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Structural Design of Steel-Framed Warehouse Buildings

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A B S T R A C T

In the "Steel Structure Building" course, Civil Engineering students are given a major project to design the structure of a shopping center in Bandung using steel as the primary material. The design specifications include BJ34 steel, a building height of 8 meters with two floors, and a 5-meter distance between beams. SAP2000 v22 software is used to analyze dead loads, live loads, and seismic forces. The structure incorporates the following steel profiles: columns (H 400 x 400), beams (IWF 400 x 200), trusses (IWF 400 x 200 channels), purlins (C 200 x 80 channels), and bracing (angle 100 x 100), all of which have been tested for load resistance. This steel structure design results in a safe and stable building model that meets real construction standards.

INTRODUCTION

The construction industry in Indonesia is growing rapidly, influenced by several factors, including the types of materials used. Steel is one of the materials now frequently chosen by industry professionals because it offers several advantages over other materials. Steel enables shorter construction times through fabrication, has a high strength-to-weight ratio that reduces the overall weight of the structure, and is highly ductile, allowing it to withstand significant deformation. The use of steel is increasingly evident in building construction, including in workshop buildings that serve industrial functions like production and other activities.

In effective construction planning, especially for earthquake-resistant structures, several design factors must be carefully considered. Civil engineering students, therefore, need to understand steel structure design techniques, which are taught in the "Steel Structure Building" course. One of the major projects in this course involves designing the structure of a shopping center located in Bandung, West Java, where the workshop building will be designed according to a specified layout. The building structure consists of two floors with a height of 8 meters and a 5-meter spacing between beams, using BJ34-grade steel.

In this design, various loads are considered, including dead loads, live loads, and seismic loads. The construction uses BJ34-grade steel, A-490 grade bolts, a multiroof roof with a 90 cm purlin spacing, and additional data, such as a wind speed of 20 m/s. The primary goal of this project is for students to be able to design a multi-story steel structure, understand the fundamental concepts of steel structure design, and create a steel structure model that meets load criteria and the necessary element specifications. This process is supported by various references and software, including SNI 03-1726-2012 for earthquake resistance, SNI 1727-1989 for load planning, as well as AutoCAD 2010 for design drafting, SAP 2000 V22 for structural force and moment analysis, and Microsoft Excel and Microsoft Word for data processing and report preparation.

LITERATURE REVIEW

Structural Modeling Method

To simplify the modeling of a building structure intended to function as a workshop, SAP 2000 v22 software is used, specifically developed for construction modeling. This program enables fast and accurate analysis and design of building structures.

In this project, the structural model of a building designed as a workshop will feature a steel frame structure with a span length of 20 meters, a width of 15 meters, and a roof slope of 20 degrees. The 20-meter span will be divided into 4 sections, while the 15-meter width will be divided into 3 sections.

Below is a 3D view of the structural model for the workshop building:

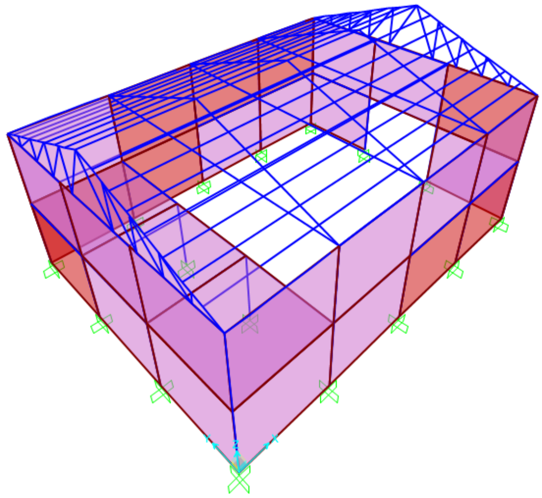


Figure 1. 3D View

Steel Material

Structural steel can be categorized by its strength into several types: BJ 34, BJ 37, BJ 41, BJ 50, and BJ 55. The yield strength (fy) and ultimate tensile strength (fu) of each type of structural steel, as specified in SNI 03-1729-2002, are shown in the table below:

Table 1. Steel Quality Specifications

Jenis Baja	Kuat Tarik Batas (fu) MPa	Tegangan Leleh (fy) MPa
BJ 34	340	210
BJ 37	370	240
BJ 41	410	250
BJ 50	500	290
BJ 55	550	410

The bolt material used for this major project, specified by the assisting professor, is A4 90. The materials specified by the professor for this project are as follows:

a. Roof Type: Multiroof
b. Maximum Purlin Spacing: 0.9 m
c. Steel Quality: BJ 34
d. Bolt Quality: A4 90

Additional data:
a. Wind Speed: 30 km/h
b. Building Function: Workshop

Steel Profile

The cross-section profiles used for each element in the workshop building are as follows:

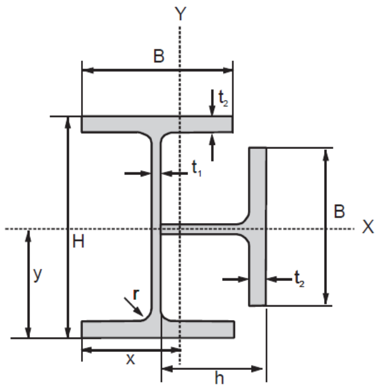


Figure 2. IWF Profile

The IWF profile, commonly known as an I-beam, is used as beams, columns, piles, top & bottom chord members in trusses, composite beams, and cantilever canopy structures in steel buildings. For structural planning, the profile dimensions shown in Table 2 below are used:

Table 2. IWF Profile in Building Structure

Informative Reference							
Center of Gravity		Geometrical Moment of Inertia		Radius of Gyration of Area		Modulus of Sectio	
x	y	I_x	I_y	i_x	i_y	Z_x	Z_y
mm	mm	cm^4	cm^4	cm	cm	cm^3	cm^3
57.3	75	691	310	5.08	3.4	92.1	53.99
76.6	100	1,907	848	6.84	4.56	190.7	110.72
76.1	99	1,637	722	6.86	4.56	165.3	94.86
95.9	125	4,197	1,844	6.82	5.71	335.8	192.34
95.4	124	3,670	1,599	8.65	5.71	296.0	167.62
114.7	150	7,464	3,260	10.31	6.82	497.6	284.16
114.2	149	6,545	2,842	10.34	6.81	439.3	248.76
134.5	175	14,092	6,096	12.2	8.02	805.3	453.30
133.3	173	11,496	4,978	12.07	7.94	664.5	373.37
153.9	200	24,570	10,661	13.95	9.19	1,228.4	692.79
152.8	198	20,725	8,984	13.84	9.11	1,047.2	588.07
159.3	225	34,436	15,472	15.4	10.02	1,530.5	914.48
165.2	250	48,871	20,386	16.89	10.91	1,954.8	1,234.3
175.7	300	78,739	32,097	19.76	12.62	2,624.6	1,826.7
229.7	294	122,509	53,713	20.6	13.64	4,167.0	2,338.0
243.7	350	206,406	86,629	24.17	15.66	5,897.1	3,555.3
255.1	400	297,859	121,518	27.25	17.41	7,446.3	4,763.9

