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Analysis Comparison of Moment Resisting Frame System and Concentrically Braced Frame System using Inverted – VBrace

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Abstract. Indonesia is a country located in the path of the Pacific earthquake and the Asian earthquake path that results in a very high risk of earthquakes. Vibrations caused by earthquakes will cause forces on the structure. The design of earthquake-resistant buildings is one of the objectives to prevent structural failure and loss of life. Adding rigidity to a building is a way to overcome resistance to earthquake response. Acquiring stiffness in the structure can be done by combining it with bracing. One type of bracing frame system that can be used is the Concentrically Braced Frame (CBF) system. The analytical method that can be used in this study to account for the effect of earthquake load on the structure is done to analyze the structure's response to lateral load with static analysis and dinamic analysis with comparative analysis of displacement, vibrating period, shear force, and shear lag in buildings. Based on the results of the analysis, the CBF system can reduce the effect of shear lag on the structure. The rigidity of the CBF System is higher than that of the MRF system so that the floor drift and deviation between floors in the system become smaller. The deviation for the x-direction CBF system produces a smaller value of 5% - 32.2%, and for the y-direction it produces 7.2% - 41.7%. In the natural vibrating period of the MRF System structure of 1.311 seconds, this period is worth greater than the period in the CBF System of 0.453 seconds.

INTRODUCTION

Indonesia is a country located in the path of the Pacific earthquake and the Asian earthquake path that results in a very high risk of earthquakes [1]. In the event of an earthquake, the structure will undergo deformation due to the lateral force caused by the earthquake load. Vibrations caused by earthquakes will cause forces on the structure [2]. A structure must be designed to withstand lateral forces to overcome deformation or structural failure. The design of earthquake-resistant buildings is one of the objectives to prevent structural failure and loss of life. Materials and structural systems are things that must be considered in planning the construction of earthquake-resistant building construction, so designing an earthquake-resistant building must prioritize safety and comfort [3,4].

Adding stiffness to a building is a way to obtain resilience to the earthquake response. Obtaining rigidity in the structure can be done by combining it with bracing [5]. The forces received by the structure will be spread to all elements including the bracing element so that the resulting deviation is smaller. One type of bracing frame system that can be used is the Concentrically Braced Frame (CBF) system. CBF is an earthquake-resistant structural system that has excellent elastic rigidity, has good ductility, can withstand axial and lateral forces where the diagonal bracing element is at one point [6].

Research on bracing has been conducted by several researchers, one of them by [7] with the pushover analysis method. Based on the results of his research, the deviation between floors for structures without bracing on the 1st floor in Y still meets the requirements of deviation between permission floors, while on the 2nd, 3rd, and 4th floors do not meet the requirements, so the structure needs to be strengthened with the addition of bracing. The results of the

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analysis after the addition of bracing were able to reduce the period of the structure and was able to reduce the displacement of the structure by 1,328% - 42,013% for the x-direction and the y-direction by 10.00% - 39,394% compared to a structure without bracing [7]. Research conducted by I. N. Sinarta (2020) with direct displacement method and pushover analysis using Moment Resisting Frame System states that the displacement thatoccurs in the structure with both methods produces almost the same value, for the total displacement value of the x-xdirection is 0.300 m, and the direction of y-y is 0.115 m [8].

Based on the explanation above, this study aims to determine the difference in structural behavior of multi-story buildings due to lateral loads in the Moment Resisting Frame System and Concentrically Braced Frame System using Inverted V – Brace using equivalent static analysis methods, and spectrum response analysis.

METHOD

This study used a comparative analysis of the structural behavior of multi-story buildings due to lateral loads in the Moment Resisting Frame System and Concentrically Braced Frame System using inverted V - brace using static analysis method, and dynamic analysis.

Structure Data

In this study, data structures were used that had been established before conducting analysis. The building being analyzed is the IRD Building of the Payangan General Hospital, which is located on Jalan Giri Kesuma, Melinggih, Payangan, Gianyar (S_{DS} = 0.983 g and S_1 = 0.348 g), Basic soil type is soft soil (F_a = 0.921 and F_v = 2.607), building function is hospital (I_e = 1.5), with system structure Moment Resisting Frame System (R = 8, Ω0 = 3, and Cd = 5.5) and Concentrically Braced Frame System (R = 6, Ω0 = 2, and Cd = 5). The values of R, Ω0, and Cd used were obtained from the seismic regulations in force in Indonesia, namely SNI 1726:2019

Structural Modeling

There are two models of steel buildings that will be reviewed, namely buildings with Moment Resisting Frame System (MRF) and with Concentrically Braced Frames System (CBF). Both models have the same floor plan, materialquality, and element profile. Structure modeling is done full 3D with the help of software SAP2000 v22. Both modelsuse the same charge by the regulation of loading SNI 1727:2020.

