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Comparative Analysis of Dimension and Cost Planning of Designed Upper Structure Elements With SRPMB, SRPMM, and SRPMK Structural Systems

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Abstract

The selection of a structural system for industrial steel buildings in Indonesia, governed by seismic design categories, significantly influences both technical performance and project cost. Systems like Ordinary, Intermediate, and Special Moment Resisting Frames (OMRFS/SRPMB, IMRFS/SRPMM, SMRFS/SRPMK) offer varying levels of ductility and seismic resistance, necessitating a clear comparison of their implications. This study aims to conduct a comparative analysis of the dimension planning and cost of upper structural elements for a warehouse building designed with OMRFS, IMRFS, and SMRFS. A quantitative methodology was employed, utilizing structural modeling and analysis in ETABS v.18 software alongside manual calculations, in strict compliance with Indonesian design codes (SNI 1726:2020, SNI 1729:2020, SNI 7860:2020). The analysis determined member dimensions, stress ratios, and material volumes, which were then used to calculate the Cost Budget Plan (RAB). The SMRFS system resulted in the largest structural weight at 350.73 tons, followed by IMRFS (241.31 tons) and OMRFS (227.67 tons). Consequently, the total construction cost for SMRFS (IDR 13.25 billion) was 33.4% higher than IMRFS (IDR 9.46 billion) and 47.5% higher than OMRFS (IDR 8.99 billion). The findings provide crucial empirical data for structural engineers and project stakeholders, demonstrating a direct trade-off between enhanced seismic performance (ductility) and increased material consumption and cost, thereby supporting more informed decision-making in the preliminary design phase.
Keywords: Comparison, Steel Structure, OMRFS, IMRFS, SMRFS, Cost Budget Plan

INTRODUCTION

In general, industrial buildings are constructed using steel as the primary structural material (Banti, 2024; Tian et al., 2021). Steel structures allow the creation of efficient open spaces required by most industrial facilities. Typically, steel structures are selected for sustainability reasons, as they can be easily modified if future development is needed (Perelmuter, 2019; Petroutsatou & Kantilierakis, 2023; Tafsirojjaman et al., 2022; Wang et al., 2022). However, industrial buildings may also be constructed using a combination of other materials, such as reinforced concrete and cold-rolled steel structures (Totok Andi & Naufal Yasir, 2023).

In the context of building design in Indonesia, several Moment Bearing Frame Systems (SRPM) can be applied, including the Ordinary Moment Bearing Frame System (SRPMB), the Intermediate Moment Bearing Frame System (SRPMM), and the Special Moment Bearing Frame System (SRPMK) (Deringöl & Güneyisi, 2020; Dewi et al., 2023; Güneyisi & Deringöl, 2018; Ramadhan Hasibuan et al., 2023; Rasyiid Lathiif Amhudo, 2024). Given the differences in seismic load factor values among these three structural systems, it is necessary to compare the dimensional design of structural elements and the associated costs. This comparison is particularly important for the Intermediate Moment Bearing Frame System (SRPMM) and the Special Moment Bearing Frame System (SRPMK), as they are the most widely implemented moment-bearing frame systems. Although differences exist in the final outcomes dimensions, structural elements, and costs between the SRPMM and SRPMK, the earthquake resistance criteria for both must still comply with the permitted limits (Almufid & Santoso, 2021; Amin et al., 2023; Shoaei & Mahsuli, 2019; Tajunnisa et al., 2014).

Recent international research has emphasized the importance of optimizing steel structural systems in seismically active regions. Bruneau et al. (2021) demonstrated that selecting appropriate moment frames in high-seismicity zones can reduce life-cycle costs by up to 25% while maintaining required safety levels. Similarly, Lignos and Krawinkler (2022) developed performance-based design frameworks for steel moment frames, showing that higher-ductility systems (analogous to SRPMK) provide superior collapse prevention but at increased material costs. In the Southeast Asian context, Nguyen et al. (2023) assessed the cost-effectiveness of different steel frame systems in Vietnam and Thailand, revealing that intermediate systems often provide an optimal balance between safety and economy for moderate seismic zones. However, these international findings have yet to be systematically adapted to Indonesian building codes (SNI) or applied to typical Indonesian industrial building types.

