Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 1900-1908
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RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Design and Foundation Load Demand Comparative Study of Engineered Timber Building Versus Steel-Concrete Solution

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DOI: https://doi.org/10.30880/rtcebe.2022.03.01.211
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: Industrial building nowadays were built using framing system due to the construction was fast and can served many purpose for the building. A framing structural building can provided more space because it had less column taking up the space. The objective of this study was to perform design of an engineered timber building and the similar layout with a steel-concrete design solution and to determine the foundation load demand for both the engineered timber building and steel-concrete solution. After that, an easy to use design spreadsheet for the engineered timber building was created. Two standard code of practice was used on the design of the building which is Eurocode 3 for steel structure and Eurocode 5 for engineered timber Specific design guide Nelson Pine LVL was also used for LVL engineered timber properties. In this study, design was performed for carry load from the roof and 1st floor. Slab on steel building used was precast concrete and slab on engineered timber used Timber-concrete composite (TCC). Loading analysis was carried out to determine the maximum shear force and maximum bending moment. Total axial load on the column was determine to obtain foundation load demand between steel building and engineered timber building. A simple design spreadsheet for simply supported LVL beam and LVL column will be produced for designing engineered timber building to speed up the designing process.

Keywords: Steel-Concrete Solution, Engineered Timber Building, Foundation Load Demand, Axial Load

1. Introduction

Construction projects may involve various kind of different materials. Each different kind of materials will have its own distinct type of properties and its own unique behavior when it is applied for a structure. In general, there are three of the most commonly used of construction materials which are

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reinforced concrete, steel and engineered timber and by having knowledge in depth the properties and behavior for the material would ensure a good, economical and safe and more importantly cost-affordable approach for the structure that are designed.

Laminated Veneer Lumber is made out of super thin veneers wood by sticking all the veneers in same direction. LVL is used in various different kind of construction. It is commonly used as a structural elements such as load bearing beams and column. It is also very suitable for structural member like rafters which is commonly used in houses, commercial and industrial structures. The benefits of using Laminated Veneer Lumber (LVL) instead of other timber-based structural materials is it can be used for long length up to 18m. Construction material using LVL has many benefits compare to steel and reinforced concrete due to lower weight of itself [4]. LVL actually have a high strength to weight ratio, and is most preferable when designing structures because it can carry big own-weight [5].

This research was compare the total foundation load demand of every column on the design building. The percentage of load different is calculated to show the differences. All the design will also need to be following the design standard code. Eurocode 3 for structural rolled steel and Eurocode 5 for design of engineered timber. Specific engineering design guide from NelsonPine LVL is also used for the design of LVL timber.

The research was aimed to show that the foundation load demand of the engineered timber building will be lesser than the steel building. Therefore, the foundation area required for that building can be reduced and timber building is very suitable to be built on ground that have low soil bearing capacity. It contributes significantly in encouraging the application of engineered LVL timber beam in Malaysia.

2. Methodology

The structural drawing of the steel building is drawn out using Autocad. Figure 1 shows completed front view of engineered timber building in Johor Bahru and figure 2 shows rear view of engineered timber building in Johor Bahru. Figure 3 shows roof view of the building. Figure 4 shows 1st floor view of the building

