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Performance Analysis of Steel Portal Structures with Braces Designed Based on Allowable Interstory Drift Limits

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Abstract. The earthquake resistant steel frame structure is designed to be able to withstand large inelastic deformations in the case of an earthquake. The applicable regulations still allow the use of elastic design methods in the form of pushover analysis and time history analysis evaluation as the basis for the design. The building under consideration consists of six floors with the function as an office building. The location of the building is in Banda Aceh with soft soil conditions. The structural analysis used the help of the Extended Three Dimensional Analysis of Building System Program (ETABS). The method of analysis of steel portal structures used was pushover analysis. Analysis of the given load was static loading based on 1987 PPPURG, and earthquake dynamic loading used a variety of response spectrum procedure analysis based on SNI 03-1726-2012. Structural analysis was assumed to be the strong column weak beam concept. From the results of calculations, it is found that the steel portal structures (with and without braces) designed based on allowable interstory drift limits have met the requirements. The performance level of the steel portal structure without bracing was LS, while the performance level of the steel portal structure using bracing was IO. The largest amount of steel used in terms of weight was found in the case of a portal without braces.

Keywords: pushover analysis, steel portals, bracing, interstory drift, strong column weak beam.

***Abstrak**. Struktur rangka baja tahan gempa dirancang untuk menahan deformasi inelastis yang besar dalam gempa bumi. Peraturan yang berlaku masih memungkinkan penggunaan desain elastis dalam bentuk analisis pushover dan evaluasi analisis sejarah waktu sebagai dasar untuk desain. Bangunan yang dipertimbangkan terdiri dari enam lantai dengan fungsi sebagai gedung kantor. Lokasi bangunan berada di Banda Aceh dengan kondisi tanah yang lunak. Analisis struktural menggunakan bantuan Extended Three Dimensional Analysis of Building System Programme (ETABS). Metode analisis struktur portal baja yang digunakan adalah analisis pushover. Analisis beban yang diberikan adalah pembebanan statis berdasarkan PPPURG 1987, dan pembebanan dinamis gempa menggunakan berbagai analisis prosedur spektrum respons berdasarkan SNI 03-1726-2012. Analisis struktural diasumsikan sebagai konsep balok lemah kolom kuat. Dari hasil perhitungan, ditemukan bahwa struktur portal baja (dengan dan tanpa kawat gigi) yang dirancang berdasarkan batas drift interstory yang diijinkan telah memenuhi persyaratan. Tingkat*

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kinerja struktur portal baja tanpa bracing adalah LS, sedangkan tingkat kinerja struktur portal baja menggunakan bracing adalah IO. Jumlah baja terbesar yang digunakan dalam hal berat ditemukan dalam kasus portal tanpa kawat gigi.

***Kata kunci**: analisis pushover, portal baja, bracing, drift interstory, balok lemah kolom kuat.*

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1 Introduction

The earthquake resistant steel frame structure is designed to be able to withstand large inelastic deformations in the case of an earthquake. The applicable regulations still allow the use of elastic design methods in the form of nonlinear static (pushover analysis) and nonlinear analysis (time history analysis) evaluation as the basis for the design [1]. The Earthquake Resistant steel frame structure consists of moment resisting frame and braced frame. The pushover analysis method is one component of performance-based design to determine the capacity of a structure [2]. Pushover analysis is a nonlinear static analysis in which the effect of the earthquake plan on the structure of the building is considered as static loads that capture the mass center of each floor with the value gradually increased until it exceeds the loading and first causes the yielding of the joint (plastic joint) in the structure of the building, then with an increase in load, it undergoes a large change in post-elastic shape until it reaches the expected transition target or until it reaches a plastic condition. In the pushover process, the structure is pushed until it has yielded in one or more locations in the structure [3]. The capacity curve will show a linear condition before it reaches the yielding condition and then behaves nonlinearly. The problem statement is focused on pushover analysis that occurs in steel portals using bracing and steel portals without bracing [4].

Building structure analysis was carried out in 2 dimensions with the help of ETABS software, earthquake load calculations were referring to SNI regulations 03-1726-2012 (earthquake resistance planning procedures for building structures and non-building structures), loading calculations was referring to SKBI regulations 1.3.53.1987 (loading planning guidelines for houses and buildings) [5]. The method of analysis of steel portal structures used was pushover analysis, the structure system analyzed was a Special Moment Resisting Frame, the building is modeled and analyzed with steel portals without bracing, steel portals with outer irregular bracing, steel portals with inner irregular bracing, and steel portals with irregular bracing, the building in this study only has 6 floors [6] . The purpose the writing is to analyze the performance of steel portal structures without bracing, steel portal structures using outer irregular bracing, steel portal structures using inner irregular bracing, steel portal structures using irregular bracing, pushover shearing forces, plastic joints, interstory drift, and optimization use of steel material. The benefits of this writing are to be able to provide information and understanding of pushover analysis, as a guide on how to evaluate the performance of steel portal structures in multilevel buildings based on SNI 03-1726-2012 [5], to give an overview of the behavior of steel portal building structures analyzed using bracing and without bracing.

2 Methods

The method of analysis of steel portal structures used is pushover analysis. The structure of the system analyzed was in the form of a special moment resisting frame system [7]. The building is modeled and analyzed with steel portals without bracing, steel portals with outer irregular bracing, steel portals with inner regular bracing, and steel portal with irregular bracing.

2.1 Steel portal design and material planning

Steel portal design planning includes the function of the building as an office, the location of the building is in Banda Aceh [8]. The structural system used is a Special Moment Resisting Frame system, the highest elevation is 22 m, This is a 6th floor building, ground floor height is 4.5 m and other typical floor height is 3.5 m, with a building area of 1968.75 m2. The steel material used ASTM A992 with a yield stress of 350 MPa, ultimate stress of 450 MPa, and modulus of elasticity of 200.000 Mpa [9].

