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Research Article

Influence of Steel Section Price Fluctuation to Cost Effective Design of Steel Frame Structural System in Malaysia

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Abstract

Steel material price fluctuation has been a problem for Malaysia steel construction industry. The price fluctuation is influence by economy policy, administrative order and macroeconomic volatility, steel industry supply and demand react to market steel price fluctuation, and the market's self-correction mechanism. With the increasing of global demand for flat steel section, the cold-formed hollow section price in Malaysia has been increasing and becoming significantly more expensive compare to I-beams. Based on the current scenario, hollow section is 19%-24% more expensive compare to I-beam. The significant price different has led to the preference of using hot-rolled beam portal frame in Malaysia. I-beam has been widely used in portal frames while hollow section is the preferred section used in truss frame. This paper objective is to find out the influence of hollow section and I-beam price fluctuation to the structural system material cost. Hot-rolled beam portal frame and truss frame weight will be compared and material cost will be calculated based on the current price of steel section. The optimize truss frame will be compared with preliminary portal frame section in ''Design of Steel Portal Frame Buildings to Eurocode 3' published by The Steel Construction Institute (SCI). The weight saving of truss frame compare to the hot-rolled beam portal frame ranging from 30%-64% depending on the building span. Structural weight saving of 30% for truss frame compare to hot-rolled beam portal frame may not necessarily give the overall saving in material price and overall steel structure cost. If the price saving of I-beam is 24% compare to hollow section, hot-rolled beam portal frame may be the best choice.

Keywords:

1. Introduction

The price fluctuation is influence by economy policy, administrative order and macroeconomic volatility, steel industry supply and demand react to market steel price fluctuation, and the market's self- correction mechanism is limited [Sui Guo et al,2018]. Referring to figure 1, China produced 51.3% of the world steel production. The market has been flooded with low price steel for the past few years from China due to the low-cost steel production and excess of steel production. On 2015, the effect of China 'steel dumping; has triggered countries such as US to impose import duty on China steel. On March 2018, the United States president Donald Trump announced that the US government will impose 25% tariffs on steel. This action induced severe volatility in the global steel markets and its related industry chain market. The construction industry has been facing the steel price fluctuation constantly due to the geopolitical effect of various countries.

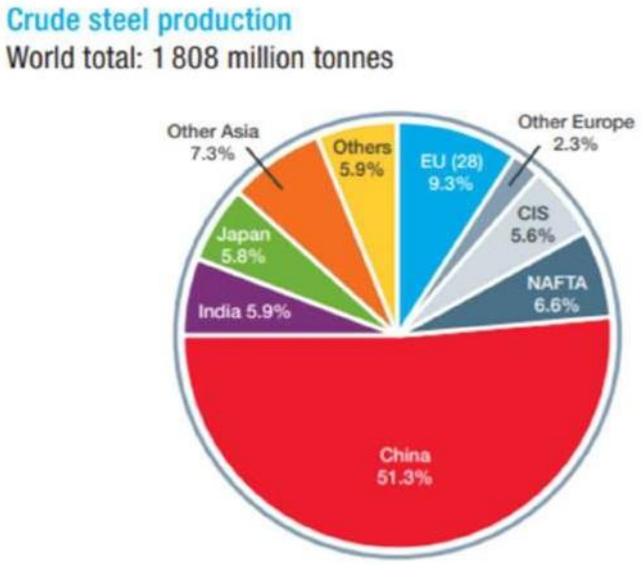


Figure **Error! No text of specified style in document.**: Global steel production. (Source from World Steel Assoc, World Steel in Figure 2019)

Since the recovery of China from 2020 COVID-19 outbreak, the world major steel producer implemented a policy that will have a major impact to the global steel material price. Steel industry is one of the most energy intensive industries and accounts for the largest share of global CO2 emissions in the manufacturing sector, which is approximately 27% of CO2 emissions from the global manufacturing sector.CO2 emissions produced by the steel industry accounted for approximately 15- 17% of industry CO2 emissions and 4-5% of the human activities. The role of China’s steel industry in the CO2 emissions cannot be ignored (Wang et al. 2007). There was an annual growth of about 70 million carbon dioxide equivalents (CO2e) in China’s steel industry from 2001 to 2010 (Tian et al. 2013). According to the data of the World Steel Association, an estimated 1-ton production of steel billet could lead to an average of 1.9 tons of CO2 emissions (Chinairn 2013).

On May 6 2021, China Ministry of industry and Information Technology (MIIT) update the regulations for steelmaking capacity swap to firmly reduce steel production and ban new capacity from June 1 2021. This policy will see capacity cut by forcing existing steelmakers using blast furnace technology to move to electric arc systems at significantly lower capacity. The China government wants to significantly curb steel production capacity. The changes have triggered a surge in iron ore prices as Chinese steel mills try to purchase as much as possible iron ore before the policy in effect. The policy aim is to lower the CO2 emissions by the steelmaking sector. Since April 2021, more than 20 plants were ordered to close for varying period and capacity cuts have been imposed. The market has faced a significant material shortage that triggered a remarkable surge in the steel material prices.

2. Current Scenario and Effect of Steel Sections Price Fluctuation in Mlaysia

By looking into the global material price of flat steel section (mainly used to produce hollow section) in figure 2, current steel price is at all time high of USD 850/T which is equivalent RM 3.51/kg (1 USD-RM 4.13,2021). Referring to table 1, is the material price for flat steel section year 2019 is around USD 526/T – USD 477/T which is equivalent to RM 2.17/kg – RM 1.97/kg (1 USD-RM 4.13,2019). The surge in the flat steel material price is due to the material shortage and high demand for the flat steel section. The flat steel consumption in China has boomed since the economy recovery from 2020 COVIC-19. The momentum has extended into 2021 with industrial output in January- February gaining 7.3% from December and 35.1% from a year earlier. The demand for home appliance, shipping containers, vehicle and other product have been high across the world.

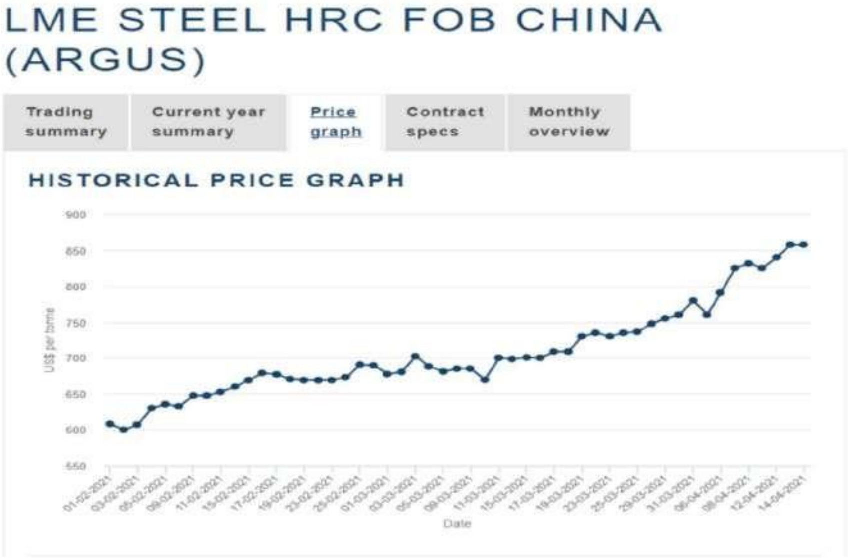


Figure 2: Flat steel price 2021. (Source from London Metal Exchange)

Table **Error! No text of specified style in document.**: Flat steel price 2021. (Source from London Metal Exchange)

1	USD/mt	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15
58	3/6/2019	498.00	504.00	504.00	502.00	502.00	499.00	496.00	493.00	490.00	487.00	484.00	481.00	478.00	478.00	478.00
59	4/6/2019	495.00	500.50	502.00	500.00	500.00	497.00	494.00	491.00	488.00	485.00	482.00	479.00	477.00	477.00	477.00
60	5/6/2019	493.00	495.00	495.00	494.00	494.00	493.00	492.00	489.00	487.00	485.00	482.00	479.00	477.00	477.00	477.00
61	6/6/2019	491.50	491.00	491.00	490.00	490.00	490.00	489.00	488.00	486.00	484.00	482.00	480.00	478.00	477.00	477.00
62	7/6/2019	491.00	494.00	494.00	493.00	493.00	493.00	491.00	489.00	487.00	485.00	482.00	479.00	477.00	477.00	477.00
63	10/6/2019	491.00	494.00	494.00	493.00	493.00	493.00	491.00	489.00	487.00	485.00	482.00	479.00	477.00	477.00	477.00
64	11/6/2019	491.00	497.00	497.00	496.00	496.00	496.00	494.00	492.00	490.00	487.00	484.00	482.00	480.00	480.00	480.00
65	12/6/2019	491.00	501.00	497.00	496.00	496.00	495.00	493.00	491.00	489.00	486.00	481.00	481.00	479.00	479.00	479.00
66	13/6/2019	489.00	498.00	498.00	498.00	496.00	494.00	493.00	491.00	489.00	485.00	482.00	481.00	480.00	479.00	478.00
67	14/6/2019	494.00	497.00	497.00	497.00	495.00	494.00	492.00	491.00	489.00	486.00	483.00	481.00	480.00	479.00	478.00
68	17/6/2019	489.00	488.50	489.00	488.50	488.00	487.50	484.00	483.00	482.00	481.00	481.00	480.00	479.00	478.00	477.00
69	18/6/2019	487.00	486.00	486.00	486.00	486.00	485.00	483.00	481.00	480.00	479.00	479.00	478.00	477.00	476.00	476.00
70	19/6/2019	487.00	486.00	485.00	484.00	483.00	482.00	481.00	480.00	479.00	478.00	477.00	476.00	475.00	474.00	473.00
71	20/6/2019	487.00	488.00	488.00	488.00	487.00	488.00	482.00	481.00	480.00	478.00	477.00	476.00	475.00	474.00	473.00
72	21/6/2019	493.50	492.50	491.00	491.00	490.00	489.00	487.00	485.00	483.00	482.00	481.00	481.00	477.00	476.00	475.00
73	24/6/2019	491.00	496.00	495.00	494.00	491.50	490.50	489.00	488.00	487.00	486.00	485.00	484.00	483.00	482.00	481.00
74	25/6/2019	490.00	500.50	504.00	498.50	502.00	498.00	497.00	492.00	491.00	491.00	490.00	490.00	487.00	484.00	481.00
75	26/6/2019	490.00	502.00	506.00	503.00	502.00	500.00	498.00	496.00	494.00	492.00	492.00	492.00	492.00	490.00	488.00
76	27/6/2019	491.00	513.50	516.00	515.00	511.00	509.00	505.00	501.00	497.00	494.50	493.00	493.00	493.00	491.00	489.00
77	28/6/2019	491.95	518.50	521.00	520.50	520.50	514.00	510.00	505.00	501.00	498.00	497.00	496.00	495.00	494.00	493.00
78	1/7/2019	517.00	522.00	521.00	521.00	515.00	511.00	506.00	503.00	499.00	498.00	497.00	496.00	495.00	495.00	495.00
79	2/7/2019	519.00	523.00	522.00	522.00	517.00	510.00	505.00	502.00	498.00	497.00	496.00	497.00	499.00	495.00	497.50
80	3/7/2019	516.00	520.00	523.00	519.00	518.00	505.50	503.00	501.00	498.00	497.00	496.00	495.00	494.00	493.00	492.50
81	4/7/2019	512.00	520.00	526.00	522.00	520.00	509.00	503.00	499.00	498.00	497.00	497.00	496.00	495.00	494.00	493.00
82	5/7/2019	512.00	514.50	515.50	512.00	509.50	507.00	504.00	494.50	493.00	493.00	491.50	491.00	490.00	489.00	489.00
83	8/7/2019	512.00	511.50	509.50	508.00	506.00	506.00	506.50	499.00	496.50	496.50	493.00	492.00	491.00	490.00	490.00
84	9/7/2019	510.00	510.50	506.50	505.00	505.00	502.00	502.00	492.50	490.00	490.00	487.00	486.00	484.50	484.50	484.00
85	10/7/2019	506.00	507.00	503.50	500.00	500.00	502.00	501.00	496.00	492.00	490.00	488.00	486.00	485.00	484.00	482.00