The 4-story building measures 30 x 14 m^2 with height on the 1st floor and the 4th floor is 3.7 meters while on the2nd floor and the 3rd floor is 4 meters with the distance between the columns of the building is 6 m as in Fig.1. Buildings with CBF Systems use bracing Inverted V configurations on each front of the building as shown in Fig. 2. The structural elements in both systems use the WF profile and H-Beam profile which refers to Gunung Garuda profile

TABLE 1. Structure Element Profile

Structure Element	Symbol	Profile
Column	K	HB 300x300x10x15
Main Beam	BI	WF 300x150x6.5x10
Beam	BA	WF 200x100x5.5x8
Bracing	B	WF 150x75x5x7

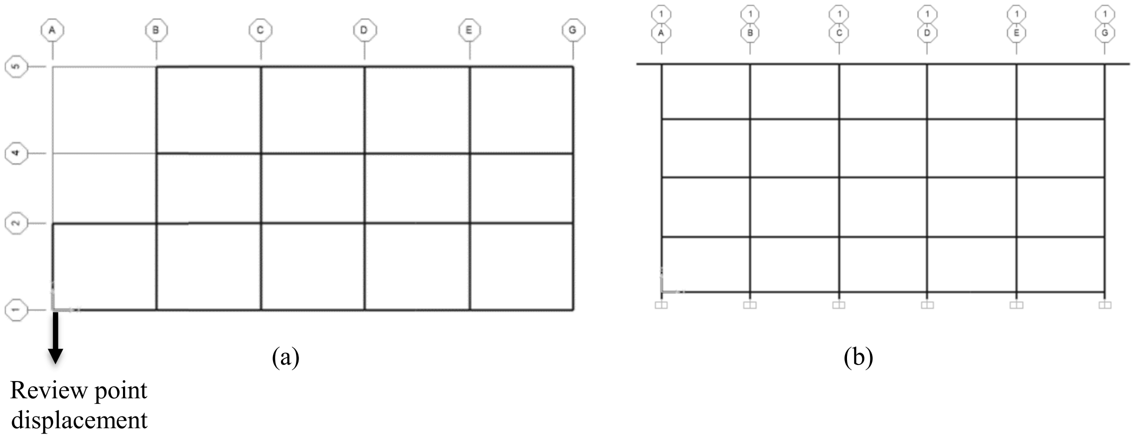


FIGURE 1. Views and Building Plan On Moment Resisting Frame System (MRF)

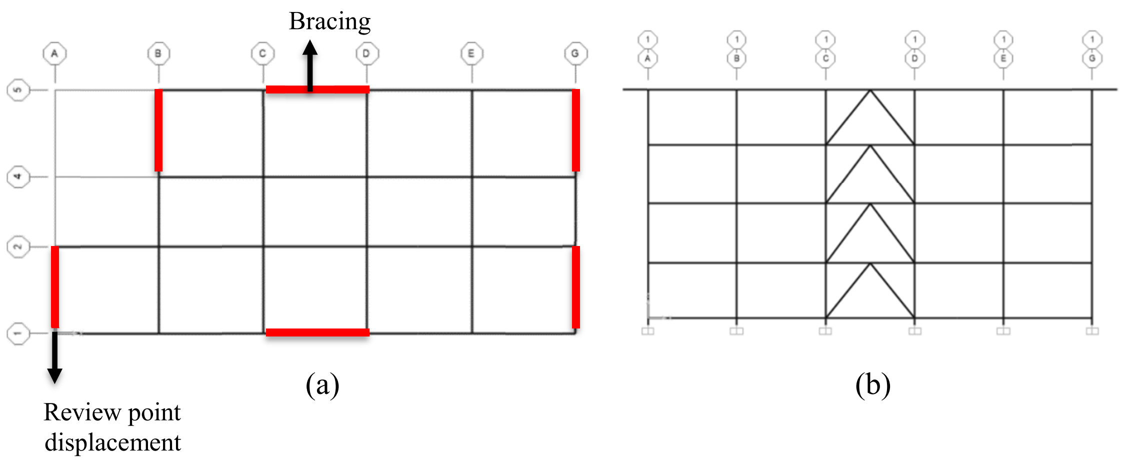


FIGURE 2. Views and Building Plan On Concentrically Braced Frames System (CBF)

Analysis Method

The analytical methods that can be used in this study to take into account the effect of earthquake load on the structure are as follows.