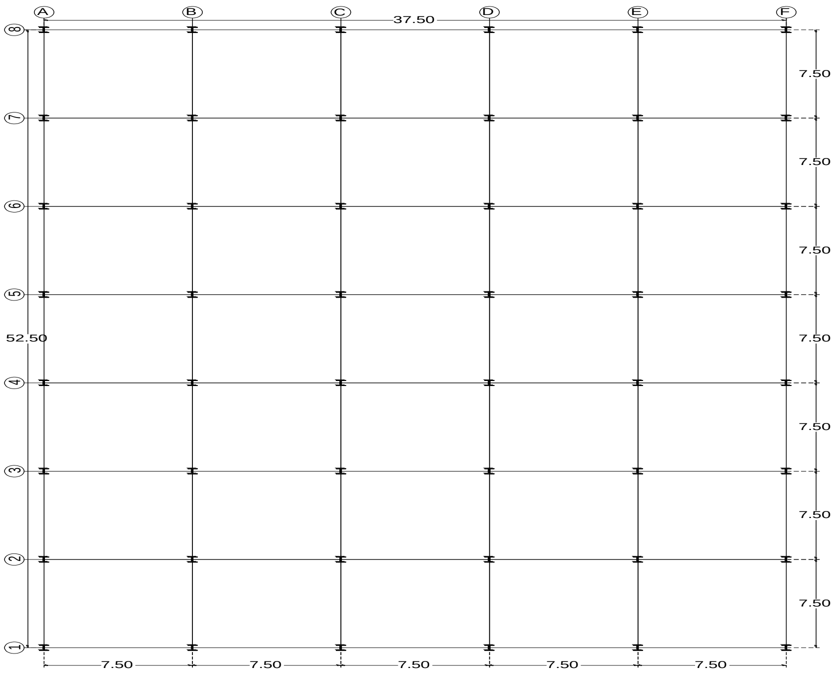


Figure 1. Steel Portal Structure Plan

2.2 Steel portal structural elements planning

Table 1. Steel Portal Structure Elements without Bracing [10]

Story Number	Beam	Column
1	W24X94	W14X398
2	W24X94	W14X398
3	W21X93	W14X342
4	W21X93	W14X342
5	W18X97	W14X283
6	W18X97	W14X283

Table 2. Steel Portal Structure Elements with Bracing [10]

Story Number	Beam	Column	Bracing
1	W21X73	W14X257	W10X30
2	W21X73	W14X257	W10X30
3	W18X71	W14X211	W10X30
4	W18X71	W14X211	W10X30
5	W16X40	W14X176	W10X30
6	W16X40	W14X176	W10X30