Standard Sectional Dimension						Sectional Area	Unit Weight
Sectional Index	Depth of Section	Width of Section	Thickness		Corner Radius		
			Web	Flange			
	H	B	t_1	t_2	r	A	
mm	mm	mm	mm	mm	mm	cm^2	kg/m
Q 150 x 75	150	75	5	7	8	26.78	21
Q 200 x 100	200	100	5.5	8	11	40.74	32
Q 198 x 99	198	99	4.5	7	11	34.77	27.3
Q 250 x 125	250	125	6	9	12	56.49	44.4
Q 248 x 124	248	124	5	8	12	49.02	38.5
Q 300 x 150	300	150	6.5	9	13	70.17	55.1
Q 298 x 149	298	149	5.5	8	13	61.2	48.1
Q 350 x 175	350	175	7	11	14	94.71	74.4
Q 346 x 174	346	174	6	9	14	79.02	62.1
Q 400 x 200	400	200	8	13	16	126.18	99.1
Q 396 x 199	396	199	7	11	16	108.24	85
Q 450 x 200	450	200	9	14	18	145.14	114
Q 500 x 200	500	200	10	16	20	171.3	134.5
Q 600 x 200	600	200	11	17	22	201.6	158.3
Q 588 x 300	588	300	12	20	28	288.75	226.7
Q 700 x 300	700	300	13	24	28	353.25	277.4
Q 800 x 300	800	300	14	26	28	401.1	315

C Profile

The "C" Channel profile is used as the main frame in light steel truss construction. It is also used in supporting structures, such as purlins, which serve as the base for roof covering or tiles.

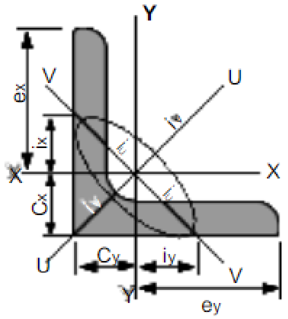


Figure 3. Siku Profile

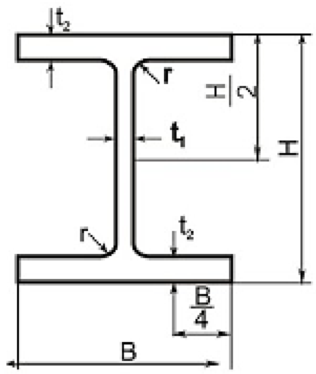


Figure 4. H-beam Profile

Loading

After the structural modeling, load assignments are made before performing the overall structural analysis.

1. Dead Load. Dead load refers to the weight of the workshop building structure itself, including the loads from its constituent elements, which in this case are made of steel.
2. Live Load. Live load refers to the load on the warehouse building structure that is assumed as follows: the live load on the floor slab is assigned as 400 kg, in accordance with the Indonesian load regulations for workshop buildings.
3. Roof Load. The roof load is based on the area, calculated by determining the Tributary Area in the region where the load is supported by the roof purlins. The roof load includes several components: the trusses weighing 39,250 AC, the bracing at 251,200 AC, the purlins at 109,900 Asiku, and the roof load itself, which is 12,752 kg.
4. Rain Load. According to the Indonesian Building Load Regulations of 1983, Section 3.2, the rain load occurs on the roof, with the magnitude of the load specified by the regulations.

Q = (40 – 0,8 x α) kg/m2
= (40 – 0,8 x 20)
= 24 kg/m2

Because this load exceeds the specified limit, it is not necessary to take a load greater than 20 kg/m².

5. Wind Load. The wind load on the building structure occurs on the roof and columns. According to existing regulations, since the structure is located far from the coastline, the wind load is calculated as q = 25 kg/m².
6. Earthquake Load. Earthquake load is a natural force that occurs due to movement in the earth's layers, causing ground acceleration that results in load on the structure due to the interaction between the ground and the structure, as well as the structural response characteristics. Earthquake load arises from this acceleration, meaning that the heavier the structure, the greater the earthquake load it will experience. The design earthquake load is set as an earthquake with a 2% probability of being exceeded over the 50-year lifespan of the structure. To design an earthquake-resistant building, several factors must be considered, including the importance factor and the risk category of the structure.

Load Combinations

For this steel project, the load combinations are shown in Table 3.

