Cross-section Strength of Hot-rolled Steel

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

JOSEPHSON JUING

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INTRODUCTION

1.1 BACKGROUND

Cross-section stability refers to member stability that is evaluated in isolation of the entire structure. The cross-section stability for an individual structural steel member typically refers to those instabilities that are driven by plate bending within the cross-section; commonly known as flange local buckling or web local buckling, or more generically, just local buckling. In structural steel design, the plate buckling solutions are employed to predict when the local buckling occurs.

Steel is an alloy consisting mostly of iron, with a carbon content in which the weight depending on the grade. Carbon is the most cost-effective alloying material for iron, but various other alloying elements are used such as manganese, vanadium, and tungsten (Ashby et al, 1992). Carbon and other elements act as a hardening agent, preventing dislocations in the iron atom crystal lattice from sliding past one another. Varying the amount of alloying elements and form of their presence in the steel (solute elements, precipitated phase) controls qualities such as the hardness, ductility and tensile strength of the resulting steel. The greater the content of carbon in steel makes the steel harder and stronger but is also more brittle and less ductile (Ashby et al, 1992).

One of the conventional methods in producing steel is the hot rolling method. Process of hot rolling means, the sheet metal is passed or deformed between a set of work rolls and the temperature of the metal is generally above its recrystallization temperature. The microstructural properties of hot-rolled steel will not be affected because the metal is worked before the structures have formed. The hot rolling is only manipulating material shape and geometry but not the mechanical properties of the steel. The cold rolling process on the other hand, takes place below this temperature. The advantage of hot rolling over cold rolling is that hot rolling permits large deformations of the metal to be achieved with a low number of rolling cycles. In addition to that, beams and channels with complex profiles can be formed easily in the hot condition but would be difficult to be produced in the cold condition. This is the reason why hot-rolled steel can be found in many shapes compared to cold-rolled steel. One of the way to differentiate between hot-rolled and cold-rolled steel is that the finished tolerance on hot-rolled are looser than cold-rolled steel. Figure 1.1 and 1.2 shows the example of hot-rolled steel and cold-rolled steel respectively.

Figure 1.1: Hot-rolled steel tube (www.metalreference.com)

Figure 1.2: Cold-rolled steel tube (www.metalreference.com)

Traditionally, the stability of hot rolled steel members is determined by using the Effective Width Principle or also known as the Unified Method. The sections can be classified as plastic, compact, semi-compact and slender based on this conventional method. The capacities are then determined using the effective section properties. This method is adopted in BS 5950 and Euro code. However, an alternative to this traditional method that is the finite strip method has been developed by Benjamin Schafer to analyze sections with various buckling failure loads such as local buckling (flange buckling and web buckling), distortional buckling and global buckling. The finite strip method is developed into a program which the results can be used to find the capacities sections using the Direct Strength Method.

1.2 PROBLEM STATEMENT

Effective Width Method is used nearly worldwide for formal design of steel members. However, the traditional method is more complicated compared with the new approach method, Direct Strength Method. The principle of Effective Width Method is that there is a necessity in reducing the gross cross-section to effective cross-section. This is due to the local plate buckling that leads to reduction in the effectiveness of the plate. However, this method ignores the inter-element equilibrium that is the compatibility between the flange and the web in determining the elastic buckling behavior.

Effective Width Method requires cumbersome iterations even for basic member strength. The method is far more difficult when there are attempts to optimize the section. Although the effective width method has been used for many years and proven to be the useful design model, the method however is only well utilized for classical plate stability. The design methodology is no more suitable for conventional steel design (hot-rolled steel) as it may hinder the use of material by engineers in certain conditions. In other words, the adoption of the traditional method may impede innovation in steel design and resulting uneconomical design.

1.3 OBJECTIVES

The objectives of this study are listed as below:

- Identify hot rolled structural steels commonly used in Malaysia-local made as well imported for offshore applications, and building constructions.
- Classify sections using "Effective Width" philosophy.

- Determine compression strength for Universal Column sections using British Standard code and Euro code for different lengths.
- Compare and validate with predictions using the Direct Strength Method.

1.4 SCOPE OF WORK

The scope of this study involves the analysis on the Universal Column (UC) section. The cross-section stability of the section is analyzed by using a few methods that comprise of Effective Width Method/British Standard code/Euro code and Direct Strength Method (with the aid of Constrained Finite Strip Method software). Comparisons are made between each section using various methods respectively. The study has been limited to hot rolled Universal Column section.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

As mentioned before, the direct strength method has been introduced by Schafer as an alternative to the commonly used Effective Width Method in steel design (Schafer, 2006). The method has been adopted in cold-formed steel design, particularly on beam and column. Schafer has also applied the method for hot rolled sections. So far, the method has not been adopted for hot rolled sections from the British standard (Schafer, 2006). Thus, this study will intend to apply the direct strength method for the design of British hot rolled sections. At the end, the results will be compared with the traditional method. The literature review of this study will cover; the principle of elastic buckling (consisting of local, distortional and global buckling), the principle of finite strip method (which applied in the Constrained Finite Strip Method software), Direct Strength Method and also the Constrained Finite Strip Method program created by Schafer as a computer-aided elastic buckling analysis. A brief introduction on the BS 5950 method in designing beam and column will also be discussed further.

2.2 ELASTIC BUCKLING

Elastic buckling is defined as a phenomenon that occurs when energy change which associated with out-of-plane deformation response to an in-plane load is equal to the energy change for in-plane response to the same in-plane load (AISI, 2002). Elastic buckling load is defined as the load where the member becomes neutral between two states that are buckled state and straight state. There are three types of elastic buckling which are local buckling, distortional buckling and global buckling. These instability phenomena occurs when thin-walled sections are subjected to compressive stress which may be caused either by bending moment or an axial load (Derrick et al, 2006). There are already existing numerical methods such as finite element, finite differences, boundary element and generalized beam theory that provide elastic buckling solutions for cold-formed steel beams and columns. Following are the explanations of the three buckling behavior.

2.2.1 Local buckling

Local buckling is described as having the involvement of plate bending of the elements (Chen et al, 2007). The fold lines of elements are also described to merely rotate without translating as each compression element buckles. The half-wavelength of the local buckling is the length which the buckling shape repeats along the member length and is usually shorter or equal to the largest dimension of the member. According to AISI, local buckling is the type of buckling mode which involves only rotation and no translation at the fold lines of the member (AISI, 2002). Following figure 2.1 shows a member which is under local buckling mode.

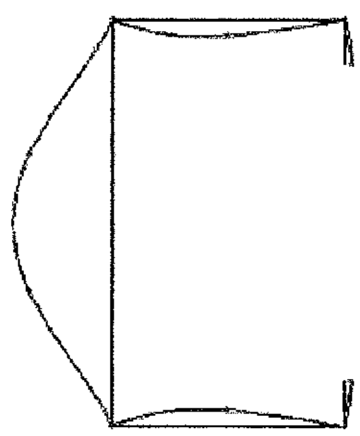

Figure 2.1: Local buckling mode (Schafer, 2006)

2.2.2 Distortional buckling

Distortional buckling is described as having deformation that visually appears as a combination of local and global buckling (Chen et al, 2007). Part of the cross-section such as flange responds rigidly at a point of flange/web junction and the other part such as the web undergoes plate bending. Therefore, different with the local buckling, distortional buckling involves both translation and rotation at the fold line of a member as mentioned in the (AISI, 2002). The half-wavelength for distortional buckling falls between the half-wavelength of the local buckling and global buckling and it is possible for a member to have distortional buckling although the section is fully braced from global buckling (Chen et al, 2007). Figure 2.2 below shows a member under distortional buckling.

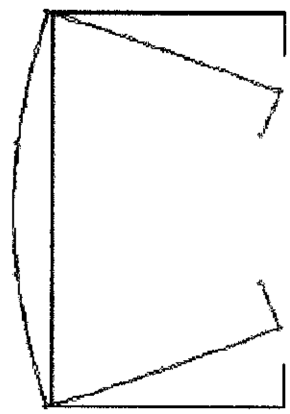

Figure 2.2: Distortional buckling mode (Schafer, 2006)

2.2.3 Global buckling

Global buckling is described as having the whole cross-section bends laterally (for flexural buckling), or rotates (for torsional buckling), or bends and rotates simultaneously (flexural-torsional buckling) (Chen et al, 2007). However, no distortion involves in the global meeting. Global buckling is also known as Euler buckling. The half-wavelength of the global buckling can be determined by the member's unbraced length (AISI, 2002). Following figure 2.3 shows a cross-section member undergoes global buckling.

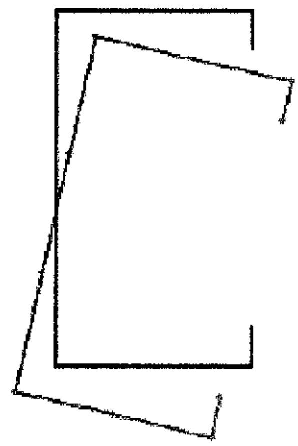

Figure 2.3: Flexural buckling mode (Schafer, 2006)

Complication found in the global buckling is that flexure and distortional may interact at relatively long half-wavelength. Thus, it is difficult to determine long column modes at certain intermediate to long lengths.

2.3 FINITE STRIP METHOD

Finite element has so far dominated the numerical methods for elastic buckling solutions (Cheung et al, 1998). The method is considered to be the most versatile tool but somehow it requires discretisation in every dimension which causes more unknowns. Furthermore, the full analysis of the method often found to be unnecessary for problems with regular geometric shapes and simple boundary conditions. Thus, finite strip method, which is a specialized variant of the finite element method, has been introduced to reduce the computational effort and core requirements. The finite strip method was originally developed by Cheung and the pioneer user of this method was Hancock's research group which they applied it in their commercial program THIN-WALL for finite strip analysis (Schafer, 1998). Besides Hancock's research group, Schafer's research group had also used the same method and implemented it in their academic program known as Constrained Finite Strip Method (CUFSM) for finite strip analysis. This numerical solution is the extension to the conventional finite strip solutions.

In the conventional finite strip method, a thin-walled member is discretized into longitudinal strips. This is shown in table 2.1. From the table, the only difference between the finite element and finite strip methods is the discretization of a member although both basic methodology and theory are identical. As compared to other method such as finite element that applies discretization in both longitudinal and transverse direction, finite strip method depends on the selection of shape function for the longitudinal displacement field and this provides accuracy to finite strip over finite element (Schafer et al, 2006). Therefore, by using the finite strip method, the number of equations needed for solutions are reduced from the typical finite element solution. The direct calculation of pure buckling modes is also possible through finite strip method. The solution of conventional finite strip is identical to the constrained finite strip employed in the open source stability analysis program: Constrained Finite Strip Method (CUFSM). The advantage of the extension version over the conventional finite strip method is the ability to identify conventional finite strip solutions as related to local, distortional and global buckling (Schafer et al, 2006). Table 2.1 shows the comparison between finite element and classical finite strip methods.

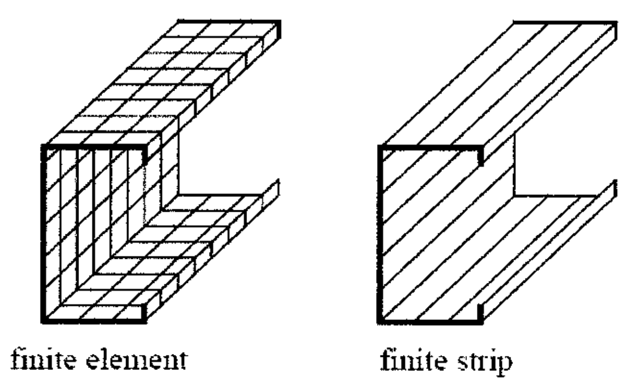

Figure 2.4: Finite element and finite strip discretization (Schafer, 1998)

Table 2.1: Comparison between finite element and finite strip methods (Cheung et al, 1998)

Category	Finite element	Finite strip
Applicability	Applicable to any geometry, boundary conditions and material variation. Extremely versatile.	In static analysis, more often used for structures with two opposite simply supported ends and with or without intermediate elastic supports. In dynamic analysis it is used for structures with all boundary conditions and with discrete supports.
Number of equations	Usually large number of equations and matrix with comparatively large bandwith. Can be very expensive and at times impossible to work out solution because of limitation in computing facilities.	Usually much smaller number of equations and matrix with narrow bandwith, especially true for problems with an opposite pair of simply supported ends. Consequently much shorter computing time for solution of comparable accuracy.
Input data	Large quantities of input data and easier to make mistakes. Requires automatic mesh and load generation schemes.	Very small amount of input data because of the small number of mesh lines involved due to the reduction in dimensional analysis.
Output data	Large quantities of output. As a rule all nodal displacements and element stresses are printed. Also many lower order elements will not yield correct stresses at the nodes and stress averaging or interpolation techniques must be used in the interpolation of results.	Easy to specify only those locations at which displacements and stresses are required and the output accordingly.
Easiness	Requires a large amount of core and is more difficult to program. Very often, advanced techniques such as mass condensation, subspace iteration or Lanczos method have to be resorted to for eigenvalue problems in order to reduce core requirements.	Requires smaller amount of core and is easier to program. Because only the lowest few eigenvalues are required (for most cases anyway), the first two or three terms of the series will normally yield sufficiently accurate results for the classical finite strip method. Matrix can usually be solved by the standard eigenvalue subroutines.

2.4 DIRECT STRENGTH METHOD

Direct Strength Method (DSM) is a new method in steel design created by Benjamin W. Schafer. It has been adopted in North America, Australia and New Zealand. The fundamental principle behind this method is determining the accurate member elastic stability. The principle is based on the determination of all the elastic instabilities for the gross section (local, distortional and global buckling) and the load or moment that causes the steel section to yield (Schafer, 2006). By these, the strength of the section can be predicted directly.

As compared with the Effective Width Method, Direct Strength Method does not require the calculation of effective-section properties. The basis of the effective width method is that local plate buckling leads to reductions in the effectiveness of the plates (Schafer, 2006). Therefore, it is necessary to reduce the gross cross-section where material is ineffective. This computation procedure is somehow becomes more tedious for members having complex cross-sections such as those with edge stiffeners (Young et al, 2004). Effective Width Method analyzes the flange and web separately by ignoring the rotational restraints provided by the adjacent elements. Moreover, Effective Width Method is intimately tied to classical plate stability and thus, the design methodology would be different for conventional hot-rolled steel design.

The advantage of Direct Strength Method is that it enables the engineer to predict the strength of members with optimized cross-sections with the aid of Constraint Finite Strip Method (CFSM) software for elastic buckling analysis (Chen et al, 2007). Through the computer analysis, it is possible to obtain the buckling loads for any type of cross-section. The other advantage of direct strength method is that it gives better understanding to engineers on the behavior of steel members as the design approach focuses on member elastic buckling instead of effective width calculations. By studying the steel members' behavior, engineers may be able to select an adequate method to increase the member strength (Chen et al, 2007).

The application of the Direct Strength Method requires the determination of the elastic behavior of the member which will be used to predict the strength of that member (AISI, 2006). In the calculation of Direct Strength Method the member strength (M_n) is the minimum of the nominal strength due to local buckling (M_{nl}), distortional buckling (M_{nd}) and global buckling (M_{ne}) (Specification Direct Strength Method, 2002). The strength due to local buckling (M_{nl}), distortional buckling (M_{nd}) and global buckling (M_{ne}) can be determined from the buckling loads determined in the computational elastic buckling analysis (Constrained Finite Strip Method program). Constrained Finite Strip Method (CFSM) program is one of the computational elastic buckling analyses that provide methods for definitively separating the buckling modes from one another. The Direct Strength Method has been so far explored for beams and columns only. The method is applicable in determining the nominal axial flexural strength of all cold-formed steel beams and columns. No provisions for members in shear, combined bending and shear, web crippling, combined bending and crippling or combined axial load and bending (beam-column) (AISI, 2002).

However, since the Direct Strength Method is verified with the same data and care as in the main specification (AISI, 2002), thus zero loss of reliability is obtained in its application. The procedure is found to employ the same empirical assumptions as to the effective width method used in the main Specification. Young's test program as included in his journal (Young et al, 2004) is to compare the fixed-ended test strengths with the design strengths obtained using the Direct Strength Method. The test data used in the calibration of column design for direct strength method were based on concentrically loaded pin-ended cold-formed steel columns for certain cross-sections and geometric limits. The cross-sections include simple lipped channel, lipped channel with web stiffeners and zed section. The tested columns were compressed between fixed ends rather than pinned ends. The specimens were brake-pressed from high strength zinc-coated grade G450 structural steel sheets having nominal yield stress of 450MPa and specified according to the Australian Standard AS 1397 (1993). The specimens were tested at various column lengths ranging from 500 to 3500mm. The sections are labeled as for example as T1.5F80L0500, where "T" refers to thickness and "F" refers to flange and "L" refers to the nominal length of the specimen. The numbers following "T" and "F" are the nominal thickness and nominal flange width respectively. Table 2.2 shows the comparison of test and design results for series T1.5F80.

Table 2.2: Comparison of test and design results for series T1.5F80 (Young et al, 2004)

	Tests		NAS		AS/NZS		DSM				Comparison			
Specimen	P_{EXP} (kN)	Failure mode	P_{NAS} (kN)	Failure mode	$P_{AS/NZS}$ (kN)	Failure mode	P_{DSM-1} (kN)	Failure mode	P_{DSM-2} (kN)	Failure mode	$\frac{P_{EXP}}{P_{NAS}}$	$\frac{P_{EXP}}{P_{AS/NZS}}$	$\frac{P_{EXP}}{P_{DSM-1}}$	$\frac{P_{EXP}}{P_{DSM-2}}$
T1.5F80L0500	172.0	L	181.8	L+FT	155.4	D	142.7	L+FT	142.7	L+FT	0.95	1.11	1.21	1.21
T1.5F80L1000	166.9	L+D	177.8	L+FT	155.4	D	139.7	L+FT	139.7	L+FT	0.94	1.07	1.19	1.19
T1.5F80L1500	163.4	L+D	171.5	L+FT	155.4	D	135.0	L+FT	135.0	L+FT	0.95	1.05	1.21	1.21
T1.5F80L2000	161.7	L+D	163.1	L+FT	155.4	D	128.7	L+FT	128.7	L+FT	0.99	1.04	1.26	1.26
T1.5F80L2500	158.8	L+FT	152.1	L+FT	152.1	L+FT	120.9	L+FT	120.9	L+FT	1.04	1.04	1.31	1.31
T1.5F80L3000	154.8	L+FT	139.2	L+FT	139.3	L+FT	112.1	L+FT	112.1	L+FT	1.11	1.11	1.38	1.38
T1.5F80L3500	124.4	L+FT	125.5	L+FT	125.6	L+FT	102.5	L+FT	102.5	L+FT	0.99	0.99	1.21	1.21
										Mean, P_m	1.00	1.06	1.25	1.25
										Coefficient of variation, V_p	0.063	0.040	0.056	0.056
										β	2.68	2.82	3.63	3.63

Note: 1 kip=4.45 kN.