2.3 Modeling of structures

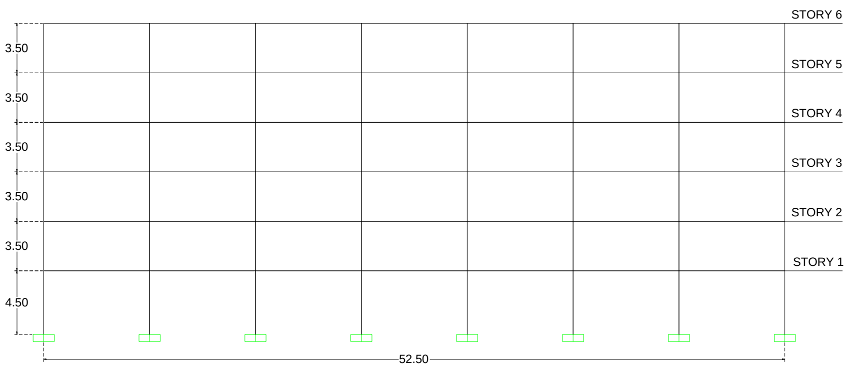


Figure 2. Steel Portal Structure without Bracing in y-direction

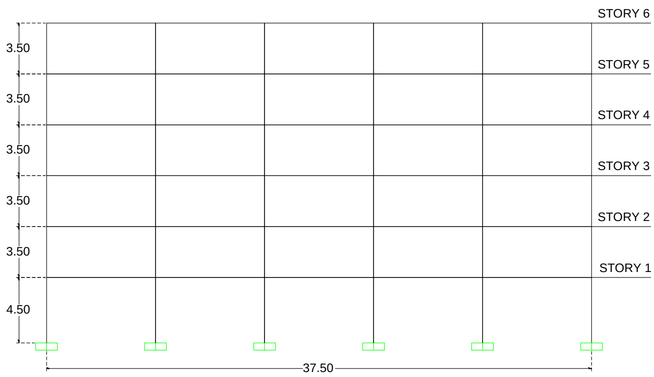


Figure 3. Steel Portal Structure without Bracing in x-direction

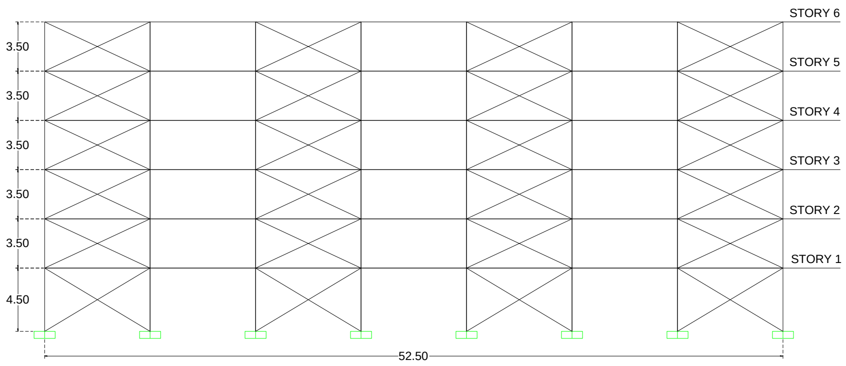


Figure 4. Steel Portal Structure with Outer Regular Bracing in y-direction

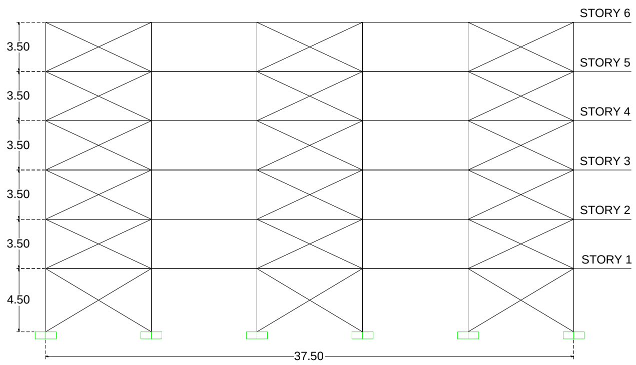


Figure 5. Steel Portal Structure with Outer Regular Bracing in x-direction

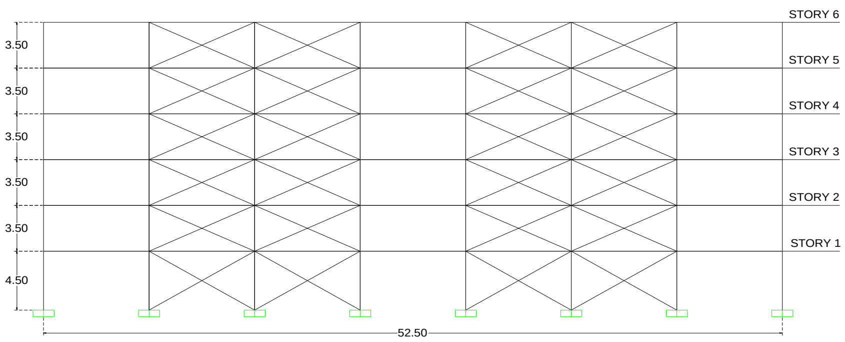


Figure 6. Steel Portal Structure with Inner Regular Bracing in y-direction

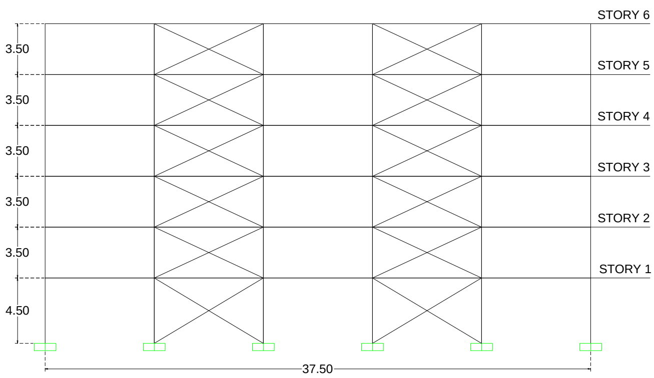


Figure 7. Steel Portal Structure with Inner Regular Bracing in x-direction

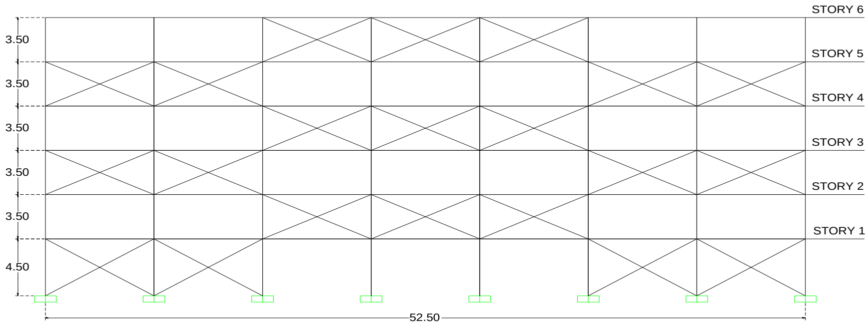


Figure 8. Steel Portal Structure with Irregular Bracing in y-direction

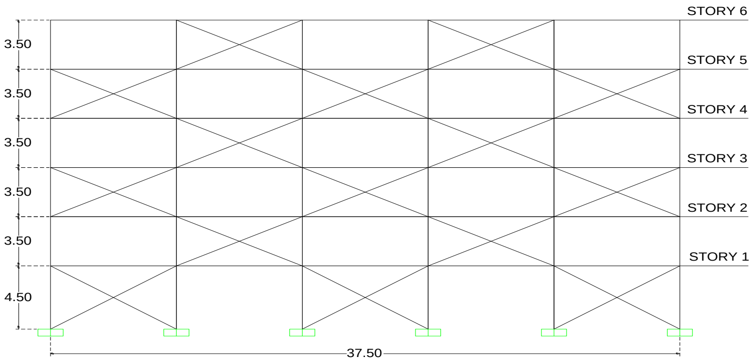


Figure 9. Steel Portal Structure with Irregular Bracing in x-direction

2.4 Loading

The combination of loading that is included in the modeling must be based on the applicable loading standards in Indonesia [11]. The weight of the steel portal structure is calculated using the ETABS program, an additional dead load of 1.5 kN, and a live load of 4.5 kN [12].

