CERTIFICATION OF APPROVAL

Comparison of Different Structural Software for Multistory Building Design in Terms of Concrete Columns Reinforcement

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.

CHAW KIT TENG

ABSTRACT

The use of computers for the analysis and design of structures has become a standard practice in today's world especially in the design of complex structures, such that space craft, aircraft, tall building, long span bridges, etc. As a result of standard practice of computational design of tall building structures, there are a number of software in the market for a solution of similar problem; however, there is not exist any comparative analysis among commercially available software for tall building design. This research study was focused on the comparative analysis of different software. The comparison was made in terms of efficiently, ease in modelling and economy of design.

Structure model with different combination of building height and bay width were used to carry out the analytical study. In order to maintain the consistency and accuracy of the results output, column sizes were kept constant for all the models. Two software, Prokon Version W1.1.02 and STAAD Pro 2002 which are very common in the structural practices in Malaysia were used for this comparative analysis.

Based on the analytical and structural design results, STAAD Pro 2002 is found to be more superior to Prokon Version W1.1.02 in term of tall building modelling. STAAD Pro software proved to be an highly efficiency software, which produced more economical design as compared to Prokon. Moreover, the differences, similarities as well as the limitations of both programs have been identified in this project. On the whole, STAAD Pro software is a more advance program which is appropriate for tall building modelling purposes.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

The suite of structural analysis and design software is developed by engineers for engineering practices. These software are globally used almost everywhere in the world which provide a quick and reliable answers to everyday structural and geotechnical engineering problems such as:

- Finite element analysis of complex building frame.
- Steel member and connection design.
- Reinforced and prestressed concrete design.
- Reinforced concrete detailing.
- Timber member design.
- Slope stability analysis
- Geotechnical design.

As the world continues to move towards the new era of information technology, it has become a necessity and trend for a design office to be equipped with at least one analysis and design software. The availability of this software helps and eases engineers' works in many ways ranging from simple loading calculation to superstructure and substructure design and analysis. However, availability of quite many software for the same purpose in the market raised a question to the end user, which is the best.

In general, the efficiency of any structural design software is judged according to the competency of the design to fulfil the required function safely, economically feasible and capable of maintaining an acceptable appearance within its specified service lifetime. Thus, the design of reinforced concrete structure is also being assessed in the same manner. Basically, it is necessary for engineers to have a strong background and experience in civil engineering in order to produce an accurate analysis and feasible design.

1.2 PROBLEM STATEMENT

Due to extensive computational modelling for carrying out building design and there are many commercial software available in the market, there is a question needed to be answered:

- "Which is the most competent software in terms of producing most efficient, feasible and economical design."

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objective of this research is:

1. To compare the differences and effectiveness of different structural software available for the design of reinforced concrete columns for multistory building with variation of building height and bay framing width.

2. This research is also intent to compare the competence of the different structural software in producing the most economical and feasible column design.

In order to achieve the above objectives, the scope of work of this study was carried out in the following stages:

i. Understanding the functions and applications of the chosen software of reinforced concrete design. In this stage, a few reinforced concrete structure examples were used as references to run and test the application of the different structural software.

ii. Verification of the application software. A few simple reinforced concrete structures were drafted and analysed by using the chosen software. The results were then used to verify the efficiency of the software in performing analysis and design.

iii. Comparison of computational result output. The result output were studied and compared within the chosen software and also compared with the manual calculations in order to determine the competence of the software in producing an economical and feasible column design.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 BASIC BEHAVIOR OF HIGH-RISE BUILDINGS

A high rise structure is essentially a vertical cantilever that is subjected to axial loads induced by gravity forces and transverse loads resulted by wind or earthquake. Basically, the gravity induced loads act on the slabs, that is transferred to the vertical walls and columns through which it passes to the foundation. Conversely, horizontal loading exerts at each level of a building cause a shear, a moment and sometimes a torque, which have maximum values at the base of the structure that increase rapidly with the building's height. The response of a structure to horizontal loading is more complex than its response to gravity loading. Generally, the structure's behaviour under horizontal loading has become the main concern in modelling analysis. [1]

The major difference between low rise and high rise buildings is the influence of the wind forces on the behaviour of the structure elements. Generally, it can be stated that a tall building structure is one in which the horizontal loads are an important factor in the structural design. [2] Hence, the structural system must be made sufficiently economical to resist lateral forces due to wind or earthquakes within the prescribed criteria for strength, drift and comforts of the occupants.

