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The Performance Assessment of the Structural Bracing Model for Multi-Story Building

Frida Anastasia [a], Aldi M. E. Saputro [a], Garup Lambang Goro [a,*], Dedi Budi Setiawan [a]

[a] *Civil Engineering Department, Politeknik Negeri Semarang, Semarang, 50275, Indonesia*
*Correspondent author: *garup.lambang.goro@polines.ac.id*

***Abstract*—Earthquakes are a severe issue for construction. The building collapsed due to the earthquake because it could not bear the earthquake load. Even more so, it was constructed using outdated and different building regulations that do not comply with modern building codes that account for seismic loads. As a result, disaster mitigation methods, such as retrofitting, must be implemented. Retrofitting procedures are commonly used in many developed countries. The bracing system is a typical retrofitting method used on building structures. In this study, a retrofitting program was carried out on The State Finance Building II Semarang, which was built in the 1980s, one of the old buildings in Semarang City, using a reinforced portal structure. This study's bracing system is a Concentrically Brace Frame (CBF) with Inverted V Brace and V Brace variations. The structural analysis software ETABS V.18.2.0 analyzes the building's structure. The structural review includes story drift, the P-Delta effect, and horizontal torsion irregularities. According to the results, steel bracing can minimize the period and displacement associated with story drift, making the structure more stable, with a maximum displacement reduction of 59.66% for inverted V-type steel bracing. Aside from that, steel bracing also can minimize the occurrence of torsion in the building. As a result, steel braces can be used to strengthen the structure.**

***Keywords* —Earthquake; disaster mitigation; retrofitting; bracing; concentrically braced frame; story drift.**

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I. INTRODUCTION

Indonesia is a country prone to earthquakes; in the last 20 years, there have been 38 destructive earthquakes with magnitudes more than 5.5 MW. The monitoring results that have been carried out by the Meteorology, Climatology, and Geophysical Agency over a period of 11 years show that there has been a trend of a significant increase in earthquake activity [1]. It is widely known that fatalities are not caused by earthquakes but due to the collapse of buildings that cannot withstand earthquake loads. An important issue that needs to be studied is the number of old or historic buildings in Indonesia that were built using old building rules that are not fulfilled with the latest building codes, which have considered earthquake loads according to earthquake analysis and history developments. Based on these conditions, it is very important to implement disaster mitigation strategies, one of which is by retrofitting the main structure of the building. Many studies have been conducted in Indonesia regarding hazard and earthquake risks, especially in urban areas [2]–[4]. One urban area with many old and historic buildings is Semarang. Several old buildings are scattered in Semarang City, Central Java, Indonesia. One of these buildings is The State Finance Building II Semarang, built in the 1980s with a reinforced concrete building structure.

With seismicity continuing to increase in many parts of the world, earthquake loads on buildings must be considered during the design process. In general, many concrete structures cannot withstand moderate to severe earthquakes that lack lateral strength resistance due to poor reinforcement detailing, so it is necessary to strengthen the building [5]–[7]. One of the usual buildings strengthening methods is retrofitting methods using bracing. Bracing is a frame with a stiffener rod to reduce lateral displacements to obtain structural stability [8], [9]. In general, there are three types of bracing systems namely Moment Resisting Frame (MRF), Concentrically Braced Frame (CBF), and Eccentrically Braced Frame (EBF). The Moment Resisting Frame (MRF) is a structural system consisting of a beam-column frame that is useful for resisting lateral loads, where infill walls are not considered to carry lateral loads [10]. Concentrically Brace Frame (CBF) is a lateral force retaining system with better elastic stiffness and the capacity to withstand lateral alternating forces [11]. In comparison, the Eccentrically

Brace Frame (EBF) structural system is a development of the CBF structural system where this system provides eccentricity in the form of a link beam by providing a reliable source of ductility and using capacity design principles. It can prevent shear in a structure from reaching a level where buckling occurs in one of the components. The EBF system has advantages over the MRF and CBF systems [11], [12]. The configuration of the Moment Resisting Frame, Concentrically Brace Frame, and Eccentrically Brace Frame systems can be seen in Figures 1, 2, and 3.

This research was carried out with the study limitation of analyzing the bracing reinforcement in the State Finance Building II Semarang, with various forms of CBF bracing, including the Inverted-Vbrace and Vbrace forms. When applying the Inverted-V brace variation, the length of the brace rod will be shorter because it is supported in the middle of the beam [13]. This support will minimize the bending deformation of the beam so that its dimensions can be reduced. Meanwhile, V-shaped bracing is used not only to withstand lateral loads but also to withstand vertical loads. The building structure was analyzed using the special moment-bearing frame system method, and the software ETABS V.18.2.0 was used to review the structure. The structural analysis results that reviewed the effect of bracing application on the building structure include the storey drift, the P-Delta effect, and horizontal torsional irregularities [14], [15].