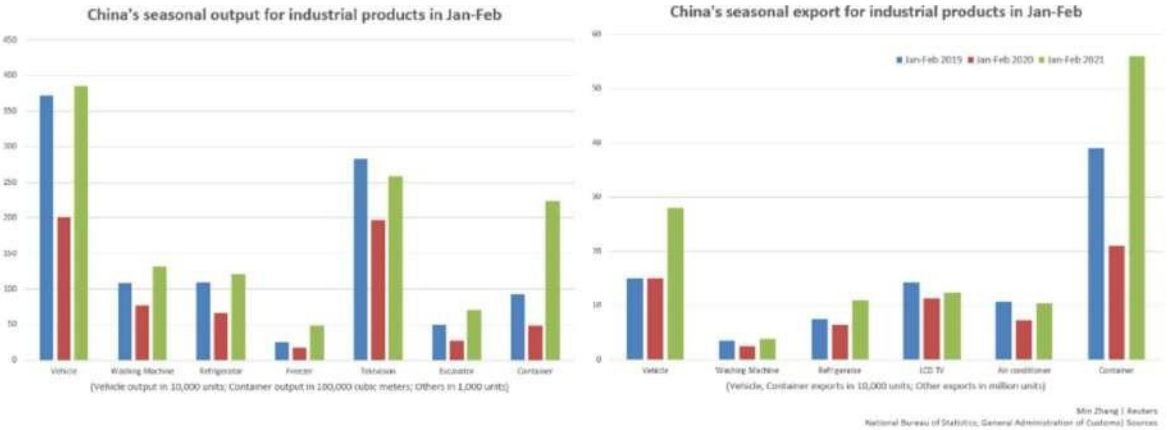


Figure 3: China seasonal export industry product. (Source from National Bureau of Statistic, General Administration of Custom)

Steel section consists of hollow section (rectangular, square & circle), universal beam, universal column, plates, channel and angle. Most of the hollow sections produced in Malaysia is cold formed steel produced by forming from a flat steel section. The term “Cold-formed” denotes a manufacturing method where the tube forming process is carried out at an ambient temperature without subsequent heat treatment, except for the weld seam, which may be heat-treated. The hollow section price in Malaysia is greatly affected by the current policy and macroeconomic of main flat steel producer such as China.

With the global fluctuation of the flat steel section price, it causes the huge price variation between the cold-formed hollow section, I-beams, steel plates, C-channel and angles Different steel section tends to have different price in terms of RM/kg. This fluctuation of steel section price plays an important factor in affecting the steel structure cost. Refer to Table 2, for 2015 Malaysia steel price for steel plates, hollow section and beams. Price varies from month to month and at certain months steel plates and hollow section is more expensive than steel beams. This trend of various steel section price fluctuation can be seen every year. By comparing the steel material price of square hollow section SHS 150x150x4.45 (SHS) against the universal beam 400mm x400mm (UB) as shown in table 2, SHS is

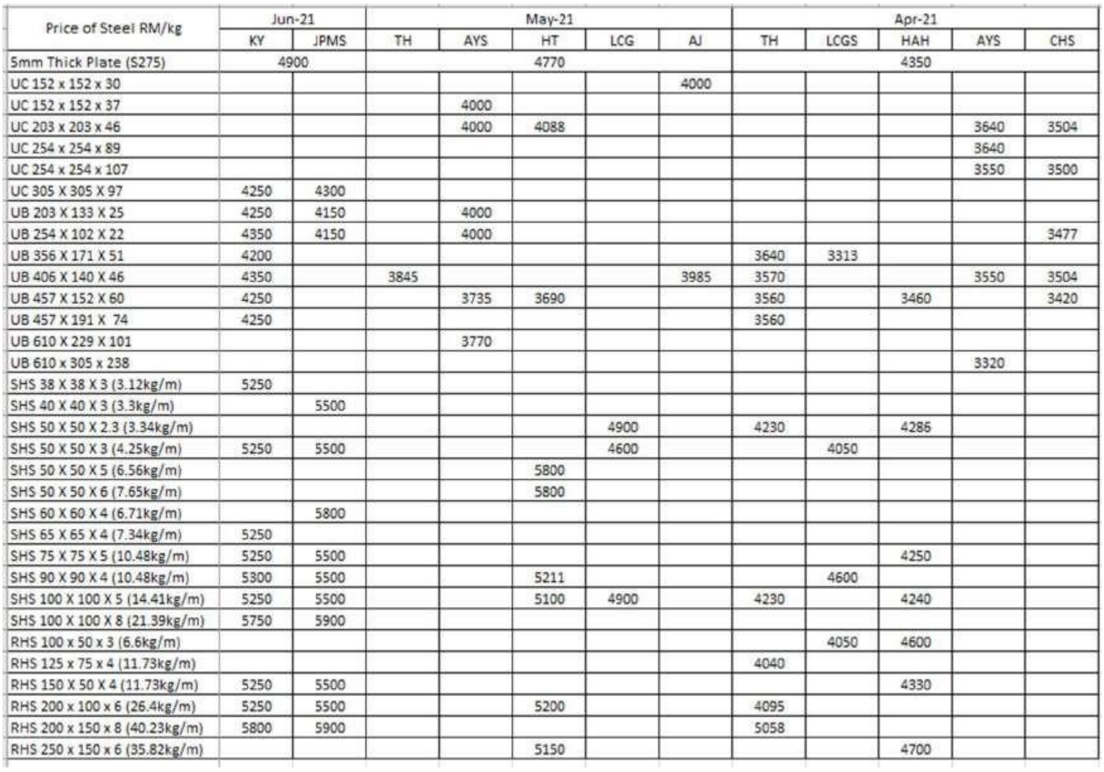
40% more expensive compare to UB for month of February. However, in the month of August, UB is more expensive than SHS by 14.2%.

Table 2: Malaysia steel price 2015 RM/tonne. (Source from CIDB Building Material Cost)

Material	Unit	2015							
		Jan	Feb	Mar	Apr	May	June	July	Aug
SHS 50 x 50 x 3	MT	2876.7	2876.7	2876.7	3084.6	3084.6	3084.6	3084.6	2968.0
SHS 150 x 150 x 4.4	MT	3022.3	3022.3	3022.3	3203.7	3203.7	3203.7	3203.7	3180.0
UB 102 x 102 x 8.76	MT	1182.7	1182.7	1182.7	1253.6	1253.6	3373.6	3374.7	3387.1
UB 400 x 400	MT	1813.3	1813.3	1813.3	1922.1	1922.1	3778.9	3672.9	3708.2
EA 38 x 38 x 3.8	MT	2983.3	2983.3	2983.3	3162.3	3162.3	3162.3	3162.3	3162.3
EA 50 x 50 x 4	MT	3050.0	3050.0	3050.0	3233.0	3233.0	3233.0	3233.0	3233.0

To validate the current situation of various material price fluctuation, steel material price of various section for I-beam and hollow section were collected from the local steel supplier. We can observe that the material price for steel plates, I-beam and hollow section has been fluctuation for month to month and at time the I-beam can be more expensive than hollow section of vice versa.

Table 3: Material price RM/tonne. (Source from Local Supplier)



Price of Steel RM/kg	Jun-21		May-21					Apr-21				
	KY	JPMS	TH	AYS	HT	LCG	AJ	TH	LCGS	HAH	AYS	CHS
5mm Thick Plate (S275)	4900		4770					4350				
UC 152 x 152 x 30							4000					
UC 152 x 152 x 37				4000								
UC 203 x 203 x 46				4000	4088						3640	3504
UC 254 x 254 x 89											3640	
UC 254 x 254 x 107											3550	3500
UC 305 X 305 X 97	4250	4300										
UB 203 X 133 X 25	4250	4150		4000								
UB 254 X 102 X 22	4350	4150		4000								3477
UB 356 X 171 X 51	4200							3640	3313			
UB 406 X 140 X 46	4350		3845				3985	3570			3550	3504
UB 457 X 152 X 60	4250			3735	3690			3560		3460		3420
UB 457 X 191 X 74	4250							3560				
UB 610 X 229 X 101				3770								
UB 610 x 305 x 238											3320	
SHS 38 X 38 X 3 (3.12kg/m)	5250											
SHS 40 X 40 X 3 (3.3kg/m)		5500										
SHS 50 X 50 X 2.3 (3.34kg/m)						4900		4230		4286		
SHS 50 X 50 X 3 (4.25kg/m)	5250	5500				4600			4050			
SHS 50 X 50 X 5 (6.56kg/m)					5800							
SHS 50 X 50 X 6 (7.65kg/m)					5800							
SHS 60 X 60 X 4 (6.71kg/m)		5800										
SHS 65 X 65 X 4 (7.34kg/m)	5250											
SHS 75 X 75 X 5 (10.48kg/m)	5250	5500								4250		
SHS 90 X 90 X 4 (10.48kg/m)	5300	5500			5211				4600			
SHS 100 X 100 X 5 (14.41kg/m)	5250	5500			5100	4900		4230		4240		
SHS 100 X 100 X 8 (21.39kg/m)	5750	5900										
RHS 100 x 50 x 3 (6.6kg/m)									4050	4600		
RHS 125 x 75 x 4 (11.73kg/m)								4040				
RHS 150 X 50 X 4 (11.73kg/m)	5250	5500								4330		
RHS 200 x 100 x 6 (26.4kg/m)	5250	5500			5200			4095				
RHS 200 x 150 x 8 (40.23kg/m)	5800	5900						5058				
RHS 250 x 150 x 6 (35.82kg/m)					5150					4700		

3. Effect of Material Price Fluctuation in Selecting A Structural System

As mentioned above, with the fluctuation of various steel section material price, it is hard to determine a cost-efficient steel construction by looking into a single structural system. The most common and widely used structural system are truss, hot rolled portal frame and fabricated beam portal frame. Different structural system may require different steel section. For example, fabricated beam portal frame will use steel plates, hot-rolled beam portal frame will used UB and hollow section or UC commonly used in truss frame.