The resistance of the structure to the external moment is provided by flexure of the vertical components, and by their axial action acting as the chords of a vertical truss. Besides that, the horizontal shear at any level in a high rise structure is resisted by shear in the vertical members and by the horizontal components of the axial force in any diagonal bracing at that level. Whereas the torsion on a building is resisted mainly by shear in the vertical components, by the horizontal components of axial force in any diagonal bracing members and by the shear and warping torque resistance of elevator, stair and service shafts. A structure's resistance to bending and torsion can also be significantly influenced by the vertical shearing action between connected orthogonal bents or walls. [1]

2.2 BASIC COLUMN DESIGN CONCEPT IN TALL BUIDLING

Columns are structural members in buildings carrying roof and floor loads to the foundations. Columns primarily carry axial loads, but most columns are subjected to moment as well as axial load. [2]

In the modern high rise building with usually large bays, the design of heavy column for the lower parts of the structures requires tedious and detail study, since the problem is not simply one of obtaining a cross section of the required area. The wind bracing scheme is also as much a governing consideration as is the load in the proportioning of such columns. [3]

In general, if the building is a long and narrow structure, wind may be a major problem in one direction only. Whereas, if the plan is that of an approximately square tower, moment connections may be needed at all faces of a column and magnitudes of the maximum moments will require details that lend to a grading or modification up through the frame without abrupt change of type and without a shifting of centrelines in either direction. Furthermore, strength is not the only requirements; stiffness must also be obtained so that occupants are not conscious of sway in slender towers. [3]

The importance of orientation is normally not that critical with concrete columns as compare with steel columns. Because of the increase in size of concrete columns from gravity loads alone, every attempt is made to resist wind forces. When space limitations exist, it is a good practice to specify higher strength concretes to control column sizes. [3]

2.3 GENERAL ASSUMPTIONS FOR TALL STRUCTURE ANALYSIS

The structural form of a building is inherently three dimensional. The development of efficient methods of analysis for tall structures is possible only if the usual complex combination of many different types of structural members can be reduced or simplified whilst still representing accurately the overall behaviour of the structure. A necessary first step is therefore the selection of an idealized structure that includes only the significant structural elements with their dominant modes of behaviour. Achieving a simplified analysis of a large structure such as tall building is based on two major considerations: [4]

- *The relative importance of individual members contributing to the solution*
  This allows a member stiffness to be taken as infinity if the associated mode of behaviour is expected to yield a negligible deformation relative to that of other members in the structure. It also allows elements of the minor influence on the final results to be given a zero stiffness.

- *The relative importance of modes of behaviour of the entire structure*
  It is often possible to ignore the asymmetry in a structural floor plan of a building, thereby making a three dimensional analysis unnecessary.

The user of a computer program, be it a simple plane frame or a general finite element program, can usually assign any value to the properties of an element even if theses are inconsistent with the actual size of that member, e.g. it is quite acceptable for a structural element to be given true values for its flexural and shear stiffness, zero torsional stiffness and an infinite axial stiffness. Several simplifying assumptions are necessary for the analysis of tall building structures subjected to lateral loading. The following are the most commonly accepted assumptions. [4]

- All concrete members behave linearly and elastically so that loads and displacements are proportional and the principle of superposition applies. Because of its own weight the structure is subjected to a compressive prestress and pure tension in individual members is not likely to occur.

- Floor slabs are fully rigid in their own plane. Consequently, all vertical members at any level are subjected to the same components of translation and rotation in the horizontal plane. This does not hold for very long narrow buildings and for slabs which have their widths drastically reduced at one or more locations.
- Contributions from the out-of-plane stiffness of floor slabs and structure bents can be neglected.
- The individual torsional stiffness of beams, columns and planar walls can be neglected.
- Additional stiffness effects from masonry walls, fireproofing, cladding and other non-structural elements can be neglected.
- Deformations due to shear in slender structural members (length-to-width ratio larger than 5) can be neglected.
- Connections between structural elements in cast-*in-situ* buildings can be taken as rigid.
- Concrete structures are elastically stable.