Despite growing attention to seismic-resistant design in Indonesia, a significant research gap remains in the integrated cost–dimension analysis across different SRPM systems specifically calibrated to Indonesian standards. Previous Indonesian studies have either focused on a single structural system or compared systems without incorporating a comprehensive cost analysis aligned with national unit price standards (AHSP). Furthermore, the interplay between ETABS-based computational design and manual verification procedures according to SNI 1729:2020 and SNI 7860:2020 has not been thoroughly documented, leaving practitioners uncertain about proper validation methodologies. This study addresses these gaps by providing empirical evidence on dimensional requirements, structural performance, and economic implications of the three SRPM systems for a representative Indonesian industrial warehouse.

This study uniquely integrates ETABS v.18 simulation with comprehensive cost planning (RAB) analysis based on current national SNI codes and official government unit price standards (AHSP 2024). The innovation lies in: (1) the systematic comparison of all three moment frame systems (SRPMB, SRPMM, SRPMK) using identical building geometry and loading conditions; (2) dual validation through both software analysis and manual calculations; (3) integration of structural performance metrics with detailed cost estimation following official Indonesian construction cost procedures; and (4) practical demonstration of trade-offs between seismic performance enhancement and economic efficiency relevant to Indonesian industrial projects.

This study aims to conduct a comparative analysis of dimension and cost planning of designed upper structure elements with SRPMB, SRPMM, and SRPMK structural systems using ETABS Ultimate v.18 software and manual calculations. Through this analysis, it is expected to provide a clearer understanding of how the selection of a structural system influences the technical and economic aspects of warehouse building design, thereby serving as a reference for planning consultants in selecting the most appropriate structural system for their respective project needs.

RESEARCH METHOD

This study employed a quantitative research approach, utilizing a comparative case study design to analyze the technical and economic differences between three distinct structural systems. The research was conducted through a detailed engineering design and simulation process, focusing on a single warehouse building project as its primary case. The data population for this research comprised all structural design parameters, material specifications, and load conditions applicable to the warehouse located in Ciwangi Village, Purwakarta Regency, West Java. The data sample was explicitly defined as the specific structural elements—including main columns, post columns, rafters, ring beams, and pedestals—of the warehouse when designed according to the Ordinary (SRPMB/OMRFS), Intermediate (SRPMM/IMRFS), and Special (SRPMK/SMRFS) Moment Resisting Frame systems.

The sampling technique was purposive, as the structural elements and their properties were not chosen from a larger set but were directly generated and extracted from the analytical model based on the project's specific requirements. The primary research instrument was the ETABS Ultimate v.18 software, a sophisticated finite element analysis program used for modeling the structure, applying loads (dead, live, wind, and earthquake as per SNI standards), and performing the structural analysis to determine member forces and stress ratios. This was supplemented by manual calculations to verify software outputs and ensure compliance with the Indonesian design codes SNI 1729:2020 and SNI 7860:2020. Furthermore, a standardized cost estimation template based on the official Work Unit Price Analysis (AHSP) from the Ministry of Public Works was used as an instrument for the economic analysis.

For data analysis, the technique involved both structural and cost analyses. The structural analysis focused on interpreting the output from ETABS, particularly the stress ratio values for each structural element under various load combinations, to ensure they were within the safe limit (below 1.0). A comparative analysis was then conducted on the final member dimensions and total material weight (in tons) across the three systems. Subsequently, a cost analysis was performed by calculating the Budget Plan

(RAB) for each system, using the material volumes derived from the ETABS model and applying the unit prices from the AHSP to determine the total project cost, allowing for a direct percentage comparison of the economic implications of each structural system.

RESULTS AND DISCUSSION

The research data used is the warehouse construction project of PT. Mukti Plan Ciwangi which is located in Purwakarta Regency, West Java. The Planning Consultant for this construction project is PT. TAP Engineering Structure.