Table 2.3: Comparison of test and design results for series T1.5F120 (Young et al, 2004)

	Tests		NAS		AS/NZS		DSM				Comparison			
Specimen	P_{EXP} (kN)	Failure mode	P_{NAS} (kN)	Failure mode	$P_{AS/NZS}$ (kN)	Failure mode	P_{DSM-1} (kN)	Failure mode	P_{DSM-2} (kN)	Failure mode	$\frac{P_{EXP}}{P_{NAS}}$	$\frac{P_{EXP}}{P_{AS/NZS}}$	$\frac{P_{EXP}}{P_{DSM-1}}$	$\frac{P_{EXP}}{P_{DSM-2}}$
T1.5F120L0500-1	168.9	L	184.1	L+FT	158.9	D	164.7	L+FT	164.7	L+FT	0.92	1.06	1.03	1.03
T1.5F120L0500-2	166.9	L	184.1	L+FT	158.9	D	164.7	L+FT	164.7	L+FT	0.91	1.05	1.01	1.01
T1.5F120L0500-3	164.9	L	184.1	L+FT	158.9	D	164.7	L+FT	164.7	L+FT	0.90	1.04	1.00	1.00
T1.5F120L1000	159.3	L+D	180.7	L+FT	158.9	D	161.8	L+FT	161.8	L+FT	0.88	1.00	0.98	0.98
T1.5F120L1500	145.7	L+D	175.2	L+FT	158.9	D	157.0	L+FT	157.0	L+FT	0.83	0.92	0.93	0.93
T1.5F120L2000	139.5	L+D	167.2	L+FT	158.9	D	150.4	L+FT	150.4	L+FT	0.83	0.88	0.93	0.93
T1.5F120L3000	131.3	L+D+FT	145.9	L+FT	146.1	L+FT	133.3	L+FT	133.3	L+FT	0.90	0.90	0.98	0.98
T1.5F120L3500	127.4	L+FT	133.6	L+FT	133.7	L+FT	123.2	L+FT	123.2	L+FT	0.95	0.95	1.03	1.03
										Mean, P_m	0.89	0.97	0.99	0.99
										Coefficient of variation, V_p	0.046	0.075	0.041	0.041
										β	2.29	2.35	2.73	2.73

Note: 1 kip=4.45 kN.

Table 2.4: Comparison of test and design results for series T1.9F80 (Young et al, 2004)

	Tests		NAS		AS/NZS		DSM				Comparison			
Specimen	P_{EXP} (kN)	Failure mode	P_{NAS} (kN)	Failure mode	$P_{AS/NZS}$ (kN)	Failure mode	P_{DSM-1} (kN)	Failure mode	P_{DSM-2} (kN)	Failure mode	$\frac{P_{EXP}}{P_{NAS}}$	$\frac{P_{EXP}}{P_{AS/NZS}}$	$\frac{P_{EXP}}{P_{DSM-1}}$	$\frac{P_{EXP}}{P_{DSM-2}}$
T1.9F80L0500	238.5	L	253.1	L+FT	234.8	D	206.0	L+FT	206.0	L+FT	0.94	1.02	1.16	1.16
T1.9F80L1000	236.3	L+D	247.5	L+FT	234.8	D	202.1	L+FT	202.1	L+FT	0.95	1.01	1.17	1.17
T1.9F80L1500	233.3	L+D	238.5	L+FT	234.8	D	195.8	L+FT	195.8	L+FT	0.98	0.99	1.19	1.19
T1.9F80L2000	232.4	L+D+FT	226.5	L+FT	226.5	L+FT	187.2	L+FT	187.2	L+FT	1.03	1.03	1.24	1.24
T1.9F80L2500	224.4	L+FT	212.0	L+FT	212.0	L+FT	176.9	L+FT	176.9	L+FT	1.06	1.06	1.27	1.27
T1.9F80L3000	198.7	L+FT	195.6	L+FT	195.6	L+FT	165.0	L+FT	165.0	L+FT	1.02	1.02	1.20	1.20
T1.9F80L3500	183.9	L+FT	177.8	L+FT	177.8	L+FT	152.0	L+FT	152.0	L+FT	1.03	1.03	1.21	1.21
										Mean, P_m	1.00	1.02	1.21	1.21
										Coefficient of variation, V_p	0.043	0.020	0.032	0.032
										β	2.78	2.71	3.58	3.58

Note: 1 kip=4.45 kN.

Table 2.5: Comparison of test and design results for series T1.9F120 (Young et al, 2004)

	Tests		NAS		AS/NZS		DSM				Comparison			
Specimen	P_{EXP} (kN)	Failure mode	P_{NAS} (kN)	Failure mode	$P_{AS/NZS}$ (kN)	Failure mode	P_{DSM-1} (kN)	Failure mode	P_{DSM-2} (kN)	Failure mode	$\frac{P_{EXP}}{P_{NAS}}$	$\frac{P_{EXP}}{P_{AS/NZS}}$	$\frac{P_{EXP}}{P_{DSM-1}}$	$\frac{P_{EXP}}{P_{DSM-2}}$
T1.9F120L0500-1	233.7	L+D	261.4	L+FT	215.7	D	234.2	D+FT	235.4	L+FT	0.89	1.08	1.00	0.99
T1.9F120L0500-2	239.7	L+D	261.4	L+FT	215.7	D	234.2	D+FT	235.4	L+FT	0.92	1.11	1.02	1.02
T1.9F120L1000	231.2	L+D	256.3	L+FT	215.7	D	230.8	D+FT	235.1	L+FT	0.90	1.07	1.00	0.98
T1.9F120L1500	227.3	L+D	248.1	L+FT	215.7	D	225.1	D+FT	227.9	L+FT	0.92	1.05	1.01	1.00
T1.9F120L2000	225.2	L+D	237.0	L+FT	215.7	D	217.3	D+FT	218.3	L+FT	0.95	1.04	1.04	1.03
T1.9F120L2500	220.2	L+D+FT	222.9	L+FT	215.7	D	206.5	L+FT	206.5	L+FT	0.99	1.02	1.07	1.07
T1.9F120L3000	209.4	L+FT	208.7	L+FT	206.5	L+FT	193.0	L+FT	195.0	L+FT	1.01	1.01	1.08	1.08
T1.9F120L3500	194.6	L+FT	189.0	L+FT	189.0	L+FT	178.2	L+FT	178.2	L+FT	1.03	1.03	1.09	1.09
										Mean, P_m	0.95	1.05	1.04	1.03
										Coefficient of variation, V_p	0.055	0.032	0.036	0.041
										β	2.53	2.82	2.96	2.92

Note: 1 kip=4.45 kN.

For comparison purposes, the test strengths are also compared with the nominal (unfactored) design strengths obtained from the North American Specification and Australian/New Zealand Standard for cold-formed steel structures. The experimental-to-design column strength ratios P_{EXP}/P_{DSM-1}, P_{EXP}/P_{DSM-2}, P_{EXP}/P_{NAS} and P_{EXP}/P_{NZS} are also included. The reliability of the column design is evaluated using reliability analysis. It is based on the specification of members in the NAS (2001) where a target reliability index (ß) of 2.5 is recommended as a lower limit. The design is considered as reliable if the value is greater than 2.5.

The design strengths of P_{DSM-1} (consider interaction of local and overall buckling as well as interaction of distortional and overall buckling) and P_{DSM-2} (consider interaction of local and overall buckling as well as distortional buckling alone) predicted by Direct Strength Method are generally accurate and reliable for series of T1.5F120 and T1.9F120 and conservative for series T1.5F80 and T1.9f120. The values of the design strengths P_{DSM-1} are identical as P_{DSM-2} except for T1.9F120 series. According to Young, the calculation of design strengths assuming local and distortional buckling stresses are not influenced by the end effects of the columns. Although the end effects may have increased the test loads for columns failing in distortional buckling, this is somehow unavoidable and negotiable for a long column. For the case of P_{NAS} and $P_{AS/NZS}$, both are having conservative design strength values and lower in reliability index as compared with the Direct Strength Method. In terms of failure mode prediction, the prediction by P_{DSM-1} and P_{DSM-2} are generally in agreement with the failure modes observed in tests for long columns except for short and intermediate columns.

Conclusively from the Young's test (Young et al, 2004), the Direct Strength Method approach provides good agreement with the column strength of the test but not for the short column and intermediate columns. Young concludes that Direct Strength Method is able to predicts accurately the column strengths of the fixed-ended cold-formed steel cross-sections even with complex edge stiffeners for section having slender flanges (such as T1.5F120 and T1.9F120) and conservatively for sections with less slender flanges (such as T1.5F80 and T1.9F80).

However, there are some limitations of the Direct Strength Method (Chen et al, 2007). Since the Direct Strength Method predicts the strength based on the member's elastic buckling loads, the local buckling load would be very low if the member section contains very slender elements. Therefore, the strength calculated by the direct strength method would be very conservative. Therefore, Direct Strength Method cannot be considered as general design concept and further investigations are necessary (Rusch et al, 2001). Another thing is that as mentioned earlier, Direct Strength Method does not provide provisions for shear, web crippling and members with holes. Besides that, Direct Strength Method cannot account for the shift of the effective centroid (Rasmussen et al, 2004). There are two important limitations which are first the method assumes the ends of the member are simply supported and the cross-section must have longitudinally uniform properties along its length (Commentary Direct Strength Method, 2002).

2.5 CONSTRAINED FINITE STRIP METHOD PROGRAM (CFSM)

Constrained Finite Strip Method (CFSM) is software that explores the buckling behavior. The software calculates the buckling stress and buckling mode arbitrarily shaped. The software is freely available and readily to be used. The advantage of using the Constrained Finite Strip Method (CFSM) software is that it able to determine the elastic buckling stress accurately by taking into consideration of the compatibility at plate junctures. The software also quantified and examined all the elastic buckling modes.

Finite Strip is a specialized version of the finite element method. In the finite strip method, element shape functions use polynomials in the transverse direction, but trigonometric functions in the longitudinal direction. The choice of the longitudinal shape function allows a single element, a 'strip' to be used. The classical finite strip which is used in the software uses a single half sine wave that is a longitudinal deformation is assumed to occur in half wavelength. Analysis is performed for systematically increased half wavelength to determine the buckling behavior of a member. Buckling mode is the shape when a member buckles or deforms under given loads or reference stress distribution. The results from the software which are elastic critical local buckling load (P_{crl}) and moment that causes first yield (M_{crl}) are used in the DSM to determine the strength of the member.

2.6 BRITISH STANDARD 5950 METHOD

British Standard 5950 Part 1 is the code of practice for designing of rolled and welded section. This standard is widely used in Malaysia for both rolled and welded sections. The code uses the principle of effective width method in designing the sections. Therefore, there is the necessary to calculate the section properties and also the effective area of the section as included in the code. The brief design procedures for column and beam are included in the methodology.

2.7 EUROCODE 3

Eurocode which is also known as EN Eurocode or EC, is a set of pan-European model building codes developed by the European Committee for standardization. The Eurocodes form a common European set of structural design codes for civil engineering work to replace the British Standard codes (e.g. BS 5950) after a period of co-existence. Some Eurocodes are still in a trial phase, so they are characterized as ENV instead of EN until they are officially adopted. Eurocode 3 that was published on 2005 is used for the design of steel structures. The method also uses the principle of Effective Width Method.

CHAPTER 3
METHODOLOGY

3.1 FLOW OF STUDY

The first step in conducting this study was to identify the commonly used hot rolled steel in Malaysia. The study included identifying the different forms (sections) as well as the grade of hot rolled steel produced locally. The reason for this was to ensure whether the sections in Malaysia follow the British standard. The study would be easier if the local steel follows exactly the British standard as later, the sections can be adopted directly from the British dimensions and properties for analysis. In fact, most steel manufacturers in Malaysia are actually producing sections according to British standard.

The next step was to study the proposed new design method for steel design that is the Direct Strength Method (DSM). This was done by thorough study on related journals and papers. Besides the direct strength method itself, study on the traditional design method which is Effective Width Method was conducted. Good understanding of both methods' principles would allow better judgments and comparisons.

Upon completion of theoretical study, the Constrained Finite Strip Method (CFSM) was explored. After studying on the theoretical sides of the study, the next move was to study the Constrained Finite Strip Method (CFSM) software. The software was used to determine the input such as elastic buckling load which then would be useful for DSM to determine the strength of a section.

After mastering the applications of Constrained Finite Strip Method (CFSM) software, universal beam and universal column sections from the British standard were taken for analysis in CFSM. Inputs such as elastic buckling load and yield moment were determined and tabulated. The buckling mode for respective sections was also determined.

All the inputs were used in the Direct Strength Method calculation to determine the final strength of the section. Finally, by knowing the strength and the corresponding failure load, engineers would find it easy to determine the corresponding dimension of the section. However, to prove the result from the direct strength method approach, comparison must be made with those from conventional effective width method as well as from the experimental testing. Therefore, sections were also required to be analyzed using the Effective Width Method.

This particular project had little scope of laboratory work since most of the works dealt with simulation in the software and hands on calculation. The laboratory work (experimental testing) would only be conducted on a few selected sections and once all the sections had been analyzed by the Direct Strength Method and Effective Width Method. However, hazard analyses are still of concern in this conducting the experimental testing. The basic safety cautions include wearing the proper laboratory coat during experimenting and proper handling of equipment involved.

3.2 APPLICATION OF CONSTRAINED FINITE STRIP METHOD SOFTWARE

The first thing to do was to define a cross-section to be analyzed. A Universal Column section was defined by clicking on the "Input". Default C-section and Z-section template were also provided in the program. After clicking the "Input" icon, following screen (figure 3.1) with the default section appeared.

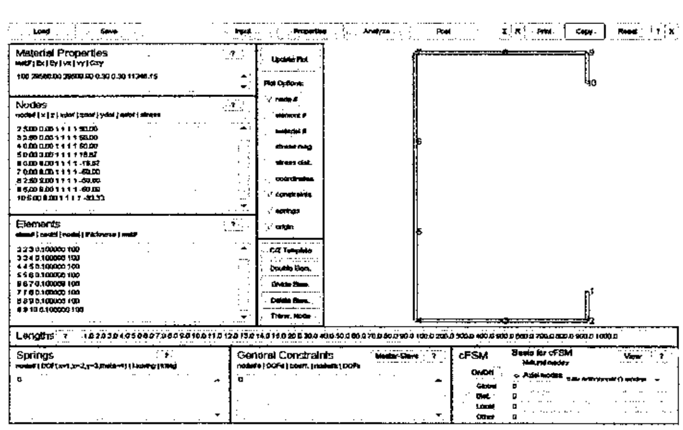

Figure 3.1

The material properties in which for the case of isotropic steel the value was taken as E = 29500 ksi and the vx = vy were taken as 0.3. The node numbers and the coordinates were assigned to define the geometry of the Universal Column section. The nodes included a node number followed by the x and z coordinate and finally followed by the four "1". These four "1" indicated that there is no external longitudinal restraint at those nodes in which for normal member analysis, this was always the case. The column stress was taken as 1.0.

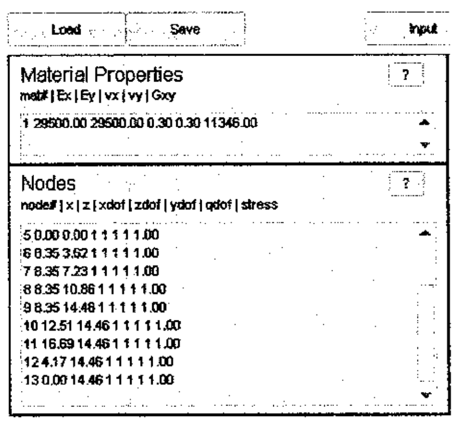

Figure 3.2

The element thickness of the section was determined. This was done by entering the element number, then its connectivity and finally the mat# where it referred to the material defined before.

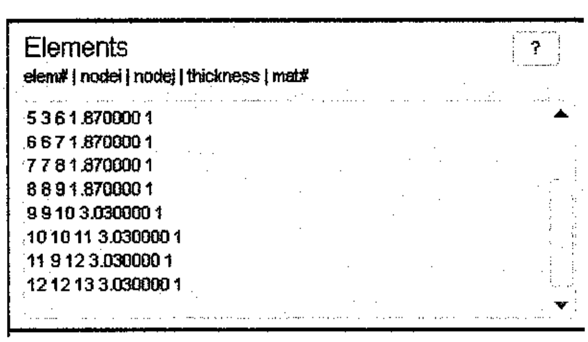

Figure 3.3

"Update plot" was clicked after last node and element number were entered to see the final geometry. Four elements were taken in any flat in compression in order to provide a nicely converged answer. The minimum would be two elements. For double discretization on your member, select "Double Element".

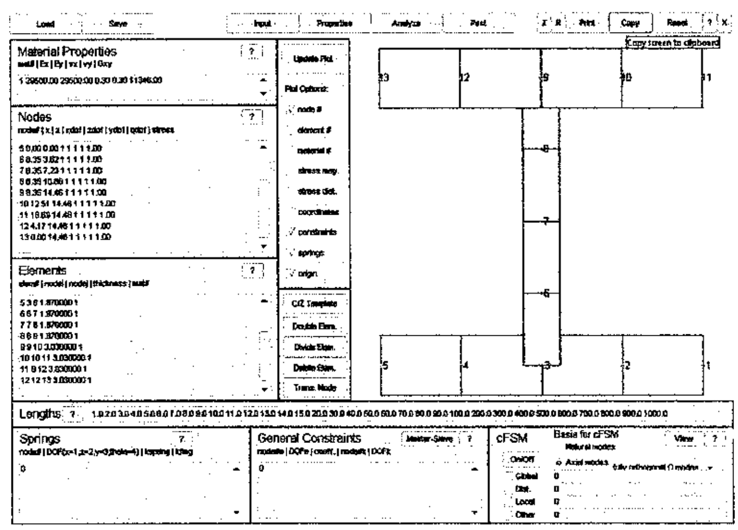

Figure 3.4

Next the length for the section was defined. It was recommended to ensure the lengths are evenly spaced in logspace as shown in figure 3.5 below. For local buckling, the half-wavelength was always close to the maximum dimension of the member. Distortional buckling on the other hand was usually 2 to 8 times that length.

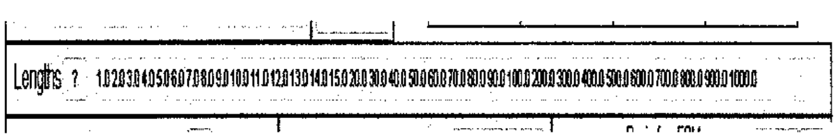

Figure 3.5

Next, the loading on the section member was put. Thus, the "Properties" icon was selected and following screen (figure 3.6) appeared.

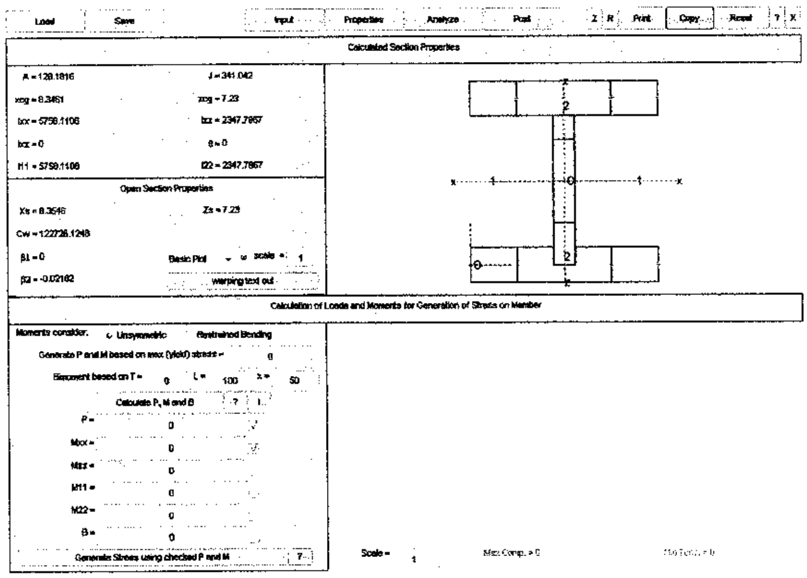

Figure 3.6

Longitudinal stress was defined as required in the program. In this case the yield stress, f_y was taken as 39.89 ksi (275 Mpa). For column section, "M" icon was unchecked and then "Generate Stress Using checked P and M" was clicked.

