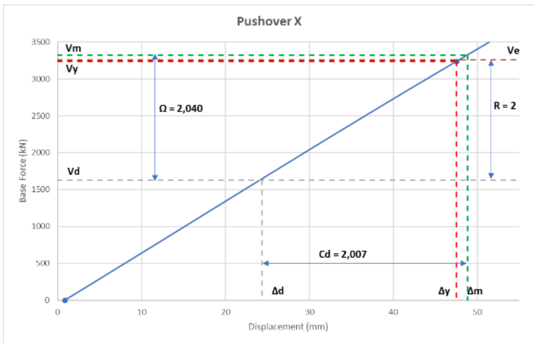

Fig. 25 Resisting System Factor of Medical Center Building in X Direction

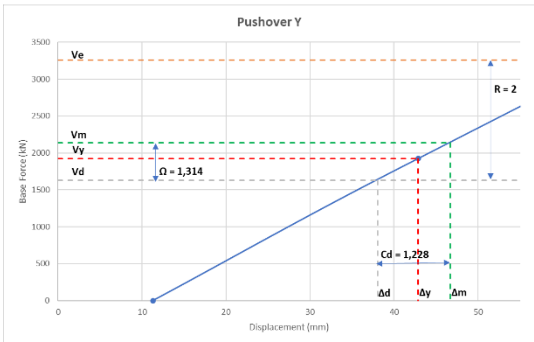

Fig. 26 Resisting System Factor of Medical Centre Building in Y Direction

Table 13. Comparison of R, Ω and Cd Values of Medical Centre Building

Factor	SNI 1726-2012	Push X	Push Y
R	3	2	2
Ω	3	2,040	1,314
Cd	2,5	2,007	1,228

3.5 Pushover Analysis Results of The Inpatient Building

a. Performance Evaluation with ATC-40

Drift Ratio of Push X

In the X direction capacity spectrum curve, the performance point value is obtained under shear force conditions 2568,550 kN with a displacement of 46,172 mm.

- Maximum total drift
  $= \frac{\text{Dt}}{\text{Htotal}} = \frac{46{,}172}{26075}$ = 0,00177 < 0,01
  then included in **Immediate Occupancy**
- Maximum in-elastic drift
  $= \frac{\text{Dt} - \text{D1}}{\text{Htotal}} = \frac{46{,}172 - 53{,}787}{26075}$ = -0,0003 < 0,005
  then included in **Immediate Occupancy**

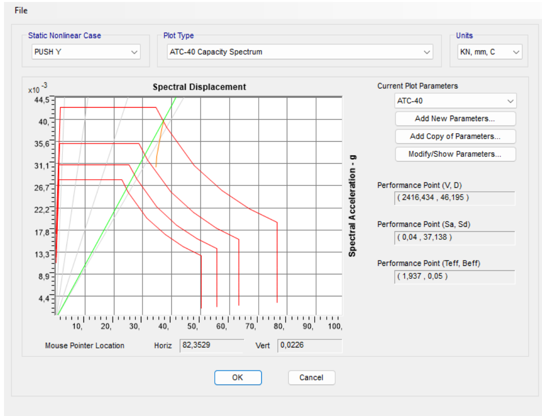

Fig. 27 Performance Point of Inpatient Building in X Direction (ATC-40)

Drift Ratio of Push Y

The performance point value is obtained under shear force conditions around 2416,434 kN with 46,195 mm of displacement in the Y direction capacity spectrum curve.

- Maximum total drift
  $= \frac{\text{Dt}}{\text{Htotal}} = \frac{46{,}195}{26075}$ = 0,00177 < 0,01
  then included in **Immediate Occupancy**
- Maximum in-elastic drift
  $= \frac{\text{Dt} - \text{D1}}{\text{Htotal}} = \frac{46{,}195 - 50{,}658}{26075}$ = -0,0002 < 0,005
  then included in **Immediate Occupancy**

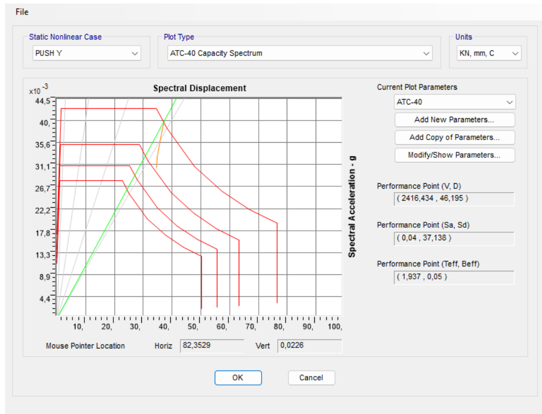

Fig. 28 Perfomance Point of Inpatient Building in Y Direction (ATC-40)

b. Performance Evaluation with FEMA 356

Drift Ratio of Push X

- Displacement Target (δ_T)
  $= C_0C_1C_2C_3S_a\frac{Te2}{4\pi 2}g$
  $= 1{,}2459.1.1.1.0{,}0425.\frac{1{,}77462}{4\pi 2}.9806{,}65$
  = 41,178 mm
- Maximum total drift
  $= \frac{\text{Dt}}{\text{Htotal}} = \frac{41{,}178}{26075} \times 100\%$
  = 0,158 % < 1%
  then included in **Immediate Occupancy**