Static Analysis.

The equivalent Static Method follows SNI 1726 – 2019 rules. In this study, the equivalent static analysis method was used to analyze the phenomenon of shear lag. With this method can be obtained axial force distribution on the columns in both models.

Dinamic Analysis

Dynamic analysis in this study was conducted using Analysis of Various Spectrum Responses based on Indonesia's Earthquake Planning Guidelines in region IV on soft soil. Hail analysis of Spectrum Response is a structural response such as structure fundamental period, switching and deviation between floors, rigidity, and maximum shear force.

1. Fundamental Period

The structure Fundamental period (T_c) obtained from the SAP2000 v22 software should be between T_a and

$C_u \times T_a$. This is so that the designed structure is not flexible and not wasteful. If the value of $T_c > C_u \times T_a$ it is better to increase the dimensions of the column and beam this is due to the structure being too flexible, whereas if the value of $T_c < T_a$ the structure is rather stiff. Then the fundamental approach period (T_a) can be found by the following calculation:

$$T_a = C_t \times h_n^x \tag{1}$$

$$T = C_u \times T_a \tag{2}$$

Information :
T = Period of fundamental structure
T_a = Approach fundamental period
H_n = Height of structure (m)
C_u = Coefficient for Upper Limit in Calculated Period
Approximate Period Parameter Value (Ct = 0.0731 and x = 0.75)

2. Displacement

SNI 1726 – 2019 concerning procedures for planning earthquake resistance for building and non-building structures, provides a limit for the deviation between floors (Δ), which must not exceed the deviation between floors of the permitted level (Δa). Structures designed for seismic design category D, E, or F must not exceed a/ρ for all levels. The value is determined by article 7.3.4.2 with the value obtained as 1.3 [9]. the calculation of the deviation between floors for the Moment Resisting Frame system can be calculated by equation (3) while for the calculation of the deviation between floors in the Concentrically Braced Frames system it is calculated by equation (4)

$$\Delta < 0.010_{hsx}/\rho \tag{3}$$

$$\Delta < 0.020_{hsx}/\rho \tag{4}$$

Information:
(Δ) = Deviation between design level floors (mm)
(Δ_a) = Drift between floors of allowable level (mm)
h_{sx} = Height between stories (m)
ρ = structure redundancy factor

3. Shear Force

The forces that occur in the structure can be determined by the method of time history analysis, the response spectrum, or by the equivalent static method. The seismic force on each floor is part of the total base shear force. The base shear force is the lateral force that occurs at the base of the building. The value of the story shear tends to be greater if the level of the level is lower because there is an accumulation of shear forces from the story above. The greater the stiffness of a story, the greater the shear force that occurs at that level.

RESULTS AND DISCUSSION

The result of the analysis shown in this paper is a summary of the results of the analysis that has been done, both static equivalent analysis and spectrum response analysis. The discussion described is displacement, fundamental period, basic shear force, and shear lag.

Analysis Effect Shear Lag

Based on the results of the shear lag analysis on the 1st, 2nd, 3rd, 4th floors of the Moment Resisting Frame System, it is concluded that the largest axial force on the column is on the 1st floor which can be seen in in Fig. 4 through Fig. 6. The axial force will decrease with increasing height floor. Therefore, a comparative analysis of the shear lag effect on the Moment Resisting Frame System and The Concentrically Braced Frames System on the 1st floor was conducted.

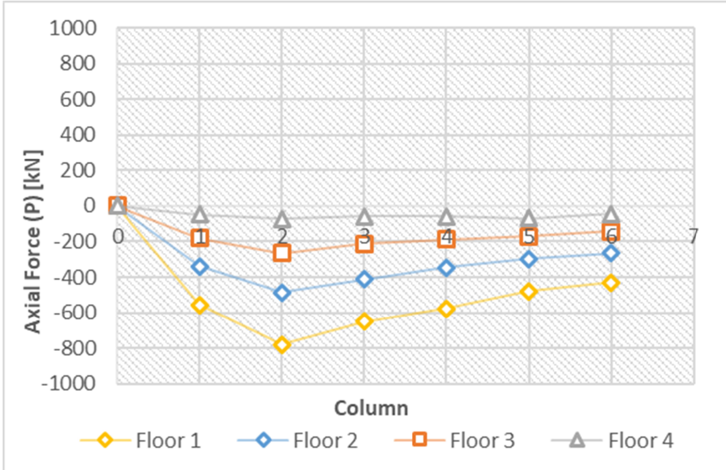


FIGURE 3. Distribution of axial force on side column of MRF System (Part.1)

In Fig. 3, it is shown that the axial force distribution that in column number 2 of the 1st floor is the largest axial force of -781,688 kN and the smallest occurs in column number 6 of the 4th floor of -44.92 kN.