2.5 Acceleration of the spectral response design

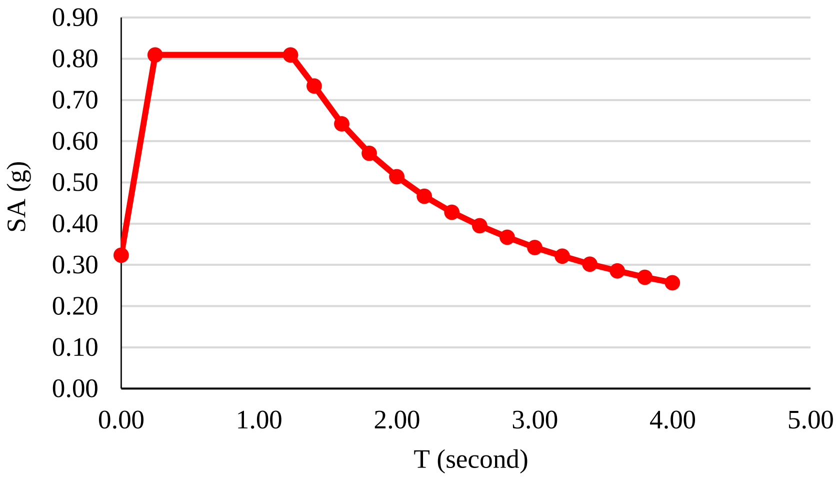


Figure 10. Graph of Soft Soil (SE) Spectrum Response Design, Located in Banda Aceh

3 Results and Discussions

3.1 Comparison between interstory drift of steel portal structures using bracing and without bracing in x-direction

From the calculation results of the limit performance analysis for the interstory drift of the steel portal structure with bracing and without bracing x-direction, the comparison of the interstory drift can be seen in Figure 11.

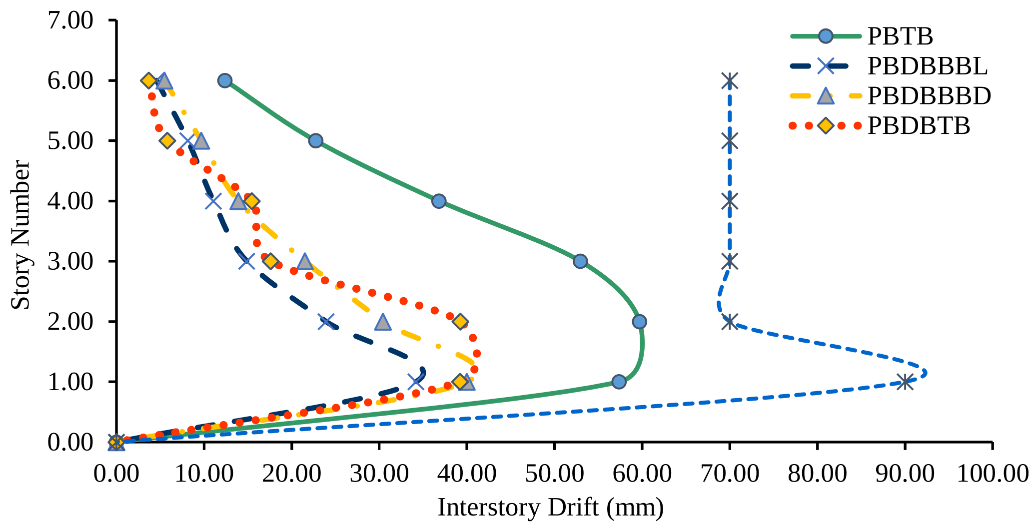


Figure 11. Allowable Interstory Drift Limits of Steel Portal Structure in x-direction

Based on the data in Figure 11, the results of the interstory drift analysis of steel portal structures without bracing and steel portal structures with bracing all meet the allowable interstory drift limits. From the figure above the deviation value between the steel portal structure without bracing is greater than the steel portal structure using bracing [13]. The steel portal structure that is designed based on the permissible cross-floor deviation permit used is the steel portal structure using the outer bracing [14].

3.2 Comparison between of interstory drift of steel portal structures using bracing and without bracing in y-direction

From the calculation results of the limit performance analysis for the interstory drift of the steel portal structure with bracing and without bracing y-direction, the comparison of the interstory drift can be seen in Figure 12.

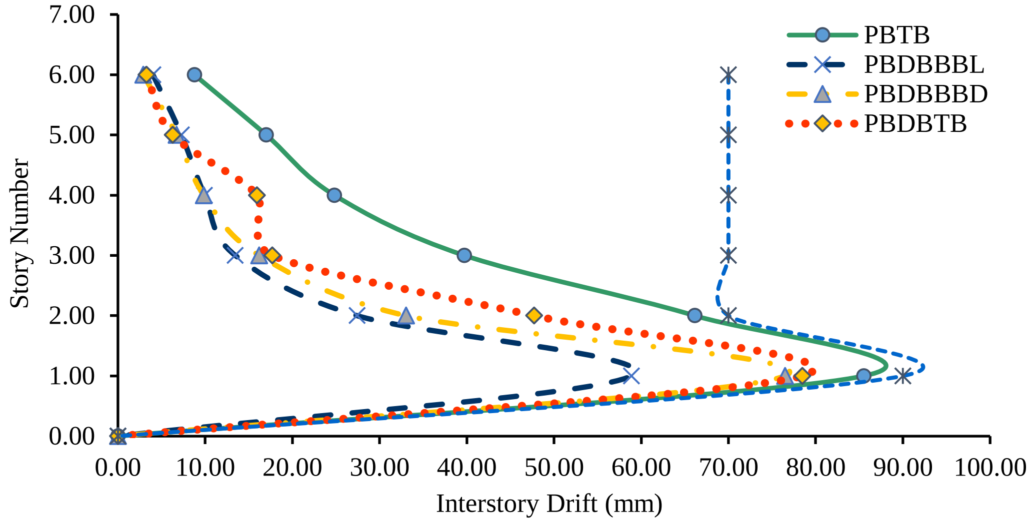


Figure 12. Allowable Interstory Drift Limits of Steel Portal Structure in y-direction

Based on the data in Figure 12, the results of the interstory drift analysis of steel portal structures without bracing and steel portal structures with bracing all meet the allowable interstory drift limits. From the figure above the deviation value between the steel portal structure without bracing is greater than the steel portal structure using bracing [15]. The steel portal structure that is designed based on the permissible cross-floor deviation permit used is the steel portal structure using the outer bracing [16].