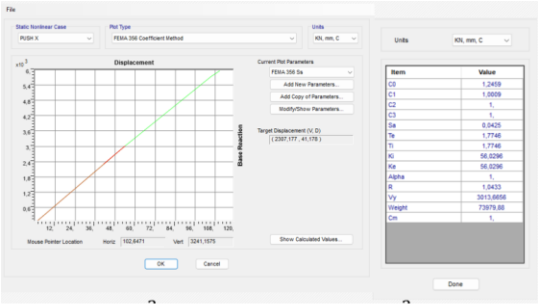

Fig. 29 Perfomance Point of Inpatient Building in X Direction (FEMA 356)

Drift Ratio of Push Y

- Displacement Target (δ_T)

  $= C_0C_1C_2C_3S_a\frac{Te2}{4\pi 2}g$

  $= 1{,}2594.1.1.1.0{,}0398.\frac{1{,}93672}{4\pi 2}.9806{,}65$

  = 46,250 mm
- Maximum total drift

  $= \frac{\text{Dt}}{\text{Htotal}} = \frac{46{,}250}{26075} \times 100\%$

  = 0,177 % < 1%

  then included in **Immediate Occupancy**

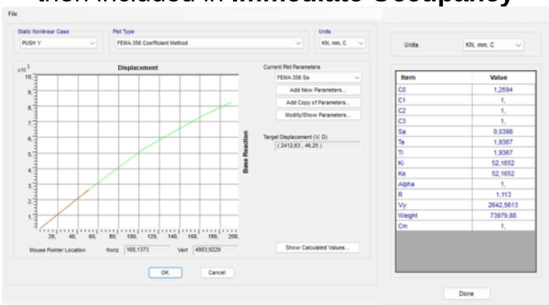

Fig. 30 Perfomance Point of Inpatient Building in Y Direction (FEMA 356)

Table 14. Performance Evaluation Recap of Inpatient Building

	PUSH X		PUSH Y	
	ATC-40	**FEMA 356**	**ATC-40**	**FEMA 356**
Base Force (kN)	2568,550	2307,177	2416,434	2412,630
Displacement (mm)	46,172	41,178	46,195	46,250
Maximum Total Drift	0,00177	0,00158	0,00177	0,00177
Performance Level	IO	IO	IO	IO

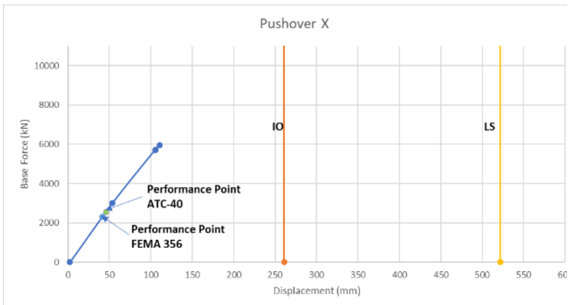

Fig. 31 Pushover of Inpatient Building in X Direction

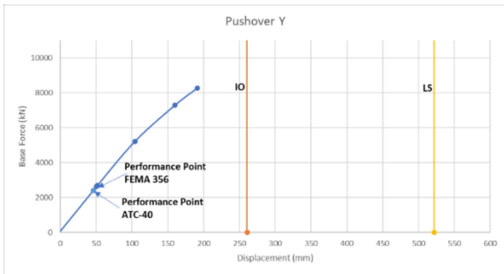

Fig. 32 Pushover of Inpatient Building in Y Direction

Checking the Value of the Earthquake Force Resisting System Factor

After the pushover analysis has been completed, then continued by checking the earthquake force resisting factor R, Ω and Cd.