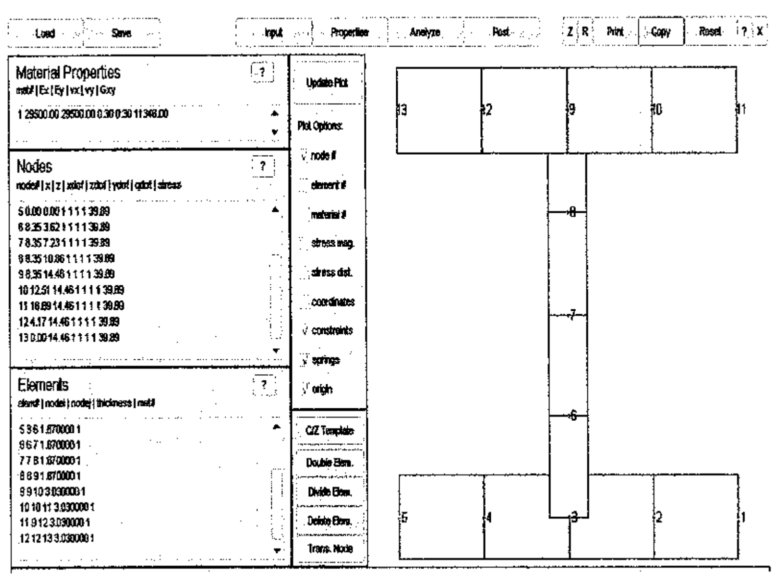

Figure 3.7

The next step was to see the result of the section's buckling behavior. "Analyze" icon was clicked and the following screen (figure 3.8) appeared. The local buckling mode was shown to the right. The load factor was 71.1192 and therefore the elastic critical local buckling (P_{crl}) was 71.1192P_y. Local buckling usually occurred at the first minima while global buckling would occur at the second or last minima. Distortional buckling may be indistinct (without minimum) although local buckling and long half-wavelength buckling were clear.

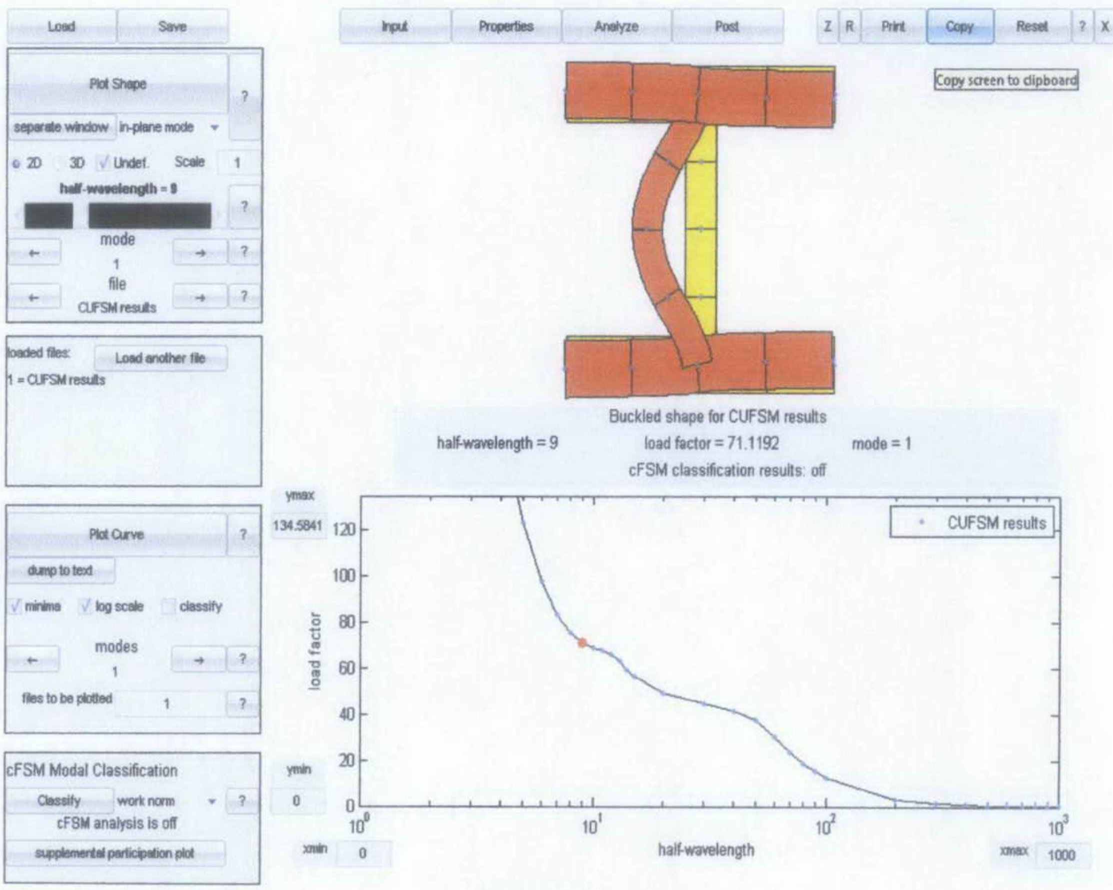

Figure 3.8

3.3 DIRECT STRENGTH METHOD CALCULATION PROCEDURE

The following calculation procedures are for the determination of the universal column (UC) compression strength. The calculation procedures were adopted from the AISI Specification 2002. In the Direct Strength Method, analyze of column requires the determination of local buckling, distortional buckling and global buckling from the Constrained Finite Strip Method (CUFSM) software. The inputs will be used in the Direct Strength Method to finally determine the compression strength for column.

3.3.1 Column

The nominal axial strength or compression strength, P_n for column is the minimum of nominal axial strength for local buckling P_{nl}, distortional buckling P_{nd} and global buckling P_{ne}. All equations are adopted from AISI specification (2002).

3.3.1.1 Local Buckling

$\lambda_l = (P_{ne}/P_{crl})^{0.5}$ (1)

P_{crl} = Critical elastic local column buckling load

For $\lambda_l \leq 0.776$;

nominal axial strength $P_{nl} = P_{ne}$ (2)

For $\lambda_l > 0.776$;

nominal axial strength $P_{nl} = (1 - 0.15(P_{crl}/P_{ne})^{0.4})(P_{crl}/P_{ne})^{0.4}\, P_{ne}$ (3)

3.3.1.2 Distortional Buckling

$\lambda_d = (P_y/P_{crd})^{0.5}$ (4)

P_{crl} = Critical elastic distortional column buckling load

For $\lambda_d \leq 0.561$;

Nominal axial strength $P_{nd} = P_y$ (5)

For $\lambda_d > 0.561$;

Nominal axial strength $P_{nl} = (1 - 0.25(P_{crd}/P_y)^{0.6})(P_{crd}/P_y)^{0.6}\, P_y$ (6)

3.3.1.3 Flexural-Torsional Buckling

$\lambda_c = (P_y/P_{cre})^{0.5}$ (7)

P_{cre} = Critical elastic flexural-torsional column buckling load

$P_y = A_g F_y$ (8)

For $\lambda_c \leq 1.5$;

Nominal axial strength $P_{ne} = (0.658^{\lambda c^{\wedge}2})Py$ (9)

For $\lambda_c > 1.5$;

Nominal axial strength $P_{ne} = (0.877/\lambda_c^2)P_y$ (10)

3.4 BS 5950 METHOD

3.4.1 Column

Following are the procedures to determine the compression capacity of a column. Procedures are adopted from BS 5950 Part 1: 2000.

- Determine the effective length of the member. (Clause 4.7.3)
- Find the class of the steel section (Table 11 and 12).
- Determine the effective area, A_{eff} for the section (slender class).
- Calculate the slenderness ratio slenderness ratio about x-axis and y-axis of the member.
- Select the suitable design curve from Table 23.
- Determine the compressive strength p_c (Table 24a, b, c, d).
- Calculate the compression capacity P_c (Clause 4.7.4)

  $P_C = A_g \times p_c$ (non-slender class)

  $P_C = A_{eff} \times p_c$ (slender class)

3.5 EUROCODE 3 METHOD

3.5.1 Column

Following are the procedures to determine the compression capacity of a column. Procedures are adopted from Eurocode 3: Design of steel structures.

- Determine the effective length of the column
- Determine the buckling curve about axis (Table 6.2)
- Determine the imperfection factor (Table 6.1)
- Calculate the non-dimensional slenderness (Equation 6.50)
- Calculate the buckling resistance (Clause 6.3.1.1)

CHAPTER 4
RESULTS AND DISCUSSION

All sections of Universal Column (UC) from the Steel Designer's Manual – 6^{th} edition (2003) have been analyzed using the Constrained Finite Strip Method (CUFSM) software to determine their corresponding local buckling, distortional buckling and global buckling. The sections were taken from the Steel Designer's Manual – 6^{th} edition (2003) that produces the dimensions and properties of steel according to the British Standard. The lengths were taken as 3m, 3.5m, 4m and 4.5m as these are the normal length of a column for headroom. The stress was taken as 275 MPa. The section strength from the British method and Eurocode method were calculated to compare with section strength obtained from the Direct Strength Method. Finally, the percentage differences between the three methods were determined. Appendix A-1 shows the buckling mode and the compression strength of the universal column sections.

From the appendix A-1, it shows that all sections were subjected to distortional buckling and flexural buckling. This was true since distortional buckling were likely to result in a lower strength as compared to local buckling (DSM Design Guide, 2006). From the appendix A-1 as well, the compression strength became smaller as the size or area of the section became smaller. Based on table 4.1, all the sections were failing due to global buckling.

Table 4.1 also shows that the percentage difference between DSM and BS method is within 10% except for a few sections and smaller sections of UC 203x203x86 down to UC 152x152x23. For the case between the DSM and Eurocode, almost all the sections fell in the 10% difference except for UC 203X203X86 down to UC 152X152X23. Initially, all the section strength obtained by the Direct Strength Method was found to have a percentage difference of more than 10% as compared to the BS Method. For design purpose, the allowable margin for percentage difference is 10%. However, according to the Direct Strength Method (DSM) Design Guide (2006), there are elastic buckling limits that need to be considered. The limits are as follow;

For columns

- If $P_{crl} > 1.66P_y$ then no reduction will occur due to local buckling.
- If $P_{crd} > 3.18P_y$ then no reduction will occur due to distortional buckling.
- If $P_{cre} > 3.97P_y$ then no reduction will occur due to global buckling.
- If $P_{cre} > 8.16P_y$ then no reduction will occur due to global buckling.
- If $P_{cre} > 41.64P_y$ then no reduction will occur due to global buckling.

According to Direct Strength Method (DSM) Design Guide (2006), the cross-section will develop its full capacity when the elastic buckling value is very high. Therefore, the above limitation may be required in order to avoid conservative results as compared to the BS Method. Furthermore, due to the nature of the global buckling column curve, the above limitation is somehow unavoidable. The limits above provide a conservative approximation range which is common in determining the buckling loads in elastic buckling finite element analysis.

After considering the above limits, almost all the sections had the percentage difference within 10%. The cause for the sections having very large percentage difference was yet to be found.

From appendix A-2, it shows that all sections were subjected to distortional buckling and flexural buckling. From the appendix A-2 as well, the compression strength became smaller as the size or area of the section became smaller. Based on table 4.2, all the sections were failing due to global buckling.

Based on table 4.2 the percentage difference between DSM and BS method is within 10% except for smaller sections of UC 203x203x86 down to UC 152x152x23 which is the same case as for 3m column. For the case between the DSM and Eurocode, almost all the sections fell in the 10% difference except for sections UC 254x254x167 down to UC 254x254x107 and smaller sections of UC 203X203X86 down to UC 152X152X23.

Appendix A-3 shows that all sections for 4m length of column were subjected to distortional buckling and flexural buckling. From the appendix A-3 as well, the compression strength became smaller as the size or area of the section became smaller. All sections were failing due to global buckling as shown in table 4.3.

Table 4.3 indicates that more sections are having percentage difference greater than 10% compared than 3m and 3.5m column. The sections are UC 305x305x283 down to UC 305x305x198 and UC 254x254x167 down to UC 152x152x23. Similar to the case between DSM and BS method, comparison between DSM and Eurocode also shows more sections are having greater than 10% difference as the length of the column increases. Those sections include UC 254x254x167 down to UC 152x152x23.

Appendix A-4 shows that all sections for 4.5m length of column were subjected to distortional buckling and flexural buckling. From the appendix A-4 as well, the compression strength became smaller as the size or area of the section became smaller. All sections were failing due to global buckling as shown in table 4.4.

Table 4.4 indicates that almost all sections are having percentage of difference greater than 10% exceptional for sections UC 356x368x153 and UC 356x368x129. The largest would be up to 20%. The comparison between DSM and Eurocode also shows more sections are having greater than 10% difference compared than the other three column length. The sections involved are UC 305x305x283 down to UC 152x152x23. The largest percentage difference is up to more than 20%.

Appendix C-1, C-2, C-3 and C-4 show the comparison between the compression strength of column by BS method with the compression strength obtained by Eurocode method. As expected the difference between the two must give small percentage of difference or at least less than 10%.

Table 4.1: Comparison between Direct Strength Method results with BS Method and Eurocode results for 3m UC sections

Section	Mode of failure	Compression strength by DSM (KN)	Compression strength by BS method (KN)	Percentage difference (%)	Compression strength by Eurocode method (KN)	Percentage difference (%)
356x406x634	Global buckling	22102.80	19025.20	16.18	20928.89	5.61
356x406x551	Global buckling	19091.30	16493.00	15.75	18154.77	5.16
356x406x467	Global buckling	16079.38	14823.83	8.47	15337.87	4.83
356x406x393	Global buckling	13421.87	12439.33	7.90	12871.21	4.28
356x406x340	Global buckling	11559.64	10731.47	7.72	11104.84	4.10
356x406x287	Global buckling	9718.04	9145.24	6.26	9369.82	3.72
356x406x235	Global buckling	7892.72	7383.51	6.90	7640.64	3.30
356x368x202	Global buckling	6722.69	6270.80	7.20	6489.91	3.59
356x368x177	Global buckling	5875.13	5710.57	2.88	5699.77	3.08
356x368x153	Global buckling	5057.50	4922.19	2.75	4912.62	2.95
356x368x129	Global buckling	4222.30	4134.44	2.13	4126.19	2.33
305x305x283	Global buckling	9388.10	8494.20	10.52	8789.30	6.81
305x305x240	Global buckling	7922.96	7194.06	10.13	7443.23	6.45
305x305x198	Global buckling	6477.40	5904.63	9.70	6108.16	6.05
305x305x158	Global buckling	5137.22	4855.63	5.80	4849.33	5.94
305x305x137	Global buckling	4415.36	4194.10	5.28	4187.83	5.43
305x305x118	Global buckling	3787.05	3607.50	4.98	3602.59	5.12
305x305x97	Global buckling	3095.55	2949.29	4.96	2945.64	5.09
254x254x167	Global buckling	5319.20	4769.07	11.54	4913.18	8.26
254x254x132	Global buckling	4171.61	3859.63	8.08	3851.5	8.31

254x254x107	Global buckling	3349.76	3110.59	7.69	3101.29	8.01
254x254x89	Global buckling	2769.10	2579.79	7.34	2571.15	7.70
254x254x73	Global buckling	2251.85	2117.09	6.37	2110.04	6.72
203x203x86	Global buckling	2537.54	2295.04	10.57	2290.11	10.80
203x203x71	Global buckling	2079.87	1878.51	10.72	1874.68	10.95
203x203x60	Global buckling	1740.71	1570.94	10.81	1568.29	10.99
203x203x52	Global buckling	1504.18	1360.21	10.58	1358.10	10.76
203x203x46	Global buckling	1321.03	1197.71	10.30	1195.99	10.45
152x152x37	Global buckling	922.31	781.67	17.99	782.47	17.87
152x152x30	Global buckling	740.24	629.42	17.61	630.23	17.46
152x152x23	Global buckling	549.69	452.13	21.58	464.97	18.22

Table 4.2: Comparison between Direct Strength Method results with BS Method and Eurocode results for 3.5m UC sections

Section	**Mode of failure**	**Compression strength by DSM (KN)**	**Compression strength by BS method (KN)**	**Percentage difference (%)**	**Compression strength by Eurocode method (KN)**	**Percentage difference (%)**
356x406x634	Global buckling	19578.60	18290.00	7.05	20328.41	3.69
356x406x551	Global buckling	16904.00	15850.00	6.65	17627.72	4.11
356x406x467	Global buckling	14219.00	14379.00	1.11	14881.77	4.45
356x406x393	Global buckling	11884.00	12058.00	1.44	12478.87	4.77
356x406x340	Global buckling	10222.00	10398.00	1.70	10762.04	5.02
356x406x287	Global buckling	8583.00	8770.50	2.14	9076.85	5.44
356x406x235	Global buckling	6983.30	7149.10	2.32	7398.60	5.61
356x368x202	Global buckling	5934.90	6056.50	2.01	6266.64	5.29
356x368x177	Global buckling	5182.60	5513.50	6.00	5501.97	5.80
356x368x153	Global buckling	4457.20	4750.60	6.18	4740.88	5.98
356x368x129	Global buckling	3740.70	3988.20	6.20	3980.67	6.03
305x305x283	Global buckling	8226.90	8262.70	0.43	8414.20	2.23
305x305x240	Global buckling	6925.20	6994.20	0.99	7118.48	2.72
305x305x198	Global buckling	6299.50	5662.40	11.25	5836.08	7.94
305x305x158	Global buckling	4977.90	4634.10	7.42	4627.40	7.57
305x305x137	Global buckling	4289.10	4001.10	7.18	3993.51	7.40
305x305x118	Global buckling	3672.60	3441.60	6.71	3433.42	6.97
305x305x97	Global buckling	2996.80	2813.40	6.52	2805.06	6.84
254x254x167	Global buckling	5114.80	4492.20	13.86	4627.79	10.52
254x254x132	Global buckling	3994.40	3634.80	9.89	3621.05	10.31

254x254x107	Global buckling	3207.50	2921.00	9.81	2910.97	10.19
254x254x89	Global buckling	2649.80	2419.60	9.52	2411.74	9.87
254x254x73	Global buckling	2157.40	1982.80	8.80	1976.83	9.13
203x203x86	Global buckling	2379.60	2089.10	13.90	2088.32	13.95
203x203x71	Global buckling	1947.50	1707.80	14.03	1707.34	14.07
203x203x60	Global buckling	1623.50	1423.90	14.01	1423.64	14.04
203x203x52	Global buckling	1402.90	1232.30	13.85	1232.01	13.87
203x203x46	Global buckling	1232.90	1083.20	13.82	1083.09	13.83
152x152x37	Global buckling	812.45	665.71	22.04	668.374	21.56
152x152x30	Global buckling	720.38	535.93	34.42	537.10	34.12
152x152x23	Global buckling	481.07	391.57	22.86	393.24	22.33