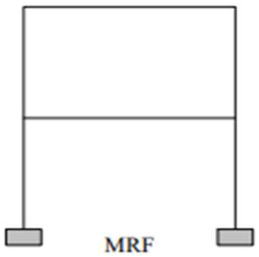

Fig. 1 Moment resisting system configuration frame (MRF)

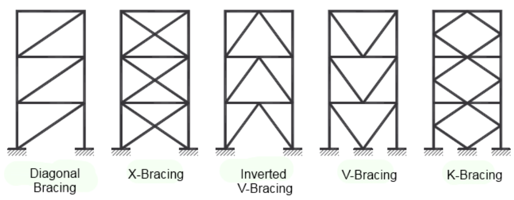

Fig. 2 Concentrically braced system configuration frame (CBF)

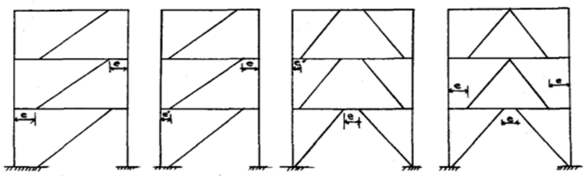

Fig. 3 Eccentrically braced system configuration frame (EBF)

II. Materials and Method

A. Existing Building Structure Modeling

The State Finance Building II Semarang was built in the 1980s. The building consists of 3 towers, namely towers A, B, and C, as seen in Fig. 4 and Fig. 5, and functions as an office building. This building consists of 7 floors and 1 rooftop; the main structure is reinforced concrete with the following specification data:

- Compressive strength of concrete fc = 18,68 MPa
- Dimensions of column = 500mm/ 1000mm
- Mean beam/girder = 500mm/1000mm
- Beam = 500mm/900mm
- Height of each floor = 4000mm
- Slab Floor thickness = 120mm

Based on SPT soil data to a depth of -30 m, an average NSPT value of 4,198, which was less than 15, was obtained, so the soil is classified as SE (Soft Soil).

B. ETABS Software

ETABS is a high-performance analysis and design application created specifically for building systems [16], [17]. It has an integrated system capable of handling the most extensive and most complicated building models and configurations, so it can be said that ETABS is an all-inclusive system. Because of this integration, users only need to generate one model of the floor systems as well as the vertical and lateral framing systems to evaluate, design, and detail the entire structure. Finite element-based linear static and dynamic analysis and finite element-based nonlinear static and dynamic analysis (available exclusively in ETABS Nonlinear and Ultimate editions) are among the integrated components [18].

In general, the finite element analysis stages in ETABS start from the process of discretizing the element structure into suitable finite elements. The next stage is to construct an element stiffness matrix for all elements. Assembling the element stiffness matrices to form the global stiffness metrics [S]. Where the global stiffness matrix is influenced by material parameters such as elastic modulus and cross-sectional area, based on the formula, the force matrix [F] is the product of the global stiffness matrix [S] with the displacement matrix [D]. Thus, the displacement matrix can be determined through the load matrix divided by the global stiffness matrix.

In ETABS Objects, Members, and Elements are frequently used. Objects in the model reflect the physical structural components. Structure elements will be models as finite elements used internally to build the stiffness matrices.

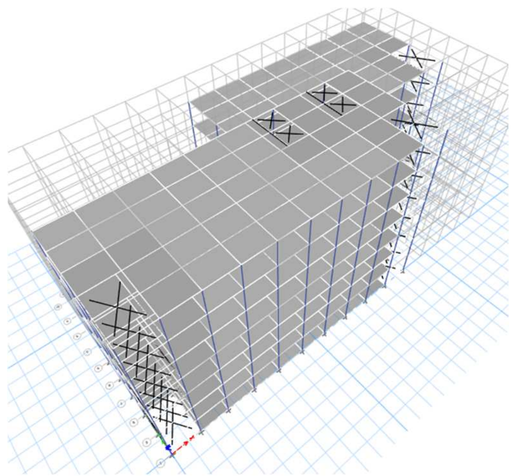

Fig. 4 Existing building structure model

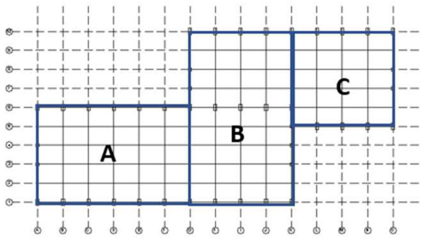

Fig. 5 Building plans before the bracing system is installed

C. Loads on The Building Structure

In principle, the types of loads acting on a building structure are divided into two types, namely:

- Vertical Load (Gravity) includes Dead Load, Live Load and Rainwater Load
- Horizontal (Lateral) Loads include Earthquake/Seismic Loads and Wind Loads

In this structural analysis of multi-storey buildings, the calculated loads include dead, live, wind, and seismic loads.