2.4 STANDARD COMPUTER ANALYSIS AND APPLICATION

Computer applications are in daily use in essentially every branch of concrete engineering. These applications cover the principal design processes of analysis, proportioning and detailing, auxiliary activities such as preparation of design document (specification text, bar schedules, drawings, etc.), quantity takeoff and estimating, and many of the control functions associated with fabrication and construction. Finally, a large portion of analytical research in concrete behaviour and concrete structures involves extensive use of computers. [5]

The range of computers applications in concrete engineering is continuously expanding. New programs are being developed for problems whose solutions were inconceivable in the past, either because of the magnitude of the numerical calculations involved (e.g., the exact analysis of large, complex structures) or because of the logical complexity involved (e.g., the direct production of design drawings). [5]

Most standard computer programs are based on the matrix method of structural analysis. Commercially available interactive computer programs demand little more of the structural engineer then the keying in of specific structural data such as geometry, member sizes, material properties and loading. Some of these programs incorporate several different types of structural elements such as beams and truss elements. These are the so called general-finite-element programs. The size of the structure that can be analysed is dependent on the way that the program is structured and the type of computer used. For analysis of less complicated structures, a computer program incorporating the use of just one type of element, i.e. the beam element, will be sufficient. Many simple plane programs have published in engineering journals and can readily be used by anyone taking the time to enter the few hundreds lines of such a program. The writers of these programs have all chosen their own favourite way of entering data into the computer and so reference should be made to the respective program guidelines. [2]

2.5 STAAD PRO 2002

STAAD Pro is a widely used structural analysis and design software. The versatility of STAAD Pro makes it the choice of most leading engineering consultancies whilst the entry level version means that it is also the choice for smaller consultants as well. STAAD Pro features a user-friendly interface, visualisation tools, powerful analysis and design engines with advanced finite element and dynamic analysis capabilities. From model generation, analysis and design to visualisation and result verification, STAAD Pro is the choice for steel, concrete, timber, aluminium and cold-formed steel structures.

On the whole, the STAAD Pro software consists of the following:

The STAAD Pro Graphical User Interface (GUI): It is used to generate the model which can then be analysed using the STAAD engine. After analysis and design is completed, the GUI can also be used to view the results graphically.

The STAAD analysis and design engine: It is a general-purpose calculation engine for structural analysis and integrated Steel, Concrete, Timber and Aluminium design.

STAAD Pro has building codes for most countries including US, Britain, Canada, Australia, France, Germany, Spain, Norway, Finland, Sweden, India, China, Euro Zone, Japan, Denmark, and Holland. More buildings codes are constantly being added. STAAD Pro is fully COM (Component Object Model) compliant and is designed using an open architecture. Any third party or in-house application can be seamlessly integrated with STAAD Pro. STAAD Pro's user interface has the industry standard features too.

Complex models can be quickly and easily generated through powerful graphics, text and spreadsheet interfaces that provide true interactive model generation, editing, and analysis. STAAD Pro generates comprehensive custom reports for management, architects, owners, etc. STAAD Pro's reports contain only the information required by users, and the users can add their own logo as well as graphical input and output results. All data can be exported to Word, Excel or WordPerfect.

2.6 PROKON VERSION W1.1.02

Prokon is also one of the most prominent structural software in the engineering consultancies industry. Similarly to STAAD Pro, Prokon features a user-friendly interface, visualisation tools, powerful analysis and design engines with advanced finite element and dynamic analysis capabilities. Basically it is able to provide reliable solution to a wide range of structural and geotechnical engineering problems which include frame and finite element analysis, steel member and connection design, reinforced and prestressed concrete design, reinforced concrete detailing, timber member design and geotechnical analysis. Unlike the latest version of Prokon software, this version is not incorporated with modelling solution.

The following are the lists of the supported units of measurement as well as the design codes available for steel, concrete and timber design provided by the software.

Supported timber design codes:

- BS 5268 - 1991 (allowable stress design).
- SABS 0163 - 1989 (allowable stress design).

Supported units of measurement:

- Imperial.
- Metric.