It is very important to select a suitable structural system. A wrong selection of structural system will cause a heavier structure and higher fabrication cost. Fabricated beam portal frame has a distinct weight advantage over hot-rolled portal frame of 15% for structural span exceeding 40m. For span under 25m, hot rolled portal frame is a feasible choice compare to fabricated beam portal frame [Ross Mckinstray et al,2004]. However, with the scenario of various steel section price fluctuation, a minimal weight structure may not be a cost-effective solution. By looking at table 3, the steel plate price is about 11.3% more expensive than I-beam for the month of May and June. Therefore, with the saving of 15% weight advantage of fabricated beam portal frame compare to hot-rolled beam portal frame may not be a cost-effective solution if we take into consideration the fabrication cost. Fabricated beam portal frame required more manhours to fabricate compare to hot-rolled beam portal frame. Another scenario of selecting a steel section for truss member. Hollow section is commonly used in truss section due to greater flexibility in use and higher strength-to-weight ratio than conventional **sections**. This enhances efficiency and reduces cost. However as shown in table 3, hollow section price averagely 20% more expensive compare to I-beams. If the I-beam weight used to replace the hollow section do not exceed the percentage of price saving in material cost, using I-beam is more cost efficient compare to hollow section. The construction cost for each structural system should be different due to the nature of the fabrication process and erection difficulties. Various structural system tends to have different fabrication process and the amount of work varies [Sang Wok Jin et al,2004].

Various optimization approaches to achieve minimal weight design have been proposed in the near past and the method are as follows;

- Simultaneous cost, topology and standard cross section optimization of single storey industrial steel building using mix integer non- linear programming (MINLP) [S.Kravanja & T Zula,2000]
- Constrained non-linear cost optimization of steel portal frame building [Lee BS & Knapton J,1975]
- Linear programming approach for optimization of pitched roof [Brian EJ & Dixon As,1997]
- Practical method for single story steel structure based on discrete minimum weight design and Eurocode design constraints [Gurlement G.Targowski et al,2001]
- Optimum design of steel pitch roof frames with haunched rafters by using genetic algorithm [Kamal et al,2003]
- Weight optimization of two hinged steel portal frames under multiple loadings [Hernandez S et al,2005]

There is few research done on the optimization approach for truss frame as follow;

- Concurrent structural optimization of buckling-resistant trusses and their initial imperfections [Hazem Madah & Oded Amir,2018]
- Discrete sizing/layout/topology optimization of truss structures with an advanced Jaya algorithm [S.O. Degertekin et al,2019]
- Optimum shape of large-span trusses according to AISC-LRFD using Ranked Particles Optimization [Amir Nasrollahi,2017]
- Topology optimization of geometrically nonlinear trusses with spurious eigenmodes control [Lei Li & Kapil Khandelwal, 2016]
- Robust topology optimization of truss structures with random loading and material properties: A multiobjective perspective [James N. Richardson et al,2015]
- Simultaneous topology, shape and sizing optimisation of a three-dimensional slender truss tower using multiobjective evolutionary algorithms [Norapat Noilublao & Sujin Bureerat,2011]

- Ray optimization for size and shape optimization of truss structures [A. Kaveh & M. Khayatazad, 2013]
- Topology optimization of trusses considering static and dynamic constraints using the CSS [A. Kaveh & A. Zolghadr, 2012]

The consideration of considering the various steel section material price is not in the consideration. Therefore, a detail study on the influence of steel section price fluctuation to cost effective design of steel frame structural system should be explored.

4. Cost Function of Steel Structure

The cost distribution of steel structure are as follows [L Pavlovcic et al,2004];

- Material cost
- Erection cost
- Painting cost
- Welding cost
- Surface preparation cost
- Cutting cost
- Bolting material cost
- Hole forming cost
- Flange aligning cost (for fabricated beam)
- Transportation cost

Fabrication

Steel construction cost can be breakdown as follows [Charles J Carter,2004];

- Material cost-25%
- Fabrication cost-35%
- Erection cost-25%
- Other cost-15%

CJ Carter & T.J Schlafy, 2008 conclude that the steel construction cost can be breakdown as shown in Figure .

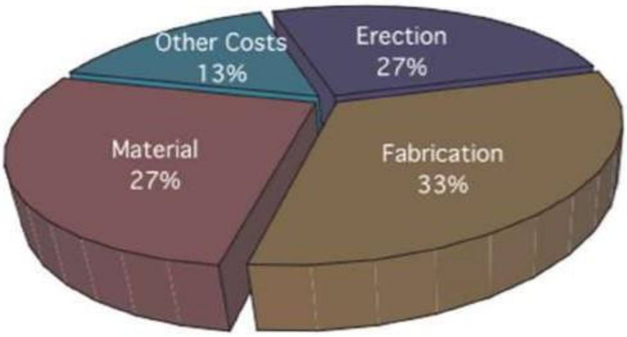


Figure 4: Cost breakdown of steel structure.

Material cost plays an important factor in influencing the overall steel structure cost. With the current volatility and various steel section fluctuation in price, minimal weight design may not give an efficient cost in optimal material cost. Material cost can be calculated as follows;

Material Cost = Material weight (kg) x Material price (RM/kg).

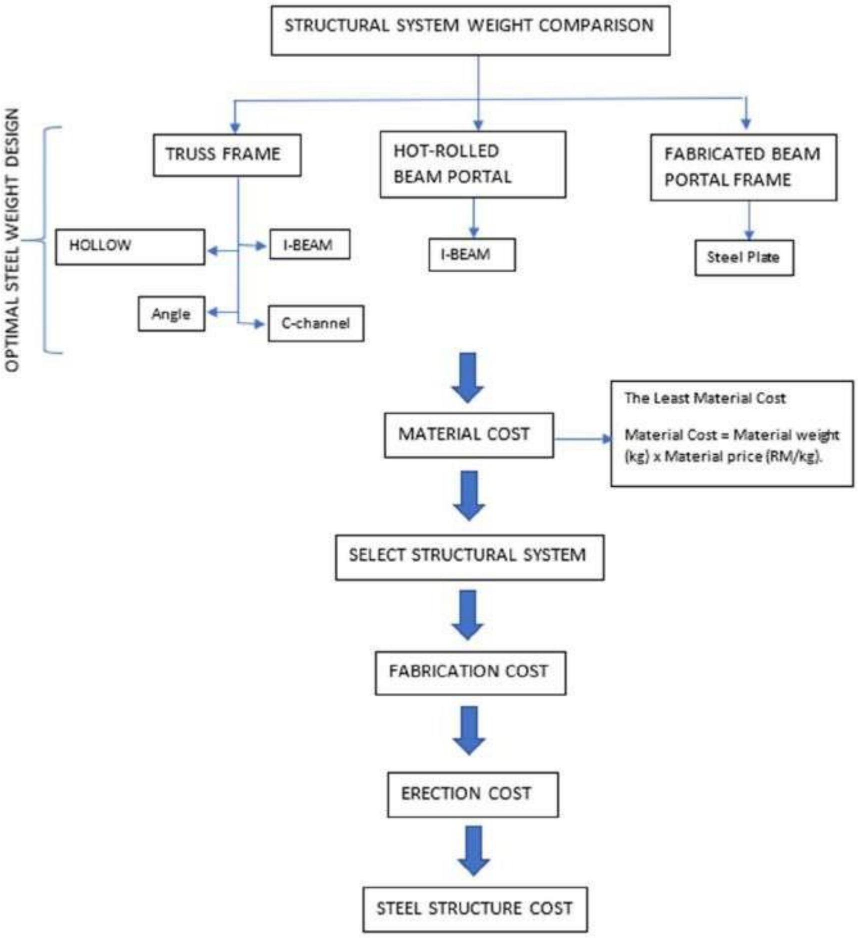


Figure 5: Flow chart of steel structure cost considering fluctuation of various material price.

5. Comparison of Structural System Weight

This paper will focus on the comparison of truss frame and hot-rolled beam portal frame material cost. Truss frame may use less steel compare to portal frame [Salter PR et al,2004] [Woolcock ST et al,2011] [Zaragoza & Jose R,1997]. For span up 45m and more, truss frame system provides a low cost and more economical alternative utilizing massively wide universal beams and beam-columns [Mohamed A. El-Aghoury et al,2020]. Based on past research, truss frame will give the most optimal structural weight compare to other structural system.

Hot-rolled portal frame may be heavier in terms of structural weight. However, based on the current material price, I-beam is the lowest compare to hollow section or plate. To validate the decision to select the hot-rolled beam portal frame as a structural system used to compare with truss frame, the results of frame comparison by R. Makinstray et al,2014 on optimal design of fabricated beam and hot- rolled beam portal frame will be used. Refer to table 4, is the optimal weight of hot-rolled beam and fabricated beam portal frame for frame with span of 40m and 10m height. With the current material price of plates and I-beam, for month of April and May, the material cost of hot-rolled beam portal frame is much lower compare to fabricated beam portal frame. Month of June the hot-rolled beam portal frame material cost is 2.22% more compare to fabricated beam portal frame. Therefore, with the advantage of 15% weight saving of fabricated beam portal frame may not necessarily lower the structural system material cost.