Table 4.3: Comparison between Direct Strength Method results with BS Method and Eurocode results for 4m UC sections

Section	Mode of failure	Compression strength by DSM (KN)	Compression strength by BS method (KN)	Percentage difference (%)	Compression strength by Eurocode method (KN)	Percentage difference (%)
356x406x634	Global buckling	19220.85	17556.00	9.48	19715.07	2.51
356x406x551	Global buckling	16551.10	15205.00	8.85	17089.04	3.15
356x406x467	Global buckling	13945.30	13934.00	0.08	14414.99	3.26
356x406x393	Global buckling	11651.30	11675.00	0.21	12076.81	3.52
356x406x340	Global buckling	10018.00	10066.00	0.47	10410.50	3.77
356x406x287	Global buckling	8407.30	8486.10	0.93	8776.19	4.20
356x406x235	Global buckling	6838.94	6914.40	1.09	7150.04	4.35
356x368x202	Global buckling	5797.78	5846.80	0.84	6036.34	3.95
356x368x177	Global buckling	5061.63	5313.30	4.74	5297.84	4.46
356x368x153	Global buckling	4353.80	4576.70	4.87	4563.59	4.60
356x368x129	Global buckling	4059.70	3840.20	5.72	3830.36	5.99
305x305x283	Global buckling	8852.14	7785.40	13.70	8023.42	10.33
305x305x240	Global buckling	7445.60	6574.10	13.26	6779.86	9.82
305x305x198	Global buckling	6091.77	5380.20	13.23	5552.18	9.72
305x305x158	Global buckling	4810.07	4403.00	9.25	4395.65	9.43
305x305x137	Global buckling	4140.84	3799.60	8.98	3790.51	9.24
305x305x118	Global buckling	3543.57	3266.70	8.48	3256.62	8.81
305x305x97	Global buckling	2891.49	2668.60	8.35	2658.09	8.78
254x254x167	Global buckling	4877.94	4207.20	15.94	4329.12	12.68
254x254x132	Global buckling	3806.08	3383.90	12.48	3380.00	12.61

254x254x107	Global buckling	3053.52	2714.60	12.49	2712.04	12.59
254x254x89	Global buckling	2518.61	2247.10	12.08	2245.17	12.18
254x254x73	Global buckling	2050.48	1839.10	11.49	1837.71	11.58
203x203x86	Global buckling	2208.00	1883.00	17.26	1883.83	17.21
203x203x71	Global buckling	1800.40	1537.30	17.11	1538.10	17.05
203x203x60	Global buckling	1498.94	1277.10	17.37	1278.13	17.28
203x203x52	Global buckling	1295.26	1104.30	17.29	1105.31	17.19
203x203x46	Global buckling	1137.57	968.90	17.41	969.99	17.28
152x152x37	Global buckling	706.38	565.01	25.02	567.60	24.45
152x152x30	Global buckling	565.08	453.24	24.68	455.28	24.12
152x152x23	Global buckling	412.43	329.49	25.17	331.36	24.47

Table 4.4: Comparison between Direct Strength Method results with BS Method and Eurocode results for 4.5m UC sections

Section	Mode of failure	Compression strength by DSM (KN)	Compression strength by BS method (KN)	Percentage difference (%)	Compression strength by Eurocode method (KN)	Percentage difference (%)
356x406x634	Global buckling	18826.20	16821.00	11.92	19084.93	1.36
356x406x551	Global buckling	16236.00	14562.00	11.49	16535.27	1.81
356x406x467	Global buckling	15159.00	13501.00	12.28	13934.57	8.79
356x406x393	Global buckling	12658.00	11308.00	11.94	11662.51	8.54
356x406x340	Global buckling	10880.00	9746.40	11.63	10048.04	8.28
356x406x287	Global buckling	9126.80	8215.20	11.10	8466.02	7.81
356x406x235	Global buckling	7420.50	6690.40	10.91	6893.46	7.65
356x368x202	Global buckling	6273.60	5620.10	11.63	5797.79	8.21
356x368x177	Global buckling	5476.00	4932.20	11.03	5086.34	7.66
356x368x153	Global buckling	4710.00	4390.60	7.27	4379.84	7.54
356x368x129	Global buckling	3951.30	3682.80	7.29	3674.54	7.53
305x305x283	Global buckling	8533.80	7386.50	15.53	7616.56	12.04
305x305x240	Global buckling	7174.60	6228.90	15.18	6427.29	11.63
305x305x198	Global buckling	5864.40	5091.90	15.17	5256.58	11.56
305x305x158	Global buckling	4622.90	4162.30	11.07	4154.37	11.28
305x305x137	Global buckling	3978.00	3585.40	10.95	3579.20	11.14
305x305x118	Global buckling	3405.80	3077.40	10.67	3072.63	10.84
305x305x97	Global buckling	2776.30	2508.70	10.67	2505.17	10.82
254x254x167	Global buckling	4628.00	3915.80	18.19	4021.06	15.09
254x254x132	Global buckling	3600.10	3132.50	14.93	3131.95	14.95

254x254x107	Global buckling	2883.90	2508.10	14.98	2507.77	15.00
254x254x89	Global buckling	2379.80	2074.70	14.71	2074.28	14.73
254x254x73	Global buckling	1937.10	1695.50	14.25	1695.24	14.27
203x203x86	Global buckling	2023.20	1688.10	19.85	1685.07	20.07
203x203x71	Global buckling	1651.40	1375.70	20.04	1374.06	20.18
203x203x60	Global buckling	1372.10	1137.70	20.60	1138.13	20.56
203x203x52	Global buckling	1180.30	982.96	20.08	983.59	20.00
203x203x46	Global buckling	1042.60	860.31	21.19	861.74	20.99
152x152x37	Global buckling	602.19	479.10	25.69	482.51	24.80
152x152x30	Global buckling	479.12	384.95	24.46	386.50	23.96
152x152x23	Global buckling	341.13	278.51	22.48	280.09	21.79

For a better view, the pattern of the difference between Direct Strength Method with BS code and Eurocode can be clearly seen from the plotted data (see Figure 4.1 until 4.12). As shown in figure 4.1 until figure 4.6, the gap between the line of DSM values and the BS method values becomes greater as the column length increases and also as the section area becomes smaller. Similar to that, the line gap between DSM values and the Eurocode values show the same pattern as for DSM and BS method. Thus, the more slender the column, the greater is the difference between the compression strength by DSM with the compression strength obtained from BS method Eurocode method.

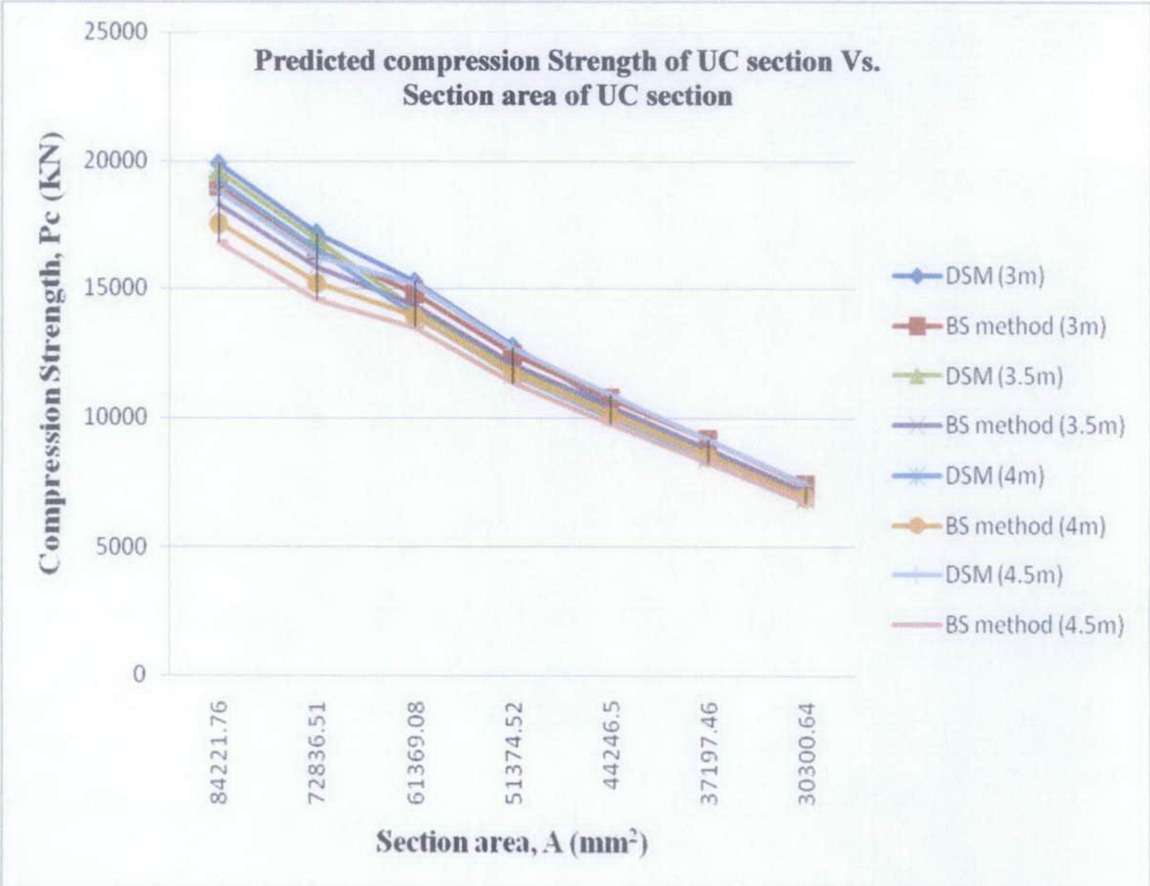

Figure 4.1: Graph shows the comparison between the compression strength by DSM and BS method for section **UC 356x406** with varied section area and length of column.

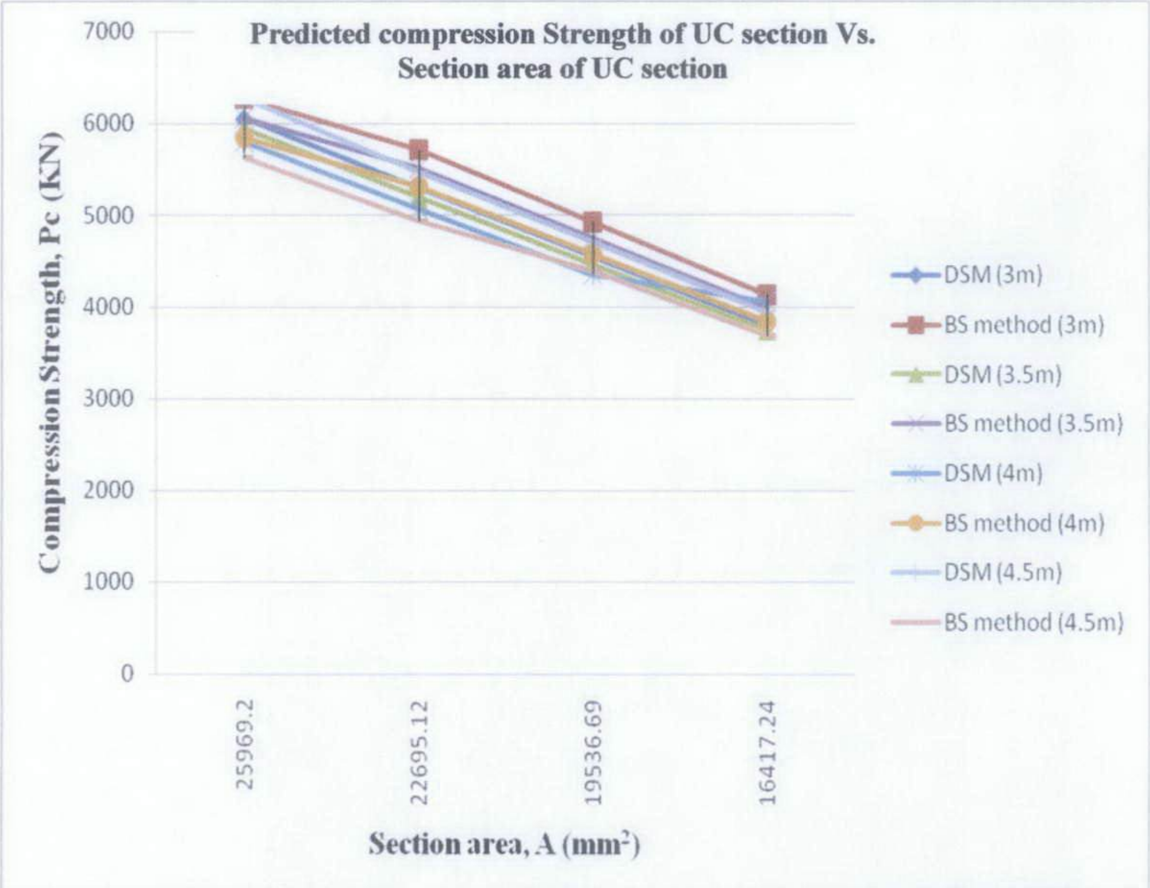

Figure 4.2: Graph shows the comparison between the compression strength by DSM and BS method for section **UC 356x368** with varied section area and length of column.

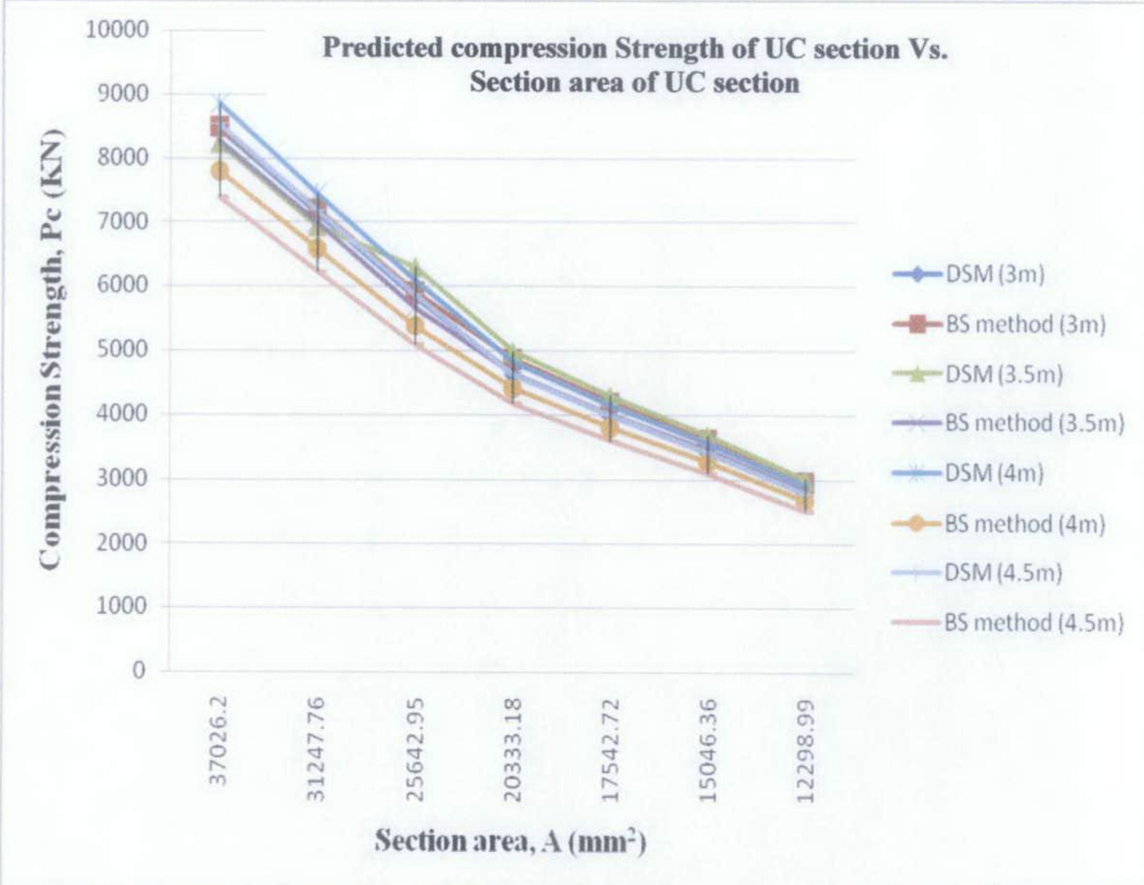

Figure 4.3: Graph shows the comparison between the compression strength by DSM and BS method for section **UC 305x305** with different section area and with different length of column.

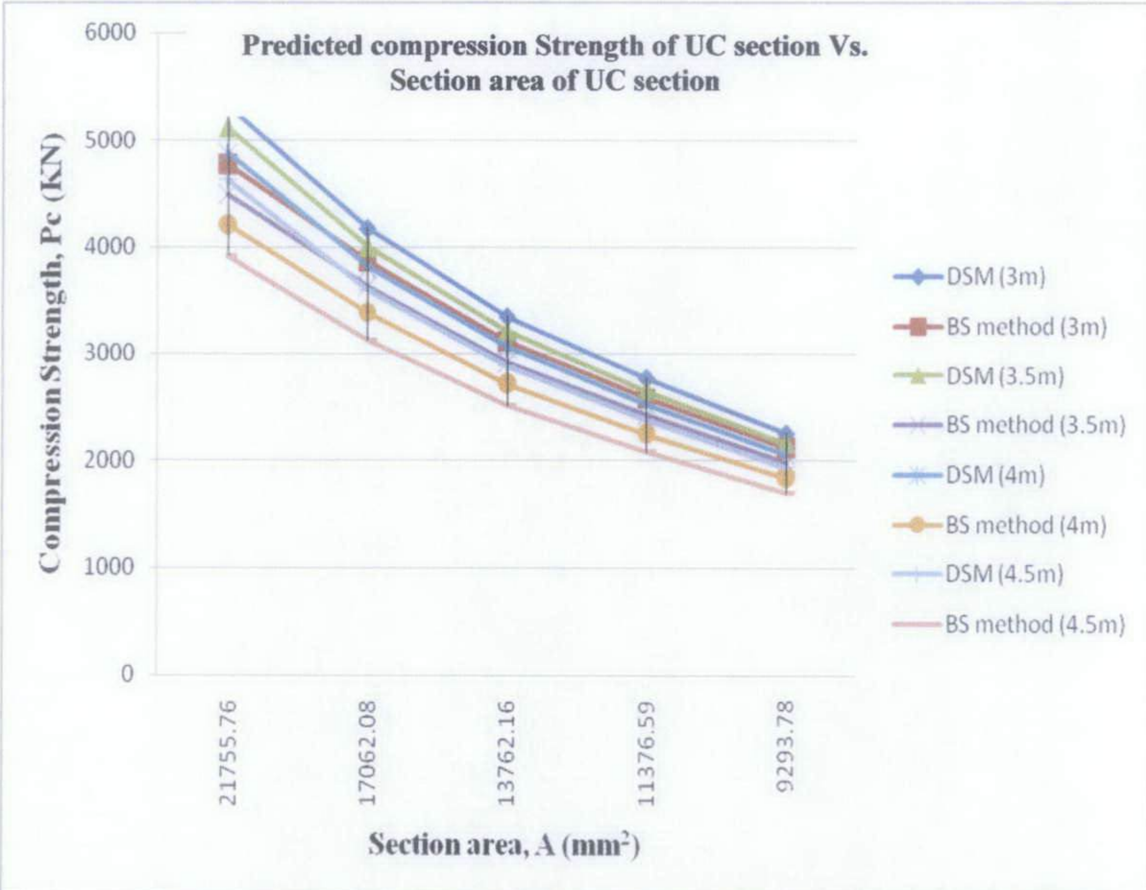

Figure 4.4: Graph shows the comparison between the compression strength by DSM and BS method for section **UC 254x254** with varied section area and length of column.