1) Dead load: a fixed load calculated from the building's weight [19]. Dead loads include installed structures such as walls, floors, roofs, ceilings, finishing, and other architectural components [20]. The loads acted on the structure are based on Indonesian codes on the 1987 Indonesian Loading Regulations for Buildings (PPIUG), which can be seen in Table 1 [21].

TABLE I
CONSIDERED DEAD LOAD COMPONENTS

Nu.	Component	Loads
1	Reinforced Concrete	2400 kg/m^3
2	Floor tile per cm thickness	24 kg/m^2
3	Cement mortar per cm thickness	21 kg/m^2
4	Hebel block masonry	200 kg/m^2
5	Plumbing Installation (Mechanical and Electrical)	30 kg/m^2
6	Ceiling structures	18 kg/m^2

This dead load will then be used to calculate the additional dead load (SIDL), which will later be added to the structure loaded with architectural components such as floor slabs, roof slabs, and beams. The additional dead load (SIDL) added to the structure is as follows:

- SIDL concrete slab floor = 1.53 kN/m²
- SIDL roof-top floor = 0.43 kN/m²
- SIDL Beams on floors 2 to 7 = 1.02 kN/m²
- SIDL Roof beam = 0.255 kN/m²

2) Live loads are loads caused by occupants in buildings or other structures that are not included as construction and environmental loads, such as wind, rain, earthquake, flood, or dead [20]. The live loads that are taken into account in the planning of this building can be seen in Table 2.

TABLE II
CONSIDERED LIVE LOAD COMPONENTS

No	Components	Loads
1	Office room	2,40 kN/m^2
2	Meeting room and Hall	4,8 kN/m^2
3	Corridor	3,83 kN/m^2
4	Warehouse and Archives	6,00 kN/m^2
5	Machine room	1,33 kN/m^2
6	Lavatory dan prayer room	1,92 kN/m^2
7	Roof tank area	6,00 kN/m^2
8	Roof top maintenance	1,33 kN/m^2

3) Wind Load: Based on the Indonesian building code SNI 1727:2020, buildings and other structures, including the Main Wind Force Resisting System (SPGAU) and all building components and cladding, must be designed and implemented to withstand wind loads as stipulated according to article 26 to article 31 with steps as follows [22]

- Determine the risk category of the building.
- Determine the wind speed.
- Determine wind load parameters consisting of Wind direction factor (Kd), Exposure category, Surface hardness category, Topography category (Kzt), Soil surface factor (Ke)
- Determine the velocity pressure exposure coefficient (Kz or Kh)
- Determine the velocity pressure (qz or qh)
- Determine the external pressure coefficient (Cp or Cn)
- Determine the wind load on the wall (Wd), as seen in Table 3.

TABLE III
CONSIDERED LIVE LOAD COMPONENTS

Floors	Hight (m)	Wd in (kN/m)	Wd out (kN/m)
8	28	2.190	-1.270
7	24	2.097	-1.216
6	20	1.982	-1.150
5	16	1.863	-1.080
4	12	1.715	-0.994
3	8	1.521	-0.882
2	4	1.293	-0.750

4) Earthquake/ Seismic Load: Based on the Indonesian building code SNI 1726:2019, it is determined that the effects of the Planned Earthquake must be considered in structural planning[23]. An earthquake response spectrum design must be made in advance for the first step. Furthermore, the acceleration of the earthquake in basic assistance in the short period Ss and long period S1 was obtained based on the 2017 earthquake map taken through the Indonesian Ministry of Public Works' website [2] to determine an earthquake response spectrum design.

Determining the Risk Category and Priority Factors for the Earthquake: Based on SNI 1726:2019, the determination of risk categories is based on the function of the building, and then the priority factor of the earthquake is determined by the value of the risk category.