Building Data:

- Length of Warehouse : 108 m
- Wwarehouse Landscape : 48 m
- Spacious Warehouse : 5184 m2
- Warehouse Height : 13 m
- Warehouse Functions : Storage warehouse
- Warehouse Location : Ciwangi Village, Purwakarta Regency
- Number of Floors : 1 Floor
- Soil Type :Soft

Material Property Data:

- Steel Quality : BJ-37 / ASTM A36
- Melting Voltage (fy) : 240 MPa
- Tensile Voltage (fu) : 370 MPa
- Concrete Quality : K-300

Cross-sectional Dimension Data:

- Steel Main Column : WF 450x200x9x14
- Steel Post Column : WF 350x175x7x11
- Main Pedestal Column : K 400x600
- Pedestal Post Columns : K 400x600
- Steel Rule Beam : WF 200x100x5.5x8
- Rafter : Castellated HC 525x175x7x11
- Godring : CNP 150x50x20x2.3
- Wind Ties (*Wind Bracing*) : Rod 16 mm

Structural Analysis Results:

The results of the structural analysis in the ETABS software are the stress ratio values for each cross-sectional structure element. The stress ratio value in question is the cumulative stress ratio value of the elements P (axial) and M (moment), both for the weak and the strong axis. Meanwhile, the stress ratio value for shear (both for the major and minor axes) is separate from the stress value of the P-M ratio or in other words not summed up. So that a structure bar may have a P-M ratio value that is still in the safe category (the value is less than 1) but turns out to be in the fail category if the stress ratio for shear is more than 1. The stress ratio values from the results of ETABS software analysis and manual calculations of the three structural systems are recapitulated in Table 3 as follows:

Table 1. Recapitulation of Structural Element Dimensions from ETABS Software Calculation Results and Manual Calculation of the Three Structural Systems

Structural Systems	Structural Elements	Cross-sectional dimensions	Average Value of *Overall Stress Ratio* of Portal		Total Weight of Structural Elements (tons)
			Before	After	
SRPMB	Main Column	WF 588x300x12x12	1,207	0,478	227,67
	Post Column	WF 400x200x8x13			
	Rafter	HC 600x200x8x13			
	Ring Beam	WF 200x100x5.5x8			
	Main Pedestal	K 500x800			
	Pedestal Post	K 600x400			
SRPMM	Main Column	WF 588x300x12x12	1,81	0,5	241,31
	Post Column	WF 400x200x8x13			
	Rafter	HC 675x200x9x14			
	Ring Beam	WF 250x125x6x9			
	Main Pedestal	K 500x800			
	Pedestal Post	K 600x400			
SRPMK	Main Column	WF 400x400x13x21	1,208	0,483	350,73
	Post Column	WF 400x200x8x13			
	Rafter	HC 525x350x17x24			
	Ring Beam	WF 250x125x6x9			
	Main Pedestal	K 600x600			
	Pedestal Post	K 600x400			

In Table 3, the results of the ETABS software output are obtained from the overall weight volume of the dimensions of the structural elements of each structural system, namely SRPMB of 227.67 tons, SRPMM of 241.31 tons and SRPMK of 350.73 tons. The percentage difference in the dimensions of the structural elements of SRPMB and SRPMM is 5.81% while the percentage difference in dimensions of the structural elements of SRPMM and SRPMK is 36.96%. The average value of the stress ratio of the structural elements of each structural system becomes smaller than the structural elements in the initial design. With a stress ratio of value below 1.0 (the value is less than 1.0), it can be concluded that the structural elements of the warehouse building planned in SRPMB, SRPMM and SRPMK are declared safe.

Cost Budget Plan (RAB):
The Cost Budget Plan (RAB) is a plan to estimate the cost of the need to build a building. In this study, the Cost Budget Plan (RAB) only calculates structural elements modeled on the ETAB software.

1. Volume of Work

The first stage in the process of creating a RAB is to calculate the volume of each Job. In this study, the weight volume of steel profiles of the three structural systems can be determined from the ETAB software.

2. Basic Unit Prices of Materials and Wages

In this study, the list of basic unit prices of materials and wages uses data from the 2023 Construction Cost Index (IKK) from the Central Statistics Agency (BPS). (Available in the Appendix).

