USING COLD-FORMED STEEL SECTION IN BUILDINGS-COMPARATIVE STUDY

[1]LORAGAYLE DOCTOLERO, [2]MUSTAFA BATIKHA

[1,2] School of Energy, Geoscience, Infrastructure and Society; Heriot-Watt University, Dubai, U.A.E
E-mail: [1]ld115@hw.ac.uk, [2]m.batikha@hw.ac.uk

Abstract - One of the major concerns of structural engineers is to implement more efficient design solutions in terms of construction speed and simplicity to achieve economy in a minimized time. Through the years, conventional solutions such as the use of reinforced concrete have been the most prevalent option. Nevertheless, construction industry has constantly evolved and more practical solutions have been recognized. In view of this, it is interesting to study new alternatives that could provide more economical solutions in design. This can be achieved by comparing conventional materials to improved material alternatives including different structural designs.This paper presents a comparative study of a 4-story office building using three different materials: Cold Formed Steel Section (CFSS), Reinforced Concrete (RC) and Hot Rolled Steel Section (HRSS). The main structural members of each building were designed according to Eurocodes and BS Standards using linear elastic analysis. Design results were obtained and many outcomes were produced regarding the weight of the building, material cost, construction cost, total cost (material cost + construction cost) and the construction duration.The findings show that using Cold-Formed Steel Sections (CFSS) in a mid-rise building offers significant economies in material and total building costs as well as major reductions in construction time, in place of reinforced concrete (RCC) and hot-rolled steel (HRS). In addition, it was discovered that the cost of material mainly influences the total HRS building cost, while construction has a great impact on the overall RCC building cost.

Index Terms - Cold Formed Steel Section, Comparative Study, Cost Analysis, Hot Rolled Steel Section, Reinforced Concrete

I. INTRODUCTION

Cold-formed steel has been one of the most widely used building material over a range of building applications. The use of cold-formed steel sections has become more common due to its lightness and high structural performance. Although formerly, cold-formed sections were only used as secondary members in concrete and steel structures, it is nowadays used as main structural elements [1]. To achieve economy as well as improve the structural function of a building, it is important to use a material that would provide high strength to weight ratio, and requires simpler and faster construction.

In comparison with other building materials, the qualities that can be realized for cold- formed steel structural members include [2]high strength and stiffness, simplicity of pre-fabrication, fast and easy erection and installation and economy in handling and transporting. Moreover, cold-formed steel material is a very sustainable material since it doesn't cause a harm effect to earth resources such as timber and concrete. Furthermore, it is a recycled material. However, the lightness of cold-formed steel frames makes this material ideal for residential buildings of no more than 6 stories height and commercial buildings of up to 4 floors [3].

In this study, atypical 4-story building is designedusing three types of materials (Reinforced Concrete (RC), Hot-Rolled Steel (HRS) and Cold-Formed Steel (CFS))to justify the possibility of cold-formed steel to be the most economical solution.Bylinear elastic analysis, the internal forces are produced and the structural design of members is carried out in accordance with Eurocode 1: Actions of Structures [4], Eurocode 2: Design of Concrete Structures[5], Eurocode 3: Design of Steel Structures [6], and BS 5950-5:1998: design of cold formed sections [7]. Then, cost analysis including the time of construction is performed for each material. Consequently, the total cost and construction time of each structural configuration are obtained to present a comparison between the overall material and construction costs of the RC, HRS and CFS building.

Few researchers have performed comparative studies that focus on the advantages and downsides of three different materials. For example, Qureshi et al. (2013) [8]studied the difference in total cost and time between reinforced concrete frame and light gauge steel construction.It was found that for one story building of a total 81m^{2}area, cold-formed steel construction is 2.5 times cheaper than conventional construction of concrete. Their work also proved that CFS is 4 times faster and much simpler to construct than RC.In 2015, Sangave et al. [9]performed a comparative study which focuses on the material cost ofa G+6 and G+10 reinforced concrete and steel bare frame building. According to the results, the cost of the steel bare frame for G+6 building is 31% higher than theRC frame, while the steel bare frame for G+10 building is 34%costlier compared to the RC frame. Thus, their study has revealed that hot-rolled steel frame is more expensivein the case of mid-risebuildings, than RC frame. On the other hand, Satpute and Varghese (2012) [10] carried out a detailed analysis of a one-story industrial building of 750m^2 areato compare the material weight and cost using hot-rolled steel and cold-formed steel.According to their results,a total material and cost saving of 35% was achieved using cold-formed steel members instead of the conventional hot-rolled steel (Fig.1).