Define the site class: Site class determination can be determined from direct Vs30 field measurements or undrained shear strength (Su) laboratory data. If this data is unavailable, it can be correlated with other field tests, such as the SPT (Standard Penetration Test) and CPT (Cone Penetration Test). Site class categories are determined based on SNI 1726:2019. Considering the result of a field test of SPT, as shown in Table 4, an average SPT Corrected ($\overline{N}$) derived from SPT Corrected (N_{60}), which are resulted $\overline{N}$ = 4, it is concluded that the site class in the study area is SE (below 15) [23].

$$\bar{N} = \frac{\sum_{i=1}^{n} di}{\sum_{i=1}^{n} \frac{di}{Ni}} \quad (1)$$

$\bar{N}$ = Average SPT Corrected
di = Layer Thickness (m)
Ni = NSPT Corrected at layer i
n = Number of layer

TABLE IV
NSPT DATA

Depth (m)	N_{60}	Di (m)	Σdi (m)	$\frac{di}{N_{60}}$	$\sum \frac{di}{N_{60}}$	$\bar{N}$
0	0	0	30	0.00	7.15	4.198
3	21	3		0.14		
6	5	3		0.60		
9	3	3		1.00		
12	3	3		1.00		
15	4	3		0.75		
18	2	3		1.50		
21	4	3		0.75		
24	5	3		0.60		
27	7	3		0.43		
30	8	3		0.38		

Determining Earthquake Acceleration Parameters. In determining the earthquake force, the SNI 1726:2019 Earthquake Resistance Planning Procedures for Buildings and Non-buildings were used on the earthquake map based on http://rsa.ciptakarya.pu.go.id/2021/ to obtain Ss and S1 values.

Determine the Site Coefficient. In determining the site coefficient according to SNI 1726:2019 Table 6, several things must be determined, such as the value of Ss and S1 as well as the value of the vibration amplification factor related to acceleration in short period vibrations (Fa) and the amplification factor related to acceleration which represents a vibration period of 1 second (Fv). The values of Fa and Fv are determined through the following linear interpolation.

To determine the acceleration in short periods, it can be calculated using the following formula:

$$SDS = \frac{2}{3} x \; Fa \; x \; Ss \quad (2)$$

$$SD1 = \frac{2}{3} x \; Fv \; x \; S1 \quad (3)$$

SDS = Short period design acceleration
SD = 1 second period design acceleration
Fa = Short period site coefficient
Fv = 1 second period site coefficient
Ss = Short period bedrock acceleration parameter 0.2 sec, 5% attenuation
S1 = Parameter of bedrock acceleration period 1,0 sec, 5% attenuation

Determining the Earthquake Force Resisting Factor. Several factors affect the seismic force-resisting system, namely the response modification coefficient (R), system overstrength factor (Ω0), and deflection amplification coefficient (Cd). The earthquake force resisting factor can be determined based on SNI 1726:2019 in Table 12.

Determining Spectrum Response Design. Based on SNI 1726:2019 to determine the design value of the spectrum response, it is necessary to know the T value for the Semarang City area by calculating the T0 and Ts values with the following formula:

$$T0 = 0,2 \times \frac{SD1}{SDS} \quad (4)$$

$$TS = \frac{SD1}{SDS} \quad (5)$$

T0 = period of the fundamental vibration of the structure for 0 second (second)
TS = period of the fundamental vibration of the structure for a short period (second)
SD1 = spectral response parameters of the design acceleration in 1 second period (g)
SDS = spectral response parameters of the design acceleration over short periods (g)

Determine the Design Period. A structure's fundamental natural period/vibration time is the time required for a structure to complete one movement cycle whose value is affected by the stiffness and mass functions. This value is used to determine the design seismic load. To calculate the fundamental period, the formula approach is used as follows:

$$Ta = Ct \times hnx \quad (6)$$

Ct and x are coefficient depend on structure type
h_n = height of the structure (m)

Determining the Seismic Base Force. Based on SNI 1726:2019 article 7.8.1.1 to calculate the seismic response coefficient (Cs), the procedure to calculate the maximum Cs is as follows:

$$Cs = \frac{SDS}{\frac{R}{Ie}} \quad (7)$$

SDS = design spectral response acceleration parameter in the short period range
R = response modification coefficient
Ie = the priority factor of the earthquake which is determined according to 0

D. Bracing Structure Modelling

Modeling of bracing reinforcement used profile steel, IWF 400.400.16.24, which is positioned on the axle as shown in Figure 7 and Figure 8. Modeling and structural analysis using ETABS.V.18.2.0. Variations of the brace model used in the analysis are the Inverted-V brace and the V brace shape. Figure 6 shows the bracing placement location for both Inverted-V and V types.