Table 3. Load Combinations

No	DL	LL	Ex	Ey	R	W
1	1.4					
2	1.2	1.6				
3	1.2	0.5	1	0.3		
4	1.2	0.5	1	-0.3		
5	1.2	0.5	-1	0.3		
6	1.2	0.5	-1	-0.3		
7	1.2	0.5	0.3	1		
8	1.2	0.5	0.3	-1		
9	1.2	0.5	-0.3	1		
10	1.2	0.5	-0.3	-1		
11	0.9		1	0.3		
12	0.9		1	-0.3		
13	0.9		-1	0.3		
14	0.9		-1	-0.3		
15	0.9		0.3	1		
16	0.9		0.3	-1		
17	0.9		-0.3	1		
18	0.9		-0.3	-1		
19	1.2	1.6			0.5	
20	1.2	1			0.5	1.6
21	1.2	1			0.5	-1.6
22	0.9					1.6
23	0.9					-1.6

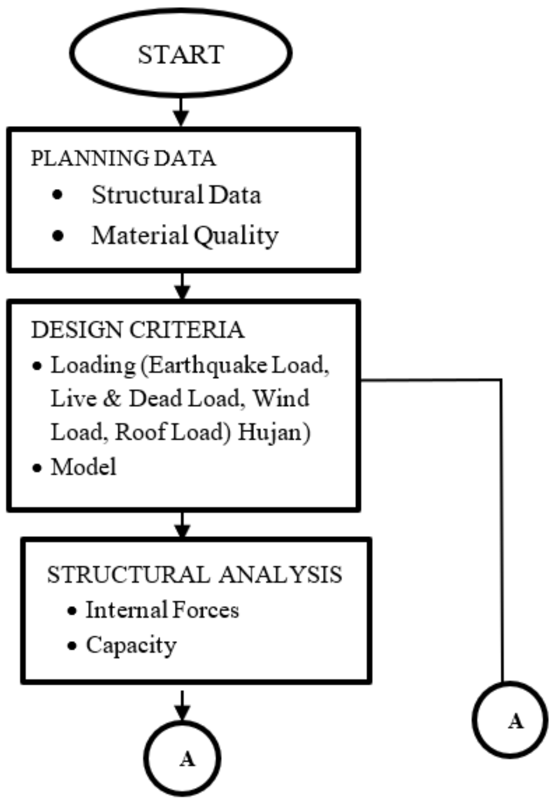
Selection of Section Profiles

In the image below, the light blue frames represent the frames that are well-designed, while the red frames indicate the frames that are less suitable. Therefore, to simplify construction and calculations, a single profile size is selected as the largest for each type of structure. The chosen profiles are as follows:

a. Columns use H 400-400-13-21
b. Beams use IWF 400-200-8-13
c. Purlins use C 200-80-7.5-11
d. Bracing uses SIKU 100-100-5-10
e. Trusses use IWF 400-200-8-13

METHODOLOGY

In designing a building structure, a structured approach is needed to facilitate the construction process. The stages followed by the author in this project can be seen in the image below:



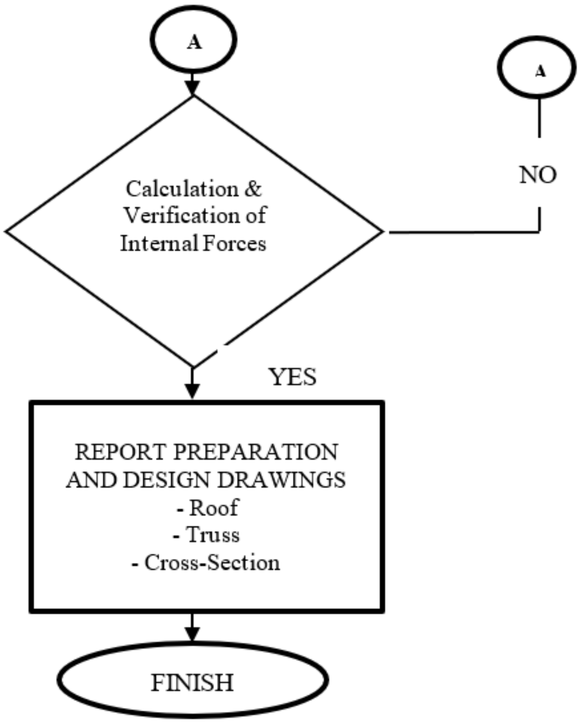


Figure 5. Conceptual Framework

RESULT

A. Analysis and Structural Design

1. Internal Forces in Ultimate Elements

The design using the LRFD (Load Resistance Factor Design) method requires the internal forces in the structure to ensure that the designed cross-sections are not over-designed.

