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Structural, economic and material comparison of various steel grades under fatigue loading

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CHAPTER FIVE

5.1 MODELING OF A TEN-STOREY BUILDING

Three simple multi-storey buildings for a typical office complex of 10 structural beam floors were analyzed using PROKON finite element model package to determine its linear and buckling behaviour. Each of the multi-storeys consists of only one type of steel grade namely, 300W, 350W and 460W with varying sections depending on the capacity. From the space frame analysis, the linear and buckling analysis were determined for each case. The overall mass of the structure was also determined.

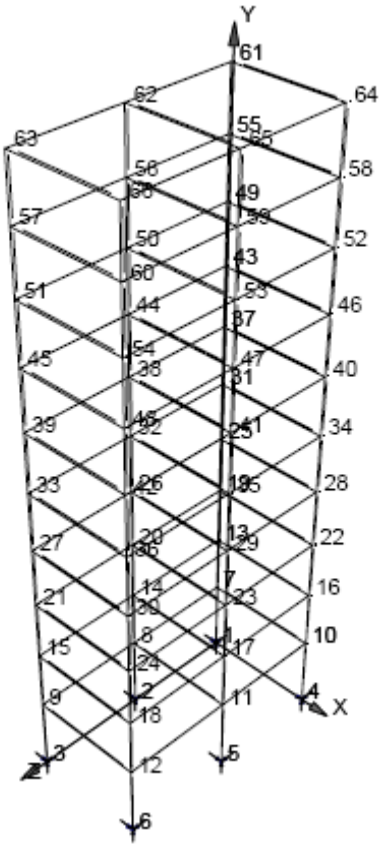

Figure 5.1 – Multi-storey building

The loading and design of the multi-storey building was determined as follows:

Loading: (BS 648: 1964 Schedule of weights of building materials)

Typical floors	KN/m^2
Dead Load:	
Raised floor	0.2
130 mm2 lightweight concrete on profiled metal decking	2.5
Steelwork and fire protection	0.5
Services	0.25
Ceiling	0.2
Total (G_k)	**3.65**
Live Load	
Imposed Load	3.0
Allowance for metal partitions	0.32
Sub total (Q_K)	3.32
Wind Load	
From BS CP3, dynamic wind pressure, q	0.76
Characteristics q = 0.9 x 0.76	0.68
Total	**4.0**

Partial safety factors:

Dead load = 1.35

Live load = 1.5

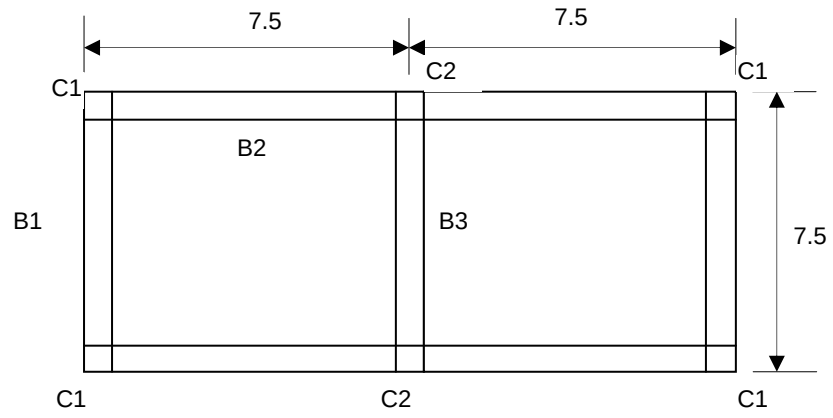

Figure 5.2 – Typical floor layout

Beam B1:

Dead load = 3.65 KN/m^2 * 3.75 m = 13.7 KN/m

Live load = 4.0 KN/m^2 * 3.75 m = 15 KN/m

Design Load, F_d = 1.35 * 13.7 KN/m + 1.5 * 5 KN/m

= 41 KN/m

B1 is simply supported at both ends and is fully restrained along its length.