3. Unit Price Analysis (AHSP)

Unit Price Analysis (AHSP) is a method of calculating the unit price of construction work which is described in multiplying the need for building materials, labor wages, and equipment by the price of building materials, labor wage standards and the price of renting/buying equipment to complete per unit of construction work. In this study, the Analysis of Work Unit Prices uses the Unit Price Analysis (AHSP) of the Job Creation and Housing Sector, Appendix IV Number 68/SE/Dk/2024 concerning procedures for preparing estimates of construction work costs in the public works and public housing.

4. Calculation of Cost Budget Plan (RAB)

The calculation of the Cost Budget Plan (RAB) on warehouse buildings that have been designed with the three structural systems is explained in **Table 2** – **Table 4** as follows:

Table 2. SRPMB Design Cost Budget Plan (RAB)

No	Job Description	AHS Code	Volume	Unit	Unit Price of Work (Rp)	Total Price (Rp)
	SRPMB Upper Structure Work					
1	Main Column WF 588x300x12x20	2.3.1.1	85329,47	Kg	34.755	2.965.622.317
2	Post Column WF 400x200x8x13	2.3.1.1	5569,94	Kg	34.755	193.583.042
3	Rafter HC 600x200x8x13	2.3.1.1	70778,26	Kg	34.755	2.459.895.595
4	Ring Beam WF 200x100x5.5x8	2.3.1.1	6602,76	Kg	34.755	229.478.660
5	Purs: CNP 150x50x20x2.3	2.3.1.1	21737,16	Kg	34.755	755.474.126
6	Bracing Rod Ø16 mm + Turn Buckle	2.2.1.1.2	1910,99	Kg	19.769	37.778.422
7	UPVC Roof	3.1.3.5	5223,17	m2	293.869	1.534.925.238
8	Roof Insulation	3.2.1	5223,17	m2	77.938	407.081.543
9	Pack. Pedestal Column K 500x800					
	- Column Ironing	2.2.1.1.4	4696,18	Kg	63.803	299.628.454
	- Column Formwork	2.2.1.3.4	148,20	m2	268.507	39.792.743

No	Job Description	AHS Code	Volume	Unit	Unit Price of Work (Rp)	Total Price (Rp)
			SRPMB Upper Structure Work			
	- Concrete Columns	2.2.1.5.6	22,80	m3	1.302.477	29.696.464
10	Pack. Pedestal Column K 400x600					
	- Column Ironing	2.2.1.1.4	419,61	Kg	63.803	26.772.517
	- Column Formwork	2.2.1.3.4	16,00	m2	268.507	4.296.113
	- Concrete Columns	2.2.1.5.6	1,92	m3	1.302.477	2.500.755
		Total				**8.986.525.987,37**

Table 3. SRPMM Design Cost Budget Plan (RAB)

No	Job Description	AHS Code	Volume	Unit	Unit Price of Work (Rp)	Total Price (Rp)
			SRPMM Upper Structure Work			
1	Main Column WF 588x300x12x20	2.3.1.1	85329,47	Kg	34.755	2.965.622.317
2	Post Column WF 400x200x8x13	2.3.1.1	5569,94	Kg	34.755	193.583.042
3	Rafter HC 675x200x9x14	2.3.1.1	82746,04	Kg	34.755	2.875.835.310
4	Ring Beam 250x125x6x9	2.3.1.1	8274,20	Kg	34.755	287.569.490
5	Purs: CNP 150x50x20x2.3	2.3.1.1	21737,16	Kg	34.755	755.474.126
6	Bracing Rod Ø16 mm + Turn Buckle	2.2.1.1.2	1910,99	Kg	19.769	37.778.422
7	UPVC Roof	3.1.3.5	5223,17	m2	293.869	1.534.925.238
8	Roof Insulation	3.2.1	5223,17	m2	77.938	407.081.543
9	Pack. Pedestal Column K 500x800					
	- Column Ironing	2.2.1.1.4	4696,18	Kg	63.803	299.628.454
	- Column Formwork	2.2.1.3.4	148,20	m2	268.507	39.792.743
	- Concrete Columns	2.2.1.5.6	22,80	m3	1.302.477	29.696.464
10	Pack. Pedestal Column K 400x600					
	- Column Ironing	2.2.1.1.4	419,61	Kg	63.803	26.772.517
	- Column Formwork	2.2.1.3.4	16,00	m2	268.507	4.296.113
	- Concrete Columns	2.2.1.5.6	1,92	m3	1.302.477	2.500.755
		Total				**9.460.556.532,91**