Figure 1: Completed front view of engineered timber building in Johor Bahru

Figure 2: Rear view of engineered timber building in Johor Bahru

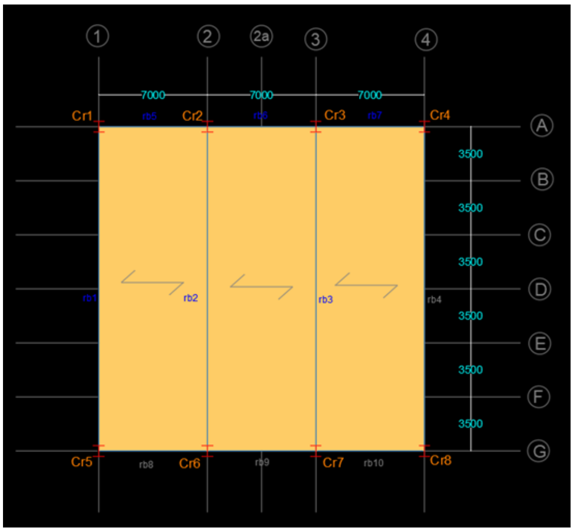


Figure 3: Roof view of the building

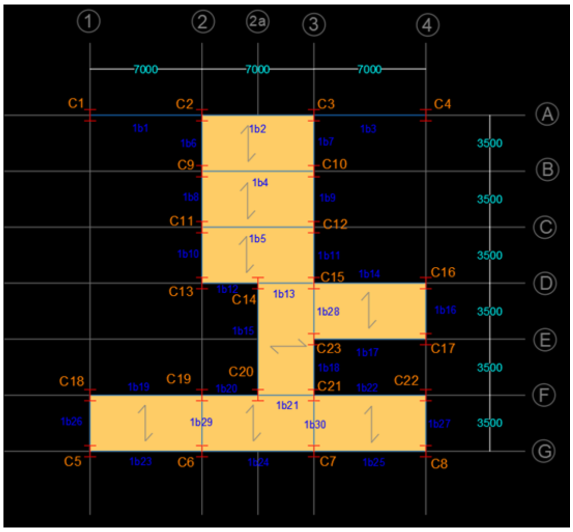


Figure 4: 1st floor view of the building

2.1 Assign of loading of the building

2.1.1 Assign the loading on the steel framing building

Loading on the steel framing building

Item	Description
Density of concrete, ρ	24 kN/m^3
Thickness of precast concrete slab	150 mm
Weight of cement board	0.25 kN/m^2
Weight of glass wall	0.5 kN/m

Loading on Roof

Elements	Permanent load (gk)	Variable load (qk)
Lightweight metal roof	0.5 kN/m^2	
Non-accessible roof		0.25 kN/m^2
Total	**0.5 kN/m^2**	**0.25 kN/m^2**

Loading on first floor

1. Permanent Action, Gk

Element	Calculation	Load (kN/m)
Self-weight of precast concrete slab	0.150 × 3.5/2 × 24	6.3
Finishing, insulation	1.5 × 3.5/2	2.625
Selfweight of steel beam		0.5
Glass wall		0.5
Cement board	0.25 × 3.5/2	0.4375

2. Variable Action, Qk

Element	Calculation	Load (kN/m)
Office Area	1.5 × 3.5/2	2.625

2.1.2 Assign the loading on the engineered timber (LVL) framing building

Item	Description
Density of concrete, ρ	24 kN/m^3
TCC floor concrete thickness	750 mm
Weight of cement board	0.25 kN/m^2
Weight of glass wall	0.5 kN/m

Loading on Roof

Elements	Permanent load (gk)	Variable load (qk)
Lightweight metal roof	0.5 kN/m^2	
Non-accessible roof		0.25 kN/m^2
Total	**0.5 kN/m^2**	**0.25 kN/m^2**

Loading on first floor

1. Permanent Action, Gk

Element	Calculation	Load (kN/m)
Self-weight of TCC	0.075 × 3.5/2 × 24	3.15
Finishing, insulation	1.0 × 3.5/2	1.75
Selfweight of LVL beam		0.2
Glass wall		0.5
Cement board	0.25 × 3.5/2	0.4375

2. Variable Action, Qk

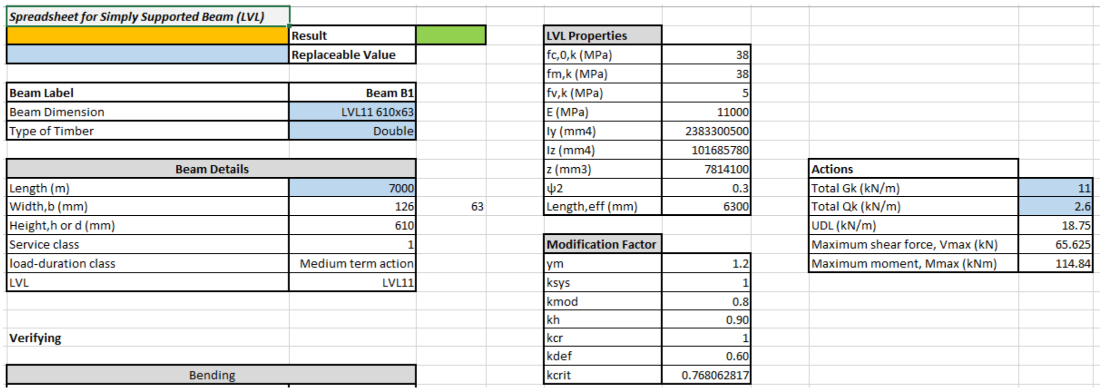
Element	Calculation	Load (kN/m)
Office Area	1.5 × 3.5/2	2.625

2.2 Design of steel building

The design of of steel purlins is based on table 2.7 BS 5950: Part 1:2000. For the design of steel beam, firstly choose one Universal beam (UB) section from SCI P363 Steel Building Design: Design Data and extract out all of section properties. All steel grade is S275. The max shear force, V_{max} and maximum bending, M_{max} is calculated out based on the loading analysis of every beam and drawing of shear force and bending moment diagram. After that the design is based on Eurocode 3.