The internal forces shown for the columns, trusses, and purlins are normal, as the global support is a frame structure. Below are the maximum internal forces experienced by each structure, calculated using SAP 2000 v22:

Table 4. Summary of Maximum Internal Forces

Gaya Dalam Maksimum				
Kolom	Kuda – kuda	Gording	Brecing	Balok
Nu = 57.14 Kn.m	Nu = 35.90 KN.M	Mu = 30,13 KN.M	Nu = 0.419 KN.M	Mu = 67.79 KN.M
Vu = 19.88 KN	Vu = 15.57 KN	Vu = 11.42 KN	Vu = 0.481 KN	Vu = 70.59 KN
PUtarik = 0	PUtarik= 23.96 KN	PUtarik= 64.92 KN	PUtarik= 5.39 KN	PUtarik= 4.02 KN
PUtekan= 24.61 KN	PUtekan= 11.51 KN	PUtekan= 6.19 KN	PUtekan=3.22KN	PUtekan=6.58KN

2. Cross-Section Capacity Check

In the four structural elements of the workshop building—columns, trusses, bracing, beams, and purlins—the internal forces are the same, so the checks must be done thoroughly to prevent failure. The checks to be performed include checking for bending moments, shear forces, the combination of shear forces and bending moments, as well as compression and tension forces. The results are as follows:

a. Compression Members: The IWF 400x200x8x13 section used is strong enough to resist the ultimate compression force acting on the building.
b. The IWF 400x200x8x13 section is strong enough to resist the ultimate bending moment.
c. The IWF 400x200x8x13 section is strong enough to resist the ultimate shear force.
d. The IWF 400x200x8x13 section can resist the interaction between bending and shear.
e. The H 400x400x13x21 section used is strong enough to resist the ultimate compression force acting on the building.
f. The H 400x400x13x21 section can resist the interaction between bending and compression.
g. The H 400x200x8x13 section can resist the interaction between bending and shear.
h. The C 200x80x7.5x11 section is strong enough to resist the ultimate bending moment.
i. The section is strong enough to resist the ultimate shear force.
j. The section is strong enough to resist the ultimate shear force.
k. It can be concluded that the Siku 100x100x7.7 section used is strong enough to resist the ultimate compression force acting on the building.
l. The Siku 100x100x7.7 section used is strong enough to resist the ultimate tensile force acting on the structural components under review.
m. The IWF 400x200x8x13 section is strong enough to resist the ultimate bending moment.
n. The IWF 400x200x8x13 section is strong enough to resist the ultimate shear force.
o. The IWF 400x200x8x13 section can resist the interaction between bending and shear.

B. Connections

In the design of the warehouse building's structure, it is also necessary to plan the connections between the structural profiles. The connection requirements in the design of a steel structure building are adjusted to the ultimate internal forces experienced by the structural elements to make the design more efficient. Generally, connections consist of two types: welded and bolted. In this building structure, bolted connections are used.

1. Use of Connections

Based on the calculations for the connection to resist tensile and shear forces, the number of bolts used in the design of the truss and column connections is 2 bolts with a diameter of 16 mm or 2D16.

C. Stair Design

1. Planned Ramp and Tread

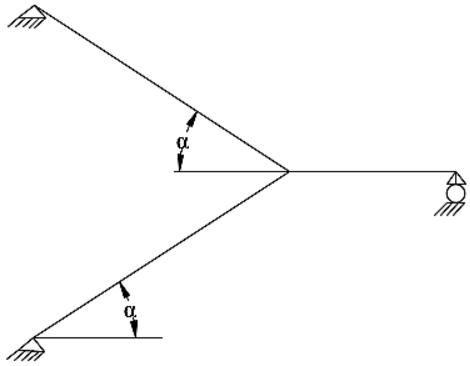


Figure 6. Stair Design Plan

Below is the stair design based on the calculations:

2. Load on Stair Treads

After modeling the stair structure, load assignments were made before performing a complete structural analysis.