Table 4: Optimal structural weight and material cost comparison of fabricated beam portal frame and hot-rolled beam portal frame (kg/m2)

	Column	Rafter	Haunch	Frame Weight (kg/m2)	June	May	April
					(RM/kg)	(RM/kg)	(RM/kg)
FBC1	986 x 321 x 156	917 x 161 x 133	395 x 182 x 128	36.06	176.69	172.01	156.86
UBC4	UB 914 x 305 x 201	UB 762 x 267 x 134	UB 610 x 305 x 179	42.52	180.71	160.30	151.37
			Material Cost Saving (%)		2.22	-7.30	-3.63

6. Frame Design Parameter

Truss frame preliminary sizing and design will be compared with 'Design of Steel Portal Frame Buildings to Eurocode 3' published by The Steel Construction Institute (SCI). SCI is the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector. The preliminary sizing is shown in the publication Appendix A and the assumption made in creating the tables are as follows:

- The tabulated sizes take no account of stability at ULS and deflection at SLS
- The roof pitch is 6 degrees
- Steel grade is S355
- The rafter load is the design value of the permanent actions (including self-weight) plus variable action (the imposed roof load). Wind load has not been included-the presumption is that gravity loading will dominate the choice of member sizes.
- The haunch length is 10% of the span of the frame.
- A column is treated as restraint when torsional restraints are provided along its length (these columns are therefore lighter than the equivalent unrestraint columns)
- A column is treated as unrestraint if no torsional restraint can be provided along its length.

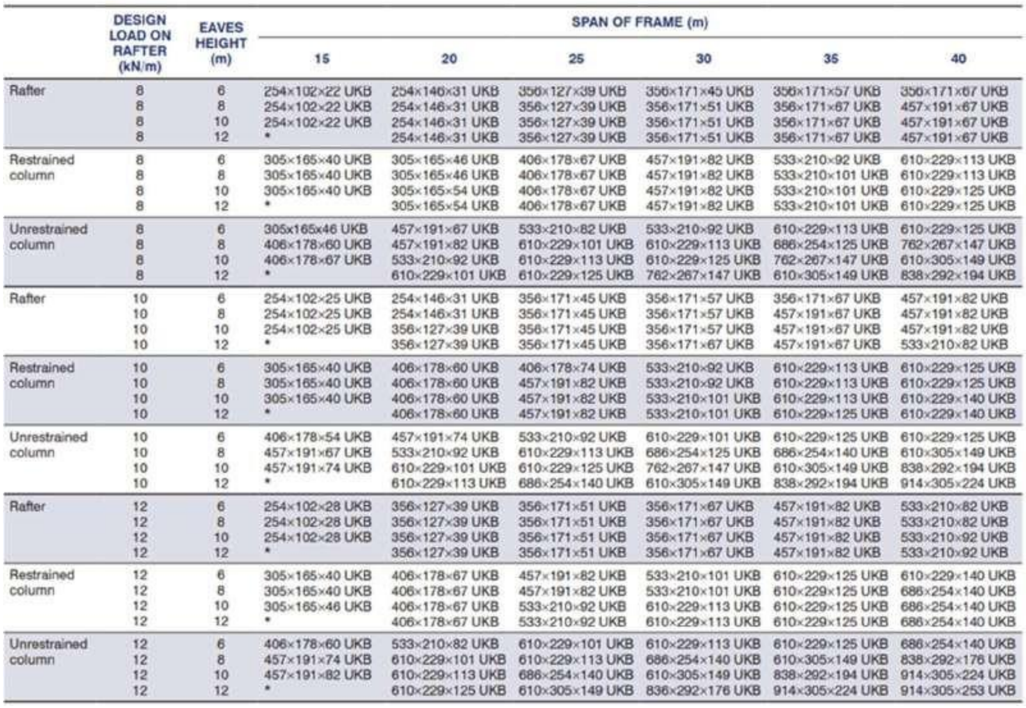
The member sizes given in the table are suitable for preliminary design and further check is required which may increase the size further. In this paper, the loading used is 12kN/m on the rafter and truss frame. The building height considered is 8m eave height. The sectional size comparison will be only on the rafter sectional size. The building span between truss frame and hot-rolled beam portal frame will be compare for span 15m, 20m, 25m, 30m, 35m and 40m.

The assumption and design parameter for the truss frames will be in accordance to the SCI preliminary sizing stated above. However, there is some additional assumptions are as follows:

- Truss depth will be in accordance to Table 7
- Steel grade is S275
- Only RHS and SHS will be consider in section selection
- Warren truss will be use since it requires the least numbers of diagonal members. Fabrication cost can be reduced
- Only 2 types of different steel section will be used for top and bottom chords and diagonal members

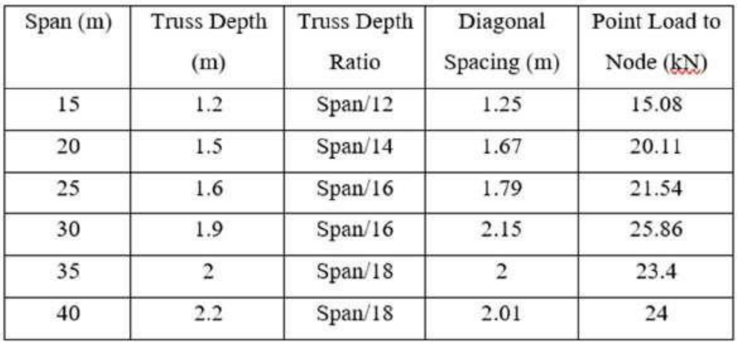
The truss frame hollow section will be selected from the list given in 'SCI P363 Steel Building Design: Design Data' book. The hollow section considered is Square Hollow Section (SHS).

Table 6: Portal frame preliminary sizing SCI.



	DESIGN LOAD ON RAFTER (kN/m)	EAVES HEIGHT (m)	SPAN OF FRAME (m)					
			15	20	25	30	35	40
Rafter	8	6	254×102×22 UKB	254×146×31 UKB	356×127×39 UKB	356×171×45 UKB	356×171×57 UKB	356×171×67 UKB
	8	8	254×102×22 UKB	254×146×31 UKB	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×67 UKB
	8	10	254×102×22 UKB	254×146×31 UKB	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×67 UKB
	8	12	*	254×146×31 UKB	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×67 UKB
Restrained column	8	6	305×165×40 UKB	305×165×46 UKB	406×178×67 UKB	457×191×82 UKB	533×210×92 UKB	610×229×113 UKB
	8	8	305×165×40 UKB	305×165×46 UKB	406×178×67 UKB	457×191×82 UKB	533×210×101 UKB	610×229×113 UKB
	8	10	305×165×40 UKB	305×165×54 UKB	406×178×67 UKB	457×191×82 UKB	533×210×101 UKB	610×229×125 UKB
	8	12	*	305×165×54 UKB	406×178×67 UKB	457×191×82 UKB	533×210×101 UKB	610×229×125 UKB
Unrestrained column	8	6	305x165x46 UKB	457×191×67 UKB	533×210×82 UKB	533×210×92 UKB	610×229×113 UKB	610×229×125 UKB
	8	8	406×178×60 UKB	457×191×82 UKB	610×229×101 UKB	610×229×113 UKB	686×254×125 UKB	762×267×147 UKB
	8	10	406×178×67 UKB	533×210×92 UKB	610×229×113 UKB	610×229×125 UKB	762×267×147 UKB	610×305×149 UKB
	8	12	*	610×229×101 UKB	610×229×125 UKB	762×267×147 UKB	610×305×149 UKB	838×292×194 UKB
Rafter	10	6	254×102×25 UKB	254×146×31 UKB	356×171×45 UKB	356×171×57 UKB	356×171×67 UKB	457×191×82 UKB
	10	8	254×102×25 UKB	254×146×31 UKB	356×171×45 UKB	356×171×57 UKB	457×191×67 UKB	457×191×82 UKB
	10	10	254×102×25 UKB	356×127×39 UKB	356×171×45 UKB	356×171×57 UKB	457×191×67 UKB	457×191×82 UKB
	10	12	*	356×127×39 UKB	356×171×45 UKB	356×171×67 UKB	457×191×67 UKB	533×210×82 UKB
Restrained column	10	6	305×165×40 UKB	406×178×60 UKB	406×178×74 UKB	533×210×92 UKB	610×229×113 UKB	610×229×125 UKB
	10	8	305×165×40 UKB	406×178×60 UKB	457×191×82 UKB	533×210×92 UKB	610×229×113 UKB	610×229×125 UKB
	10	10	305×165×40 UKB	406×178×60 UKB	457×191×82 UKB	533×210×101 UKB	610×229×113 UKB	610×229×140 UKB
	10	12	*	406×178×60 UKB	457×191×82 UKB	533×210×101 UKB	610×229×125 UKB	610×229×140 UKB
Unrestrained column	10	6	406×178×54 UKB	457×191×74 UKB	533×210×92 UKB	610×229×101 UKB	610×229×125 UKB	610×229×125 UKB
	10	8	457×191×67 UKB	533×210×92 UKB	610×229×113 UKB	686×254×125 UKB	686×254×140 UKB	610×305×149 UKB
	10	10	457×191×74 UKB	610×229×101 UKB	610×229×125 UKB	762×267×147 UKB	610×305×149 UKB	838×292×194 UKB
	10	12	*	610×229×113 UKB	686×254×140 UKB	610×305×149 UKB	838×292×194 UKB	914×305×224 UKB
Rafter	12	6	254×102×28 UKB	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×82 UKB	533×210×82 UKB
	12	8	254×102×28 UKB	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×82 UKB	533×210×82 UKB
	12	10	254×102×28 UKB	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×82 UKB	533×210×92 UKB
	12	12	*	356×127×39 UKB	356×171×51 UKB	356×171×67 UKB	457×191×82 UKB	533×210×92 UKB
Restrained column	12	6	305×165×40 UKB	406×178×67 UKB	457×191×82 UKB	533×210×101 UKB	610×229×125 UKB	610×229×140 UKB
	12	8	305×165×40 UKB	406×178×67 UKB	457×191×82 UKB	533×210×101 UKB	610×229×125 UKB	686×254×140 UKB
	12	10	305×165×46 UKB	406×178×67 UKB	533×210×92 UKB	610×229×113 UKB	610×229×125 UKB	686×254×140 UKB
	12	12	*	406×178×67 UKB	533×210×92 UKB	610×229×113 UKB	610×229×125 UKB	686×254×140 UKB
Unrestrained column	12	6	406×178×60 UKB	533×210×82 UKB	610×229×101 UKB	610×229×113 UKB	610×229×125 UKB	686×254×140 UKB
	12	8	457×191×74 UKB	610×229×101 UKB	610×229×113 UKB	686×254×140 UKB	610×305×149 UKB	838×292×176 UKB
	12	10	457×191×82 UKB	610×229×113 UKB	686×254×140 UKB	610×305×149 UKB	838×292×194 UKB	914×305×224 UKB
	12	12	*	610×229×125 UKB	610×305×149 UKB	836×292×176 UKB	914×305×224 UKB	914×305×253 UKB

Table 7: Truss frame depth.