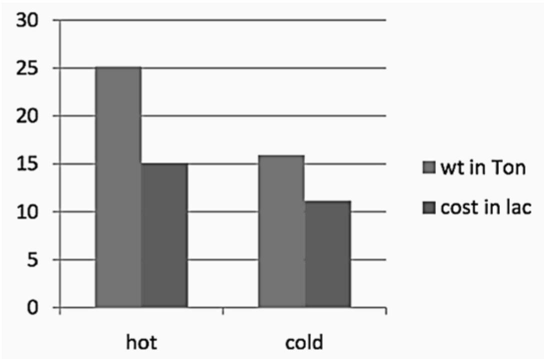


Fig. 1Total weight and cost of CFS and HRS building [10]

It is valuable to note that limited studies have only been available regarding the use of CFS in multi-story buildings. Moreover, it is very rare to find a study which undertakes the reflection of construction cost on the overall cost of the building.This viewpoint shows the important objective of this paper.

II. DESIGN OF4-STORY BUILDING WITH DIFFERENT MATERIALS

A. Description of the Building

A 16.6 m high, 4-story office building with plan dimensions of 48 m x 20 m was studied using reinforced concrete, hot-rolled steel, and cold-formed steel. The considered building plan during the design process is presented in Appendix A.

B. Actions

Structural linear elastic analysis was performed through manual calculations, taking only into account gravitational loads which include the self-weight and the overall imposed loads of 3kN/m2 [4] contained in the building.

C. Design Formulations

This study involves the structural design of a multi-story building using RC, HRS and CFS. Each structural system was designed in accordance with different building codes and standards.Eurocode 2: Part 1- 1 was applied in the design of Reinforced Concrete (RC) building, Eurocode 3: Part 1-1 was used for the Hot-Rolled Steel (HRS) design, whileCold-Formed Steel (CFS)design was performed based on BS 5950: Part 5. It is important to note that footing design for each building was carried out according to Eurocode 2: Part 1-1 and concrete foundation was used for each structural configuration. In addition, pad footing was used for both RC and HRS buildings, whereas mat footing for the CFS building. Tables B-I, B-II and B-IIIin Appendix Bdemonstrate the dimensions and the quantity of the structural elements for the designed RC building, HRS building and CFS building respectively.

III. MATERIAL QUANTITY AND COST ANALYSIS

The overall material usage for each building type was obtained based on the acquired structural configurations. Consequently, the associated construction costs as well asthe total construction duration for each buildingtype was evaluated. Results were producedto compare the differences between the overall material usage of CFS and the other two building types. For instance,Fig. 2 shows that by using CFS, the weight of the building could be 67% less than that using RC. However, the weight ratio of HRS to CFS was found to be 0.95 which indicate that using HRS would offer 5% lessbuilding weight. The very small increase in CFS weight in comparison with HRS is due mat foundation is required in the case of using CFS. However, it can be deduced from Fig. 2 that the use of CFS in place of RC allows a significant reduction in the building weight which helps in decreasing the loads concerning the weight magnitude such as the seismic action. The total cost and construction time of each building were produced using many references from reference [11] to reference [16]. In terms of material cost, Fig. 3showsthat using CFS is 34% cheaper than RC building construction, and saves up to 89% of the HRS material cost.In view of this, the use of hot-rolled steel is much costlier compared to RCC and CFS. It is also found in Fig. 4 that RC construction costs 85% higher than CFS. However, Fig. 4reveals CFS construction to be 15% costlier than HRS. Since the CFS sections tend to be more lightweight compared to HRS, more elements are required than that during HRS construction where less elements are being used. It is also worth mentioning that although CFS sections tend to be cheaper than HRS (Fig. 3), the required usage of mat foundation in the CFS building seems to have a great effecton the total construction cost. In view of the total building costs (material cost + construction cost), Fig. 5 presents CFS to be 61% more cost-effective than RCC, and 35% cheaper than HRS.