3.3 Comparison between of pushover curves of steel portal structures using bracing and without bracing in x-direction

From the results of pushover analysis of steel portal structures using bracing and without bracing x-direction, the comparison of the pushover curve can be seen in Figure 13.

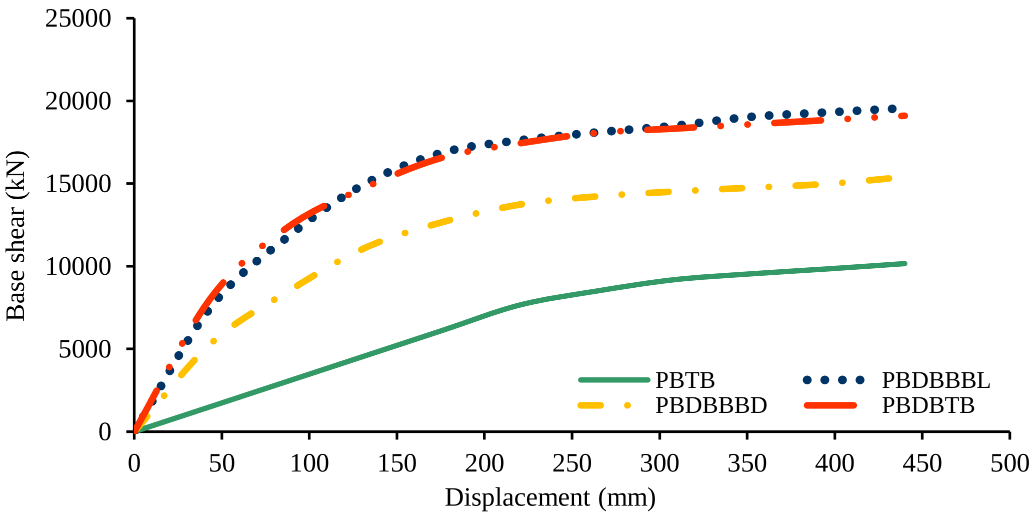


Figure 13. Comparison of Base Shear with Displacement in x-direction

Based on the data in Figure 13, the comparison of base shear with x direction displacement on steel portal structure without bracing was 10163.43 kN, steel portal structure using outer regular bracing was 19563.70 kN, steel portal structure using inner regular bracing was 15398.65 kN, steel portal structure using an irregular bracing was 19104.10 kN, the pushover curve in the figure above shows that there is a difference in the pushover curve on the steel portal structure without bracing and the steel portal structure using bracing [17]. The ultimate basic shear force (basic shear force before experiencing a decrease in strength) that occurs in the steel portal structure with bracing is much greater [18].

3.4 Comparison between of pushover curves of steel portal structures using bracing and without bracing in x-direction

From the results of pushover analysis of steel portal structures using bracing and without bracing y-direction, the comparison of the pushover curve can be seen in Figure 14.

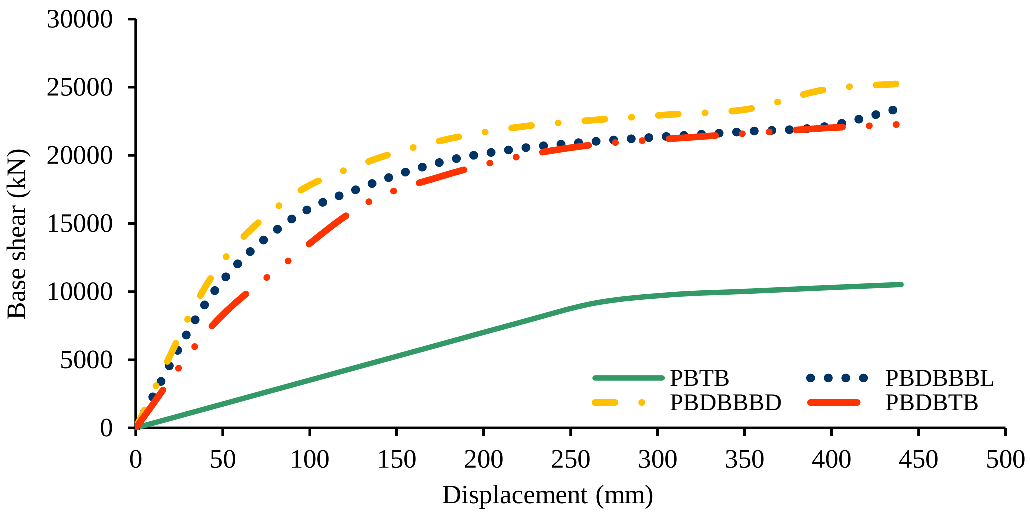


Figure 14. Comparison of Base Shear with Displacement in y-direction

Based on the data in Figure 14, the comparison of base shear with x direction displacement on steel portal structure without bracing was 10522.56 kN, steel portal structure using outer regular bracing was 23474.45 kN, steel portal structure using inner regular bracing was 25269.63 kN, steel portal structure using an irregular bracing was 22278.42 kN, the pushover curve in the figure above shows that there is a difference in the pushover curve on the steel portal structure without bracing and the steel portal structure using bracing. The ultimate basic shear force (basic shear force before experiencing a decrease in strength) that occurs in the steel portal structure with bracing is much greater.

3.5 Structural performance level

Each model produces various levels of structural performance [19]. The performance level of steel portal structure using bracing and without bracing for the x-direction and y-direction can be seen in Table 3, Table 4, Table 5, and Table 6.