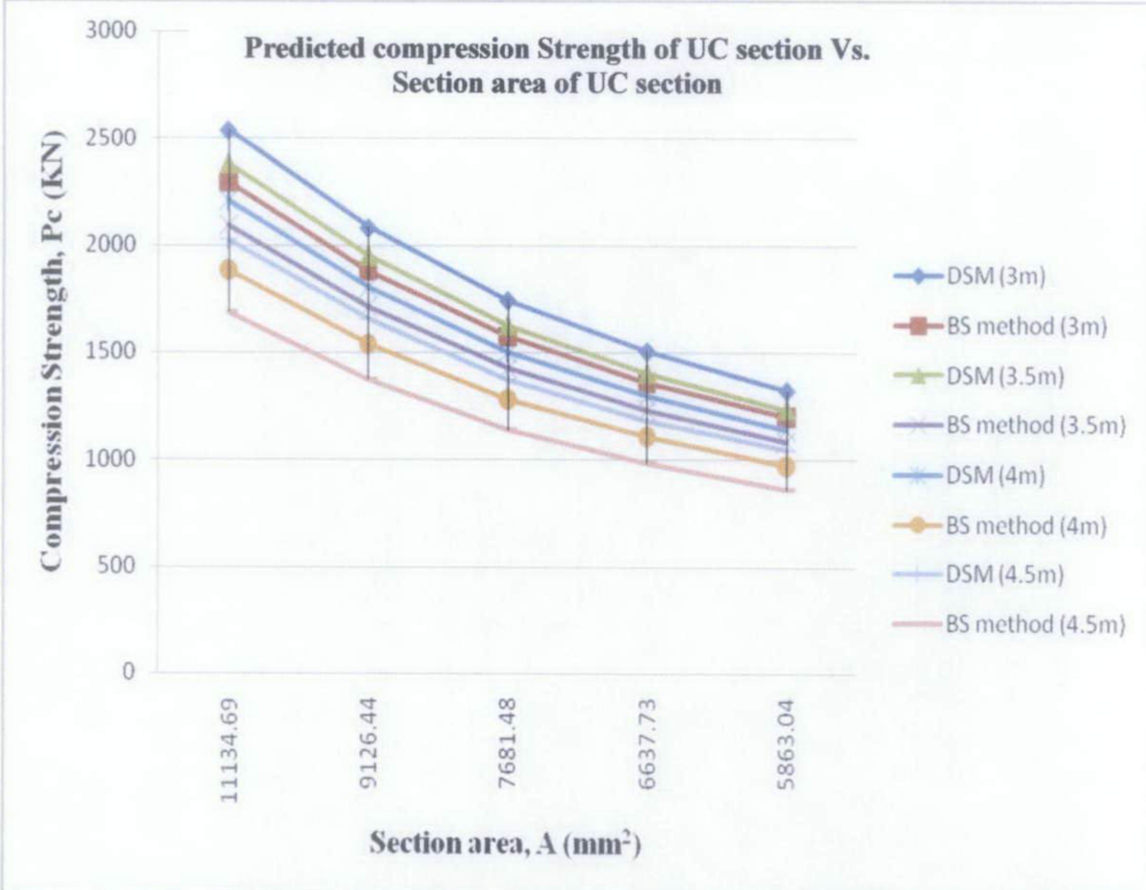

Figure 4.5: Graph shows the comparison between the compression strength by DSM and BS method for section **UC 203x203** with varied section area and length of column.

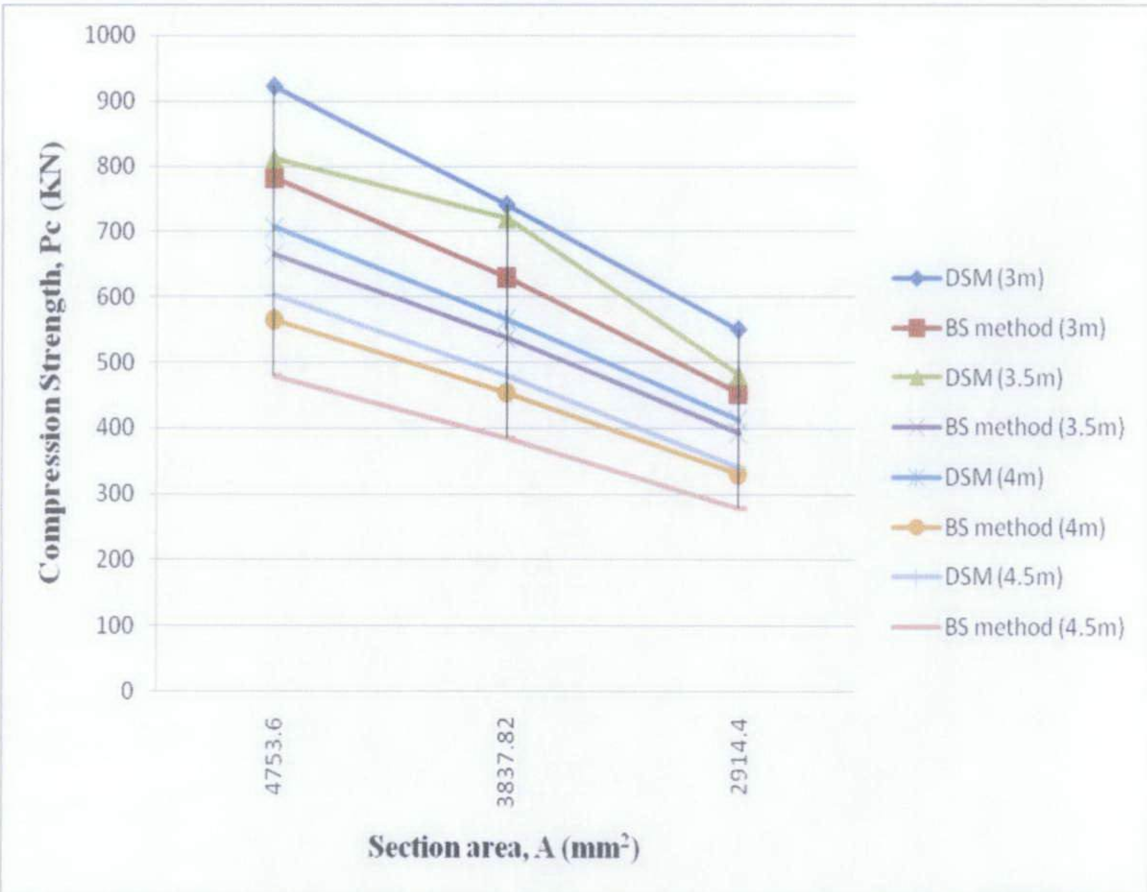

Figure 4.6: Graph shows the comparison between the compression strength by DSM and BS method for section **UC 152x152** with varied section area and length of column.

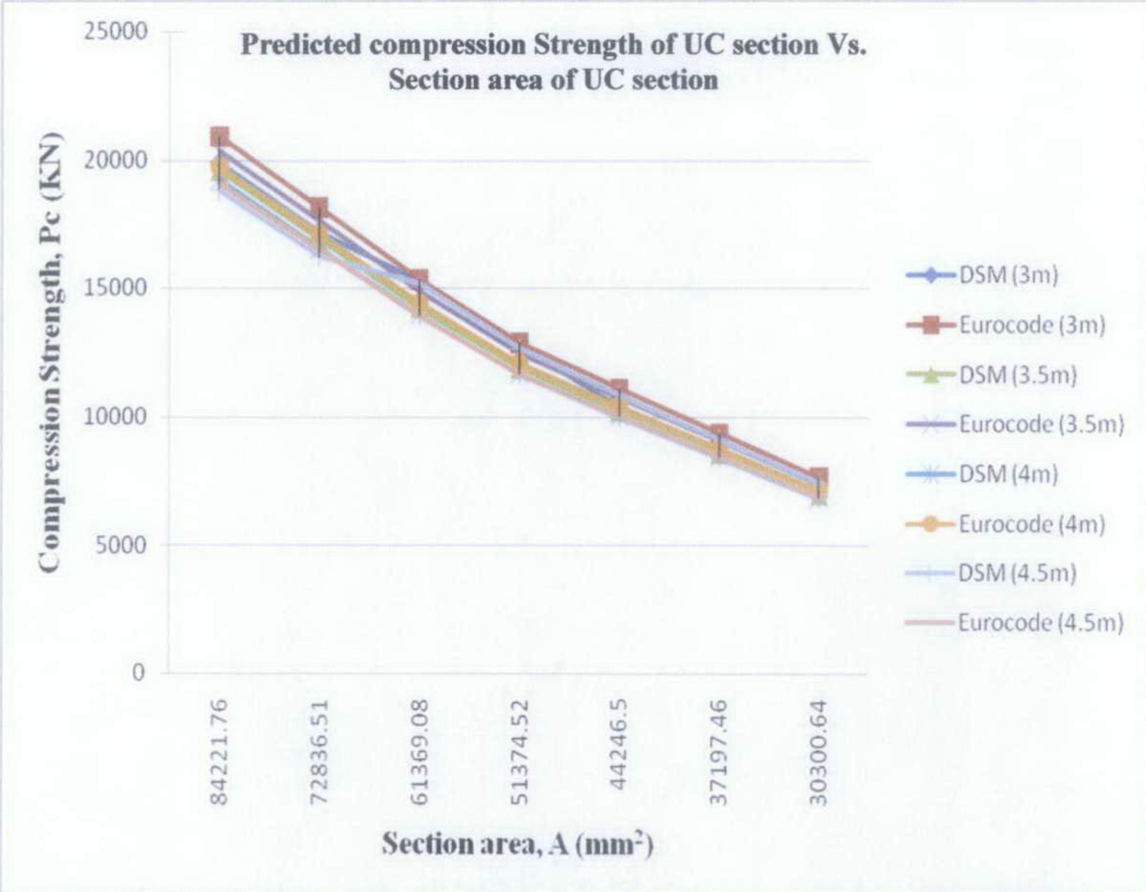

Figure 4.7: Graph shows the comparison between the compression strength by DSM and Eurocode method for section **UC 356x406** with varied section area and length of column.

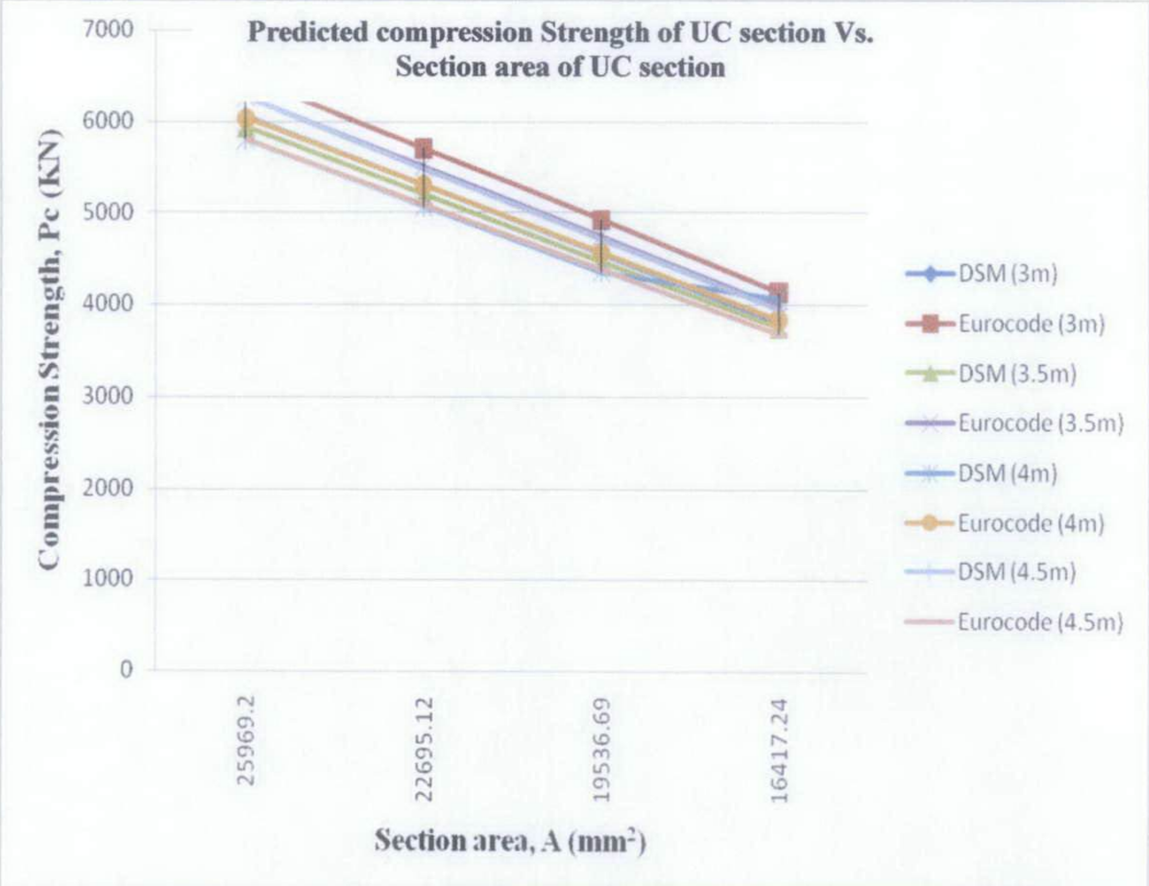

Figure 4.8: Graph shows the comparison between the compression strength by DSM and Eurocode method for section **UC 356x368** with varied section area and length of column.

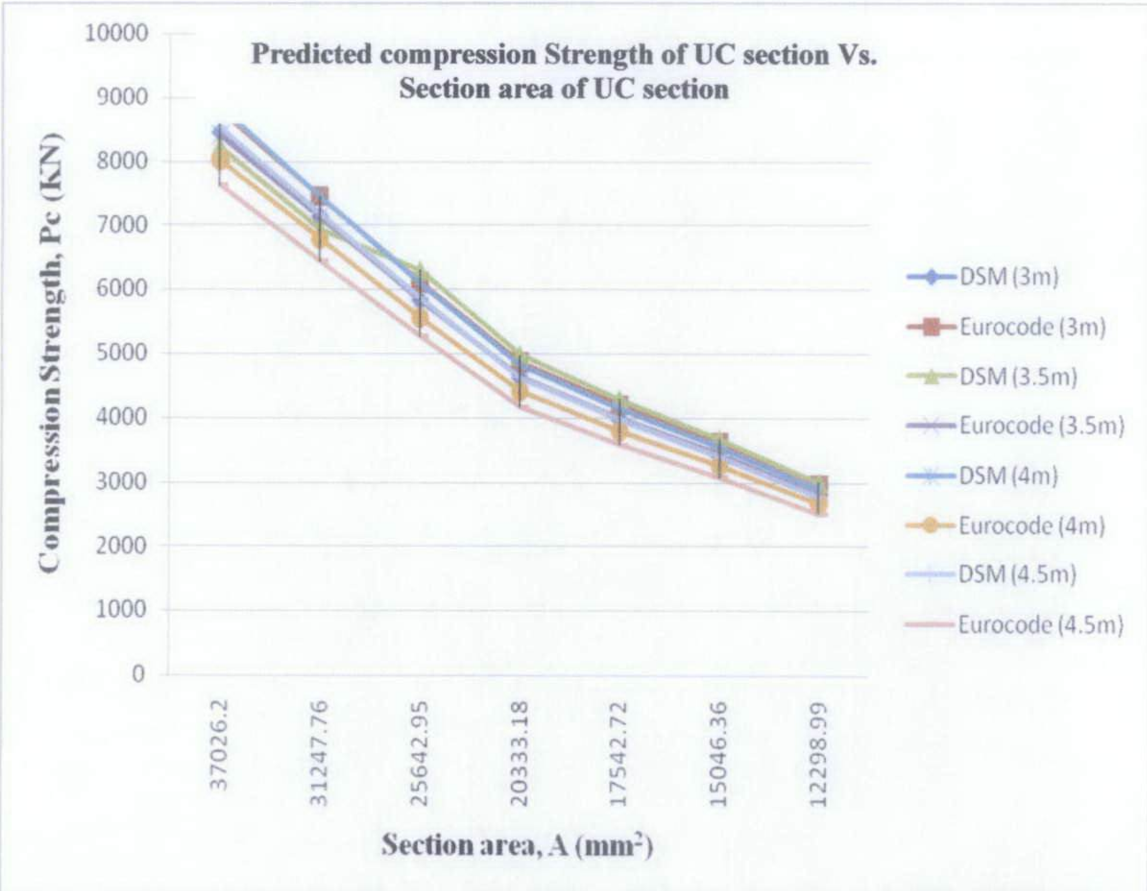

Figure 4.9: Graph shows the comparison between the compression strength by DSM and Eurocode method for section **UC 356x305** with varied section area and length of column.

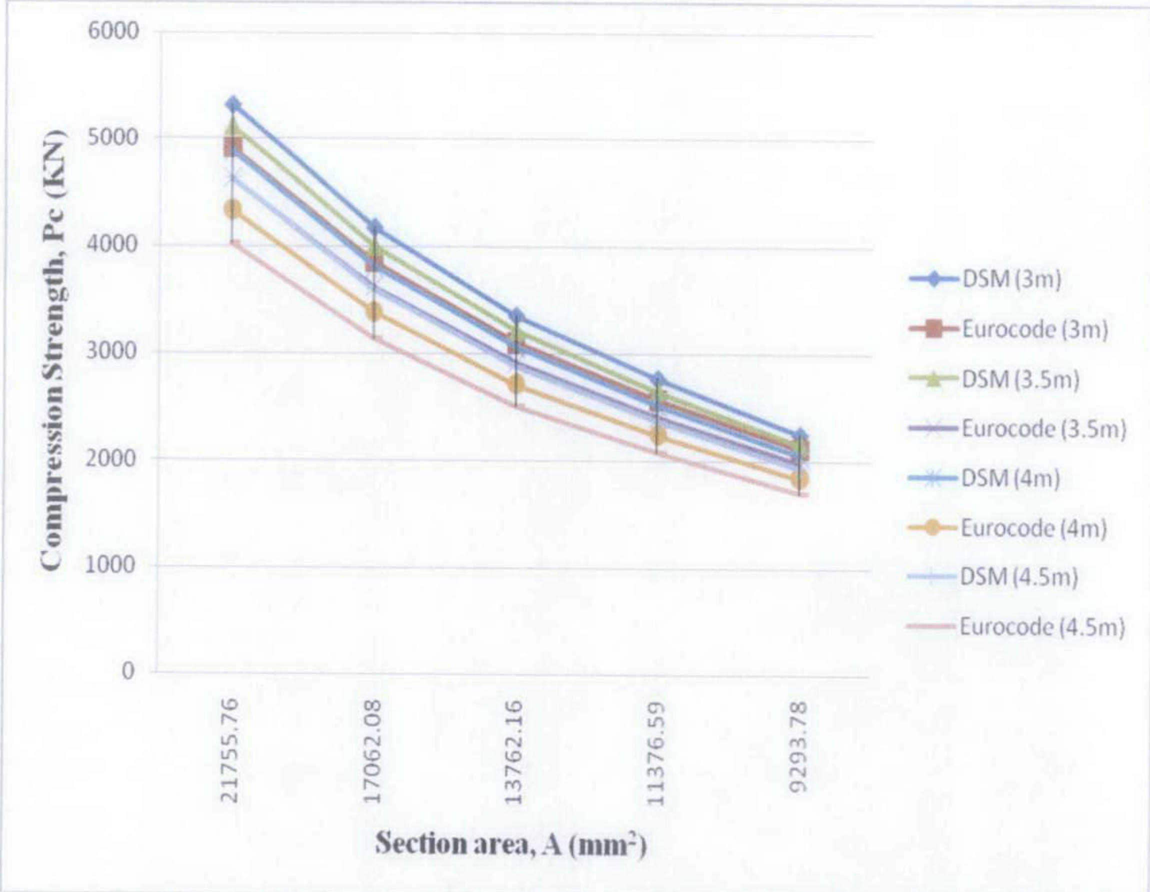

Figure 4.10: Graph shows the comparison between the compression strength by DSM and Eurocode method for section **UC 254x254** with varied section area and length of column.