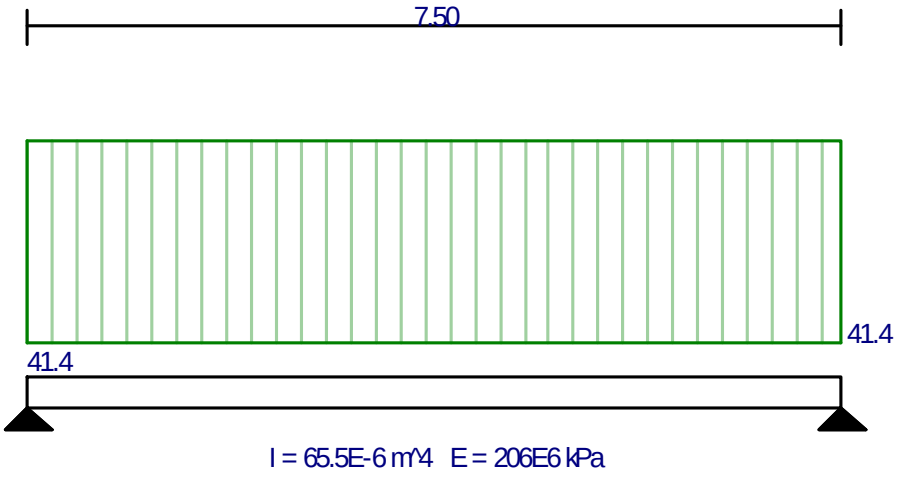

Figure 5.3 – Beam B1

$Design\,Moment$:

$$M_D = \frac{F_D x L^2}{8}$$

$$= \frac{41KN/m * 7.5^2\, m^2}{8} = 288.28KNm$$

$Design\,Shear\,Force$:

$$F_D = \frac{F_D x L}{2}$$

$$= \frac{41KN/m * 7.5m}{8} = 153.75KN$$

To determine the section size, the flange thickness is assumed to be less than 40 mm and that design strength is 300 N/mm^2. Also, class 1 or 2 assumed.

$M_D \le M_p$ where M_p is the moment capacity of the section

$$M_p = 0.9 Z_{pl} f_y$$

For 300W

Assume 406 x 178 x 60 UB

Section properties:

Depth	h	= 406.4 mm
Width	b	= 177.8 mm
Web thickness	t_w	= 7.8 mm
Flange thickness	t_f	= 12.8 mm
Depth between fillets	d	= 360 mm
Plastic modulus	Z_{pl}	= 1195 x 10^3 mm^3

$$M_p = 0.9 * 1195x10^3 * 300N/mm^2 x10^{-6}$$

$$M_p = 322.65KNm$$

Percentage increase = $\frac{322.65 - 288.28}{288.28} = 12\%$

For 350W

Assume 356 x 171 x 57 UB

Section properties:

Depth	h	= 358.6 mm
Width	b	= 172.1 mm
Web thickness	t_w	= 8.0 mm
Flange thickness	t_f	= 13.0 mm
Depth between fillets	d	= 313 mm
Plastic modulus	Z_{pl}	= 1009 x 10^3 mm^3

$$M_p = 0.9 * 1009x10^3 * 350N/mm^2 x10^{-6}$$

$$M_p = 318KNm$$

Percentage increase = $\frac{318 - 288.28}{288.28} = 10\%$

For 460W

Assume 356 x 171 x 45 UB

Section properties:

Depth	h	= 352.0 mm
Width	b	= 171.0 mm

Web thickness	t_w	= 6.9 mm
Flange thickness	t_f	= 9.7 mm
Depth between fillets	d	= 313 mm
Plastic modulus	Z_{pl}	= 773.3 x 10^3 mm^3

$$M_p = 0.9 * 773.3x10^3 * 460 N/mm^2 x10^{-6}$$

$$M_p = 320 KNm$$

Percentage increase = $\frac{320 - 288.28}{288.28} = 11\%$

Percentage increase in the choice of section was approximately constant.

The same sections of B1 are assumed for B2.

Beam B3:

Dead load = 3.65 KN/m^2 * 7.5 m = 27.4 KN/m

Live load = 4.0 KN/m^2 * 7.5 m = 30 KN/m

Design Load, F_d = 1.35 * 13.7 KN/m + 1.5 * 5 KN/m

= 82 KN/m

B3 is simply supported at both ends and is fully restrained along its length.