Table 3. Elements of the Steel Portal Structure Without Bracing

Model	Category	x-direction	y-direction
PBTB	Pushover step i	8	7
	Performance point Δ_i (mm)	352	308
	Basic shearing force V_i (kN)	9543,83	9102,65
	Building performance level	IO-LS	IO-LS
	Average structure performance	IO	IO

Table 4. Elements of the Steel Portal Structure With Outer Regular Bracing

Model	Category	x-direction	y-direction
PBDBBBL	Pushover step i	3	6
	Performance point Δ_i (mm)	132	264
	Basic shearing force V_i (kN)	15001.25	21022.83
	Building performance level	LS-CP	LS-CP
	Average structure performance	LS	LS

Table 5. Elements of the Steel Portal Structure with Inner Regular Bracing

Model	Category	x-direction	y-direction
PBDBBBD	Pushover step i	3	5
	Performance point Δ_i (mm)	132	220
	Basic shearing force V_i (kN)	11124.69	22073.40
	Building performance level	LS-CP	LS-CP
	Average structure performance	LS	LS

Table 6. Elements of the Steel Portal Structure With Irregular Bracing

Model	Category	x-direction	y-direction
PBDBTB	Pushover step i	3	3
	Performance point Δ_i (mm)	132	132
	Basic shearing force V_i (kN)	14768.11	16457.43
	Building performance level	LS-CP	LS-CP
	Average structure performance	LS	LS

3.6 Plastic joint distribution scheme

The plastic joint distribution scheme in the pushover analysis [20] shown in the figure below shows the behavior of the planned structure.

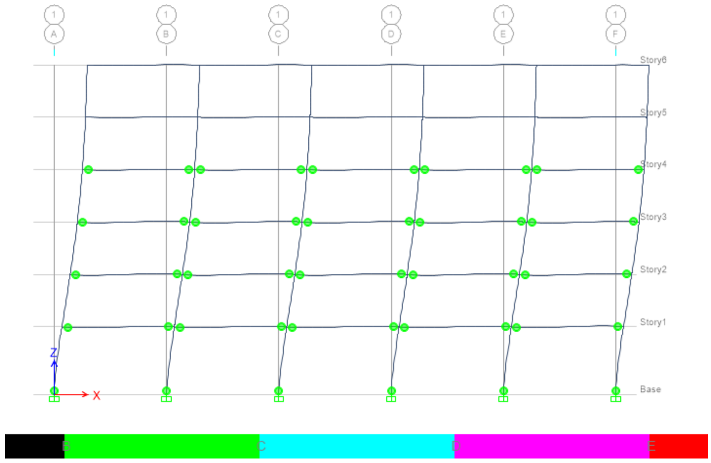


Figure 15. Plastic Joints of Steel Portal without Bracing in x-direction

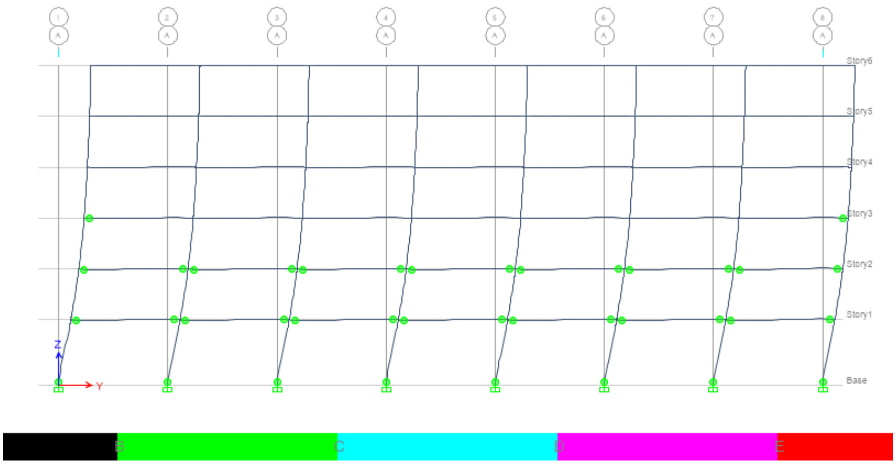


Figure 16. Plastic Joints of Steel Portal without Bracing in y-direction

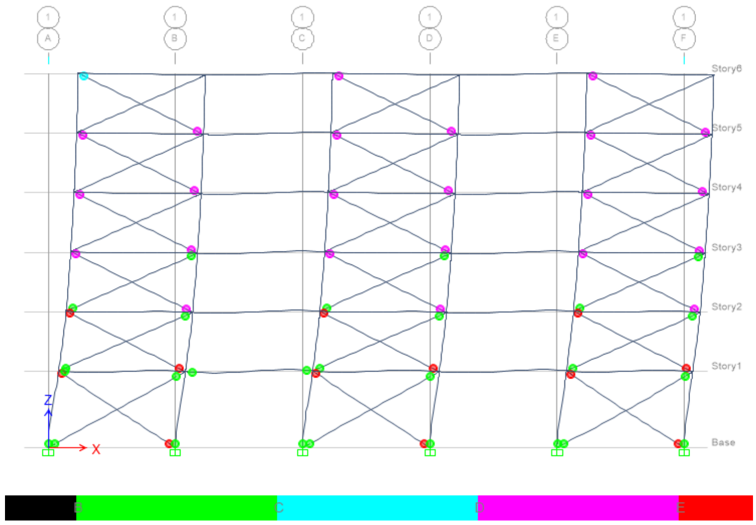


Figure 17. Plastic Joints of Steel Portal Structure with Outer Regular Bracing in x-direction