Table 15. Force and Displacement Recap of Inpatient Building

Ket.	***Push*** **X**	***Push*** **Y**
Ve (kN)	2.097,097	2.097,097
Vm (kN)	2.307,177	2412,630
∆m (mm)	41,178	46,250
Vy (kN)	3.013,666	2.642,561
∆y (mm)	53,787	50,658
Vd (kN)	1.048,048	1.048,048
∆d (mm)	20,159	19,190

<u>X Direction</u>

R = 2097,097 / 1048,048 = 2

Ω = 2307,177 / 1048,048 = 2,201

Cd = 41,178 / 20,159 = 2,043

<u>Y Direction</u>

R = 2097,097 / 1048,048 = 2

Ω = 2412,630 / 1048,048 = 2,302

Cd = 46,250 / 19,190 = 2,410

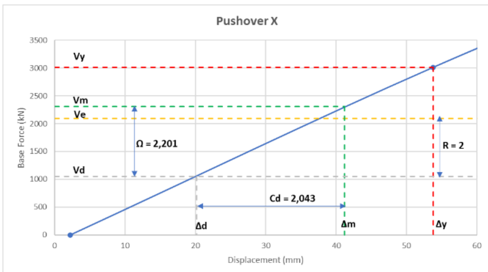

Fig. 33 Resisting System Factor of Inpatient Building in X Direction

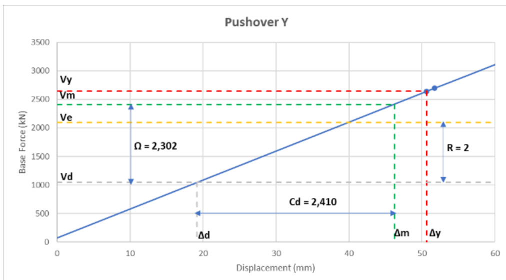

Fig. 34 Resisting System Factor of Inpatient Building in Y Direction

Table 16. Comparison of R, Ω and Cd Values of Inpatient Building

Factor	SNI 1726-2012	Push X	Push Y
R	3	2	2
Ω	3	2,201	2,302
Cd	2,5	2,043	2,410

3.6 Dilatation Analysis Between the Buildings

The dilation between the buildings is designed in the direction of the Y axis with a distance of 150 mm. Therefore, dilatation analysis between buildings will be calculated only on the Y pushover. Dilation is calculated with Cd = 2,5 and Ie = 1,5.

Based on SNI 1726-2012, structure separation must accommodate the maximum inelastic response displacement (δM) which is calculated at critical locations using the equation: $\delta_M = \frac{C_d \, x \, \delta\text{max}}{I_e}$

After obtaining the δ_M value for each building, then the dilatation that occurs can be calculated with the equation: $\delta_{MT} = \sqrt{(\delta_{M1})^2 + (\delta_{M2})^2}$

- Displacement of Medical Center Building at performance point

  δy = 46,714 mm

  $\delta_{M1} = \frac{2{,}5 \, x \, 46{,}714}{1{,}5} = 77{,}857$ mm

- Displacement of Inpatient Building at performance point

  δy = 46,250 mm

  $\delta_{M1} = \frac{2{,}5 \, x \, 46{,}250}{1{,}5} = 77{,}083$ mm

- Minimal Dilation Requirements

  $\delta_{MT} = \sqrt{77{,}857^2 + 77{,}083^2}$

  = **109,555 mm < 150 mm** (design dilation)

4. Conclusion

From the analyses that have been carried out, it can be seen both Medical Centre and Inpatient building still in elastic condition with the capacity curve that is formed is still a straight line without any significant change in slope. Based on regulations of ATC-40 and FEMA 356, both buildings classified in Immediate Occupancy (IO) level performance and the structure elements are safe without exceeding the IO limit. The amount of dilatation that occurs due to pushover analyses is still smaller than the design dilatation of 150 mm, so there will be no collision that will affect both structures.

Some suggestions that can be given for the improvement that related to this study are:

- There needs to be further analysis to determine the effect of the newest SNI on the existing structure.
- Pushover analysis will be better used to analyse structures with a seismic design category above category B. This affects the differences in the factor values of the seismic force resisting system R, Ω and Cd obtained from the pushover and SNI design results.
- It is necessary to do a comparison with the dynamic analysis of Non-Linear Time Historical Analysis (NLTHA) in order to obtain accurate results.

5. Acknowledgement

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6. Author's Note

This article is purely written from the results of my learning and discussions with my lecturers, Mr. Gatot Setya Budi, S.T., M.T. and Mr. Dr. Herwani, S.T., M.T. The contents of this article have been reviewed in a thesis defense at the Department of Civil Engineering, The University of Tanjungpura, on 13 June 2023 by Mr. Ir. Faisal, M.T. and Mrs. Ir. Yoke Lestyowati, M.T., IPM.

As the author of this journal, I state that there is no conflict in the publication of this journal; no other party has ever published this journal, and this journal is free from plagiarism.

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