2.3 Design of engineered LVL timber building

The design will use spreadsheet that have been created to simplify the calculation. Figure 5 and 6 shows spreadsheet design for LVL beam interface and figure 7 and 8 show the spreadsheet design for LVL column interface.



Spreadsheet for Simply Supported Beam (LVL)

🟧	**Result**	🟩
🟦	**Replaceable Value**	

Beam Label	**Beam B1**
Beam Dimension	LVL11 610x63
Type of Timber	Double

Beam Details		
Length (m)	7000	
Width,b (mm)	126	63
Height,h or d (mm)	610	
Service class	1	
load-duration class	Medium term action	
LVL	LVL11	

LVL Properties	
fc,0,k (MPa)	38
fm,k (MPa)	38
fv,k (MPa)	5
E (MPa)	11000
Iy (mm4)	2383300500
Iz (mm4)	101685780
z (mm3)	7814100
ψ2	0.3
Length,eff (mm)	6300

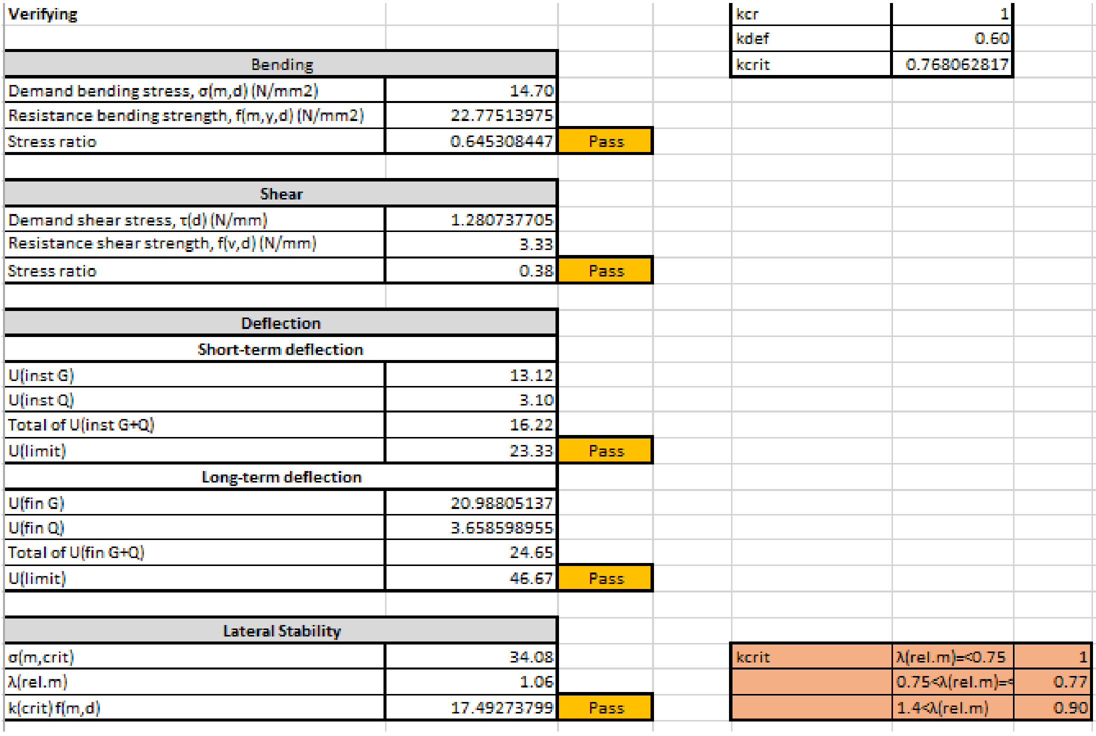
Modification Factor	
ym	1.2
ksys	1
kmod	0.8
kh	0.90
kcr	1
kdef	0.60
kcrit	0.768062817

Actions	
Total Gk (kN/m)	11
Total Qk (kN/m)	2.6
UDL (kN/m)	18.75
Maximum shear force, Vmax (kN)	65.625
Maximum moment, Mmax (kNm)	114.84