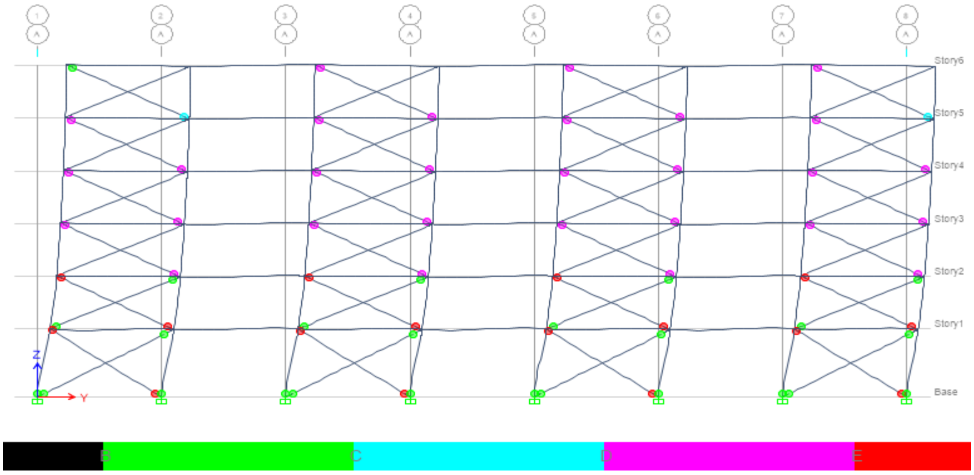


Figure 18. Plastic Joints of Steel Portal Structure with Outer Regular Bracing in y-direction

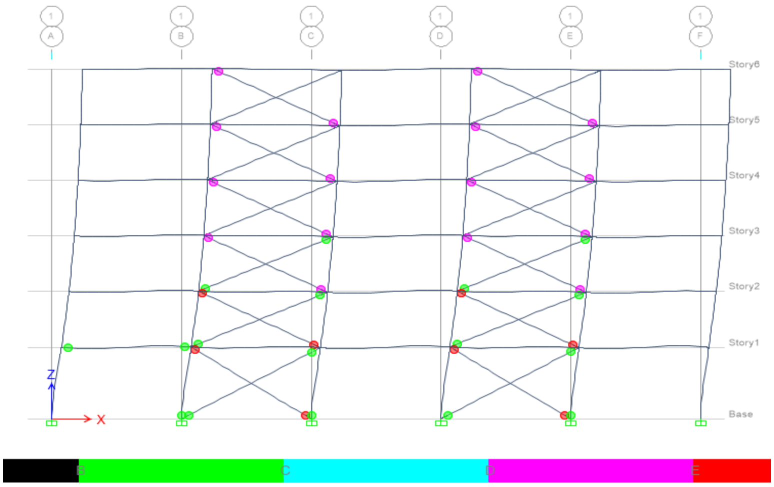


Figure 19. Plastic Joints of Steel Portal Structure with Inner Regular Bracing in x-direction

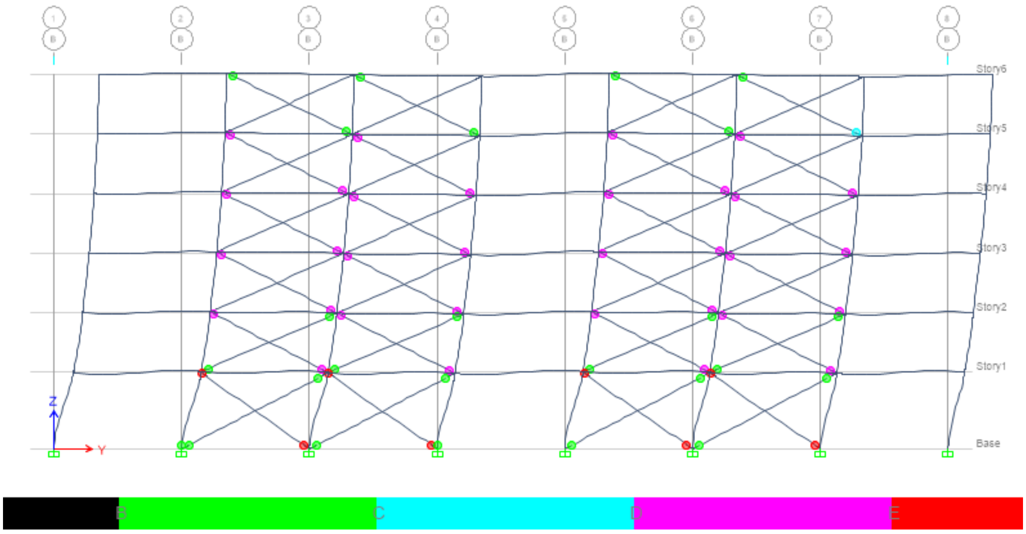


Figure 20. Plastic Joints of Steel Portal Structure with Inner Regular Bracing in y-direction

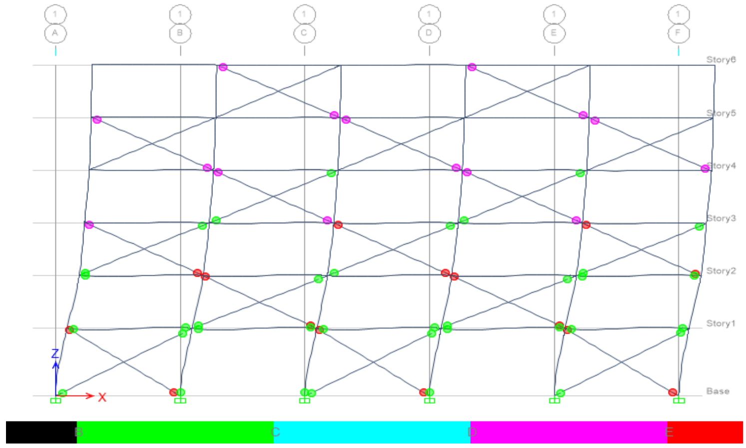


Figure 21. Plastic Joints of Steel Portal Structure with Irregular Bracing in x-direction