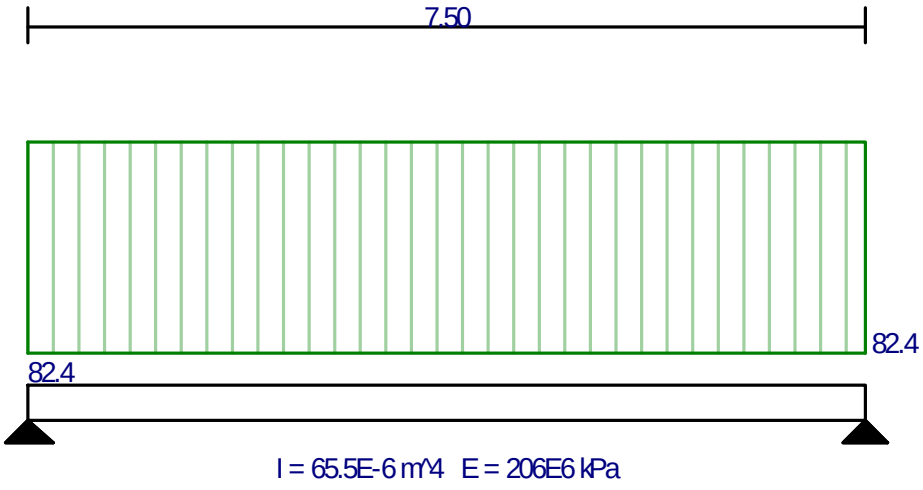

Figure 5.4 – Beam B3

$Design\,Moment$:

$$M_D = \frac{F_D x L^2}{8}$$

$$= \frac{82KN/m * 7.5^2\, m^2}{8} = 576.6KNm$$

$Design\,Shear\,Force$:

$$F_D = \frac{F_D x L}{2}$$

$$= \frac{82\,KN/m * 7.5\,m}{8} = 307.5KN$$

To determine the section size, the flange thickness is assumed to be less than 40 mm and that design strength is 300 N/mm^2. Also, class 1 or 2 assumed.

$M_D \le M_p$ where M_p is the moment capacity of the section

$$M_p = 0.9 Z_{pl} f_y$$

For 300W

Assume 533 x 210 x 93 UB

Section properties:

Depth	h	= 533.1 mm
Width	b	= 209.3 mm
Web thickness	t_w	= 10.2 mm
Flange thickness	t_f	= 15.6 mm
Depth between fillets	d	= 477 mm
Plastic modulus	Z_{pl}	= 2076 x 10^3 mm^3

$$M_p = 0.9 * 2076x10^3 * 300N/mm^2 x10^{-6}$$

$$M_p = 639KNm$$

Percentage increase = $\frac{639 - 577}{572} = 11\%$

For 350W

Assume 457 x 191 x 90 UB

Section properties:

Depth	h	= 463.6 mm
Width	b	= 192.0 mm
Web thickness	t_w	= 10.6 mm
Flange thickness	t_f	= 17.7 mm
Depth between fillets	d	= 408 mm
Plastic modulus	Z_{pl}	= 1775 x 10^3 mm^3

$$M_p = 0.9 * 1775 x 10^3 * 350 N/mm^2 x 10^{-6}$$

$$M_p = 636 KNm$$

Percentage increase = $\frac{636 - 577}{577} = 10\%$

For 460W

Assume 406 x 178 x 75 UB

Section properties:

Depth	h	= 412.8 mm
Width	b	= 179.7 mm
Web thickness	t_w	= 9.7 mm
Flange thickness	t_f	= 16.0 mm
Depth between fillets	d	= 360 mm
Plastic modulus	Z_{pl}	= 1329 x 10^3 mm^3

$$M_p = 0.9 * 1329 x 10^3 * 460 N/mm^2 x 10^{-6}$$

$$M_p = 623 KNm$$

Percentage increase = $\frac{623 - 577}{577} = 8\%$

Percentage increase in the choice of section was approximately constant.