Span (m)	Truss Depth (m)	Truss Depth Ratio	Diagonal Spacing (m)	Point Load to Node (kN)
15	1.2	Span/12	1.25	15.08
20	1.5	Span/14	1.67	20.11
25	1.6	Span/16	1.79	21.54
30	1.9	Span/16	2.15	25.86
35	2	Span/18	2	23.4
40	2.2	Span/18	2.01	24

7. Design and Analysis of Frame

7.1 Elastic analysis of Frame

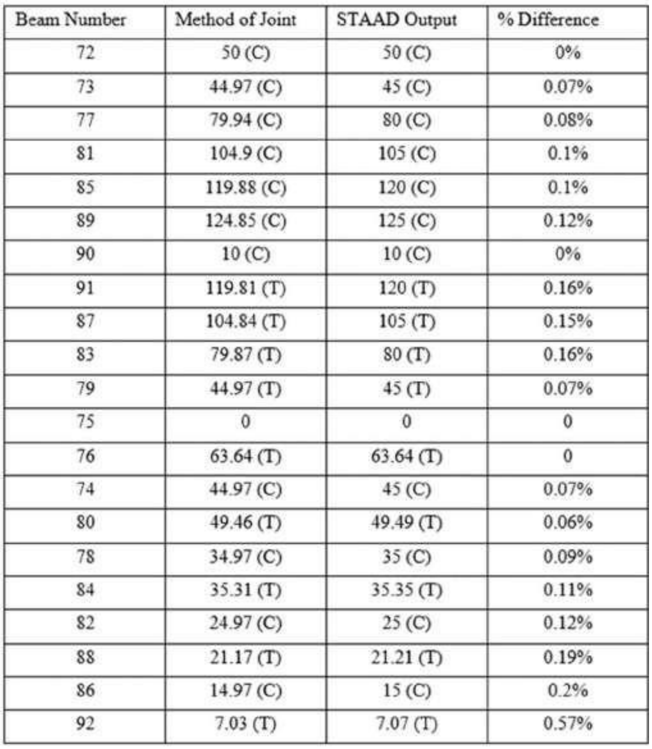
For the analysis the truss frame, the analysis program used is STAADPro. For verification purpose, the truss frame internal forces will be analyse using method of joints. The internal forces obtained will be compared with the STAADPro analysis output. The analysis parameter are as follows;

Truss span = 20 m Frame height = 11 m Truss Depth = 2m

Support Condition = Pinned and Roller Support Point Load = 10 kN nodal load and 5kN at column

The truss frame internal force obtained by method of joint is tabulated and compared with the STAADpro analysis output. The comparison is shown in Table 8. The internal force result between method of joint and STAADpro is almost identical with the maximum deviation of 0.04 kN. Therefore, the STAADpro V8i software can be accepted to conducted the design and analysis of this research.

Table 8: Comparison of internal forces.



Beam Number	Method of Joint	STAAD Output	% Difference
72	50 (C)	50 (C)	0%
73	44.97 (C)	45 (C)	0.07%
77	79.94 (C)	80 (C)	0.08%
81	104.9 (C)	105 (C)	0.1%
85	119.88 (C)	120 (C)	0.1%
89	124.85 (C)	125 (C)	0.12%
90	10 (C)	10 (C)	0%
91	119.81 (T)	120 (T)	0.16%
87	104.84 (T)	105 (T)	0.15%
83	79.87 (T)	80 (T)	0.16%
79	44.97 (T)	45 (T)	0.07%
75	0	0	0
76	63.64 (T)	63.64 (T)	0
74	44.97 (C)	45 (C)	0.07%
80	49.46 (T)	49.49 (T)	0.06%
78	34.97 (C)	35 (C)	0.09%
84	35.31 (T)	35.35 (T)	0.11%
82	24.97 (C)	25 (C)	0.12%
88	21.17 (T)	21.21 (T)	0.19%
86	14.97 (C)	15 (C)	0.2%
92	7.03 (T)	7.07 (T)	0.57%

7.2 Ultimate Limit State Design Requirement

The truss frames will be design in accordance to Eurocode 3. The members will be checked for capacity under tension and compression force only. Joint failure of the intersection between chord and diagonal member are excluded in this paper.

7.3 Design Procedure Compression Member

Procedure 1.0	EN 1993-1-1:2005 references	Remarks
1. Determine the ultimate limit state axial compressive force N_{ED} for the relevant load case		1. The internal forces shall be extracted from the analysis software
2. Select the steel grade	Table 3.1	1. S275 will be considered for this research
3. Select trial size		1. For truss members, only SHS and RHS to be considered for the member selection 2. For column, only UB section to be considered for member selection 3. Preliminary selection will be using ‘Bluebook’ published by The Steel Construction Institute

4. Classify cross section in compression.	Clause 5.5, Table 5.2	Four classes of cross-sections are defined, as follows: 1. Class 1 – cross section is those can form a plastic hinge with the rotation capacity required from plastic analysis without reduction of the resistance 2. Class 2 – cross section is those which can develop their plastic moment resistance, but have limited rotation capacity because of local buckling 3. Class 3 – cross section is those in which the stress in the extreme compression fiber of the steel member assuming an elastic distribution of stresses can reach the yield strength, but local buckling is liable to prevent development of the plastic moment resistance 4. Class 4 – cross section is those in which local buckling will occur before the attainment of yield stress in one or more parts of the cross section.
5. Determine the buckling length of each axis for truss compression chord and column		1. For every 1m increase of restraint length, there is 2.6% increase in member weight (Ross & BP Lim) 2. Restraint length for truss chord compression member shall be equal to roof purlin spacing
6. Determine the slenderness ,λ for each axis	Clause 6.3.1.3, 6.3.1.4, Table 6.2, Figure 6.4	1. Truss restraint length shall be 1.5m 2. $\bar{\lambda} = J\frac{\AE\ f_y}{N_{cr}}$ (For Class 1,2 & 3) 3. $\bar{\lambda} = J\frac{\AE\ eff f_y}{N_{cr}}$ (For Class 4)
7. Select appropriate buckling curve for each axis	Table 6.1, Figure 6.4	1. Cold formed hollow section will be considered in this research. Buckling curve ‘c’ shall be use.
8. Determine the reduction factor, χ	Clause 6.3.1.2	1. $\chi = \frac{1}{\$+J\$^2-\bar{\ss}^2}$ 2. $\phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2]$
9. Determine the buckling resistance, $N_{b,Rd}$	Clause 6.3.1.1	1. $N_{b,Rd} = \frac{3\AE f_y}{yN1}$ (Class 1,2 & 3) 2. A_{eff} if section is Class 4
10. Compare buckling resistance with the design axial force	Clause 6.3.1.1	1. $N_{b,Rd} < N_{ED}$

7.4 Design Procedure Tension Member

Procedure 2.0	EN 1993-1-1:2005 references	Remarks
1. Determine the ultimate limit state axial tension force N_{ED} for the relevant load case		1. The internal forces shall be extracted from the analysis software
2. Select the steel grade	Table 3.1	1. S275 will be considered for this research

3. Select trial size		1. For truss members, only SHS and RHS to be considered for the member selection 2. Preliminary selection will be using 'Bluebook' published by The Steel Construction Institute
4. Determine the section tensile capacity	Clause 6.2.3	1. design plastic resistance of the gross cross-section, $N_{pS,Rd} = \frac{Æf_y}{\gamma_{M0}}$ 2. the design ultimate resistance of the net cross-section at holes for fastener $N_{uS,Rd} = \frac{0.9 A_{net} f_u}{\gamma_{M2}}$
5. Compare tension resistance with the design axial tension force	Clause 6.2.3	1. $N_{pS,Rd} < N_{ED}$

8. Optimization Model Of Truss Frame

The objective is to use the minimum weight of steel section while satisfying the Eurocode design requirement. Since the member under axial buckling govern most of the design, an optimal restraint length should be determined in order to achieve the maximum member buckling capacity.

8.1 Optimal Restraint Length

Research by Ross Mckinstray et al,2004 shows that or every 1m increase of restraint length, there is 2.6% increase in member weight. Therefore, the restraint length should be kept as minimal as possible. The restraint length used are as follow;

Out of Plane = 1.5m c/c

In plane = Diagonal Spacing (refer Table 7)

8.2 Topology Optimization for Optimal Truss Depth and Diagonal Arrangement

Topology optimization considers presence or absence of structural members [Farqad K.J. Jawad et al,2021]. Topology optimization is the most general form of structural optimization [Rozvany GN et al,1995]. Topology optimization has been used by mechanical and civil engineers for many years, for example in order to minimize the amount of used material and the strain energy of structures while maintaining their mechanical strength [Bendsoe et al, 2003].Topology optimization is a mathematical method which spatially optimizes the distribution of material within a defined domain, by fulfilling given constraints previously established and minimizing a predefined cost function. Topology optimization can be defined as by removing unnecessary members from highly connected ground structures while nodal locations are fixed [Kirsch U,1989] [Rozvany GN,1992]. For such an optimization procedure, the three main elements are design variables, the cost function and the constraints.

For truss optimal truss depth, Steel Construction Industry (SCI) and AISC recommended 'Building span/12-24' whereas SECHALO-RFS2-CT-2008-0030 publication recommend 'building span/10-15'. A tubular truss of parallel chords should have an optimum height (distance between chords) that minimizes the structural cost [J Farkas,2005]. By taking into consideration both recommendations, the truss depth used can be shown in table 7. The diagonal members can be reduced significantly as shown in figure 6 by using Warren truss instead of Pratt truss.