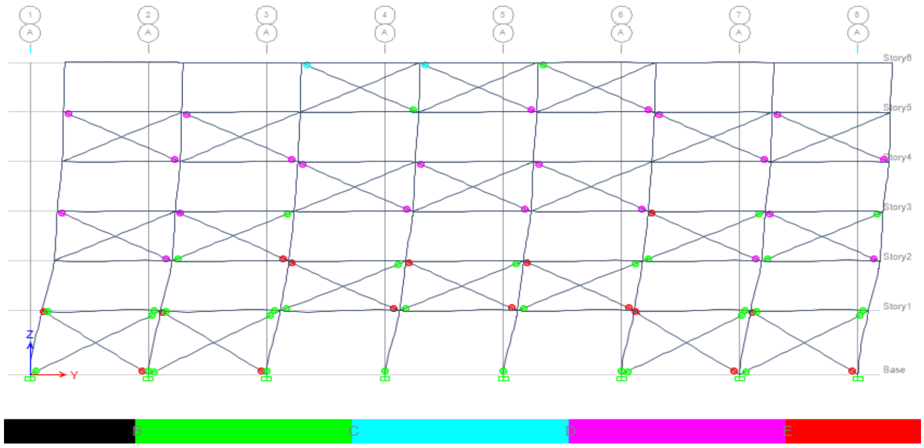
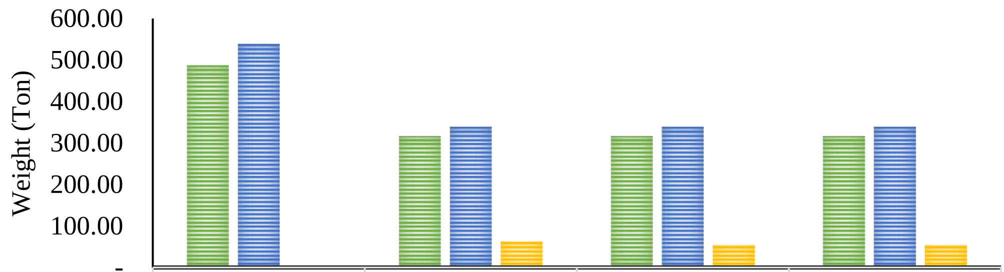


Figure 22. Plastic Joints of Steel Portal Structure With Irregular Bracing in y-direction

3.7 Evaluation of the use of steel material in steel portal structures

The weight of structural elements of steel portal obtained from the analysis with the ETABS program can be seen in Figure 23.



	PBTB	PBDBBBL	PBDBBBD	PBDBTB
Beam	487.06	316.35	316.35	316.35
Column	538.72	338.71	338.71	338.71
Bracing	-	62.08	53.56	53.65

Type of Steel Portal

Figure 23. The Weight of Structural Elements of Steel Portal (Ton)

Based on data Figure 23, The weight of structural elements of steel portal without bracing (PBTB) was 1025.78 Ton, of steel portal with outer regular bracing (PBDBBBL) was 717.14 Ton, steel portal with inner regular bracing (PBDBBBD) was 708.62 Ton, and steel portal with irregular bracing (PBDBTB) was 708.70 Ton. The largest use of the steel material on the steel portal without bracing was 1025.78 Ton, where the steel portal structure without bracing is greater the use of steel material by designing the column profile is greater than the beam profile to meet the concept of strong column weak beam. In the steel portal structure using bracing, it is re-evaluated that the use of steel material in the column profile can be reduced by the steel portal structure using bracing, so that the steel portal structure using bracing uses less steel. From the results of the analysis of the use of efficient steel material used is steel portal with inner regular bracing.

4 Conclusion

1. Mass participation control for buildings without bracing and using bracing has fulfilled the requirements with a mass participation value exceeding 90%.
2. Comparison of the x-direction and y-direction pushover curves in the steel portal structure without bracing using bracing, the ultimate shear forces that occur in the steel portal structure using bracing are much larger can be seen in Table 7.

Table 7. Comparison of Pushover Curves

No.	Model	Base shear (kN)	
		x-direction	y-direction
1	PBTB	10163,43	10522,56
2	PBDBBBL	19563,70	23474,45
3	PBDBBBD	15398,65	25269,63
4	PBDBTB	19104,10	22278,42

3. Deviation values between steel portal floors without bracing for x-direction with an average of 55% and for y direction with an average of 53%.
4. A comparison of the value of the deviation between the steel portal floor without bracing with steel portal using bracing can be seen in Table 8.

Table 8. Comparison of Deviations between Floors

No.	Model	Base Shear (kN)	
		x-direction	y-direction
1	PBDBBBL	62%	55%
2	PBDBBBD	52%	51%
3	PBDBTB	56%	42%

5. Steel portal with outer regular bracing is good to be used on the concept of the performance of the steel portal structure which is designed based on the boundary between the floor permits.
6. The performance level of the steel portal structure without bracing is IO (Immediate Occupancy), the damage caused by the earthquake is very small. The vertical and horizontal forces of a building can withstand all the strength from earthquake and structural stiffness. The risk of loss of life as a result of structural damage is very low, although some minor nonstructural repairs are still needed.
7. The performance level of steel portal structures using bracing is LS (Life Safety), structural damage occurs after an earthquake, but partial or complete collapse of the building does not occur. Some structural elements and components are damaged. The risk of loss of life as a result of structural damage is expected to be low. It is possible to improve the structure, even though it is economically not implemented. When damage to the structure does not approach the risk of collapse, the careful repair is needed.
8. The use of the largest steel material in steel port without bracing is 1025.78 Ton where the steel portal structure without bracing is greater in the use of steel material by designing a column profile larger than the beam profile to meet the concept of strong column weak beam.

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