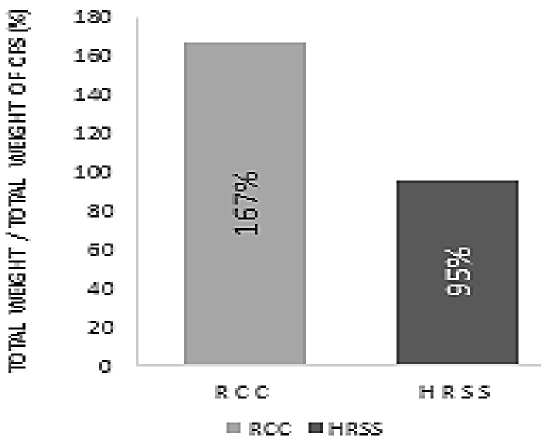


Fig.2:Relative differences between CFS building and other building types regarding the weight of the building

Although CFS construction was found to be 15% costlier than HRS (Fig. 4), it was obtained that CFS material is 89% cheaper than HRS (Fig. 3). On the other hand, the reason of the 61% total cost saving offered by CFS is clear from Fig. 3 and Fig. 4, where both material and construction costs are lesser compared to RC. In addition to this, the considerable difference between CFS and RC construction can be the main reason of the great reduction in the total cost. This also implies that CFS is far more economic than RC, since laborious construction jobs are no longer needed in CFS construction.

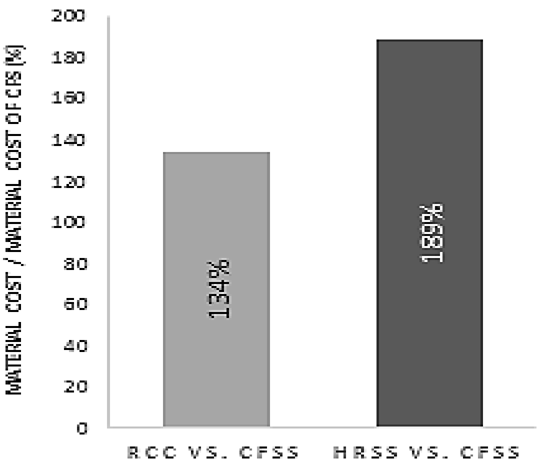


Fig. 3:Relative differences between CFS building and other building types regarding the material costs

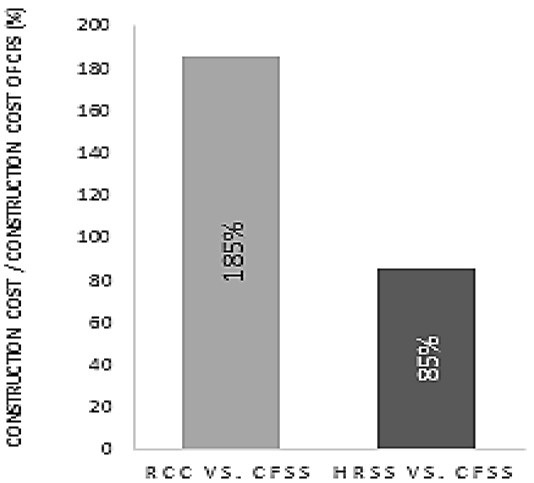


Fig. 4: Relative differences between CFS building and other building types regardingthe construction costs

In terms of total costs, Fig. 5 shows that HRS is 20% cheaper than RCC. Although it was known that HRS is costlier than RCC, such difference in total cost is dominated by the required costs in RC construction. This presents that despite of using relatively expensive material, the required costs for RC construction is still much greater.After all, the relative differences between the construction duration for each type were analyzed. Fig. 6 presents CFS construction to be 164% faster than RC construction, and saves up to 38% construction time compared to HRS. One of the main reasons of the huge difference between the duration of CFS and RC construction is the activities involved in RC that are not required in steel construction. As studied, the duration of RC construction is lengthened due to the time required for the concrete to harden. In this case, subsequent floors may only be constructed if enough strength is attained at lower levels. This is much different from CFS construction because the lightness of the material allows it to be assembled easily without the need for heavy equipment. CFS construction is of more advantage than conventional steel since it requires heavy equipment during assembly, which requires longer time to construct. On the other hand, Fig. 6 also shows that HRS construction is 92% faster than RC. It is well known that the construction activities in RC differ with HRS construction where erection of structural steel in subsequent floors can be executed more than two stories at a time.