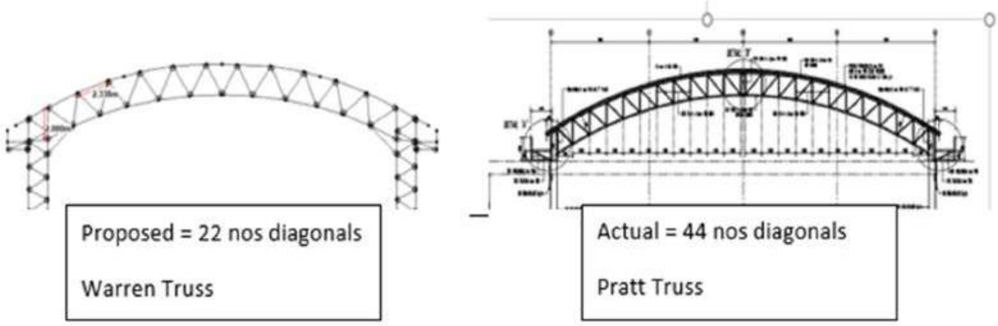
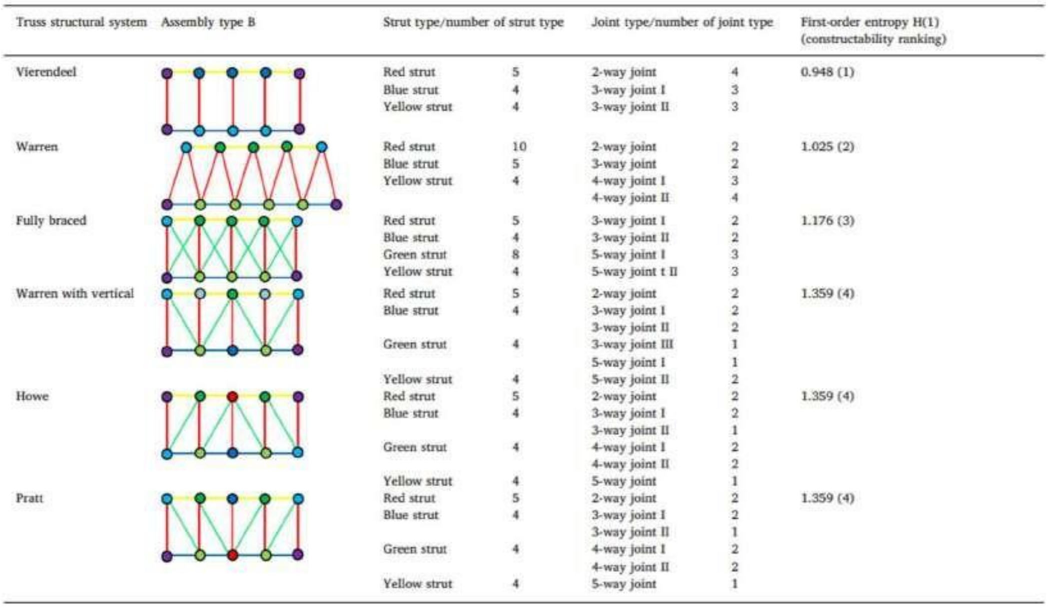


Figure 6: Comparison of Warren truss and Pratt truss diagonal member.

Another reason of using Warren truss is the simplicity in the design and fabrication. Constructability of truss frame will affect the truss fabrication cost as studies by Mei Chi-Chang et al,2017 tabulated various type of truss frame and ranked the truss frame by constructible ranking. As indicate in figure 7, the lesser the component, the higher the ranking in terms of constructability.



Truss structural system	Assembly type B	Strut type/number of strut type		Joint type/number of joint type		First-order entropy H(1) (constructability ranking)
Vierendeel		Red strut Blue strut Yellow strut	5 4 4	2-way joint 3-way joint I 3-way joint II	4 3 3	0.948 (1)
Warren		Red strut Blue strut Yellow strut	10 5 4	2-way joint 3-way joint 4-way joint I 4-way joint II	2 2 3 4	1.025 (2)
Fully braced		Red strut Blue strut Green strut Yellow strut	5 4 8 4	3-way joint I 3-way joint II 5-way joint I 5-way joint t II	2 2 3 3	1.176 (3)
Warren with vertical		Red strut Blue strut Green strut Yellow strut	5 4 4 4	2-way joint 3-way joint I 3-way joint II 3-way joint III 5-way joint I 5-way joint II	2 2 2 1 1 2	1.359 (4)
Howe		Red strut Blue strut Green strut Yellow strut	5 4 4 4	2-way joint 3-way joint I 3-way joint II 4-way joint I 4-way joint II 5-way joint	2 2 1 2 2 1	1.359 (4)
Pratt		Red strut Blue strut Green strut Yellow strut	5 4 4 4	2-way joint 3-way joint I 3-way joint II 4-way joint I 4-way joint II 5-way joint	2 2 1 2 2 1	1.359 (4)

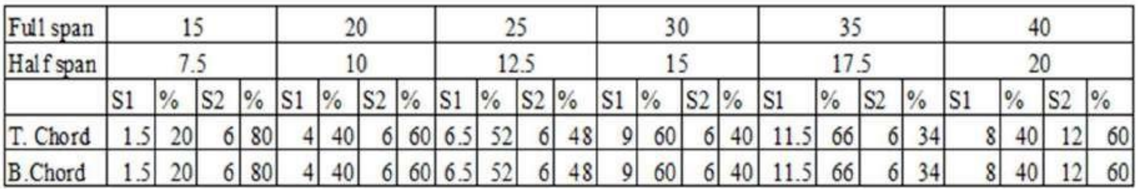
Figure 7 Truss Frame Constructability Ranking [35]

8.3 Optimal Steel Section Placement and Selection Along Truss Frame

The truss frame hollow section will be selected from the list given in ‘SCI P363 Steel Building Design: Design Data’ book. The hollow section considered is Square Hollow Section (SHS) depending on which section gives the least weight. To achieve an optimal weight design, the members selected along the truss frame will be mixed with maximum of two different section.

The various size placement will be select in accordance to Figure 8 and the section length will be in accordance to Table 9. Table 6 were determined to give the least wastage to the fabrication of truss frame. Steel section standard length comes in 6m, 9m and 12m.

Table 9: Proposed steel section length along truss frame.



Full span	15				20				25				30				35				40			
Half span	7.5				10				12.5				15				17.5				20			
	S1	%	S2	%	S1	%	S2	%	S1	%	S2	%	S1	%	S2	%	S1	%	S2	%	S1	%	S2	%
T. Chord	1.5	20	6	80	4	40	6	60	6.5	52	6	48	9	60	6	40	11.5	66	6	34	8	40	12	60
B.Chord	1.5	20	6	80	4	40	6	60	6.5	52	6	48	9	60	6	40	11.5	66	6	34	8	40	12	60

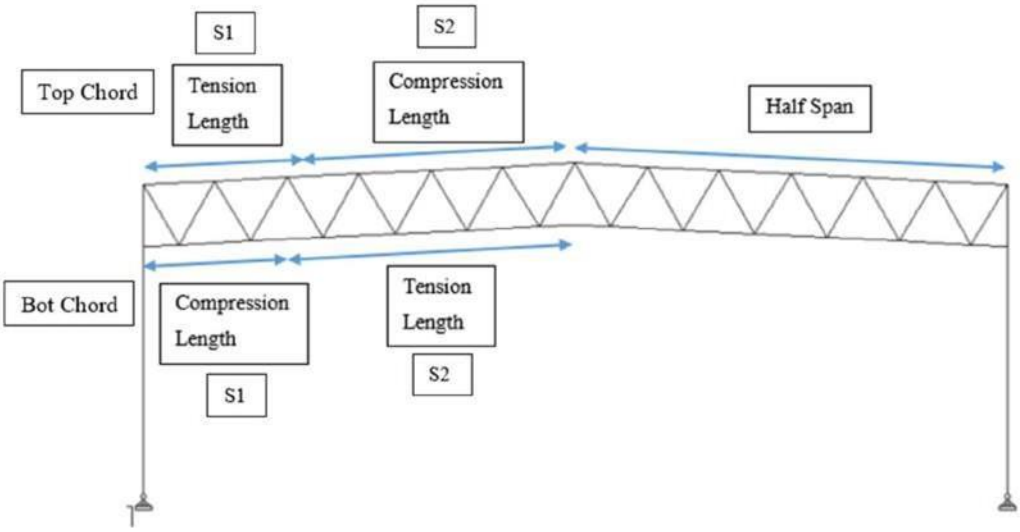


Figure 8: Proposed steel section placement.

9. Optimization Methodology

The sizing optimization for the truss frame member will be using the trial-and-error method. Since the restraint length for out of plane buckling is fixed at 1.5m and the in-plane restraint length is in accordance to table 7. Preliminary sizing will be obtained by referring to SCI P363 Steel Building Design: Design Data' book. For the various restraint length for in -plane buckling, the axial capacity will be calculated in accordance to section 7.3 and 7.4. Refer the flow chart shown in Figure 9 for the member's design.

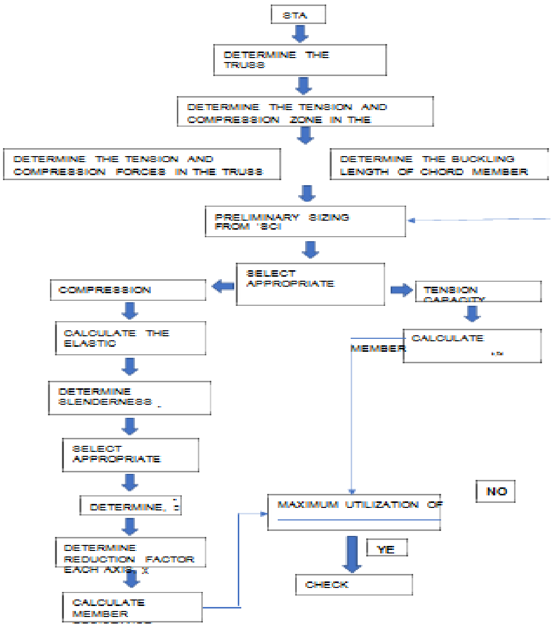


Figure 9: Member design flow chart.

10. Results and Discussion

10.1 Truss Frame Member Design

The member selection of the truss frame will be based on trial-and-error method and the trial section selection for each design check varies from 4 to 6 different types of steel hollow section. The wall thickness of the hollow selected for trial design check shall not exceed 6mm thickness. The optimal design section for the truss frame is tabulated in Table 10-15. In the table, the weight comparison of the hot-rolled portal frame and truss frame is included.