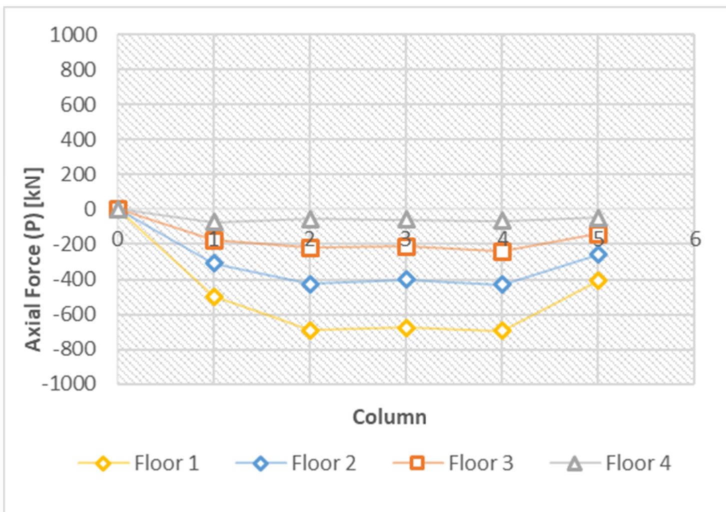


FIGURE 4. Distribution of axial force on side column of MRF System (Part.5)

In Fig. 4, it is shown that the axial force distribution that in column number 4 of the 1st floor is the largest axial force of -693,134 kN and the smallest occurs in column number 5 of the 4th floor of -46.874 kN

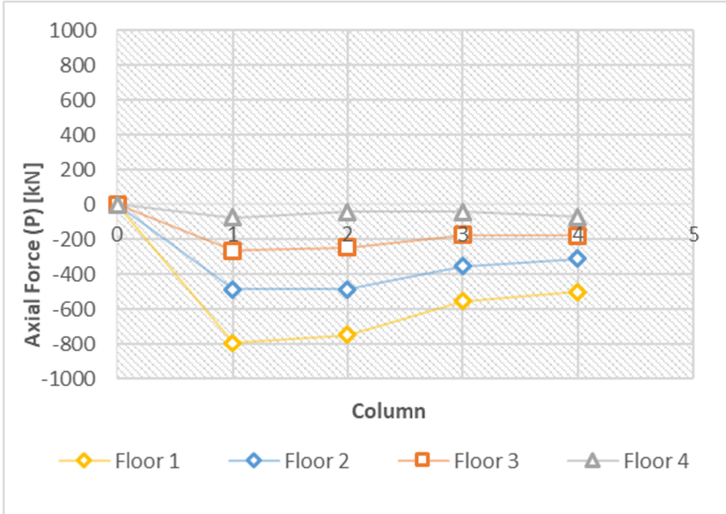


FIGURE 5. Distribution of axial force on side column of MRF System (Part.B)

In Fig. 5, it is shown that the axial force distribution that in column number 1 of the 1st floor is the largest axial force of -791,688 kN and the smallest occurs in column number 2 of the 4th floor of -42.55 kN.

Comparison of Axial Force on MRF System and CBF System

The use of bracing on the outer side of the building can reduce the phenomenon of shear lag, but the use of bracing results in a reaction to the restrained of the edge column becomes larger because the axial force working on bracing will be held by the focus on the outer column of the building. The distribution of axial forces on the 1st-floor column of the MRF system and CBF system can be seen in Fig. 6 to 8.