Verifying

Bending

Figure 5: Spreadsheet design for LVL beam



Verifying

kcr	1
kdef	0.60
kcrit	0.768062817

Bending		
Demand bending stress, σ(m,d) (N/mm2)	14.70	
Resistance bending strength, f(m,y,d) (N/mm2)	22.77513975	
Stress ratio	0.645308447	Pass

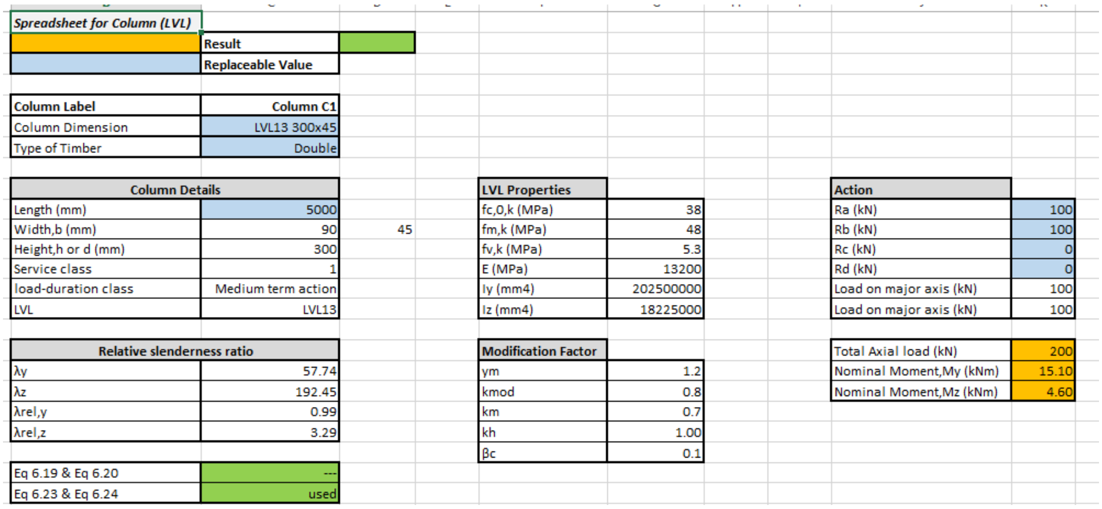
Shear		
Demand shear stress, τ(d) (N/mm)	1.280737705	
Resistance shear strength, f(v,d) (N/mm)	3.33	
Stress ratio	0.38	Pass

Deflection		
Short-term deflection		
U(inst G)	13.12	
U(inst Q)	3.10	
Total of U(inst G+Q)	16.22	
U(limit)	23.33	Pass
Long-term deflection		
U(fin G)	20.98805137	
U(fin Q)	3.658598955	
Total of U(fin G+Q)	24.65	
U(limit)	46.67	Pass

Lateral Stability		
σ(m,crit)	34.08	
λ(rel.m)	1.06	
k(crit) f(m,d)	17.49273799	Pass

kcrit	λ(rel.m)=<0.75	1
	0.75<λ(rel.m)=<	0.77
	1.4<λ(rel.m)	0.90

Figure 6: Spreadsheet design for LVL beam



Spreadsheet for Column (LVL)

🟧	**Result**	🟩
🟦	**Replaceable Value**	

Column Label	**Column C1**
Column Dimension	LVL13 300x45
Type of Timber	Double

Column Details		
Length (mm)	5000	
Width,b (mm)	90	45
Height,h or d (mm)	300	
Service class	1	
load-duration class	Medium term action	
LVL	LVL13	

LVL Properties	
fc,0,k (MPa)	38
fm,k (MPa)	48
fv,k (MPa)	5.3
E (MPa)	13200
Iy (mm4)	202500000
Iz (mm4)	18225000

Action	
Ra (kN)	100
Rb (kN)	100
Rc (kN)	0
Rd (kN)	0
Load on major axis (kN)	100
Load on major axis (kN)	100