10.2 Validation of Results with STAADPro

To validate the design of the truss frame, each frame will be checked using STAADPro and the comparisons is shown in table 16. The validation for comparison of the design output with STAADPro will be using critical members in the truss frame. As shown in figure 10, segment 2 maximum axial force for tension is at member no 81 and maximum compression is at member no 74. At segment 1, the maximum compression is at member no 69 and maximum tension is at member no 115. Member number 74 and 81 will be selected for validation with STAADPro

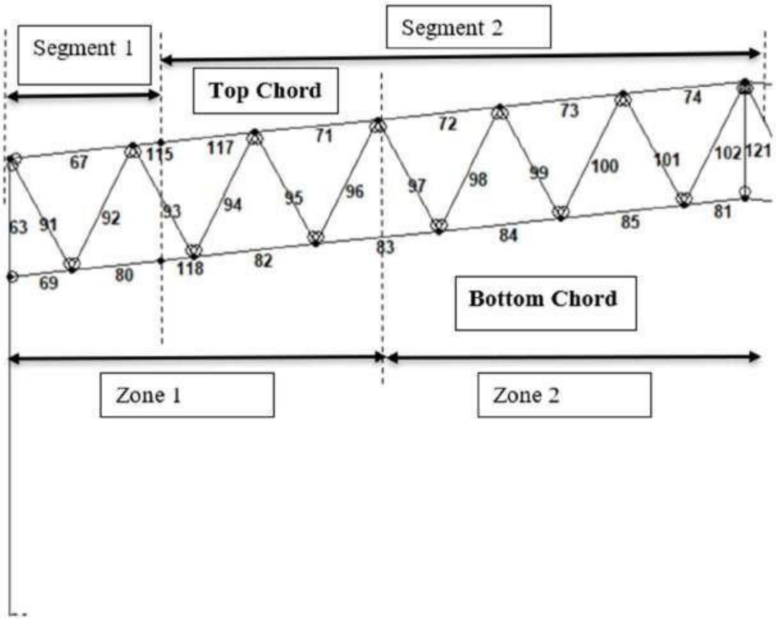
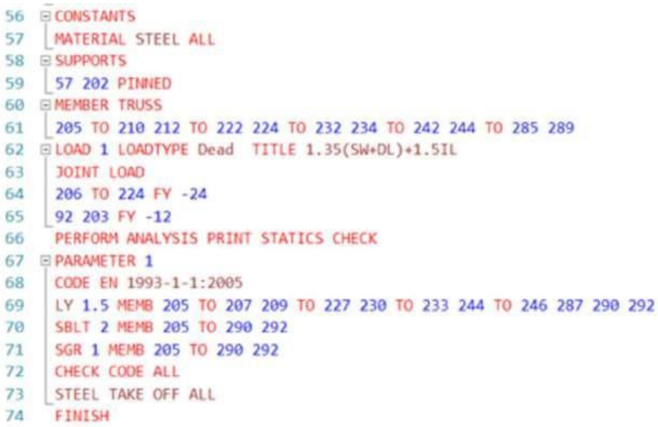


Figure 10: Truss frame weight calculation diagram.

The design parameters for the STAAD modelling and design are as follows;

1. The column base is pinned
2. The truss frame geometry and loads applied is in accordance to table 7, figure 6 and building height is 8m.
3. The hollow section yield strength is S275
4. The truss frame is assigned as truss with only axial load as the internal force.
5. The out-of-plane restraint length for compression member is 1.5m c/c

The STAADPro design input can be referred to Figure 11 below;



```
CONSTANTS
MATERIAL STEEL ALL
SUPPORTS
57 202 PINNED
MEMBER TRUSS
205 TO 210 212 TO 222 224 TO 232 234 TO 242 244 TO 285 289
LOAD 1 LOADTYPE Dead  TITLE 1.35(SW+DL)+1.5IL
JOINT LOAD
206 TO 224 FY -24
92 203 FY -12
PERFORM ANALYSIS PRINT STATICS CHECK
PARAMETER 1
CODE EN 1993-1-1:2005
LY 1.5 MEMB 205 TO 207 209 TO 227 230 TO 233 244 TO 246 287 290 292
SBLT 2 MEMB 205 TO 290 292
SGR 1 MEMB 205 TO 290 292
CHECK CODE ALL
STEEL TAKE OFF ALL
FINISH
```

Figure 11: Design input for STAADPro.

Table 10: 15m span frame weight comparison.

Span	S1	S2	D	Portal Frame (SCI- Section)				Truss Frame				Saving	
				Size		Frame Weight	Frame Weight /m	Size		Frame Weight	Frame Weight /m		
				B x D	kg/m	kg	kg/m	B x D x t	kg/m	kg	kg/m	kg	%
15	3.08	12	1.4	UB 254 x 102 x	28	422.35	30.96	SHS 50 x 50 x 3(TS1)	4.39	13.54	22.99	119.44	28
				Haunch 10%		42		SHS 80 x 80 x 3.6(TS2)	8.54	102.48			
				Total		464.35		SHS 50 X 50 X 3(BS1)	4.39	13.54			
								SHS 60 X 60 X 4(BS2)	6.97	83.64			
								SHS 50 x 50 x 3 (Z1-12)	4.39	73.75			
								SHS 40 X 40 X 3 (Z2-13)	3.45	57.96			
								Total		344.91			

Table 11: 20m span frame weight comparison.

Span	S1	S2	D	Portal Frame (SCI-Section)				Truss Frame				Saving	
				Size		Frame Weight	Frame Weight/ m	Size		Frame Weight	Frame Weight /m		
				B x D	kg/m	kg	kg/m	B x D x t	kg/m	kg	kg/m	kg	%
20	8.10	12	1.8	UB 356 x 127 x	39	783.9	43.10	SHS 70 x 70 x 3(TS1)	6.28	50.87	26.62	329.41	42
				Haunch 10%		78		SHS 90 x 90 x 3.6 (TS2)	9.72	116.64			
				Total		861.9		SHS 70 X 70 X 3(BS1)	6.28	50.87			
								SHS 60 X 60 X 4(BS2)	6.97	83.64			
								SHS 70 x 70 x 3 (Z1-10)	6.28	135.65			
								SHS 50 X 50 X 3 (Z2-15)	4.39	94.82			
								Total		532.49			

Table 12: 25m span frame weight comparison.

Span	S1	S2	D	Portal Frame (SCI-Section)				Truss Frame				Saving	
				Size		Frame Weight	Frame Weight /m	Size		Frame Weight	Frame Weight /m		
				B x D	kg/m	kg	kg/m	B x D x t	kg/m	kg	kg/m	kg	%
25	13.12	12	1.8	UB 356 x 171 x 5	51	1281.1	56.34	SHS 80 x 80 x 3.6(TS1)	8.59	112.70	30.62	643.00	50
				Haunch 10%		127.5		SHS 80 x 80 x 6.3(TS2)	14.4	172.80			
				Total		1408.6		SHS 80 X 80 X 3.6(BS1)	8.59	112.70			
								SHS 90 X 90 X 3.6(BS2)	9.72	116.64			
								SHS 80 x 80 x 3 (Z1-14)	7.22	155.95			
								SHS 50 X 50 X 3 (Z2-15)	4.39	94.82			
								Total		765.62			

Table 13: 30m span frame weight comparison.

Span	S1	S2	D	Portal Frame (SCI-Section)				Truss Frame				Saving	
				Size		Frame Weight	Frame Weight /m	Size		Frame Weight	Frame Weight /m		
				B x D	kg/m	kg	kg/m	B x D x t	kg/m	kg	kg/m	kg	%
30	18.16	12	2.3	UB 356 x 171 x 5	67	2020.7	74.06	SHS 100 x 100 x 4(TS1)	12	217.92	39.29	1,043.0	52
				Haunch 10%		201		SHS 120 x 120 x 5(TS2)	18	216.00			
				Total		2221.7		SHS 80 x 80 x 5(BS1)	11.7	212.47			
								SHS 90 X 90 X 3.6(BS2)	9.72	116.64			
								SHS 90 x 90 x 3.6 (Z1-16)	9.72	268.27			
								SHS 60 X 60 X 3 (Z2-13)	5.34	147.38			
								Total		1178.69			

Table 14: 35m span frame weight comparison.

Span	S1	S2	D	Portal Frame (SCI-Section)				Truss Frame				Saving	
				Size		Frame Weight	Frame Weight /m	Size		Frame Weight	Frame Weight /m		
				B x D	kg/m	kg	kg/m	B x D x t	kg/m	kg	kg/m	kg	%
35	10.76	24	2.3	UB 457 x 191 x	82	2885.7	90.65	SHS 100 x 100 x 4(TS1)	12	129.10	38.01	1,842.6	64
				Haunch 10%		287		SHS 120 x 120 x 4(TS2)	14.5	354.29			
				Total		3172.7		SHS 120 x 120 x 5(BS1)	18	193.64			
								SHS 90 X 90 X 3.6(BS2)	9.72	237.50			
								SHS 90 x 90 x 3.6 (Z1-16)	9.72	268.27			
								SHS 70 X 70 X 3 (Z2-21)	5.34	147.38			
								Total		1330.19			

Table 15: 40m span frame weight comparison.

Span	S1	S2	D	Portal Frame (SCI-Section)				Truss Frame				Saving	
				Size		Frame Weight	Frame Weight /m	Size		Frame Weight	Frame Weight /m		
				B x D	kg/m	kg	kg/m	B x D x t	kg/m	kg	kg/m	kg	%
40	16.08	24	2.5	UB 533 x 210 x 8	82	3286.6	90.36	SHS 80 x 80 x 5(TS1)	11.7	188.14	43.01	1,894.4	58
				Haunch 10%		328		SHS 120 x 120 x 5(TS2)	18	432.00			
				Total		3614.6		SHS 120 x 120 x 6.3(BS1)	22.3	358.58			
								SHS 90 X 90 X 3.6(BS2)	9.72	233.28			
								SHS 90 x 90 x 3.6 (Z1-16)	9.72	291.60			
								SHS 80 X 80 X 3 (Z2-25)	7.22	216.60			
								Total		1720.20			

Table 16: Summary of Forces Validation Using STAADPro

Truss Members	Forces Comparison	STAAD			Manual Calculation		% Difference	
		Stress Ratio	Axial Capacity		Axial Capacity			
			Pcz	Pcy	Pcz	Pcy	Pcz	Pcy
15m	TS2-74 (compression)	0.92	258.20	243.00	257.69	242.32	0.20	0.28
	BS2-81 (Tension)	0.90	241.70		244.20		1.02	
20m	TS2-74 (compression)	0.95	275.70	286.70	276.99	288.19	0.47	0.52
	BS2-81 (Tension)	0.98	241.70		244.20		1.02	
25m	TS2-74 (compression)	0.99	363.40	397.50	367.09	402.21	1.01	1.19
	BS2-81 (Tension)	0.93	338.30		341.00		0.79	
30m	TS2-74 (compression)	0.78	515.70	570.30	518.06	573.99	0.46	0.65
	BS2-81 (Tension)	0.97	338.30		341.00		0.79	
35m	TS2-74 (compression)	0.99	433.00	463.10	433.87	464.51	0.20	0.30
	BS2-81 (Tension)	0.90	338.30		341.00		0.79	
40m	TS2-74 (compression)	0.91	528.10	570.30	530.90	573.99	0.53	0.65
	BS2-81 (Tension)	0.90	338.30		341.00		0.79	

Table 17: Summary of weight comparison of hot-rolled portal frame and truss frame.