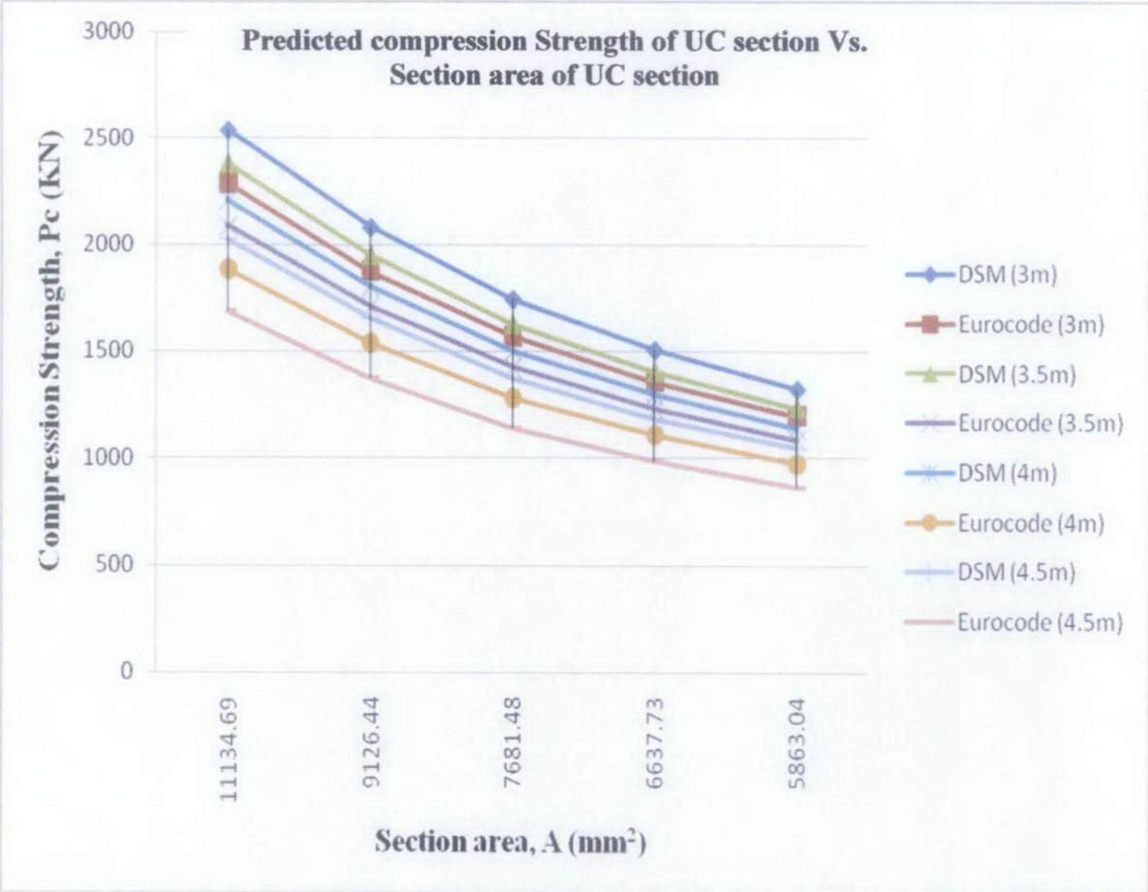

Figure 4.11: Graph shows the comparison between the compression strength by DSM and Eurocode method for section **UC 203x203** with varied section area and length of column.

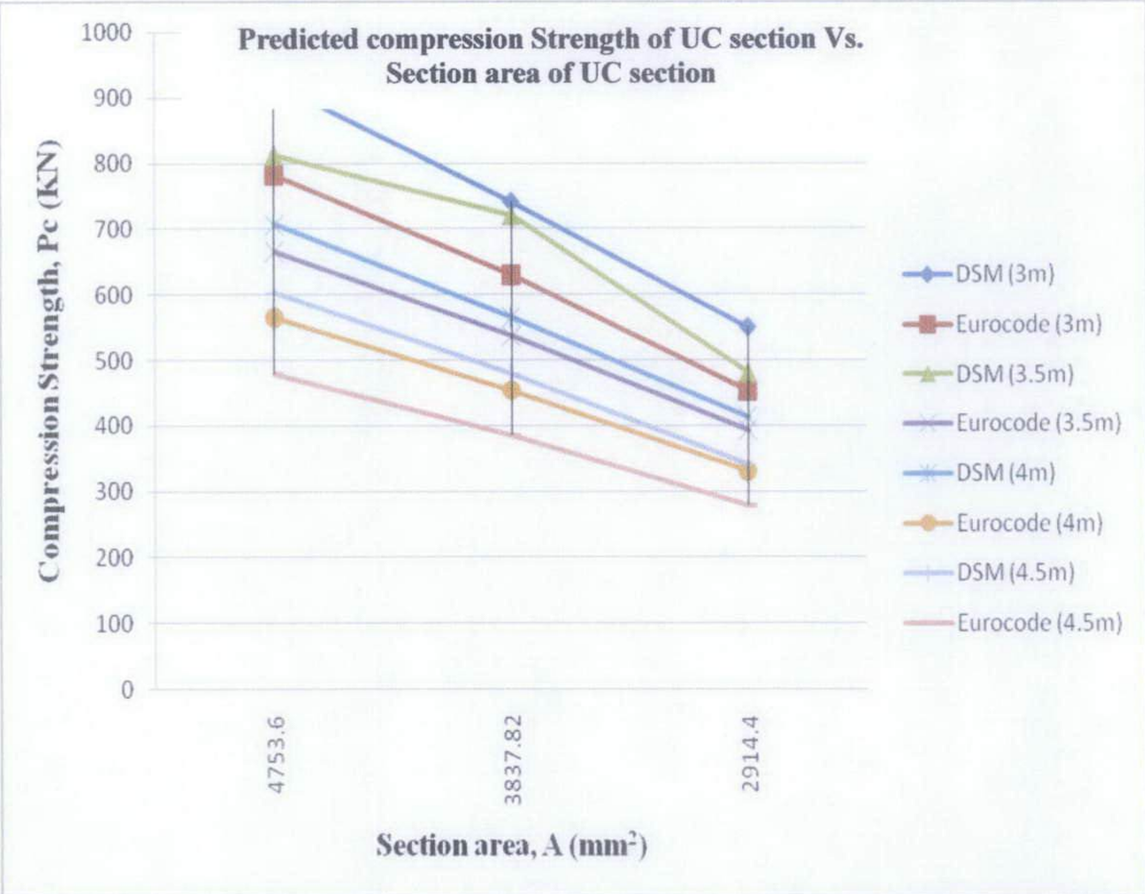

Figure 4.12: Graph shows the comparison between the compression strength by DSM and Eurocode method for section **UC 152x152** with varied section area and length of column.

CONCLUSION

The study was more focusing on the application of the Constrained Finite Strip Method program which is an open software program created for analysis of buckling behavior. This software which was created by Schafer who also developed the Direct Strength Method help to provide the result of buckling behavior of a member which will be used in the calculation of the Direct Strength Method to determine the member strength. A few selected hot-rolled sections were taken for buckling analysis mainly on Universal Column section.

Conclusively, since the hot-rolled UC sections have not been included in pre-qualified members, modifications on the rational analysis maybe necessary. Additional factors, equations or modified limiting buckling value are probably the solutions to predict the hot-rolled UC members accordingly to BS method.

The main concern on this project is to produce the design strength of hot-rolled columns which dimensions are based from the British standard. The design strength produced by the Direct Strength Method will be compared to the available traditional method such as effective width method in order to show the reliability of the new method. The Direct Strength Method has proven its reliability in cold-formed steel design from the results of many previous papers by a number of researchers. Therefore, this study will extend the application of Direct Strength Method on the hot-rolled steel design. It will be a great advantage if the Direct Strength Method proves to be a reliable method in hot-rolled steel design as it provides much easier procedures as compared by the existing traditional method.

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Appendix A-1: Buckling load and compression strength by DSM of 3m Universal Column sections

Section	Section area (mm^2)	Reference stress (f_{ref}) (MPa)	Yield load (P_y) (KN)	Local buckling mode					
				Half wavelength (mm)	Load factor	Reference load (P_{cr}) (KN)	Nominal axial strength (P_{ne}) (KN)	Compression strength (KN)	Remark
356x406x467	61369.08	275	16876.50	-	-	-	-	15275.41	
356x406x393	51374.52	275	14127.99	-	-	-	-	12750.78	
356x406x340	44246.5	275	12167.79	-	-	-	-	10403.68	
356x406x287	37197.46	275	10229.30	-	-	-	-	8746.24	
356x406x235	30300.64	275	8332.68	-	-	-	-	7103.45	
356x368x202	25969.20	275	7141.53	-	-	-	-	6050.42	
356x368x177	22695.12	275	6241.16	-	-	-	-	5287.62	
356x368x153	19536.69	275	5372.59	-	-	-	-	4551.75	
356x368x129	16417.24	275	4514.74	-	-	-	-	3800.07	
305x305x283	37026.20	275	10182.21	-	-	-	-	8449.29	
305x305x240	31247.76	275	8593.13	-	-	-	-	7130.66	
305x305x198	25642.95	275	7051.81	-	-	-	-	5829.66	
305x305x158	20333.18	275	5591.62	-	-	-	-	4623.50	
305x305x137	17542.72	275	4824.25	-	-	-	-	3973.82	
305x305x118	15046.36	275	4137.75	-	-	-	-	3408.34	
305x305x97	12298.99	275	3382.22	-	-	-	-	2785.99	
254x254x167	21755.76	275	5982.83	-	-	-	-	5319.20	
254x254x132	17062.08	275	4692.07	-	-	-	-	4171.61	
254x254x107	13762.16	275	3784.59	-	-	-	-	3349.76	

254x254x89	11376.59	275	3128.56	-	-	-	-	2769.10	
254x254x73	9293.78	275	2555.79	-	-	-	-	2251.85	
203x203x86	11134.69	275	3062.04	-	-	-	-	2537.54	
203x203x71	9126.44	275	2509.77	-	-	-	-	2079.87	
203x203x60	7681.48	275	2112.41	-	-	-	-	1740.71	
203x203x52	6637.73	275	1825.38	-	-	-	-	1504.18	
203x203x46	5863.04	275	1612.34	-	-	-	-	1321.03	
152x152x37	4753.60	275	1307.24	-	-	-	-	924.33	
152x152x30	3837.82	275	1055.40	-	-	-	-	740.57	
152x152x23	2914.40	275	801.46	-	-	-	-	549.33	

Section	**Section area (mm^2)**	**Reference stress (f_{ref})**	**Yield load (P_y)**	**Distortional buckling mode**					
				Half wavelength (mm)	**Load factor**	**Reference load (P_{cr})**	**Nominal axial strength (P_{ne}) (KN))**	**Compression strength (KN)**	**Remark**
356x406x467	61369.08	275	16876.50	915.9	27.36	461741.04	16876.50	15275.41	
356x406x393	51374.52	275	14127.99	758.9	20.37	287787.16	14127.99	12750.78	
356x406x340	44246.5	275	12167.79	758.9	15.84	192737.80	12167.79	10403.68	
356x406x287	37197.46	275	10229.30	758.9	11.73	119989.69	10229.30	8746.24	
356x406x235	30300.64	275	8332.68	758.9	8.18	68161.32	8332.68	7103.45	
356x368x202	25969.20	275	7141.53	758.9	7.15	51061.94	7141.53	6050.42	
356x368x177	22695.12	275	6241.16	758.9	5.61	35012.91	6241.16	5287.62	
356x368x153	19536.69	275	5372.59	758.9	4.27	22940.96	5372.59	4551.75	
356x368x129	16417.24	275	4514.74	758.9	3.09	13950.55	4513.72	3800.07	

305x305x283	37026.20	275	10182.21	628.9	24.75	252009.70	10182.21	8449.29	
305x305x240	31247.76	275	8593.13	628.9	18.69	160605.60	8593.13	7130.66	
305x305x198	25642.95	275	7051.81	628.9	13.36	94212.18	7051.81	5829.66	
305x305x158	20333.18	275	5591.62	628.9	8.84	49429.92	5591.62	4623.50	
305x305x137	17542.72	275	4824.25	628.9	6.78	32708.42	4824.25	3973.82	
305x305x118	15046.36	275	4137.75	628.9	5.13	21226.66	4137.75	3408.34	
305x305x97	12298.99	275	3382.22	628.9	3.54	11973.06	3382.22	2785.99	
254x254x167	21755.76	275	5982.83	521.1	19.17	114690.85	5982.83	5319.20	
254x254x132	17062.08	275	4692.07	521.1	12.66	59401.61	4692.07	4171.61	
254x254x107	13762.16	275	3784.59	521.1	8.62	32623.17	3784.59	3349.76	
254x254x89	11376.59	275	3128.56	521.1	6.16	19271.93	3128.56	2769.10	
254x254x73	9293.78	275	2555.79	521.1	4.25	10862.11	2555.79	2251.85	
203x203x86	11134.69	275	3062.04	431.8	13.08	40051.48	3062.04	2537.54	
203x203x71	9126.44	275	2509.77	431.8	9.34	23441.25	2509.77	2079.87	
203x203x60	7681.48	275	2112.41	357.8	6.73	14216.52	2112.41	1740.71	
203x203x52	6637.73	275	1825.38	431.8	5.19	9473.72	1825.38	1504.18	
203x203x46	5863.04	275	1612.34	357.8	4.12	6642.84	1612.34	1321.03	
152x152x37	4753.6	275	1307.24	296.5	7.91	10340.27	1307.24	924.33	
152x152x30	3837.82	275	1055.40	296.5	5.39	5688.61	1055.40	740.57	
152x152x23	2914.40	275	801.46	245.7	3.20	2564.67	801.46	549.33	

Section	Section area (mm^2)	Reference stress (f_{ref})	Yield load (P_y) (KN)	Global buckling mode					Remark
				Half wavelength (mm)	Load factor	Reference load (P_{cr}) (KN)	Nominal axial strength (P_{ne}) (KN)	Compression strength (KN)	
356x406x467	61369.08	275	16876.50	3000	8.50	143450.25	6580.98	15275.41	
356x406x393	51374.52	275	14127.99	3000	8.30	117262.32	5509.20	12750.78	
356x406x340	44246.5	275	12167.79	3000	8.14	99045.81	4744.82	10403.68	
356x406x287	37197.46	275	10229.30	3000	8.00	81834.40	3988.91	8746.24	
356x406x235	30300.64	275	8332.68	3000	7.84	65328.21	3249.32	7103.45	
356x368x202	25969.2	275	7141.53	3000	7.02	50133.54	2784.84	6050.42	
356x368x177	22695.12	275	6241.16	3000	6.92	43188.83	2433.74	5287.62	
356x368x153	19536.69	275	5372.59	3000	6.80	36533.61	2095.04	4551.75	
356x368x129	16417.24	275	4514.74	3000	6.40	28894.34	1760.52	3800.07	
305x305x283	37026.20	275	10182.21	3000	5.23	53252.96	3970.55	8449.29	
305x305x240	31247.76	275	8593.13	3000	5.11	43910.89	3350.89	7130.66	
305x305x198	25642.95	275	7051.81	3000	5.00	35259.05	2749.85	5829.66	
305x305x158	20333.18	275	5591.62	3000	4.86	27175.27	2180.45	4623.50	
305x305x137	17542.72	275	4824.25	3000	4.79	23108.16	1881.21	3973.82	
305x305x118	15046.36	275	4137.75	3000	4.72	19530.18	1613.51	3408.34	
305x305x97	12298.99	275	3382.22	3000	4.64	15693.50	1318.89	2785.99	
254x254x167	21755.76	275	5982.83	3000	3.61	21598.02	2333.00	5319.20	
254x254x132	17062.08	275	4692.07	3000	3.51	16469.17	1829.67	4171.61	
254x254x107	13762.16	275	3784.59	3000	3.42	12943.30	1475.80	3349.76	

254x254x89	11376.59	275	3128.56	3000	3.40	10637.10	1219.98	2769.10	
254x254x73	9293.78	275	2555.79	3000	3.34	8536.34	996.63	2251.85	
203x203x86	11134.69	275	3062.04	3000	2.25	6889.59	1194.04	2537.54	
203x203x71	9126.44	275	2509.77	3000	2.23	5596.79	978.68	2079.87	
203x203x60	7681.48	275	2112.41	3000	2.16	4562.81	823.73	1740.71	
203x203x52	6637.73	275	1825.38	3000	2.15	3924.57	711.81	1504.18	
203x203x46	5863.04	275	1612.34	3000	2.12	3418.16	1612.34	1321.03	
152x152x37	4753.6	275	1307.24	3000	1.20	1568.69	509.76	924.33	
152x152x30	3837.82	275	1055.40	3000	1.18	1245.37	411.55	740.57	
152x152x23	2914.40	275	801.46	3000	1.11	889.62	312.53	549.33	

Appendix A-2: Buckling load and compression strength by DSM of 3.5m Universal Column section

Section	Section area (mm^2)	Reference stress (f_{ref}) (MPa)	Yield load (P_y) (KN)	Local buckling mode					
				Half wavelength (mm)	Load factor	Reference load (P_{crl}) (KN)	Nominal axial strength (P_{nl}) (KN)	Compression strength (KN)	Remark
356x406x634	84221.76	275	23160.98	-	-	-	-	19578.6	
356x406x551	72836.51	275	20030.04	-	-	-	-	16904.0	
356x406x467	61369.08	275	16876.50	-	-	-	-	14219	
356x406x393	51374.52	275	14127.99	-	-	-	-	11884	
356x406x340	44246.5	275	12167.79	-	-	-	-	10222	
356x406x287	37197.46	275	10229.30	-	-	-	-	8583	
356x406x235	30300.64	275	8332.68	-	-	-	-	6983.3	
356x368x202	25969.20	275	7141.53	-	-	-	-	5934.9	
356x368x177	22695.12	275	6241.16	-	-	-	-	5182.6	
356x368x153	19536.69	275	5372.59	-	-	-	-	4457.2	
356x368x129	16417.24	275	4514.74	-	-	-	-	3740.7	
305x305x283	37026.20	275	10182.21	-	-	-	-	8226.9	
305x305x240	31247.76	275	8593.13	-	-	-	-	6925.2	
305x305x198	25642.95	275	7051.81	-	-	-	-	6299.5	
305x305x158	20333.18	275	5591.62	-	-	-	-	4977.9	
305x305x137	17542.72	275	4824.25	-	-	-	-	4289.1	
305x305x118	15046.36	275	4137.75	-	-	-	-	3672.6	
305x305x97	12298.99	275	3382.22	-	-	-	-	2996.8	