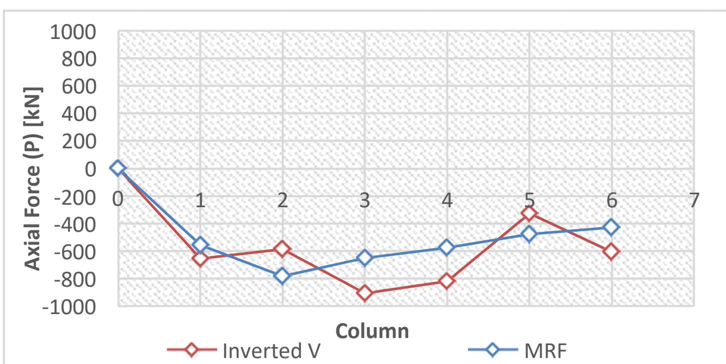


FIGURE 6. Comparison of Axial Force Distribution of MRF and CBF – Inverted V (Part.1)

Figure 6 shows that the largest axial force comparison occurs in CBF systems – inverted V which is – 908,474kN compared to MRF systems.

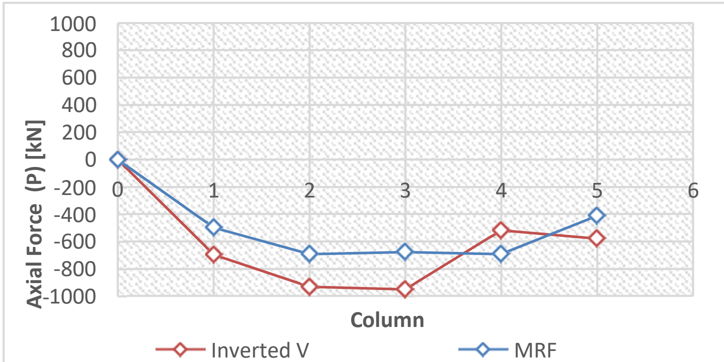


FIGURE 7. Comparison of Axial Force Distribution of MRF and CBF – Inverted V (Part.5)

Figure 7 shows that the largest axial force comparison occurs in CBF systems – inverted V i.e. – 950.3 kN compared to MRF systems.

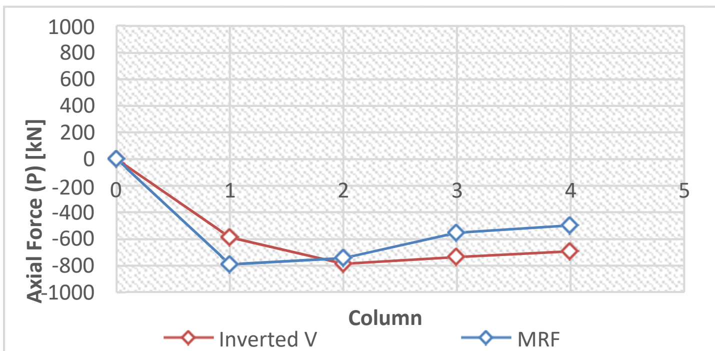


FIGURE 8. Comparison of Axial Force Distribution of MRF and CBF – Inverted V (Part.B)

Figure 8 shows that the largest axial force comparison occurs in CBF systems – inverted V i.e. – 786,575 kN compared to MRF systems.

Response Spectrum Analysis

Based on the linear analysis of the response spectrum of the MRF system and the CBF – Inverted V system, the following results were obtained.

1. Fundamental Period

   Based on Eq. 1 and Eq. 2, the T_a value is 0.568 seconds, and the T value is 0.796 seconds. From the results of the capital analysis, the structure period in the model with the MRF system of 1,312 seconds, this period is worth greater than 64.55% of the period in the CBF System - Inverted V of 0.453 seconds. Based on the control period of the structure, the value of T_c in the CBF system is still smaller than the C_u. T_a value compared to the T_c value of the MRF system. So the analysis of the building structure with the CBF system still meets the requirements of SNI 03-1726-2019.

TABLE 2. MRF System and CBF System Fundamental Period

Mode	Fundamental Period			
	MRF System		CBF System	
	T (SAP 2000)	Ratio %	T (SAP2000)	Ratio %
1	1.312		0.453	
2	1.036	21%	0.391	14%
3	0.937	10%	0.292	25%
4	0.471	50%	0.209	28%

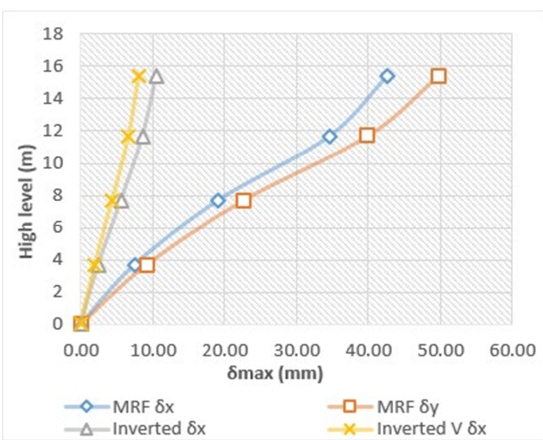
2. Displacement
Based on Table 3 and Table 4, the displacement of the top floor in the MRF System is greater than that of the CBF – Inverted V System, this is because the bracing will provide very large stiffness to be able to withstand the working earthquake load. From the results of the analysis of displacements that occur in the CBF system for the x-direction, the value is 5% - 32.2% smaller, and for the y-direction, it is 7.2% - 41.7% compared to the displacement that occurs in the MRF system.