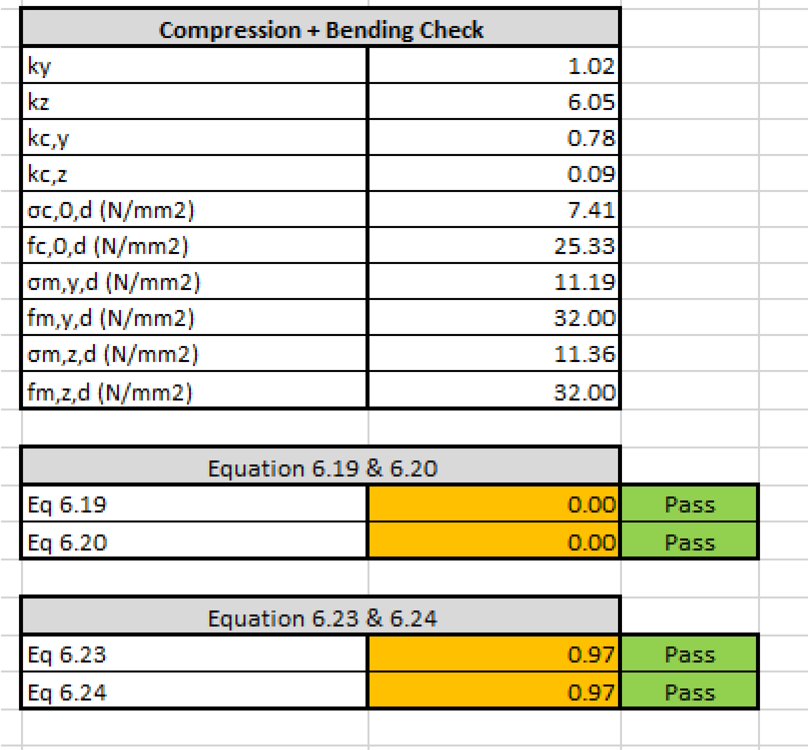
Relative slenderness ratio	
λy	57.74
λz	192.45
λrel,y	0.99
λrel,z	3.29

Modification Factor	
ym	1.2
kmod	0.8
km	0.7
kh	1.00
βc	0.1

Total Axial load (kN)	200
Nominal Moment,My (kNm)	15.10
Nominal Moment,Mz (kNm)	4.60

Eq 6.19 & Eq 6.20	---
Eq 6.23 & Eq 6.24	used

Figure 7: Spreadsheet design for LVL column



Compression + Bending Check	
ky	1.02
kz	6.05
kc,y	0.78
kc,z	0.09
σc,0,d (N/mm2)	7.41
fc,0,d (N/mm2)	25.33
σm,y,d (N/mm2)	11.19
fm,y,d (N/mm2)	32.00
σm,z,d (N/mm2)	11.36
fm,z,d (N/mm2)	32.00

Equation 6.19 & 6.20		
Eq 6.19	0.00	Pass
Eq 6.20	0.00	Pass

Equation 6.23 & 6.24		
Eq 6.23	0.97	Pass
Eq 6.24	0.97	Pass

Figure 8: Spreadsheet design for LVL column

2.4 Analysis and comparison of foundation load demand

The results from the calculation were analysis and studied. The result of total axial load to the foundation. The percentage of load that reduced is calculated using equation 1.

$$\%\text{ less load required} = \frac{load\ from\ steel - load\ from\ engineered\ timber}{load\ from\ steel}\ x\ 100\% \qquad \textbf{[eqn. 1]}$$

3. Results and Discussion

Table 1 shows the steel beam section for the steel building. Table 2 shows steel column section for the steel building. Table 3 shows the LVL beam sizes for the engineered timber building. Table 4 shows the LVL column sizes for the engineered timber building.

3.1 Results

3.1.1 For steel building design part

Beam	Section UB	Status
Rb1 rb2 rb3 rb4	533x210x138 UB	Pass
1b2 1b14 1b15 1b17 1b19 1b22 1b23 1b24 1b25 1b4 1b5 1b1 1b3 rb5 rb6 rb7 rb8 rb9 rb10	457x191x82 UB	Pass
1b12 1b13 1b20 1b21 1b18 1b28 1b6, 1b7, 1b8, 1b9, 1b10, 1b11, 1b16, 1b26, 1b27, 1b29, 1b30	305x102x33 UB	Pass

Table 1: Steel beam section for the steel building

Column	**Section UC**	**Status**
All except Cr5 Cr6 Cr7 Cr8	203x203x52 UC	Pass
Cr5 Cr6 Cr7 Cr8	203x203x71 UC	Pass

Table 2: Steel column section for the steel building.