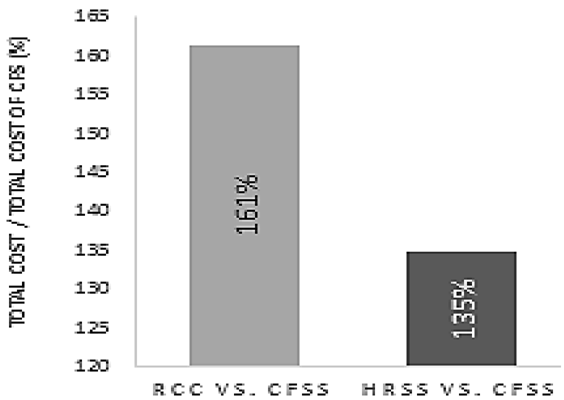


Fig.5:Relative differences between CFS building and other building types regarding the total costs (material cost + construction cost)

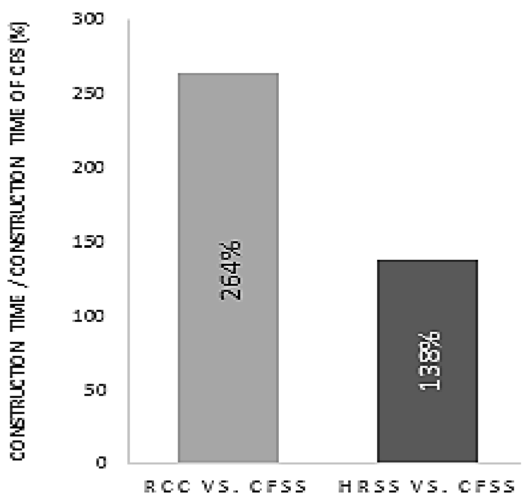


Fig.6:Relative differences between CFS building and other building types regarding the construction duration

To finalize the total gain that the CFS offers from both total cost and construction time, Fig. 7 was created by using an index reflecting both cost and time. It can be seen that CFS has more advantages up to 325% than building from RC in consideration of the both total cost and the construction time, whereas it may reach 86% more characteristic than HRS usage.

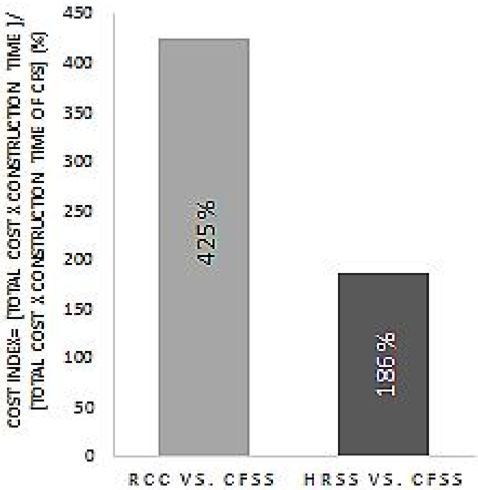


Fig. 7:Relative differences between CFS building and other building types regardingboth total costs and the construction duration

CONCLUSION

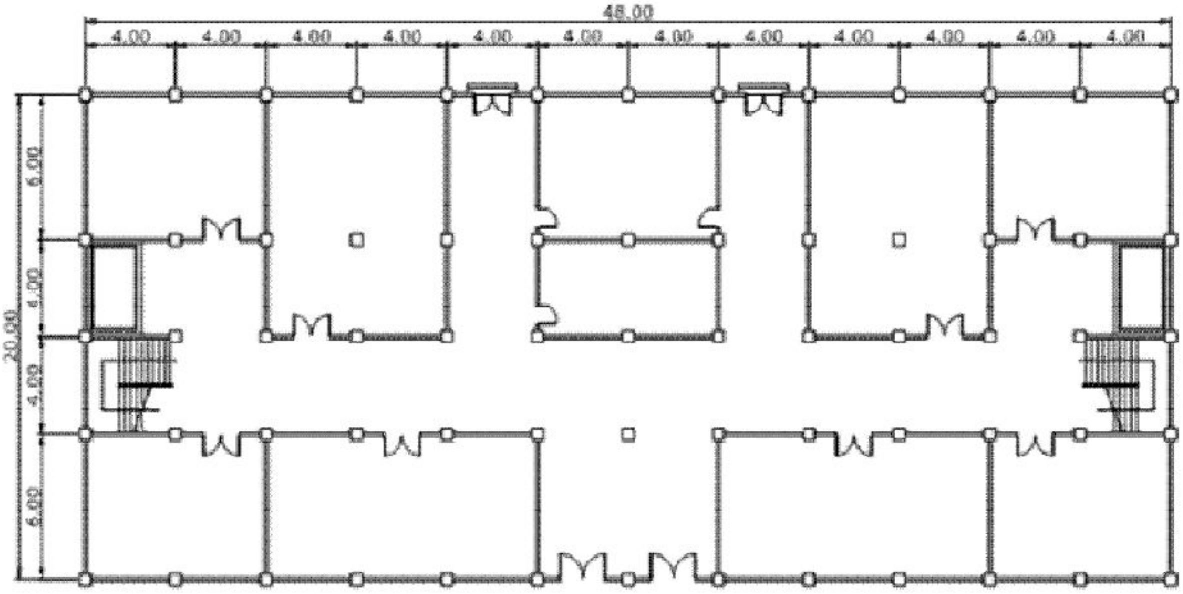
In this paper, the application of cold-formed steel sections in building has been investigated by evaluating the construction costs of three building materials. A 4-story building has been designed using reinforced concrete, hot formed sections and cold formed sections. Member sections for each were produced according to the design codes related to each material type. Then, the total weight of the structure, the material costs, the construction costs and construction duration for each building were analyzed and compared to justify the efficiency of using CFS.Many valuable data were concluded from this research as follows:

1. Buildings from CFS members are 67% lighter than using RC sections and 5% more weight than HRS members. In other words, HRS buildings weight 72% less than RC buildings.
2. In terms of material cost, CFS is 34% cheaper than RC and 89% less expensive compared to HRS. In this case, the HRS-material building is 55% more costly than RC-material building.
3. The construction cost of RC buildings may add extra 85% more than using CFS in construction, while having building from HRS ischeaper in construction cost than CFS and RC buildings by 15% and 100% respectively.
4. From the view of the total cost by both material cost and construction cost, CFS results a final 61% saving than RC structure and 35% more cost-effective than HRS-material in building.Other important outcome is that HRS is 26% lesser in total cost than RC.
5. It was found that CFS gains up to 164% less construction time than RC and 38% lower than HRS. Again, HRS construction time is faster than RC by 126%.
6. It was explored that the cost of material mainly influences the total HRS building cost, while construction has a great impact on the overall RCC building cost.
7. The combined index of total cost and construction time refers that CFS has 325% more advantages regarding the cost than RC and 86% more features than HRS.On the other hand, HRS registers 239% beneficial construction index than RC.

REFERENCES

[1] D. Dubina and J. Rondal, “Light gauge metal structures: recent advances”, CISM International Centre for Mechanical Sciences, Udine, Italy, 2005.
[2] W.W. Yu and R.A. LaBoube, “Cold-Formed Steel Design”, John Wiley and Sons, Hoboken, NJ, 2010.
[3] P.J. Grubb and R.M. Lawson, “Building Design using Cold Formed Steel Sections: Construction Detailing and Practice”, The Steel Construction Institute, Publication P165, Berkshire, UK, 1997.
[4] EN 1991-1-1, “Eurocode 1: Actions on structures — Part 1-1: General actions – Densities, self-weight, imposed loads for buildings”, Brussels: CEN, 2002.
[5] EN 1992-1-1, “Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings”, Brussels: CEN, 2004
[6] EN 1993-1-1, “Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for building”, Brussels: CEN, 2005.
[7] BS 5950-5, “Structural use of steelwork in building — Part 5: Code of practice for design of cold formed thin gauge sections”, London: BSI, 1998.
[8] L.A. Qureshi, A. Shehzad, E. Ejaz and F. Zaman, “Comparison of energy efficient cold rolls steel construction with the prevailing conventional construction”, Proc. of International Conference on Sustainable Built Environment. Kandy, Sri Lanka, 14-16 December, 2013.
[9] P. Sangave, M. N. Madur, M.S. Waghmare, M.R. Shete, M.V. Mankondi and M.V. Gundla, “Comparative Study of Analysis and Design of RC and Steel Structures”, International Journal of Scientific & Engineering Research, vol. 6, no. 2, pp. 256-267, 2015.
[10] R. Satpute and V. Varghese, “Building Design Using Cold Formed Steel Section”, International Refereed Journal of Engineering and Science, vol. 1, no. 2, pp. 01-16, 2012
[11] RSMeans, “RSMeans Cost Data”, John Wiley and Sons, Hoboken, NJ, 2012.
[12] AECOM, “Middle East Construction Handbook”,Available at: http://www.aecom.com/bh/wp-content/uploads/2016/11/Handbook-2016 Final_Lowres-spreads.pdf (Accessed: 02-April-2017), 2016.
[13] Turner and Townsend, “International construction market survey 2016”,Available at: http://www.turnerandtownsend.com/media/1518/international-construction-market-survey-2016.pdf(Accessed: 02-May-2017), 2016.
[14] D.D. Fanella, “Reinforced concrete structures: analysis and design”, McGraw Hill Professional, New York, USA, 2010.
[15] AISC, “Construction Management of Steel Construction”, Available at: http://cloud.aisc.org/teaching_aids/MgmtManual_2.pdf (Accessed: 05-March-2017), 1999.
[16] P.J. Grubb and R.M. Lawson, “Building Design using Cold Formed Steel Sections: Construction Detailing and Practice”, The Steel Construction Institute, Berkshire, UK, 1997.