Supported steel design codes:

- BS 5950 - 1990
- CSA S16.1 - M89
- Eurocode 3 - 1992
- SABS 0162 - 1984 (allowable stress design)
- SABS 0162 - 1993 (limit state design)

Supported concrete design codes:

- ACI 318 - 1994
- BS 8110 - 1997
- CSA A23.3 - 1994
- Eurocode 2 - 1992
- SABS 0100 - 1992

Calculation reports prepared in the Prokon system are totally customisable by the user. They include tables, diagrams and maps of results, plus any view of the structure. The report always keeps track of any changes made to the structural model, thereby ensuring that the calculations and results are always associated with the current structural model.

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 PROCEDURE IDENTIFICATION

The multistory building models were modelled as three dimensional structure (space analysis) using STAAD Pro software and as two dimensional structure (frame analysis) using Prokon software and manual calculation. In order to carry out this research systematically, the project work was divided into 5 steps which could be summarized as following:

Step 1: The application and functions of the selected software which include STAAD Pro 20002 and Prokon Version W1.1.02 were learned consecutively in order to be able to run the program smoothly.

Step 2: A few work examples which were available in the software manuals were tried out by using the respective software.

Step 3: The effectiveness of the software was verified by analysing and comparing the result output obtains from the different work examples using the two selected software and manual calculation.

Step 4: Columns were designed using the selected structural software and manual calculation. The amount of reinforcement required in the columns of the different structural models was determined. In this study, column sizes were remain constant throughout the entire modelling analysis. These fixed column sizes were determined using the manual calculation since it employed the most conventional design approaches.

Step 5: The result outputs were compared in order to validate the efficiency of the selected software in producing the most economical and feasible column design with respect to the manual calculation.