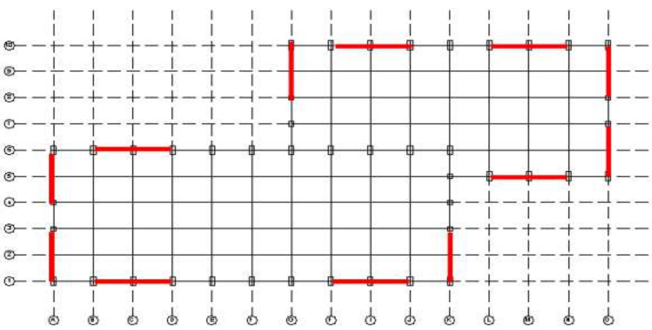

Fig. 6 Bracing installation placement

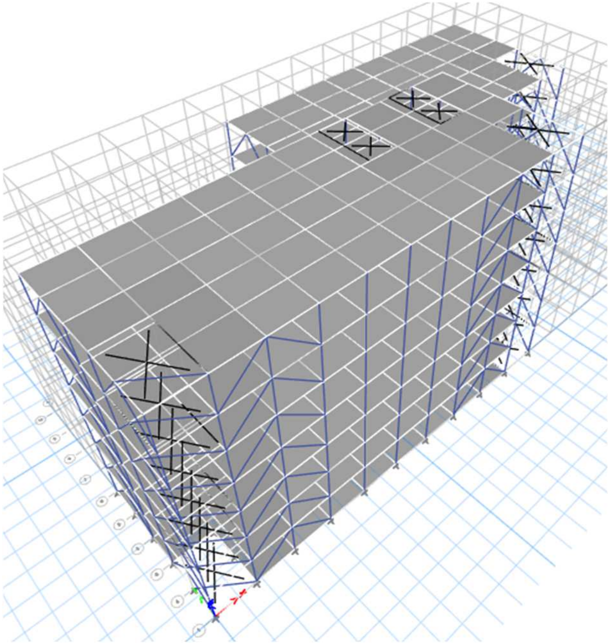

Fig. 7 Structure with Inverted V Bracing

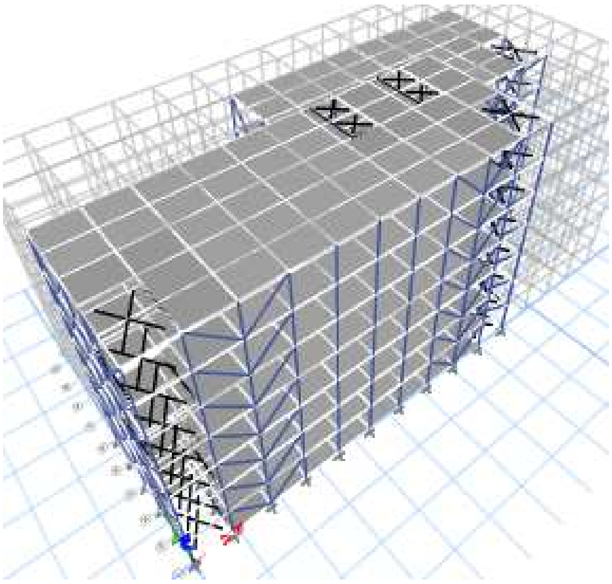

Fig. 8 Structure with V Bracing

E. *Loading Combination*

The loading combination used in this structural analysis is under the provisions stated in SNI 1726:2019 as follows:

1) Basic Loading and Influence of Seismic Loads Combination

TABLE V
BASIC LOADING COMBINATION

No	Basic loading combination
1	1.4D
2	1.2D + 1.6L + (Lr or R)
3	1.2D + 1.6(Lr or R) + (L or 0.5W)
4	1.2D + 1.0W + L + 0.5(Lr or R)
5	0.9D + 1.0W

If the structural elements are affected by seismic loads, then the following combinations must be calculated with the combinations of essential loads.

TABLE VI
LOADING COMBINATIONS BY INCLUDING SEISMIC LOADS

No	Loading Combination with Effect of Seismic Load
1	1,2D + Ev + Eh + L
2	0,9D – Ev + Eh

F. *Structural Evaluation*

The parameters evaluated in the structural analysis for the effect of installing various bracing on the building structure include the storey drift, P-Delta effect, and horizontal torsion irregularities.

1) Storey drift: Represent of lateral displacement to system structure, calculated using the following formula:

$$\delta x = \frac{Cd\ .\delta xe}{Ie} \tag{8}$$

Cd = lateral displacement enlargement factor
δxe = the required deviation in the x-storey determined by elastic analysis
i.e., = earthquake priority factor

Drift between storeys must be less than the maximum drift ratio between storeys of the structural system. If the drift exceeds the permissible drift between storeys, bracing is required on the structure as a stiffener.