Column C2

The load determination is tabulated as follows:

Table 5.1 – Load determination

	Beam	Design load	Sub-total	Cumulative totals
10th floor	2	153.75		
	2	153.75		
	3	307.5	615	
9th floor				
as 10th floor			615	1230
8th floor				
as 10th floor			615	1845
7th floor				
as 10th floor			615	2460
6th floor				
as 10th floor			615	3075
5th floor				
as 10th floor			615	3690
4th floor				
as 10th floor			615	4305
3rd floor				
as 10th floor			615	4920
2nd floor				
as 10th floor			615	5535
1st floor				
as 10th floor			615	**6150**

Axial compressive load, N_{SD} = 6150 KN

$N_{SD} \leq N_p$ where N_p is compressive capacity of the sections.

$$N_p = \frac{A^* f_y}{\gamma_{MO}}$$

$where\ \gamma_{MO} = 1.05$

For 300W

Assume 305 x 305 x 198 UC

Section properties:

Depth	h	= 339.9 mm
Width	b	= 314.1 mm
Web thickness	t_w	= 19.2 mm
Flange thickness	t_f	= 31.4 mm
Depth between fillets	d	= 247 mm
Area	Z_{pl}	= 25.24 x 10^3 mm^2

$$N_p = \frac{25240 * 300}{1.05} = 6814KN$$

Percentage increase = $\frac{6814 - 6150}{6150} = 11\%$

For 350W

Assume 254 x 254 x 167 UC

Section properties:

Depth	h	= 289.1 mm
Width	b	= 264.5 mm
Web thickness	t_w	= 19.2 mm
Flange thickness	t_f	= 31.7 mm
Depth between fillets	d	= 200 mm
Area	Z_{pl}	= 21.24 x 10^3 mm^2

$$N_p = \frac{21240 * 300}{1.05} = 6690KN$$

Percentage increase = $\frac{6690 - 6150}{6150} = 9\%$

For 460W

Assume 254 x 254 x 132 UC

Section properties:

Depth	h	= 276.4 mm
Width	b	= 261.0 mm
Web thickness	t_w	= 15.6 mm
Flange thickness	t_f	= 25.1 mm
Depth between fillets	d	= 200 mm
Area	Z_{pl}	= 16.77 x 10^3 mm^2

$$N_p = \frac{16770 * 300}{1.05} = 6942 KN$$

Percentage increase = $\frac{6942 - 6150}{6150} = 13\%$

Percentage increase in the choice of section was approximately constant.

After the sections were determined, the buildings were analyzed as described below:

The structure consisted of 66 nodes, 130 beam elements and 6 supports. Both linear and buckling analysis was conducted.

The support of the structure is shown in the following table:

Table 5.2 – Support

Support Nodes	X (m)	Y (m)	Z (m)	X-Rot (rad)	Y-Rot (rad)	Z-Rot (rad)
1	Restraint	Restraint	Restraint	Allowed	Allowed	Allowed
2	Restraint	Restraint	Restraint	Allowed	Allowed	Allowed
3	Restraint	Restraint	Restraint	Allowed	Allowed	Allowed
4	Restraint	Restraint	Restraint	Allowed	Allowed	Allowed
5	Restraint	Restraint	Restraint	Allowed	Allowed	Allowed
6	Restraint	Restraint	Restraint	Allowed	Allowed	Allowed

In general, the support nodes were all allowed to rotate but their translation were restrained. The summary of the analysis is given is appendix A.

The results were as follows:

Table 5.3 – Results from modeling

Beam	Overall weight (kg)	Cost of steel per kg (Rand)	Cost of steel (Rand)	Horizontal Drift (mm)
300W	80917	5.5	445, 044	12.36
350W	71758	6.5	466, 427	18.27
460W	57077	12.0	684, 924	24.15

After the analysis, the horizontal drifts for the structures are shown below:

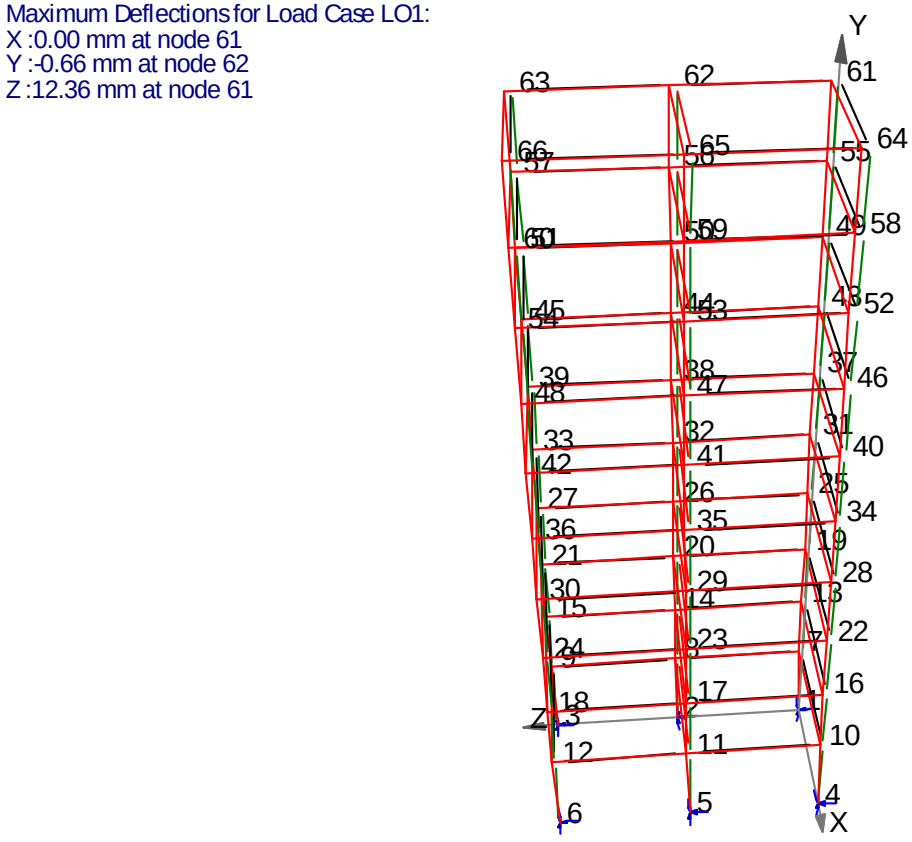

Figure 5.5 – Horizontal drift for 300W

Maximum Deflections for Load Case LO1:
X :0.00 mm at node 61
Y :-0.71 mm at node 62
Z :18.27 mm at node 61

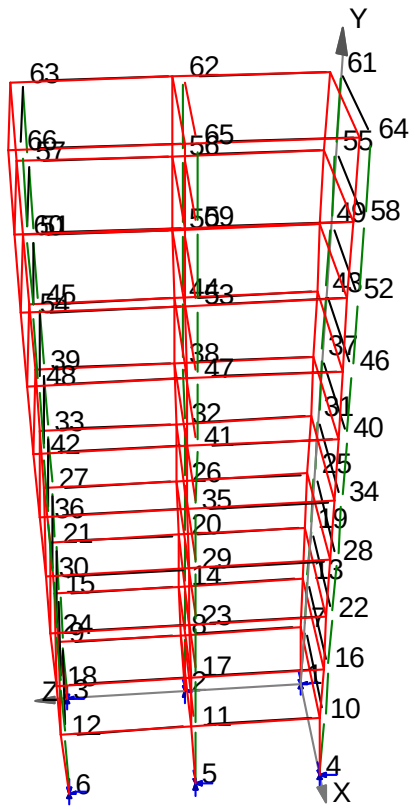

Figure 5.6 – Horizontal drift for 300W

Maximum Deflections for Load Case LO1:
X :0.00 mm at node 61
Y :-0.72 mm at node 62
Z :24.15 mm at node 61