Appendix A: Building Plan



Appendix B: Elements' dimensions and Quantity

Table B-I. Details of structural elements of RC building

Position	Structural element	Thickness (mm)	Dimensions (mm)	Qty. per floor
Slabs and Footing				
Ground	Pad footing	350	1750 x 1750	65
1^{st} floor – 4^{th} floor	Slabs	150	4000 x 6000	24
		120	4000 x 4000	24
Columns and Beams				
Position	Structural element	Length (mm)	Dimensions (mm)	Qty. per floor
Ground floor	Columns	6000	350 x 350	65
1^{st} floor and 3^{rd} floor		3500		
2^{nd} floor		3600		
1^{st} floor – 3^{rd} floor	Beams	4000	250 x 600	86
		6000		26
4^{th} floor		4000	250 x 500	86
		6000		26

Table B- II. **Details of structural elements *of HRS building***

Position	Structural element	Thickness (mm)	Dimensions (mm)	Qty. per floor
Slabs and Footing				
Ground	Pad footing	400	1650 x 1650	65
1^{st} floor – 4^{th} floor	Composite Slabs	150	4000 x 6000	24
		120	4000 x 4000	24
Columns and Beams				
Position	Structural element	Section	Length (mm)	Qty. per floor
1^{st} floor – 4^{th} floor	Secondary Beams	203 x 102 x 23 UB	4000	132
	Primary Beams	203 x 133 x 25 UB	4000	4
		305 x 127 x 42 UB	6000	4
		406 x 178 x 54 UB	6000	22
Ground floor	Columns	203 x 203 x 60 UC	6000	65
1^{st} floor		152 x 152 x 44 UC	3500	
2^{nd} floor		152 x 152 x 30 UC	3600	
3^{rd} floor		152 x 152 x 23 UC	3500	

Table B- III. Details of structural elements *of CFS building*

		Footing		
Position	**Structural element**	**Thickness (mm)**	**Area (mm^2)**	**Qty. per floor**
Ground	Mat footing	250	453	1
		Slabs		
Position	**Structural element**	**Thickness (mm)**	**Dimensions (mm)**	**Qty. per floor**
1st floor – 4th floor	Composite Slabs	150	4000 x 6000	24
		120	4000 x 4000	24
		Columns and Beams		
Position	**Structural element**	**Section**	**Length (mm)**	**Qty. per floor**
1st floor – 4th floor	Secondary Beams	302 x 89 x 2.3 Double Section	6000	47
		342 x 97 x 2.9 Double Section	6000	12
		302 x 89 x 2.3 Single Section	4000	14
		262 x 80 x 2.3 Single Section	4000	34
		262 x 80 x 2.0 Single Section	4000	40
		302 x 89 x 2.9 Single Section	4000	6
		342 x 97 x 2.9 Double Section	8000	6
		342 x 97 x 3.2 Double Section	8000	5
	Primary Beams	302 x 89 x 2.9 Double Section	4000	4
		342 x 97 x 2.9 Single Section	4000	4
		342 x 97 x 2.9 Double Section	4000	9
Ground floor	Columns	172 x 69 x 2.3 Double Section	6	304
1st floor		262 x 80 x 2.5 Double Section	3.5	
2nd floor		170 x 66 x 2.4 Double Section	3.6	
3rd floor		100 x 65 x 1.6 Double Section	3.5	

★★★