2) P-delta Effects: P-delta effect refers to the effect due to relative displacement between members. The storey shear and moments, the forces and moments result on elements structure, and the storey drift result need not be considered when stability coefficient (θ) is equal to or less than 0.10. The stability coefficient (θ) is calculated using the following formula:

$$\theta = \frac{Px\ \Delta Ie}{VxhsxCd} \tag{9}$$

P_x = Total vertical design load at or and over x-level, (kN); when calculating Px, the individual load factor need not exceed 1.0
Δ = design storey drift, as defined in 0, occurs simultaneously with Vx (mm)
Ie = earthquake priority
V_x = seismic shear force, which work between the storey x and storey x-1 (kN)
h_{sx} = storey height (mm)
C_d = lateral deviation enlargement factor

3) Horizontal Torsion irregularity: The torsion irregularity can be determined using the following formula:

$$Ax = \left(\frac{\delta max}{1{,}2\delta avg}\right)^2 \tag{10}$$

δ_{max} = maximum displacement at storey x (mm) which is calculated assuming Ax = 1
δ_{avg} = average displacement at the farthest point of the structure at storey x which is calculated assuming Ax = 1

The torsional irregularity is defined to exist where the maximum story drift computed, including accidental torsion, at one end of the structure transverse to an axis more than 1.2 times the average of the story drifts at the two ends of the structure, and over-torsion irregularities when torsion irregularity more than 1.4 times. [24].

III. Results and Discussion

Structural analysis on the condition when building under seismic loads, both before and after being given steel bracing with Concentrically Brace Frame using inverted V brace and V brace. The parameters reviewed are time period, storey drift, P-Delta effect, and horizontal torque irregularities.

A. Time Period Result

Tables 7 and 8 show a variation of the time period for unbraced structure, inverted V brace, and V brace. From that table, it is observed that the time period for the unbraced structure is 1.704 seconds for the X-direction and 1.833 seconds for the Y-direction. Moreover, that changes significantly with additional steel brace with a reduction up to 62.80% for inverted V and 59.66% in V brace shape, so it can be concluded that steel brace can reduce the period. This result is similar to the study conducted in India, where adding steel bracing in high-rise buildings can reduce the time period by up to 36.43% [25]. Moreover, in another study, with the addition of a V brace with various bracing sizes, there is a significant reduction in the time period, around 44% to 76% [26]. Therefore, the addition of steel bracing will reduce the time period, which means it can stabilize building structures.

TABLE VII
TIME PERIOD

	Unbraced	**Inverted V Brace**	**V Brace**
X-direction (second)	1.704	0.593	0.634
Y-direction (Second)	1.833	0.726	0.797

TABLE VIII
TIME PERIOD EFFECTIVITY

	Time Period Effectivity	
	Inverted V Brace	**V Brace**
X-direction	65.20%	62.79%
Y-direction	60.39%	56.52%
Average	62.80%	59.66%

B. Story Drift Result

As is observed from Table 9, the addition of steel bracing can reduce displacement with a maximum displacement reduction of 59.66% in the inverted V brace and 58.22% in V brace shape. This is similar to research conducted in Bangladesh, where unbrace structures had higher displacement than cross-brace and eccentrically brace structures [27].

TABLE IX
MAXIMUM LATERAL DISPLACEMENT

Type	**Maximum displacement (mm)**	**% Reduction in Displacement**
Unbraced	47.646	-
Inverted V Brace	19.221	59.66%
V Brace	19.9045	58.22%

On the other hand, the displacement value in this research is lower than the single diagonal brace, with a maximum displacement reduction value of 68.43% [28]. So, it can be concluded that steel bracing is suitable for strengthening and retrofitting existing structures.

TABLE X
STORY DRIFT RESULT

Storey	**Unbraced**		**Braced**				**Drift Limit**
			Inverted V Brace		**V Brace**		
	Δx (mm)	**Δy (mm)**	**Δx (mm)**	**Δy (mm)**	**Δx (mm)**	**Δy (mm)**	**(mm)**
8	12.39	36.43	9.19	16.52	11.49	19.90	61.54
7	11.01	18.74	8.27	13.96	10.07	17.00	61.54
6	16.49	22.06	9.75	15.65	11.19	18.22	61.54
5	22.25	30.64	10.79	17.12	12.07	19.64	61.54
4	27.18	36.87	10.96	16.67	12.18	19.51	61.54
3	35.23	48.94	10.20	14.50	11.53	18.06	61.54
2	103.75	68.37	9.19	11.29	10.66	15.88	61.54

TABLE XI
STORY DRIFT EFFECTIVITY

Storey	**Bracing Effectiveness**			
	Inverted V Brace		**V Brace**	
	X direction	**Y direction**	**X direction**	**Y direction**
8	25.83%	54.65%	7.28%	45.37%
7	24.84%	25.50%	8.55%	9.30%
6	40.88%	29.05%	32.18%	17.41%
5	51.50%	44.11%	45.76%	35.89%
4	59.69%	54.79%	55.18%	47.09%
3	71.05%	70.38%	67.26%	63.11%
2	91.14%	83.48%	89.73%	76.77%
Average	52.13%	51.71%	43.70%	42.13%
	51.92%		42.92%	