3.2 DESCRIPTION OF STRUCTURE MODEL

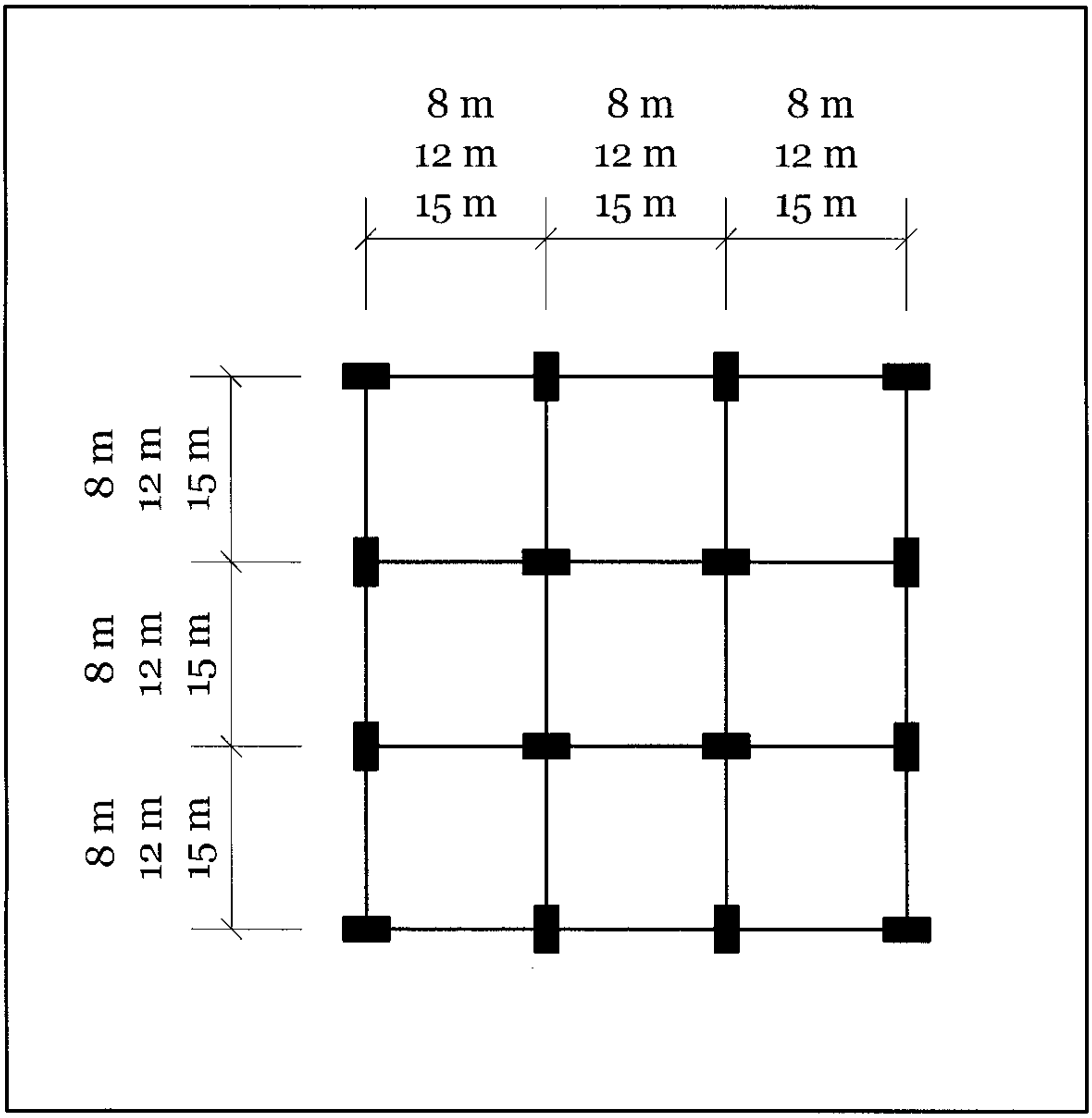

Figure 3.1: Typical floor framing and column layout plan

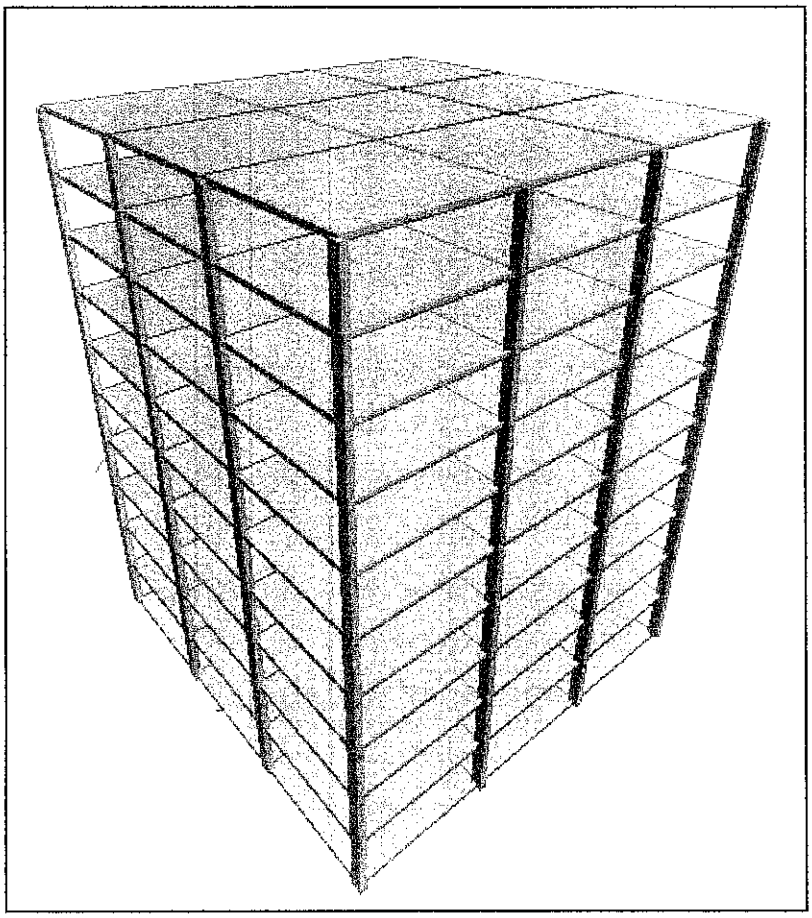

Figure 3.2: Paradigm of a three dimensional computer model

Figure 3.1 shows the typical floor framing and column layout plan of the multistory model. The shape of the external and internal columns would be rectangular. All columns were spaced 8 m, 12 m and 15 m apart according to the respective structure model. The height of the structure models also vary from 10 to 40 storeys tall with a common storey height of 3 m. A total of 12 different structure models were used to carry out this modelling analysis. Each structure model had a different combination of bay width and building height as specified.