TABLE 3. Story Displacement on the MRF System

h	x-x		y-y		Δ_a	Control
	δmax	$\Delta_{max} \cdot C_d/I_e$	δmax	$\Delta_{max} \cdot C_d/I_e$		
(m)	(mm)		(mm)			
3.7	42.59	26.8	49.7	32.4	56.92	OK
4	34.56	51.7	39.9	57.6	61.54	OK
4	19.04	38.7	22.6	45.1	61.54	OK
3.7	7.41	7.4	9.1	9.1	56.92	OK
0	0.00	0.0	0.0	0.0	0	OK

TABLE 4. Story Displacement on the CBF System

h	x-x		y-y		Δ_a	Control
	δmax	$\Delta_{max} \cdot C_d/I_e$	δmax	$\Delta_{max} \cdot C_d/I_e$		
(m)	(mm)		(mm)			
3.7	10.39	6.9	8.00	5.1	28.46	OK
4	8.51	11.0	6.62	8.4	30.77	OK
4	5.52	11.4	4.34	8.8	30.77	OK
3.7	2.40	2.4	1.94	1.9	28.46	OK
0	0.00	0.0	0.00	0.0	0	OK



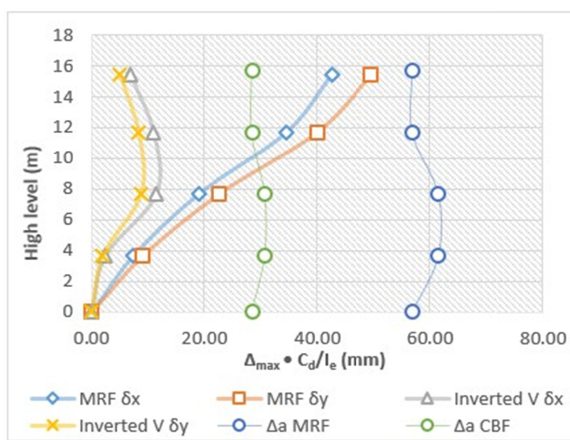


FIGURE 9. Comparison Story Displacement

3. Shear Forces Maximum

Based on the results of the analysis in Table 5, it can be concluded that the basic shear force of the CBF – Inverted V model has a greater value compared to the MRF System. This is related to the rigidity of the level in the CBF System – Inverted V which is greater than the MRF System.

TABLE 5. Maximum Shear Force

Floor	High level (m)	Structural System	
		MRF (kN)	CBF - Inverted V (kN)
4	15.4	24.858	6.38
3	11.7	37.694	10.025
2	7.7	39.301	22.667
1	3.7	54.206	89.984
Base	0	0	0

CONCLUSSION

Based on the results of the analysis that has been done on the structure of buildings with Momen Resisting Frame System (MRF) and Concentrically Braced Frames (CBF) System with static equivalent analysis and spectrum response analysis, can be obtained several conclusions as follows.

1. Based on the results of the equivalent static analysis, the magnitude of axial force on the column edge of the building is influenced by the height between floors. The higher the floor, the axial force on the edge column becomes smaller and closer to the large axial force on the other column. This indicates that, as a floor increasesin height, the shear lag effect will decrease.
2. Based on the response spectrum analysis, the following conclusions are obtained.

a. The period of structure on models with MRF System is 1.311 seconds, this period is worth greater than 64.55% while the period of structure on models with CBF System is 0.453 seconds.

b. The maximum floor deviation of the building with the CBF System is smaller than the MRF System. Therefore, in both conditions, the CBF system is better. The deviation for the x-direction CBF system produces a smaller value of 5% - 32.2%, and for the y-direction it produces 7.2% - 41.7%.

c. The maximum base shear force of the CBF – Inverted V model has a greater value compared to the MRF System due to the higher rigidity level of the CBF – Inverted V System compared to the MRF System.

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