3.1.2 For engineered timber LVL building design part

Beam	**Section size**	**Status**
purlin	LVL11 360x90 single	Pass
rb2 rb3 rb1 rb4	LVL11 1220x90 double	Pass
1b2 1b14 1b15 1b17 1b19 1b22 1b23 1b24 1b25 1b12 1b13 1b20 1b21 1b18 1b28 1b4 1b5	LVL11 610x63 double	Pass
1b1 1b3 rb5 rb6 rb7 rb8 rb9 rb10 1b6, 1b7, 1b8, 1b9, 1b10, 1b11, 1b16, 1b26, 1b27, 1b29, 1b30	LVL11 170x63 single	Pass

Table 3: LVL beam sizes for the engineered timber building.

Column	**Section size**	**Status**
All	LVL11 300x90 single	Pass

Table 4: LVL column sizes for the engineered timber building.

3.2 Discussion

Comparison of foundation load between steel building and engineered timber building

Load demand from column	Steel building (kN)	Engineered timber building (kN)	% less load required
C2	155	71	54.2%
C3	155	71	54.2%
C6	222	164	26.1%
C7	222	164	26.1%

Table 5: Comparison of foundation load demand

From the analysis.is it found that the engineered timber required less foundation load demand than steel building. Maximum reduced load can up to 54.2% which is on column C2 and C3.This will make the area of foundation to be build decrease thus reduce the cost of the project. An average of reduced load is about 30%. Therefore, we can estimate the foundation cost on this project if built by engineered timber LVL will have 30% less cost than steel building. The highest foundation load falls on column C6 and C7, the steel building have 222kN foundation load demand and engineered timber LVL building have 164kN. The percentage of load that have been reduced if built by engineered timber is about 26.1%. This shows that engineered timber LVL building required less foundation area and can be built on area that has less soil bearing capacity. Figure 9 shows a bar chart of comparison of foundation load on column C6 and C7.

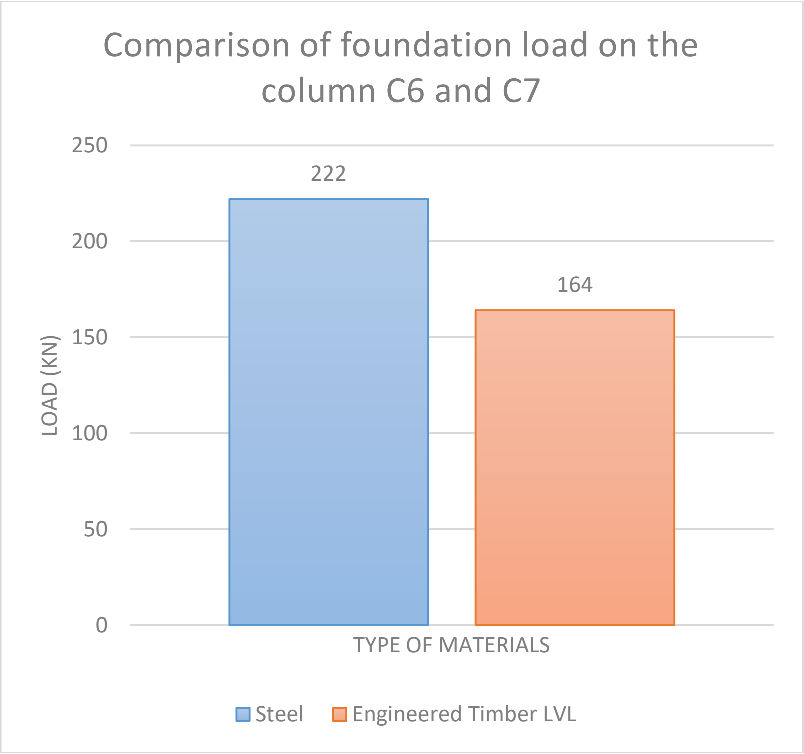


Figure 9: comparison of foundation load on column C6 and C7

4. Conclusion

The objectives that was to perform design of an engineered timber building and the similar layout with a steel-concrete design solution. From the previous chapter, design for steel building and engineered timber building have been done based on Eurocode 3 and Eurocode 5 to find the suitable section UB, UB and section size for LVL.

For the second objective, determine the foundation load demand for both the engineered timber building and steel-concrete solution. The analysis from foundation load demand shows that foundation load demand required by engineered timber building was lesser compare to steel building. Therefore, we should start to consider using engineered timber in industry because it not only reduced the foundation area of the building but also brings benefit to the environment.

An easy to use design spreadsheet for the engineered timber building have been created. Manual calculation is very tedious therefore, design spreadsheet is very important to speed up the design process and to reduce human mistakes.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support and appreciation to all parties who have contributed to this research.

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