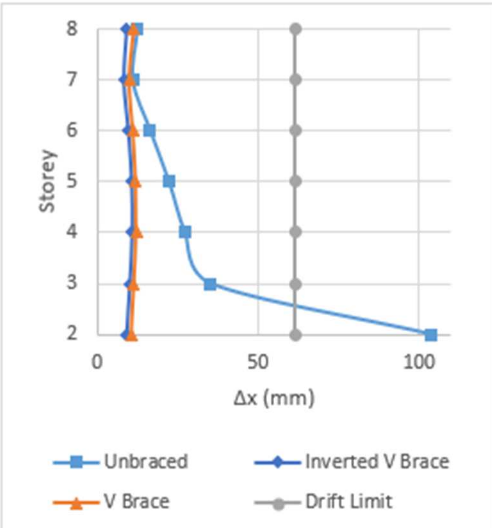

Fig. 9 Storey Drift for X-direction

As is observed from Table 10, Figure 9, and Figure 10 the 2nd's storey drift in unbraced structure crosses drift limit in both X and Y direction, which means the building is unsafe and unstable. And after applying steel bracing, it shows a significant decrease of drift in all stories, with a reduction by 51.92% for inverted V brace and 42.92% for V brace.

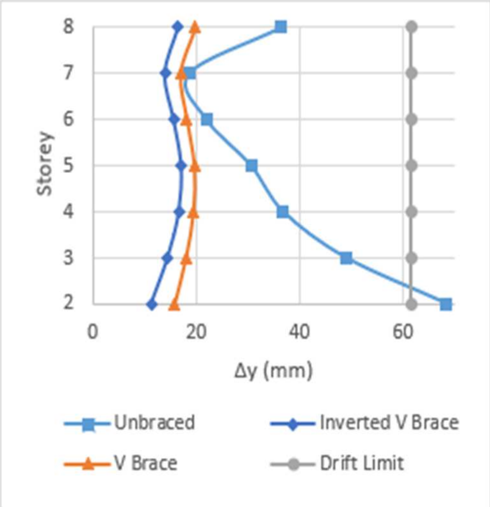

Fig. 10 Storey Drift for Y- direction

This is in accordance with a study conducted in India where after additional mega X bracing there was a significant drift decrease with a reduction reaching 55.23% in y direction [29]. From table 11 explains the effectivity various bracing which the effectiveness of the Inverted V brace is more than the V brace. It can be concluded that Inverted V brace is more effective than V brace [30], [31].

C. P-Delta Effect Result

The P-Delta Effect parameter, as shown at Table 12 to table 13 that both types of bracing could significantly minimize the stability coefficient of P-Delta effect in the range of 0.002 to 0.009 with the effectiveness of 71.70% for inverted-V brace and 66.28% for V brace shape. This value is very small compared to research conducted in India, where the value of the stability coefficient for all bracing types is in the range 0.05 to 0.1. However, this value is still below the P-Delta limit, so it can be concluded that the structure is still stable [32].

TABLE XII
P-DELTA EFFECT

Storey	Unbraced		Braced				P-Delta Limit	Structural Stability Limit θmax
			Bracing Λ		Bracing V			
	Stability Coefficient							
	θX	θY	θX	θY	θX	θY		
8	0.006	0.014	0.002	0.004	0.003	0.005	0.100	0.09091
7	0.006	0.009	0.003	0.004	0.003	0.005	0.100	0.09091
6	0.011	0.013	0.003	0.005	0.004	0.006	0.100	0.09091
5	0.015	0.019	0.004	0.007	0.005	0.008	0.100	0.09091
4	0.020	0.026	0.005	0.007	0.005	0.009	0.100	0.09091
3	0.027	0.037	0.005	0.007	0.006	0.009	0.100	0.09091
2	0.088	0.058	0.005	0.006	0.006	0.009	0.100	0.09091

TABLE XIII
P-DELTA EFFECT BRACE EFFECTIVITY

Storey	Inverted V Brace		V Brace	
	X direction	Y direction	X direction	Y direction
8	63.66%	72.05%	55.30%	65.74%
7	60.13%	55.22%	51.86%	44.61%
6	66.91%	57.09%	62.10%	49.29%
5	71.63%	65.60%	68.24%	60.07%
4	75.38%	71.42%	72.59%	66.29%
3	81.43%	80.56%	78.98%	75.71%
2	93.97%	88.76%	93.01%	84.18%
Average	71.70%		66.28%	