Basically, the structure model consist no beams, as rigid slab was used. A uniformly thick, two-way flat plate was used as the floor system. Table 3.1 illustrates the specified flat plate thickness for the various combinations of bay width and building height of the structure models.

No. of stories	Bay sizes			Flat plate thickness (mm)
	8 m	12 m	15 m	
10	x			225
10		x		275
10			x	350
20	x			225
20		x		275
20			x	350
30	x			225
30		x		275
30			x	350
40	x			225
40		x		275
40			x	350

Table 3.1: Plate thickness for the various combinations of bay width and building height

Similar column sizes were used and they were extended up to 5 storeys before experienced any changes in dimension. The dimensions of the columns were gradually being reduced from the lowest 5 storeys to the topmost 5 storeys. Typically, as the structure model increase in height, all column dimensions were reduced accordingly as describe in Table 3.2.

No. of stories	10	20	30	40
Column size reduction for every additional of 5 storeys	50 mm	25 mm	25 mm	25 mm

Table 3.2: Reduction of column size for every additional of 5 storeys

3.3 DESIGN SPECIFICATION AND ASSUMPTIONS

The main dimension, structural features, loads, material, etc. are set out below.

3.3.1 Design Standards and Codes of Practices

The following codes of practices provide the general guide for column design of the structure models.

- Uniform Building Code (UBC 1994) – Design Wind Pressure
- BS 8110: Part 1: 1985: Structural Use of Concrete
- BS 8110: Part 3: 1985: Structural Use of Concrete

3.3.2 Material Properties

Reinforced concrete is used as the frame material for the structure models.

Concrete	Grade 40 (40 N/mm^2)
Reinforcement	Grade 460 (460 N/mm^2)

3.3.3 Base Support

All base supports of the structure models are fully fixed.

3.3.4 Fire Resistance

All columns are designed to have a fire resistance period of 2 hours.

3.3.5 Exposure Condition

All the columns are considered to have a mild exposure conditions.

3.3.6 Nominal Cover

All columns would have a nominal cover of 25 mm to all reinforcement based on the code.

3.3.7 Types of Occupancy

The multistory buildings are designed for office and residential purposes.

3.3.8 Structural Form

The type of structural form used in this modelling analysis is an unbraced rigid frame.

3.3.9 Dead Load and Imposed Load

Dead Load	Self-weights of the reinforced concrete columns and flat plate
Imposed Load	3.0 kN/m^2

3.3.10 Wind Load

The design wind pressure is computed based on UBC 1994 and subsequently used to calculate the wind load exerting at each level.

$$\text{Design wind pressure, } p = C_e\, C_q\, q_s\, I_w$$

Where,

C_e is the coefficient of gust factor

C_q is the coefficient of pressure

I_w is the building importance factor specified by UBC

q_s is the wind stagnation pressure in psf unit

The wind stagnation pressure, q_s is calculated using the following equation.

$$\text{Wind stagnation pressure, } q_s = 0.00256V^2$$

Where,

V is the basic wind speed in mph

In this case, the basic wind velocity is assumed to be 35 m/sec (78.29 mph). The building site is assumed to be located at the centre of large cities where over half the buildings have a height in excess of 70 ft which is approximately 21 m. Hence the site is classified as Exposure B. Besides that, office and residential buildings are typically assigned a Standard Occupancy of 1.00.

Basically the prevailing wind at the site is not being considered in calculating the wind forces exerting on the structures. However, the wind forces are assumed to be acting at each level as horizontal point load onto the structure in a single direction. The value for gust factor coefficient, C_e can be obtained from Appendix A whereas the value for pressure coefficient, C_p in the windward and leeward direction is taken as 0.8 and -0.5 respectively (refer to Appendix B). Consequently, the value for wind stagnation pressure, q_s is 15.69 psf.