- Dead Load. Dead load refers to the weight of the stair structure itself, which includes the weight of the elements making up the structure, in this case, the steel material.
- Live Load. Live load on the stair structure is assumed as follows: the live load on the stair treads is 300 kg/m², in accordance with the Indonesian load regulations for stairs.
- Stair Analysis Results Using SAP 2000 v22. Using SAP 2000 v22, the following stair design results are shown in Figures 6 and 7:

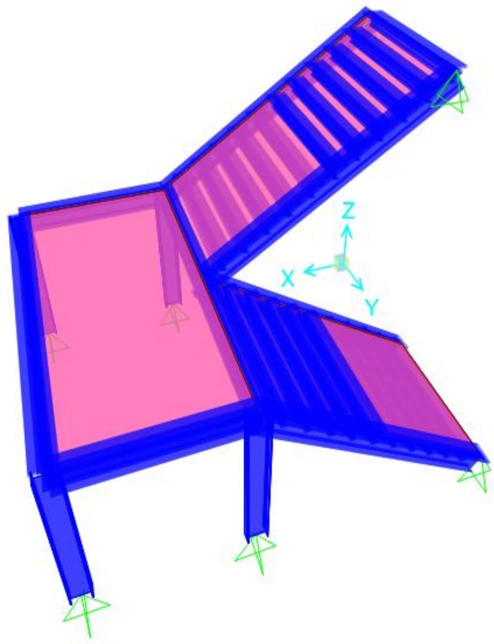


Figure 7. Live Load on Stairs

3. Ultimate Internal Forces of the Elements

Below is a summary of the internal forces occurring in the main staircase, stair treads, and the beam on the slab, using the SAP 2000 v15 application, as shown in Table 5:

Table 5. Summary of Internal Forces in Main Staircase and Stair Treads

Gaya Dalam Maksimum	
Induk Tangga	Anak Tangga
Mu = 25.03 Kn.m	Mu = 0,813 KN.M
Vu = 44.41 KN	Vu = 2,746 KN
PUtarik = 83 KN	PUtarik= 0,83 KN
PUtekan= 84.9 KN	PUtekan= 0,168 KN

4. Capacity Check

Capacity of the Stair Tread Beam

For bending moments, it was found that the IWF 150x75x7x5 section is strong enough to withstand the ultimate bending moment, while for shear forces, the IWF 150x75x7x5 section is capable of handling the ultimate shear force.

The interaction between the bending moment and shear forces in the structure is calculated as follows:

$$\frac{Mu}{\emptyset Mn} + \frac{0.625\ Vu}{\emptyset Vn} \leq 1{,}375$$

$$\frac{0{,}813}{16,{,}051} + \frac{0{,}625(44.41)}{85.05} \leq 1{,}375$$

$$0{,}069 \leq 1{,}375$$

Based on the calculations above, it was determined that the IWF 150x75x7x5 section can withstand the interaction between bending and shear forces.

Capacity of the Main Staircase Beam

For bending moments, it was found that the IWF 200x125x6x9 section is strong enough to resist the ultimate bending moment, while for shear forces, the IWF 200x125x6x9 section can handle the ultimate shear force.

The interaction between the bending moment and shear forces in the structure is calculated as follows:

$$\frac{Mu}{\emptyset Mn} + \frac{0.625\ Vu}{\emptyset Vn} \leq 1{,}375$$

$$\frac{25{,}03}{132{,}42} + \frac{0{,}625(44.41)}{170{,}01} \leq 1{,}375$$

$$0{,}35 \leq 1{,}375$$

Based on the calculations above, it was determined that the IWF 200x125x6x9 section can withstand the interaction between bending and shear forces.