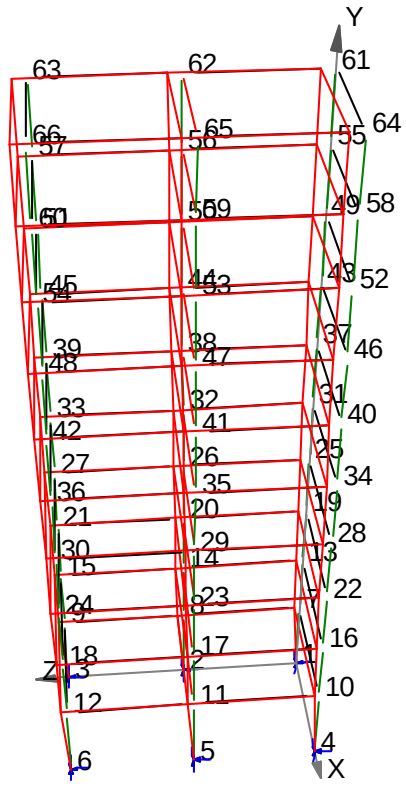

Figure 5.7 – Horizontal drift for 460W

From table 5.3, 300W was more economical and its horizontal drift was smaller than others although having a higher weight in mass than other grades.

In order to determine the appropriate steel grade for a selection criterion, an optimization was also conducted using the parameters previously determined from laboratory testing and computer modeling, or discussed in the literature report. A numerical value was assigned to each of these parameters. These values can either be positive or negative as the case may be. In most cases like drift, fatigue resistance and cost, grade 300W was chosen as the bench mark and given a value of 1.00, and others became a fraction of it. These values were multiplied to a weighting factor, from 1 to 5 (the lower the weighting the more optimum the result) and added together to give us an optimized result. The lowest value gave us the optimum choice. The factors are the parameters discussed above. The values of the factors depend on the desirability of this particular design. These are summarized in Tables 5.4 and 5.5.

Table 5.4 – Summary of the results obtained

	300W	**350W**	**460W**
Horizontal drift (mm)	12.36	18.27	24.15
Total Mass of Steel (kg)	80917	71758	57077
Fabrication Costs (Rand)	100	100	100
Strength (N/mm^2)	300	350	460
Fatigue Resistance (Cycles)	1.2×10^6	0.786×10^6	0.182×10^6
Cost of Steel (Rand/kg)	5.50	6.50	12.00
Total cost of Steel	445, 044	466, 427	684, 924
Internationalization	50	100	50

Table 5.5 – Structural and material index table

Characteristics	**300W**	**350W**	**460W**
Horizontal drift	+1.00	1.48	1.95
Total Mass	1.42	1.25	+1.00
Fabrication	1.00	1.00	1.00
Fatigue Resistance	+1.00	1.34	1.85
Cost of Steel	+1.00	1.05	1.54
Internationalization	1.5	+1.00	1.50

Due to the fact the South African code is a reflection of the Canadian coding system, CSA Standard G40.21 grade 350W (or 50W in the imperial system), the highest weighting point was assigned to internationalization as seen in table 5.6. This was done in order to take cognizant of the global world given the fact that learners and users could get familiar with South African system if we adjust to the level of the global community vis-à-vis, Canadian coding system. As a result, 350W was chosen as the bench mark for internationalization in the structural and material index table. Details of the calculations can be seen in Appendix B.

Table 5.6 – Weighting of indices

Characteristics	**Weighting**	**More**	**Less**
Horizontal drift	3	-	+
Total Mass	4	-	+
Fabrication	4	-	+
Fatigue Resistance	2	+	-
Cost of Steel	2	-	+
Internationalization	1	+	-

Table 5.7 – Summary of Calculation

	300W	**350W**	**460W**
Horizontal drift	3.00	4.44	5.85
Total Mass	5.68	5.00	4.00
Fabrication	4.00	4.00	4.00
Fatigue Resistance	2.00	2.68	3.70
Cost of Steel	2.00	2.10	3.08
Internationalization	1.50	1.00	1.50
Total	**18.18**	**19.22**	**22.13**

From the optimization of this particular situation, it can be seen clearly that grade 300W structural steel was the best optimal grade to select. This was possible because parameters like cost of steel and fatigue resistance which have low weighting values were considered as important in the optimization. A case may arise where different parameters like overall mass of the structure may be considered as the most important parameter and their factors will influence the optimization process in favour of higher steel grades.