Span	Hot-Rolled Beam Portal Frame Weight (kg)	Truss Frame Weight (kg)	Saving in %
15	464.4	344.9	28%
20	861.9	532.5	42%
25	1408.6	765.6	50%
30	2221.7	1178.7	52%
35	3172.7	1330.2	64%
40	3614.6	1720.2	58%

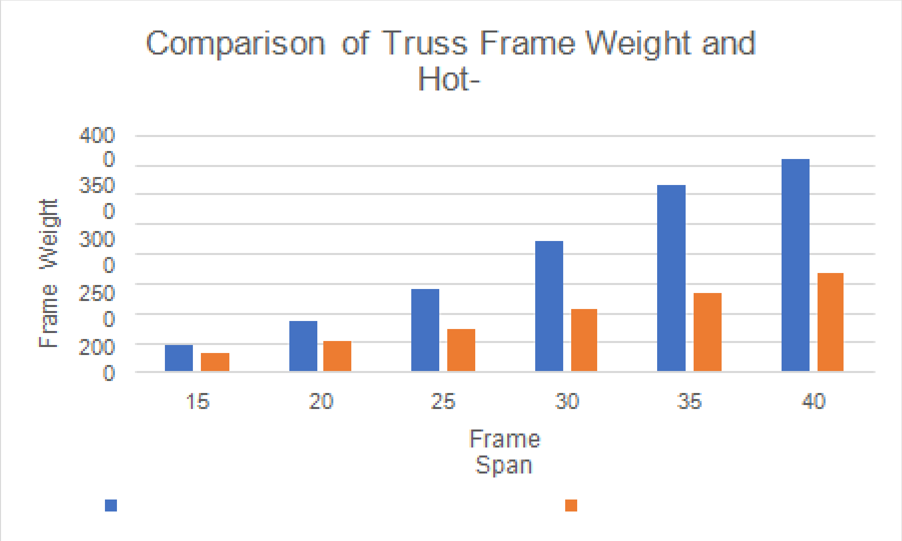


Figure 12: Comparison of truss frame weight and hot-rolled beam portal frame.

10.3 Material Cost Calculation

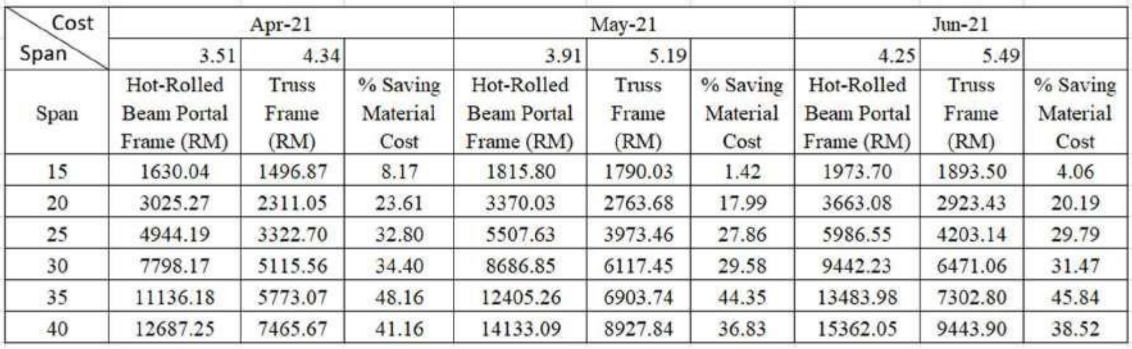
The calculation of material cost, the average material price for hollow will be taken from month-to-month base on the supplier price shown in table 3. Base on the average from all supplier material price, the price taken to calculate material cost is shown in Table 18.

Table 18: Summary of hollow section and I-beam material price.

	Hollow Section (RM/T)	I-Beam (RM/T)	% Different
April 2021	4339	3512	19.1%
May 2021	5185	3911	24.6%
June 2021	5485	4250	22.5%

Base on the material price average, hollow section is more expensive that I-beam. The difference in material price ranges from 19%-25%. Material cost will be calculate based on section 4.0.

Table 19: Summary of material price for truss frame and hot-rolled beam portal frame.



Cost / Span	Apr-21			May-21			Jun-21		
	3.51	4.34		3.91	5.19		4.25	5.49	
Span	Hot-Rolled Beam Portal Frame (RM)	Truss Frame (RM)	% Saving Material Cost	Hot-Rolled Beam Portal Frame (RM)	Truss Frame (RM)	% Saving Material Cost	Hot-Rolled Beam Portal Frame (RM)	Truss Frame (RM)	% Saving Material Cost
15	1630.04	1496.87	8.17	1815.80	1790.03	1.42	1973.70	1893.50	4.06
20	3025.27	2311.05	23.61	3370.03	2763.68	17.99	3663.08	2923.43	20.19
25	4944.19	3322.70	32.80	5507.63	3973.46	27.86	5986.55	4203.14	29.79
30	7798.17	5115.56	34.40	8686.85	6117.45	29.58	9442.23	6471.06	31.47
35	11136.18	5773.07	48.16	12405.26	6903.74	44.35	13483.98	7302.80	45.84
40	12687.25	7465.67	41.16	14133.09	8927.84	36.83	15362.05	9443.90	38.52

11. Observations

11.1 Truss Frame Moment of Inertia

Generally, truss frame is significantly lighter than hot-rolled beam portal frame. As shown in table 17, the weight saving in the range of 30% - 65%. The weight saving is much significant as the span of the frame is longer. One of the main reasons is the increase of the truss frame vertical and lateral stiffness as the depth increased. As shown in Figure 13, the truss depth plays a significant role in increasing the truss frame moment of inertia. Referring to table 7, the truss depth gradually increases from 1.2m depth for 15m span to 2.2m depth for 40m span.

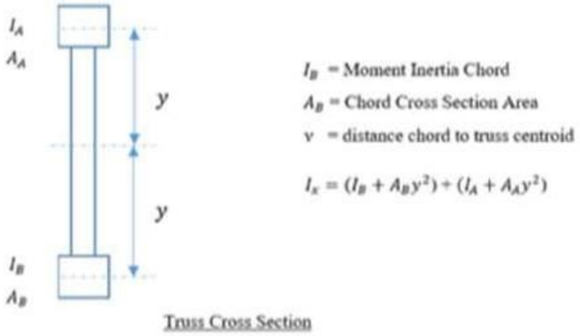


Figure 13: Truss frame moment of inertia calculation.

11.2 Truss Frame Chord

Generally, under vertical load, truss frame top chord will be under compression. The maximum compression force is at mid-span and gradually reduce toward the column. As the top chord approaching to the column, tension force will occur.

Frame span exceeding 25m, the bottom chord compression force and compression length at segment 1 is gradually increasing. As shown in table 13-15, for span exceeding 30m, the hollow section selected for the segment 1 bottom chord is much bigger compare to the bottom chord segment 2. The out-of-plane buckling length for compression chord at segment selected is 1.5m centre to centre. By

adding a closer restraint length, the design of the member can be optimized. The bottom chord segment 2 consist mainly tension force. Steel section have advantage in resisting tension force compare to compression force. As shown in table 13-15, the bottom chord segment 2 is much smaller or lighter compare to the section used in the bottom chord segment 1.

The truss diagonal force is gradually increase as it approaching the column. As shown in all frames Zone 1 diagonal, the sectional size much bigger compare to Zone 2.

11.3 Material Cost

Overall, with the price advantage of I-beam compare to hollow section, the material cost for hot-rolled beam portal frame is much higher compare to truss frame for span 15m to 40m. The weight saving of truss frame is the reason of the lower material cost compare to hot-rolled beam portal frame. As shown in table

17, the weight saving of truss frame comparing to hot-rolled beam portal frame is in the range of 28% - 65%. Base on the material cost calculation shown in section 4.0, the average material cost saving of truss frame compare to hot-rolled beam portal frame is 30.9%. This is taken averagely for the month of April, May and June.

The 28% weight saving for truss frame compare hot-rolled portal frame did not translate to significant saving in material cost. As shown in table 19, with the price fluctuation, the material cost saving ranging from 2% - 49% for truss frame. As the price of hollow section is 24% higher compare to I-beams, the saving in material cost for truss frame compare to hot-rolled beam portal frame is not significant and may be equal. With the consideration of the fabrication cost, hot-rolled beam portal frame may prove to be a cost optimal solution for overall steel structure cost.

12.Conclusion

Truss frame have distinct weight advantage over hot-rolled beam portal frame with the weight saving ranging from 28% to 64%. For span exceeding 25m, the weight saving is more than 50%. The significant weight saving is contributed mainly with the increase of truss frame vertical stiffness as the truss depth increased. The mixture of various steel section along the truss frame chord contribute to the significant weight saving compare to hot-rolled beam portal frame.

The price fluctuation of steel section is becoming a decision factor in selecting a suitable structural system to achieve optimal steel structure cost. Building span exceeding 20m, truss frame is the best option due to the significant weight saving advantage and saving in material cost. Structural weight saving of 30% for truss frame compare to hot-rolled beam portal frame may not necessarily give the overall saving in material price and overall steel structure cost. Building span below 20m, hot-rolled beam portal frame is the best solution compare to truss frame if the material price gap of I-beam is 24% compare to hollow section and the weight difference not exceeding 30%. As the price gap between I- beam and hollow not exceeding 50%, truss frame is the best solution as a structural system with the significant saving in material cost

Further work can be carried out considering the fabrication cost and overall steel structure cost of both structural systems taking into consideration the material price fluctuation.

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