254x254x167	21755.76	275	5982.83	-	-	-	-	5114.8	
254x254x132	17062.08	275	4692.07	-	-	-	-	3994.4	
254x254x107	13762.16	275	3784.59	-	-	-	-	3207.5	
254x254x89	11376.59	275	3128.56	-	-	-	-	2649.8	
254x254x73	9293.78	275	2555.79	-	-	-	-	2157.4	
203x203x86	11134.69	275	3062.04	-	-	-	-	2379.6	
203x203x71	9126.44	275	2509.77	-	-	-	-	1947.5	
203x203x60	7681.48	275	2112.41	-	-	-	-	1623.5	
203x203x52	6637.73	275	1825.38	-	-	-	-	1402.9	
203x203x46	5863.04	275	1612.34	-	-	-	-	1232.9	
152x152x37	4753.60	275	1307.24	-	-	-	-	812.45	
152x152x30	3837.82	275	1055.40	-	-	-	-	720.38	
152x152x23	2914.40	275	801.46	-	-	-	-	481.07	

Section	**Section area (mm^2)**	**Reference stress (f_{ref})**	**Yield load (P_y)**	**Distortional buckling mode**					
				Half wavelength (mm)	**Load factor**	**Reference load (P_{crd})**	**Nominal axial strength (P_{nd}) (KN))**	**Compression strength (KN)**	**Remark**
356x406x634	84221.76	275	23160.98	-	-	-	-	19578.6	
356x406x551	72836.51	275	20030.04	915.9	35.62	713470.02	20030.04	16904.0	
356x406x467	61369.08	275	16876.50	915.9	27.36	461741.04	16876.50	14219	
356x406x393	51374.52	275	14127.99	758.9	20.37	287787.16	14127.99	11884	
356x406x340	44246.5	275	12167.79	758.9	15.84	192737.80	12167.79	10222	
356x406x287	37197.46	275	10229.30	758.9	11.73	119989.69	10229.30	8583	

356x406x235	30300.64	275	8332.68	758.9	8.18	68161.32	8332.68	6983.3	
356x368x202	25969.20	275	7141.53	758.9	7.15	51061.94	7141.53	5934.9	
356x368x177	22695.12	275	6241.16	758.9	5.61	35012.91	6241.16	5182.6	
356x368x153	19536.69	275	5372.59	758.9	4.27	22940.96	5372.59	4457.2	
356x368x129	16417.24	275	4514.74	758.9	3.09	13950.55	4513.72	3740.7	
305x305x283	37026.20	275	10182.21	628.9	24.75	252009.70	10182.21	8226.9	
305x305x240	31247.76	275	8593.13	628.9	18.69	160605.60	8593.13	6925.2	
305x305x198	25642.95	275	7051.81	628.9	13.36	94212.18	7051.81	6299.5	
305x305x158	20333.18	275	5591.62	628.9	8.84	49429.92	5591.62	4977.9	
305x305x137	17542.72	275	4824.25	628.9	6.78	32708.42	4824.25	4289.1	
305x305x118	15046.36	275	4137.75	628.9	5.13	21226.66	4137.75	3672.6	
305x305x97	12298.99	275	3382.22	628.9	3.54	11973.06	3382.22	2996.8	
254x254x167	21755.76	275	5982.83	521.1	19.17	114690.85	5982.83	5114.8	
254x254x132	17062.08	275	4692.07	521.1	12.66	59401.61	4692.07	3994.4	
254x254x107	13762.16	275	3784.59	521.1	8.62	32623.17	3784.59	3207.5	
254x254x89	11376.59	275	3128.56	521.1	6.16	19271.93	3128.56	2649.8	
254x254x73	9293.78	275	2555.79	521.1	4.25	10862.11	2555.79	2157.4	
203x203x86	11134.69	275	3062.04	431.8	13.08	40051.48	3062.04	2379.6	
203x203x71	9126.44	275	2509.77	431.8	9.34	23441.25	2509.77	1947.5	
203x203x60	7681.48	275	2112.41	357.8	6.73	14216.52	2112.41	1623.5	
203x203x52	6637.73	275	1825.38	431.8	5.19	9473.72	1825.38	1402.9	
203x203x46	5863.04	275	1612.34	357.8	4.12	6642.84	1612.34	1232.9	
152x152x37	4753.6	275	1307.24	296.5	7.91	10340.27	1307.24	812.45	
152x152x30	3837.82	275	1055.40	296.5	5.39	5688.61	1055.40	720.38	

152x152x23	2914.40	275	801.46	245.7	3.20	2564.67	801.46	481.07	

Section	Section area (mm^2)	Reference stress (f_{ref})	Yield load (P_y) (KN)	Global buckling mode					
				Half wavelength (mm)	Load factor	Reference load (P_{cre}) (KN)	Nominal axial strength (P_{ne}) (KN)	Compression strength (KN)	Remark
356x406x634	84221.76	275	23160.98	3500	6.68	154715	21754.00	19578.6	Flexural buckling
356x406x551	72836.51	275	20030.04	3500	6.51	130396	18783.00	16904.0	
356x406x467	61369.08	275	16876.50	3500	6.34	106997	15798.00	14219	
356x406x393	51374.52	275	14127.99	3500	6.19	87452	13204.00	11884	
356x406x340	44246.5	275	12167.79	3500	6.08	73980	11358.00	10222	
356x406x287	37197.46	275	10229.30	3500	5.97	61069	9536.70	8583	
356x406x235	30300.64	275	8332.68	3500	5.87	48913	7759.20	6983.3	
356x368x202	25969.2	275	7141.53	3500	5.25	37493	6594.30	5934.9	
356x368x177	22695.12	275	6241.16	3500	5.2	32454	5758.50	5182.6	
356x368x153	19536.69	275	5372.59	3500	5.14	27615	4952.40	4457.2	
356x368x129	16417.24	275	4514.74	3500	5.06	22845	4156.30	3740.7	
305x305x283	37026.20	275	10182.21	3500	3.88	39507	9141.00	8226.9	
305x305x240	31247.76	275	8593.13	3500	3.79	32568	7694.70	6925.2	
305x305x198	25642.95	275	7051.81	3500	3.71	26162	6299.50	6299.5	
305x305x158	20333.18	275	5591.62	3500	3.6	20130	4977.90	4977.9	
305x305x137	17542.72	275	4824.25	3500	3.56	17174	4289.10	4289.1	
305x305x118	15046.36	275	4137.75	3500	3.51	14524	3672.60	3672.6	
305x305x97	12298.99	275	3382.22	3500	3.46	11702	2996.80	2996.8	

254x254x167	21755.76	275	5982.83	3500	2.67	15974	5114.80	5114.8	
254x254x132	17062.08	275	4692.07	3500	2.6	12199	3994.40	3994.4	
254x254x107	13762.16	275	3784.59	3500	2.53	9575	3207.50	3207.5	
254x254x89	11376.59	275	3128.56	3500	2.52	7884	2649.80	2649.8	
254x254x73	9293.78	275	2555.79	3500	2.47	6312.8	2157.40	2157.4	
203x203x86	11134.69	275	3062.04	3500	1.66	5083	2379.60	2379.6	
203x203x71	9126.44	275	2509.77	3500	1.65	4141.1	1947.50	1947.5	
203x203x60	7681.48	275	2112.41	3500	1.59	3358.7	1623.50	1623.5	
203x203x52	6637.73	275	1825.38	3500	1.59	2902.4	1402.90	1402.9	
203x203x46	5863.04	275	1612.34	3500	1.56	2515.3	1232.90	1232.9	
152x152x37	4753.6	275	1307.24	3500	0.88	1150.4	812.45	812.45	
152x152x30	3837.82	275	1055.40	3500	0.87	918.2	720.38	720.38	
152x152x23	2914.40	275	801.46	3500	0.82	657.2	481.07	481.07	

Appendix A-3: Buckling load and compression strength by DSM of 4m Universal Column section

Section	Section area (mm^2)	Reference stress (f_{ref}) (MPa)	Yield load (P_y) (KN)	Local buckling mode					
				Half wavelength (mm)	Load factor	Reference load (P_{crl}) (KN)	Nominal axial strength (P_{nl}) (KN)	Compression strength (KN)	Remark
356x406x634	84221.76	275	23160.98	-	-	-	-	19220.85	
356x406x551	72836.51	275	20030.04	-	-	-	-	16551.10	
356x406x467	61369.08	275	16876.50	-	-	-	-	13945.30	
356x406x393	51374.52	275	14127.99	-	-	-	-	11651.30	
356x406x340	44246.5	275	12167.79	-	-	-	-	10018.00	
356x406x287	37197.46	275	10229.30	-	-	-	-	8407.30	
356x406x235	30300.64	275	8332.68	-	-	-	-	6838.94	
356x368x202	25969.20	275	7141.53	-	-	-	-	5797.78	
356x368x177	22695.12	275	6241.16	-	-	-	-	5061.63	
356x368x153	19536.69	275	5372.59	-	-	-	-	4353.80	
356x368x129	16417.24	275	4514.74	-	-	-	-	4059.70	
305x305x283	37026.20	275	10182.21	-	-	-	-	8852.14	
305x305x240	31247.76	275	8593.13	-	-	-	-	7445.60	
305x305x198	25642.95	275	7051.81	-	-	-	-	6091.77	
305x305x158	20333.18	275	5591.62	-	-	-	-	4810.07	
305x305x137	17542.72	275	4824.25	-	-	-	-	4140.84	
305x305x118	15046.36	275	4137.75	-	-	-	-	3543.57	
305x305x97	12298.99	275	3382.22	-	-	-	-	2891.49	
254x254x167	21755.76	275	5982.83	-	-	-	-	4877.94	

254x254x132	17062.08	275	4692.07	-	-	-	-	3806.08	
254x254x107	13762.16	275	3784.59	-	-	-	-	3053.52	
254x254x89	11376.59	275	3128.56	-	-	-	-	2518.61	
254x254x73	9293.78	275	2555.79	-	-	-	-	2050.48	
203x203x86	11134.69	275	3062.04	-	-	-	-	2208.00	
203x203x71	9126.44	275	2509.77	-	-	-	-	1800.40	
203x203x60	7681.48	275	2112.41	-	-	-	-	1498.94	
203x203x52	6637.73	275	1825.38	-	-	-	-	1295.26	
203x203x46	5863.04	275	1612.34	-	-	-	-	1137.57	
152x152x37	4753.60	275	1307.24	-	-	-	-	706.38	
152x152x30	3837.82	275	1055.40	-	-	-	-	565.08	
152x152x23	2914.40	275	801.46	-	-	-	-	412.43	

Section	**Section area (mm^2)**	**Reference stress (f_{ref})**	**Yield load (P_y)**	**Distortional buckling mode**					
				Half wavelength (mm)	**Load factor**	**Reference load (P_{crd})**	**Nominal axial strength (P_{nd}) (KN))**	**Compression strength (KN)**	**Remark**
356x406x634	84221.76	275	23160.98	-	-	-	-	19220.85	
356x406x551	72836.51	275	20030.04	915.9	35.62	713470.02	20030.04	16551.10	
356x406x467	61369.08	275	16876.50	915.9	27.36	461741.04	16876.50	13945.30	
356x406x393	51374.52	275	14127.99	758.9	20.37	287787.16	14127.99	11651.30	
356x406x340	44246.5	275	12167.79	758.9	15.84	192737.80	12167.79	10018.00	
356x406x287	37197.46	275	10229.30	758.9	11.73	119989.69	10229.30	8407.30	
356x406x235	30300.64	275	8332.68	758.9	8.18	68161.32	8332.68	6838.94	

356x368x202	25969.20	275	7141.53	758.9	7.15	51061.94	7141.53	5797.78	
356x368x177	22695.12	275	6241.16	758.9	5.61	35012.91	6241.16	5061.63	
356x368x153	19536.69	275	5372.59	758.9	4.27	22940.96	5372.59	4353.80	
356x368x129	16417.24	275	4514.74	758.9	3.09	13950.55	4513.72	4059.70	
305x305x283	37026.20	275	10182.21	628.9	24.75	252009.70	10182.21	8852.14	
305x305x240	31247.76	275	8593.13	628.9	18.69	160605.60	8593.13	7445.60	
305x305x198	25642.95	275	7051.81	628.9	13.36	94212.18	7051.81	6091.77	
305x305x158	20333.18	275	5591.62	628.9	8.84	49429.92	5591.62	4810.07	
305x305x137	17542.72	275	4824.25	628.9	6.78	32708.42	4824.25	4140.84	
305x305x118	15046.36	275	4137.75	628.9	5.13	21226.66	4137.75	3543.57	
305x305x97	12298.99	275	3382.22	628.9	3.54	11973.06	3382.22	2891.49	
254x254x167	21755.76	275	5982.83	521.1	19.17	114690.85	5982.83	4877.94	
254x254x132	17062.08	275	4692.07	521.1	12.66	59401.61	4692.07	3806.08	
254x254x107	13762.16	275	3784.59	521.1	8.62	32623.17	3784.59	3053.52	
254x254x89	11376.59	275	3128.56	521.1	6.16	19271.93	3128.56	2518.61	
254x254x73	9293.78	275	2555.79	521.1	4.25	10862.11	2555.79	2050.48	
203x203x86	11134.69	275	3062.04	431.8	13.08	40051.48	3062.04	2208.00	
203x203x71	9126.44	275	2509.77	431.8	9.34	23441.25	2509.77	1800.40	
203x203x60	7681.48	275	2112.41	357.8	6.73	14216.52	2112.41	1498.94	
203x203x52	6637.73	275	1825.38	431.8	5.19	9473.72	1825.38	1295.26	
203x203x46	5863.04	275	1612.34	357.8	4.12	6642.84	1612.34	1137.57	
152x152x37	4753.6	275	1307.24	296.5	7.91	10340.27	1307.24	706.38	
152x152x30	3837.82	275	1055.40	296.5	5.39	5688.61	1055.40	565.08	
152x152x23	2914.40	275	801.46	245.7	3.20	2564.67	801.46	412.43	

Section	Section area (mm^2)	Reference stress (f_{ref})	Yield load (P_y) (KN)	Global buckling mode					
				Half wavelength (mm)	Load factor	Reference load (P_{cre}) (KN)	Nominal axial strength (P_{ne}) (KN)	Compression strength (KN)	Remark
356x406x634	84221.76	275	23160.98	4000	5.16	119510.66	21356.50	19220.85	Flexural buckling
356x406x551	72836.51	275	20030.04	4000	4.90	98147.20	18390.10	16551.10	
356x406x467	61369.08	275	16876.50	4000	4.90	82694.85	15494.80	13945.30	
356x406x393	51374.52	275	14127.99	4000	4.79	67673.07	12945.90	11651.30	
356x406x340	44246.5	275	12167.79	4000	4.70	57188.61	11131.10	10018.00	
356x406x287	37197.46	275	10229.30	4000	4.61	47157.07	9341.50	8407.30	
356x406x235	30300.64	275	8332.68	4000	4.54	37830.37	7598.82	6838.94	
356x368x202	25969.2	275	7141.53	4000	4.06	28994.61	6441.98	5797.78	
356x368x177	22695.12	275	6241.16	4000	4.02	25089.46	5624.03	5061.63	
356x368x153	19536.69	275	5372.59	4000	3.99	21436.63	4837.56	4353.80	
356x368x129	16417.24	275	4514.74	4000	3.94	17788.08	4059.70	4059.70	
305x305x283	37026.20	275	10182.21	4000	2.99	30444.81	8852.14	8852.14	
305x305x240	31247.76	275	8593.13	4000	2.92	25091.94	7445.60	7445.60	
305x305x198	25642.95	275	7051.81	4000	2.86	20168.18	6091.77	6091.77	
305x305x158	20333.18	275	5591.62	4000	2.78	15544.70	4810.07	4810.07	
305x305x137	17542.72	275	4824.25	4000	2.74	13218.45	4140.84	4140.84	
305x305x118	15046.36	275	4137.75	4000	2.70	11171.93	3543.57	3543.57	
305x305x97	12298.99	275	3382.22	4000	2.67	9030.53	2891.49	2891.49	
254x254x167	21755.76	275	5982.83	4000	2.05	12264.80	4877.94	4877.94	

254x254x132	17062.08	275	4692.07	4000	2.00	9384.14	3806.08	3806.08	
254x254x107	13762.16	275	3784.59	4000	1.95	7379.95	3053.52	3053.52	
254x254x89	11376.59	275	3128.56	4000	1.93	6038.12	2518.61	2518.61	
254x254x73	9293.78	275	2555.79	4000	1.90	4856.00	2050.48	2050.48	
203x203x86	11134.69	275	3062.04	4000	1.28	3919.41	2208.00	2208.00	
203x203x71	9126.44	275	2509.77	4000	1.26	3162.31	1800.40	1800.40	
203x203x60	7681.48	275	2112.41	4000	1.22	2577.14	1498.94	1498.94	
203x203x52	6637.73	275	1825.38	4000	1.22	2226.96	1295.26	1295.26	
203x203x46	5863.04	275	1612.34	4000	1.20	1934.80	1137.57	1137.57	
152x152x37	4753.6	275	1307.24	4000	0.68	888.92	706.38	706.38	
152x152x30	3837.82	275	1055.40	4000	0.67	707.11	565.08	565.08	
152x152x23	2914.40	275	801.46	4000	0.63	504.92	412.43	412.43	

Appendix A-4: Buckling load and compression strength by DSM of 4.5m Universal Column sections

Section	Section area (mm^2)	Reference stress (f_{ref}) (MPa)	Yield load (P_y) (KN)	Local buckling mode					
				Half wavelength (mm)	Load factor	Reference load (P_{crl}) (KN)	Nominal axial strength (P_{nl}) (KN)	Compression strength (KN)	Remark
356x406x634	84221.76	275	23160.98	-	-	-	-	18826.20	
356x406x551	72836.51	275	20030.04	-	-	-	-	16236	
356x406x467	61369.08	275	16876.50	-	-	-	-	15159	
356x406x393	51374.52	275	14127.99	-	-	-	-	12658	
356x406x340	44246.5	275	12167.79	-	-	-	-	10880	
356x406x287	37197.46	275	10229.30	-	-	-	-	9126.8	
356x406x235	30300.64	275	8332.68	-	-	-	-	7420.5	
356x368x202	25969.20	275	7141.53	-	-	-	-	6273.6	
356x368x177	22695.12	275	6241.16	-	-	-	-	5476	
356x368x153	19536.69	275	5372.59	-	-	-	-	4710	
356x368x129	16417.24	275	4514.74	-	-	-	-	3951.3	
305x305x283	37026.20	275	10182.21	-	-	-	-	8533.8	
305x305x240	31247.76	275	8593.13	-	-	-	-	7174.6	
305x305x198	25642.95	275	7051.81	-	-	-	-	5864.4	
305x305x158	20333.18	275	5591.62	-	-	-	-	4622.9	
305x305x137	17542.72	275	4824.25	-	-	-	-	3978	