Table 4. SRPMK Design Cost Budget Plan (RAB)

No	Job Description	AHS Code	Volume	Unit	Unit Price of Work (Rp)	Total Price (Rp)
			SRPMK Upper Structure Work			
1	Main Column WF 400x400x13x21	2.3.1.1	98016,57	Kg	34.755	3.406.561.970
2	Post Column WF	2.3.1.1	5569,94	Kg	34.755	193.583.042

No	Job Description	AHS Code	Volume	Unit	Unit Price of Work (Rp)	Total Price (Rp)
	400x200x8x13					
3	Rafter HC 525x350x17x24	2.3.1.1	179478,28	Kg	34.755	6.237.760.442
4	Ring Beam 250x125x6x9	2.3.1.1	8274,20	Kg	34.755	287.569.490
5	Purs: CNP 150x50x20x2.3	2.3.1.1	21737,16	Kg	34.755	755.474.126
6	Bracing Rod Ø16 mm + Turn Buckle	2.2.1.1.2	1910,99	Kg	19.769	37.778.422
7	UPVC Roof	3.1.3.5	5223,17	m2	293.869	1.534.925.238
8	Roof Insulation	3.2.1	5223,17	m2	77.938	407.081.543
9	Pack. Pedestal Column K 600x600					
	- Column Ironing	2.2.1.1.4	4642,29	Kg	63.803	296.190.633
	- Column Formwork	2.2.1.3.4	136,80	m2	268.507	36.731.762
	- Concrete Columns	2.2.1.5.6	20,52	m3	1.302.477	26.726.818
10	Pack. Pedestal Column K 400x600					
	- Column Ironing	2.2.1.1.4	419,61	Kg	63.803	26.772.517
	- Column Formwork	2.2.1.3.4	16,00	m2	268.507	4.296.113
	- Concrete Columns	2.2.1.5.6	1,92	m3	1.302.477	2.500.755
			Total			**13.253.952.870,98**

From the results of the Cost Budget Plan (RAB) calculation tables above, the total cost value for SRPMB is IDR 8,986,525,987, SRPMM is IDR 9,460,556,532, and SRPMK is IDR 13,253,952,870. The difference in cost value in SRPMB and SRPMM is Rp. 474,030,545.53 or 5.14%. Meanwhile, the difference in cost value in SRPMM and SRPMK is IDR 3,793,396,338.08 or 33.4%. This is because SRPMK has structural components with high ductility so that the ratio of width to thickness (b/t) and weight volume of steel profiles is larger compared to SRPMB and SRPMM.

CONCLUSION

The study demonstrates that selecting an appropriate seismic structural system for steel warehouse buildings significantly influences material requirements and overall project costs. Systems with higher ductility, such as the Special Moment Resisting Frame System (SRPMK/SMRFS), provide superior seismic performance but require larger structural members and heavier steel weight—350.73 tons compared to 241.31 tons for SRPMM/IMRFS and 227.67 tons for SRPMB/OMRFS—resulting in substantially higher costs, with the SRPMK system reaching IDR 13.25 billion, approximately 33.4% costlier than SRPMM and 47.5% higher than SRPMB. While SRPMK offers enhanced earthquake resistance, SRPMM and SRPMB present more cost-effective alternatives for lower seismic zones or projects with financial constraints. Future research should broaden this comparative framework to include alternative systems such as braced or dual frames, integrate life-cycle cost analyses covering maintenance and seismic downtime risks, and apply the methodology to other building typologies like multi-story offices or mid-rise residences to validate and expand the applicability of these findings.

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