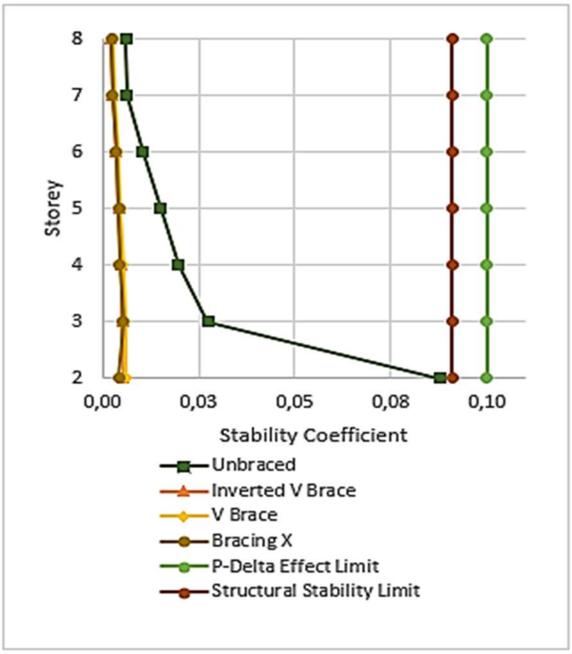

Fig. 11 P-Delta Effect for X Direction

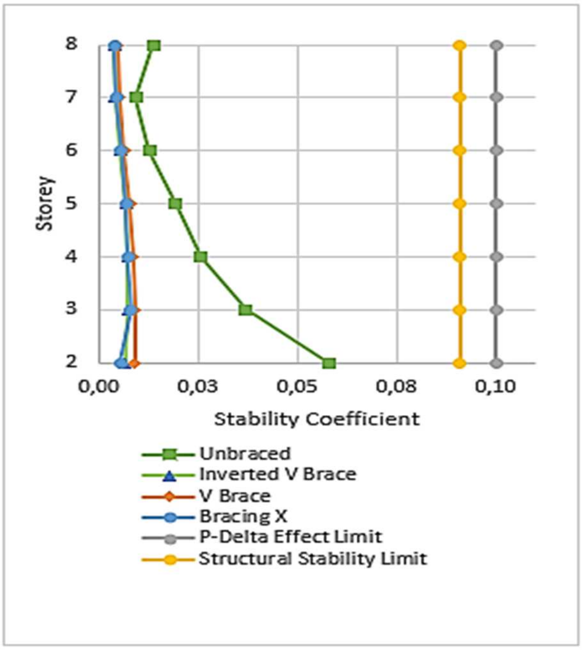

Fig. 12 P-Delta Effect for Y Direction

D. *Horizontal Torsion Irregularities Result*

Table 14 show that in unbraced structure has A1 horizontal torsion irregularities in Y-direction so it can be said that structure is unstable in Y-direction, structure with torsion irregularities would experience severe damage during an earthquake, this will result in minor or major damage and even structural failure. However, after the addition of steel braces the results are more stable which shows that for the X and Y directions there are no A1 horizontal torsion irregularities or it can be said that the addition of bracing can minimize the occurrence of torsion in the building [33]. According to the four parameters, bracing could improve the structural capacity in resisting applied loads [34]. Inverted V braces have a good performance compared to V brace shape.

TABLE XIV
HORIZONTAL TORSION IRREGULARITIES RESULT

Storey	Unbraced		Inverted V Brace		*V Brace*	
	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
	$\Delta_{max}/\Delta_{avg}$					
8	1.07	1.256	1.089	1.061	1.052	1.078
7	1.13	1.321	1.117	1.169	1.109	1.129
6	1.11	1.303	1.105	1.162	1.104	1.135
5	1.1	1.289	1.100	1.157	1.101	1.135
4	1.09	1.279	1.096	1.153	1.099	1.134
3	1.09	1.276	1.089	1.150	1.096	1.133
2	1.05	1.277	1.073	1.139	1.088	1.127
Control	OK	H.1a	OK	OK	OK	OK

IV. CONCLUSION

The conclusions of this research are limited to the results of the structural analysis of The State Finance Building II Semarang, using the reinforcement method of inverted V and V-shaped bracing. The addition of steel bracing can reduce the time period of the structure, where a shorter time period will reduce the structure's flexibility and can mean that the structure becomes more stable compared to unbraced structure. With the addition of steel bracing, it can reduce displacement related to story drift with a maximum displacement reduction of 59.66% for inverted V brace. The addition of steel braces can minimize the occurrence of torsion in the building. Steel bracing reduces the bending and shear loads that occur in beams and columns by transferring lateral loads through the axial load mechanism. From the above results, the inverted V brace is very effective in minimizing displacement and time period compared to the V brace.

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