305x305x118	15046.36	275	4137.75	-	-	-	-	3405.8	
305x305x97	12298.99	275	3382.22	-	-	-	-	2776.3	
254x254x167	21755.76	275	5982.83	-	-	-	-	4628	
254x254x132	17062.08	275	4692.07	-	-	-	-	3600.1	
254x254x107	13762.16	275	3784.59	-	-	-	-	2883.9	
254x254x89	11376.59	275	3128.56	-	-	-	-	2379.8	
254x254x73	9293.78	275	2555.79	-	-	-	-	1937.1	
203x203x86	11134.69	275	3062.04	-	-	-	-	2023.2	
203x203x71	9126.44	275	2509.77	-	-	-	-	1651.4	
203x203x60	7681.48	275	2112.41	-	-	-	-	1372.1	
203x203x52	6637.73	275	1825.38	-	-	-	-	1180.3	
203x203x46	5863.04	275	1612.34	-	-	-	-	1042.6	
152x152x37	4753.60	275	1307.24	-	-	-	-	602.19	
152x152x30	3837.82	275	1055.40	-	-	-	-	479.12	
152x152x23	2914.40	275	801.46	-	-	-	-	341.13	

Section	**Section area (mm^2)**	**Reference stress (f_{ref})**	**Yield load (P_y)**	**Distortional buckling mode**					
				Half wavelength (mm)	**Load factor**	**Reference load (P_{crd})**	**Nominal axial strength (P_{nd}) (KN))**	**Compression strength (KN)**	**Remark**
356x406x634	84221.76	275	23160.98	-	-	-	-	18826.20	
356x406x551	72836.51	275	20030.04	915.9	35.62	713470.02	20030.04	16236	
356x406x467	61369.08	275	16876.50	915.9	27.36	461741.04	16876.50	15159	
356x406x393	51374.52	275	14127.99	758.9	20.37	287787.16	14127.99	12658	

356x406x340	44246.5	275	12167.79	758.9	15.84	192737.80	12167.79	10880	
356x406x287	37197.46	275	10229.30	758.9	11.73	119989.69	10229.30	9126.8	
356x406x235	30300.64	275	8332.68	758.9	8.18	68161.32	8332.68	7420.5	
356x368x202	25969.20	275	7141.53	758.9	7.15	51061.94	7141.53	6273.6	
356x368x177	22695.12	275	6241.16	758.9	5.61	35012.91	6241.16	5476	
356x368x153	19536.69	275	5372.59	758.9	4.27	22940.96	5372.59	4710	
356x368x129	16417.24	275	4514.74	758.9	3.09	13950.55	4513.72	3951.3	
305x305x283	37026.20	275	10182.21	628.9	24.75	252009.70	10182.21	8533.8	
305x305x240	31247.76	275	8593.13	628.9	18.69	160605.60	8593.13	7174.6	
305x305x198	25642.95	275	7051.81	628.9	13.36	94212.18	7051.81	5864.4	
305x305x158	20333.18	275	5591.62	628.9	8.84	49429.92	5591.62	4622.9	
305x305x137	17542.72	275	4824.25	628.9	6.78	32708.42	4824.25	3978	
305x305x118	15046.36	275	4137.75	628.9	5.13	21226.66	4137.75	3405.8	
305x305x97	12298.99	275	3382.22	628.9	3.54	11973.06	3382.22	2776.3	
254x254x167	21755.76	275	5982.83	521.1	19.17	114690.85	5982.83	4628	
254x254x132	17062.08	275	4692.07	521.1	12.66	59401.61	4692.07	3600.1	
254x254x107	13762.16	275	3784.59	521.1	8.62	32623.17	3784.59	2883.9	
254x254x89	11376.59	275	3128.56	521.1	6.16	19271.93	3128.56	2379.8	
254x254x73	9293.78	275	2555.79	521.1	4.25	10862.11	2555.79	1937.1	
203x203x86	11134.69	275	3062.04	431.8	13.08	40051.48	3062.04	2023.2	
203x203x71	9126.44	275	2509.77	431.8	9.34	23441.25	2509.77	1651.4	
203x203x60	7681.48	275	2112.41	357.8	6.73	14216.52	2112.41	1372.1	
203x203x52	6637.73	275	1825.38	431.8	5.19	9473.72	1825.38	1180.3	
203x203x46	5863.04	275	1612.34	357.8	4.12	6642.84	1612.34	1042.6	

152x152x37	4753.6	275	1307.24	296.5	7.91	10340.27	1307.24	602.19	
152x152x30	3837.82	275	1055.40	296.5	5.39	5688.61	1055.40	479.12	
152x152x23	2914.40	275	801.46	245.7	3.20	2564.67	801.46	341.13	

Section	**Section area (mm^2)**	**Reference stress (f_{ref})**	**Yield load (P_y) (KN)**	**Global buckling mode**					
				Half wavelength (mm)	**Load factor**	**Reference load (P_{cre}) (KN)**	**Nominal axial strength (P_{ne}) (KN)**	**Compression strength (KN)**	**Remark**
356x406x634	84221.76	275	23160.98	4500	4.11	95191.63	20918.00	18826.20	Flexural buckling
356x406x551	72836.51	275	20030.04	4500	4.00	80120.16	18040.00	16236.00	
356x406x467	61369.08	275	16876.50	4500	3.90	65818.35	15159.00	15159.00	
356x406x393	51374.52	275	14127.99	4500	3.81	53827.64	12658.00	12658.00	
356x406x340	44246.5	275	12167.79	4500	3.74	45507.53	10880.00	10880.00	
356x406x287	37197.46	275	10229.30	4500	3.67	37541.53	9126.80	9126.80	
356x406x235	30300.64	275	8332.68	4500	3.61	30080.97	7420.50	7420.50	
356x368x202	25969.2	275	7141.53	4500	3.23	23067.14	6273.60	6273.60	
356x368x177	22695.12	275	6241.16	4500	3.20	19971.71	5476.00	5476.00	
356x368x153	19536.69	275	5372.59	4500	3.18	17084.83	4710.00	4710.00	
356x368x129	16417.24	275	4514.74	4500	3.14	14176.28	3951.30	3951.30	
305x305x283	37026.20	275	10182.21	4500	2.37	24131.83	8533.80	8533.80	
305x305x240	31247.76	275	8593.13	4500	2.32	19936.06	7174.60	7174.60	
305x305x198	25642.95	275	7051.81	4500	2.27	16007.61	5864.40	5864.40	
305x305x158	20333.18	275	5591.62	4500	2.20	12301.56	4622.90	4622.90	
305x305x137	17542.72	275	4824.25	4500	2.17	10468.62	3978.00	3978.00	

305x305x118	15046.36	275	4137.75	4500	2.15	8896.16	3405.80	3405.80	
305x305x97	12298.99	275	3382.22	4500	2.12	7170.31	2776.30	2776.30	
254x254x167	21755.76	275	5982.83	4500	1.63	9752.01	4628.00	4628.00	
254x254x132	17062.08	275	4692.07	4500	1.58	7413.47	3600.10	3600.10	
254x254x107	13762.16	275	3784.59	4500	1.54	5828.27	2883.90	2883.90	
254x254x89	11376.59	275	3128.56	4500	1.53	4786.70	2379.80	2379.80	
254x254x73	9293.78	275	2555.79	4500	1.51	3859.24	1937.10	1937.10	
203x203x86	11134.69	275	3062.04	4500	1.01	3092.66	2023.20	2023.20	
203x203x71	9126.44	275	2509.77	4500	1.00	2509.77	1651.40	1651.40	
203x203x60	7681.48	275	2112.41	4500	0.97	2049.04	1372.10	1372.10	
203x203x52	6637.73	275	1825.38	4500	0.96	1752.36	1180.30	1180.30	
203x203x46	5863.04	275	1612.34	4500	0.96	1547.85	1042.60	1042.60	
152x152x37	4753.6	275	1307.24	4500	0.54	705.91	602.19	602.19	
152x152x30	3837.82	275	1055.40	4500	0.53	559.36	479.12	479.12	
152x152x23	2914.40	275	801.46	4500	0.49	392.72	341.13	341.13	

Appendix B-1

CALCULATION SHEET FOR COMPRESSION STRENGTH OF COLUM
by: Josephson Juing 6245

Stress = 275 Mpa

Section	=	UC 356x406x393	
Length	=	3000	mm
K	=	1	
Le	=	3000	mm
B	=	407	mm
b	=	203.5	mm
T	=	49.2	mm
t	=	30.6	mm
d	=	290.2	mm
rx	=	171	mm
ry	=	105	mm
A	=	50100	mm^2

Section Classification

Flange

Py	=	255	N/mm^2	
ε	=	1.0385		
b/T	=	4.1362		Flange is non-slender

Web

Py	=	265	N/mm^2	
ε	=	1.0187		
d/t	=	9.4837		Web is non-slender

Slenderness ratio

λxx	=	17.544
λyy	=	28.571

From Table 23 (rolled H-section)

Design curve for xx-axis bending is table 24 c
Design curve for yy-axis bending is table 24 c

Compressive strength, pc for xx-axis bending	=	253.47	N/mm^2
Compressive strength, pc for yy-axis bending	=	248.29	N/mm^2

Min pc = 248.29 N/mm^2

Thus, compression strength, Pc = 12439 KN

Compression strength by DSM	=	12750.8	KN
Compression strength by BS Method	=	12439	KN
Percentage difference	=	2.5052	%

Appendix B-2

CALCULATION OF BUCKLING RESISTANCE OF UC MEMBER BY EUROCODE

Stress	275Mpa
Section	356x406x393

Length, L	=	3000	mm
K	=	1	mm
Buckling length, Lcr	=	3000	mm
Width, h	=	419	mm
Breadth, b	=	407	mm
Flange thickness, T	=	49.2	mm
yield strength, fy	=	275	mm
rz	=	105	mm
Area, A	=	50100	mm

h/b	=	1.02948
α	=	0.49
ε	=	0.92442
$\lambda 1$	=	86.8027
λ	=	0.32915
Φ	=	0.58581
χ	=	0.93422

Buckling resistance, N	=	12871.21	KN
DSM	=	19892.52	KN
Percentage difference	=	35.2962	%

Appendix B-3

CALCULATION OF DIRECT STRENGTH METHOD FOR COLUMN
by: Josephson Juing
6245

Section	=	356x406x393	
Pcre	=	117262	KN
Pcrd	=	287787	KN
Pcrl	=	0	KN
Py	=	14128	KN

Global buckling

λc	=	0.3471	
Pne	=	13433	KN

Local buckling

λl	=	0	
Pnl	=	0	KN

Distortional buckling

λd	=	0.2216	
Pnd	=	14128	KN

Compression strength, Pn = 13433 KN Reduction required

Fail due to global buckling

Allowable percentage reduction = %

Final compression strength, Pn = 13433 KN

Appendix C-1: Comparison between compression strength by Eurocode and BS code for 3m column length

Section	Mode of failure	Compression strength by Eurocode (KN)	Compression strength by BS code (KN)	Percentage difference (%)
356x406x634	Global buckling	20928.89	19025.20	10.01
356x406x551	Global buckling	18154.77	16493.00	10.08
356x406x467	Global buckling	15337.87	14823.83	3.47
356x406x393	Global buckling	12871.21	12439.33	3.47
356x406x340	Global buckling	11104.84	10731.47	3.48
356x406x287	Global buckling	9369.819	9145.24	2.46
356x406x235	Global buckling	7640.639	7383.51	3.48
356x368x202	Global buckling	6489.911	6270.80	3.49
356x368x177	Global buckling	5699.766	5710.57	0.19
356x368x153	Global buckling	4912.615	4922.19	0.19
356x368x129	Global buckling	4126.193	4134.44	0.20
305x305x283	Global buckling	8789.296	8494.20	3.47
305x305x240	Global buckling	7443.229	7194.06	3.46
305x305x198	Global buckling	6108.162	5904.63	3.45
305x305x158	Global buckling	4849.329	4855.63	0.13
305x305x137	Global buckling	4187.825	4194.10	0.15
305x305x118	Global buckling	3602.589	3607.50	0.14
305x305x97	Global buckling	2945.639	2949.29	0.12
254x254x167	Global buckling	4913.183	4769.07	3.02
254x254x132	Global buckling	3851.5	3859.63	0.21
254x254x107	Global buckling	3101.285	3110.59	0.30
254x254x89	Global buckling	2571.15	2579.79	0.33
254x254x73	Global buckling	2110.044	2117.09	0.33
203x203x86	Global buckling	2290.11	2295.04	0.21
203x203x71	Global buckling	1874.678	1878.51	0.20
203x203x60	Global buckling	1568.289	1570.94	0.17
203x203x52	Global buckling	1358.101	1360.21	0.16
203x203x46	Global buckling	1195.99	1197.71	0.14
152x152x37	Global buckling	782.4684	781.67	0.10
152x152x30	Global buckling	630.232	629.42	0.13
152x152x23	Global buckling	464.9695	452.13	2.84

Appendix C-2: Comparison between compression strength by Eurocode and BS code for 3.5m column length

Section	Mode of failure	Compression strength by Eurocode (KN)	Compression strength by BS code (KN)	Percentage difference (%)
356x406x634	Global buckling	20328.41	18290.00	11.14
356x406x551	Global buckling	17627.72	15850.00	11.22
356x406x467	Global buckling	14881.77	14379.00	3.50
356x406x393	Global buckling	12478.87	12058.00	3.49
356x406x340	Global buckling	10762.04	10398.00	3.50
356x406x287	Global buckling	9076.845	8770.50	3.49
356x406x235	Global buckling	7398.602	7149.10	3.49
356x368x202	Global buckling	6266.642	6056.50	3.47
356x368x177	Global buckling	5501.968	5513.50	0.21
356x368x153	Global buckling	4740.882	4750.60	0.20
356x368x129	Global buckling	3980.669	3988.20	0.19
305x305x283	Global buckling	8414.206	8262.70	1.83
305x305x240	Global buckling	7118.477	6994.20	1.78
305x305x198	Global buckling	5836.078	5662.40	3.07
305x305x158	Global buckling	4627.401	4634.10	0.14
305x305x137	Global buckling	3993.509	4001.10	0.19
305x305x118	Global buckling	3433.415	3441.60	0.24
305x305x97	Global buckling	2805.056	2813.40	0.30
254x254x167	Global buckling	4627.794	4492.20	3.02
254x254x132	Global buckling	3621.049	3634.80	0.38
254x254x107	Global buckling	2910.973	2921.00	0.34
254x254x89	Global buckling	2411.744	2419.60	0.32
254x254x73	Global buckling	1976.829	1982.80	0.30
203x203x86	Global buckling	2088.318	2089.10	0.04
203x203x71	Global buckling	1707.337	1707.80	0.03
203x203x60	Global buckling	1423.637	1423.90	0.02
203x203x52	Global buckling	1232.006	1232.30	0.02
203x203x46	Global buckling	1083.089	1083.20	0.01
152x152x37	Global buckling	668.3743	665.71	0.40
152x152x30	Global buckling	537.0953	535.93	0.22
152x152x23	Global buckling	393.2438	391.57	0.43

Appendix C-3: Comparison between compression strength by Eurocode and BS code for 4.0m column length

Section	Mode of failure	Compression strength by Eurocode (KN)	Compression strength by BS code (KN)	Percentage difference (%)
356x406x634	Global buckling	19715.07	17556.00	12.30
356x406x551	Global buckling	17089.04	15205.00	12.39
356x406x467	Global buckling	14414.99	13934.00	3.45
356x406x393	Global buckling	12076.81	11675.00	3.44
356x406x340	Global buckling	10410.5	10066.00	3.42
356x406x287	Global buckling	8776.189	8486.10	3.42
356x406x235	Global buckling	7150.041	6914.40	3.41
356x368x202	Global buckling	6036.338	5846.80	3.24
356x368x177	Global buckling	5297.844	5313.30	0.29
356x368x153	Global buckling	4563.589	4576.70	0.29
356x368x129	Global buckling	3830.364	3840.20	0.26
305x305x283	Global buckling	8023.417	7785.40	3.06
305x305x240	Global buckling	6779.863	6574.10	3.13
305x305x198	Global buckling	5552.181	5380.20	3.20
305x305x158	Global buckling	4395.645	4403.00	0.17
305x305x137	Global buckling	3790.509	3799.60	0.24
305x305x118	Global buckling	3256.624	3266.70	0.31
305x305x97	Global buckling	2658.088	2668.60	0.39
254x254x167	Global buckling	4329.122	4207.20	2.90
254x254x132	Global buckling	3380.004	3383.90	0.12
254x254x107	Global buckling	2712.04	2714.60	0.09
254x254x89	Global buckling	2245.167	2247.10	0.09
254x254x73	Global buckling	1837.708	1839.10	0.08
203x203x86	Global buckling	1883.825	1883.00	0.04
203x203x71	Global buckling	1538.096	1537.30	0.05
203x203x60	Global buckling	1278.132	1277.10	0.08
203x203x52	Global buckling	1105.313	1104.30	0.09
203x203x46	Global buckling	969.9883	968.90	0.11
152x152x37	Global buckling	567.596	565.01	0.46
152x152x30	Global buckling	455.276	453.24	0.45
152x152x23	Global buckling	331.3639	329.49	0.57

Appendix C-4: Comparison between compression strength by Eurocode and BS code for 4.5m column length

Section	Mode of failure	Compression strength by Eurocode (KN)	Compression strength by BS code (KN)	Percentage difference (%)
356x406x634	Global buckling	19084.93	16821.00	13.46
356x406x551	Global buckling	16535.27	14562.00	13.55
356x406x467	Global buckling	13934.57	13501.00	3.21
356x406x393	Global buckling	11662.51	11308.00	3.14
356x406x340	Global buckling	10048.04	9746.40	3.09
356x406x287	Global buckling	8466.016	8215.20	3.05
356x406x235	Global buckling	6893.462	6690.40	3.04
356x368x202	Global buckling	5797.787	5620.10	3.16
356x368x177	Global buckling	5086.341	4932.20	3.13
356x368x153	Global buckling	4379.839	4390.60	0.25
356x368x129	Global buckling	3674.536	3682.80	0.22
305x305x283	Global buckling	7616.555	7386.50	3.11
305x305x240	Global buckling	6427.29	6228.90	3.18
305x305x198	Global buckling	5256.583	5091.90	3.23
305x305x158	Global buckling	4154.372	4162.30	0.19
305x305x137	Global buckling	3579.202	3585.40	0.17
305x305x118	Global buckling	3072.627	3077.40	0.16
305x305x97	Global buckling	2505.169	2508.70	0.14
254x254x167	Global buckling	4021.059	3915.80	2.69
254x254x132	Global buckling	3131.951	3132.50	0.02
254x254x107	Global buckling	2507.769	2508.10	0.01
254x254x89	Global buckling	2074.283	2074.70	0.02
254x254x73	Global buckling	1695.239	1695.50	0.02
203x203x86	Global buckling	1685.069	1688.10	0.18
203x203x71	Global buckling	1374.061	1375.70	0.12
203x203x60	Global buckling	1138.127	1137.70	0.04
203x203x52	Global buckling	983.5921	982.96	0.06
203x203x46	Global buckling	861.7442	860.31	0.17
152x152x37	Global buckling	482.5138	479.10	0.71
152x152x30	Global buckling	386.5042	384.95	0.40
152x152x23	Global buckling	280.0879	278.51	0.57