5. Staircase Connection Calculations

These are divided into two categories: the connection between the Staircase Child Beam and the Main Staircase Beam, and the connection between the Landing Plate and the Main Staircase Beam.

The design of beam and column connections is influenced by the shear and tensile forces acting on the workshop building structure. The shear force (Pu) and moment (Mu) for the design of the workshop building structure are obtained through SAP calculations. The following data is needed to calculate the number of bolts required:

Table 6. Normal Bolt Specifications

Spesifikasi Baut Normal		
f1 = fu	340	Mpa
f2 = fy	210	Mpa
r2	1.9	Ulir
reduksi f	0.75	-
r1	0.4	Ulir
diameter baut	16	Mm
Abd	200.96	Mm

Based on the connection calculations to resist the tensile and shear forces, the number of bolts used in the beam and column connection design is 2 bolts with a diameter of 16 mm or 3D16.

For the landing plate and main staircase beam connection, the following data is needed to calculate the required number of bolts:

Table 7. Normal Bolt Specifications

Spesifikasi Baut Normal		
f1=fu	340	Mpa
f2=fy	210	Mpa
r2	1.9	Ulir
reduksi f	0.75	-
r1	0.4	Ulir
diameter baut	16	Mm
Abd	200.96	Mm

Based on the connection calculations to resist the tensile and shear forces, the number of bolts used in the design of the landing plate and main staircase beam connection is 2 bolts with a diameter of 16 mm or 2D16.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions from the report on the Steel Structure Project SP 1218 are as follows:

1. The column profile used is H 400 x 400, which was analyzed in Chapter IV, and is capable of supporting the loads used in the design of the warehouse structure.
2. The beam profile used is IWF 400 x 200, which was analyzed in Chapter IV, and is capable of supporting the loads used in the design of the warehouse structure.
3. The truss profile used is IWF 400 x 200, which was analyzed in Chapter IV, and is capable of supporting the loads used in the design of the warehouse structure.
4. The purlin profile used is C 200 x 80, which was analyzed in Chapter IV, and is capable of supporting the loads used in the design of the warehouse structure.
5. The bracing profile used is SIKU 100 x 100, which was analyzed in Chapter IV, and is capable of supporting the loads used in the design of the warehouse structure.
6. The conclusions regarding the connections in the warehouse structure design are shown in the table below:

Elemen Struktur	Sambung
Balok ke Kolom	4 buah sambungan baut ϕ16 untuk menahan gaya geser
	2 buah sambungan baut ϕ16 untuk menahan aksial
Brecing ke Kuda-kuda	2 buah sambungan baut ϕ16 untuk menahan geser
	2 buah sambungan baut ϕ16 untuk menahan gaya geser
Kuda-kuda ke Kolom	2 buah sambungan baut ϕ16 untuk menahan geser
	2 buah sambungan baut ϕ16 untuk menahan gaya geser

From the Steel Structure SP 1218 project on the design of the steel warehouse structure, the following recommendations can be made for future projects:

1. Intensive assistance should be provided.
2. A thorough review of the calculations made is necessary.
3. Coordination and teamwork among group members should be emphasized to ensure optimal results and that all group members achieve a uniform understanding.

ADVANCED RESEARCH

Based on the findings of the Steel Structure SP 1218 project, further research can focus on improving the efficiency of steel structure designs by exploring alternative materials and construction methods that may reduce overall costs and enhance structural performance. Additionally, future studies could investigate the integration of advanced software tools, such as the latest versions of SAP, to refine load analysis and optimize connection designs in complex building structures. Further research could also examine the environmental impact of different steel profiles and their sustainability, exploring how recycled materials or more eco-friendly construction techniques could be incorporated into the design process. Another area for investigation could be the development of more detailed guidelines for coordination and collaboration among team members to improve the accuracy of calculations and overall project outcomes. This research would provide valuable insights for both structural engineers and project managers, contributing to more efficient and sustainable steel structure designs in future construction projects.

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