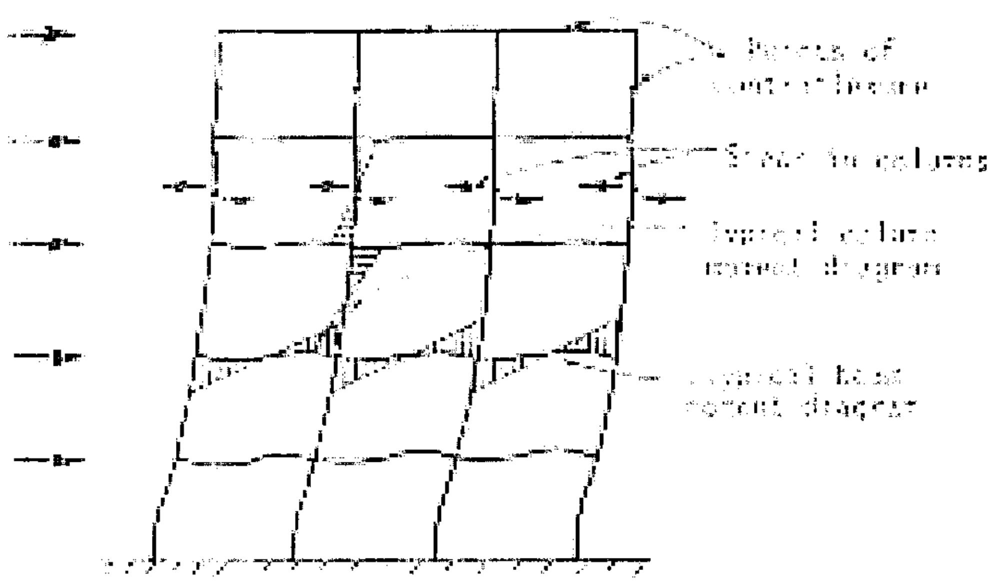

Figure 3.3: Forces and deformation caused by external shear

The column-end moment of the multistory building model is calculated using Portal Method. This analysis is based on the following assumptions:

- Horizontal loading on the frame causes double curvature bending of all the columns and girders, with points of contraflexure at the mid height of columns and mid span of the girders as shown in Figure 3.3.
- The horizontal shear at mid storey levels is shared between the columns in proportion to width of aisle each column supports.

The results of the wind load calculation and maximum column-end moment for each structure model are displayed in Table 3.3, 3.4, 3.5 and 3.6 respectively.

Floor level	C_e	8 m		12 m		15 m	
		Wind Load per level (kN)	**Max. col. moment (kNm)**	**Wind load per level (kN)**	**Max. col. moment (kNm)**	**Wind load per level (kN)**	**Max. col. moment (kNm)**
10	1.12	13.13	6.57	19.69	14.77	24.61	23.07
9	1.08	25.78	19.46	38.67	43.77	48.34	68.39
8	1.03	24.73	31.82	37.09	71.59	46.36	111.85
7	0.99	23.67	43.66	35.51	98.22	44.39	153.47
6	0.94	22.62	54.97	33.93	123.67	42.41	193.23
5	0.89	21.45	65.69	32.17	147.80	40.21	230.93
4	0.83	20.16	75.77	30.24	170.48	37.79	266.35
3	0.76	18.63	85.09	27.95	191.44	34.94	299.11
2	0.67	16.76	93.47	25.14	210.29	31.42	328.57
1	0.62	15.12	101.03	22.68	227.30	28.35	355.14

Table 3.3: Results of the wind load calculation and maximum column-end moment for a 10 storeys building

Floor level	C_e	8 m		12 m		15 m	
		Wind load per level (kN)	Max. col. moment (kNm)	Wind load per level (kN)	Max. col. moment (kNm)	Wind load per level (kN)	Max. col. moment (kNm)
20	1.41	16.52	8.26	24.79	18.59	30.98	29.04
19	1.38	32.70	24.61	49.05	55.38	61.31	86.52
18	1.36	32.11	40.67	48.17	91.51	60.21	142.97
17	1.33	31.52	56.43	47.29	126.98	59.11	198.38
16	1.30	30.82	71.84	46.23	161.65	57.79	252.56
15	1.28	30.24	86.96	45.35	195.66	56.69	305.71
14	1.25	29.65	101.78	44.47	229.01	55.59	357.83
13	1.22	28.95	116.26	43.42	261.58	54.28	408.71
12	1.19	28.24	130.38	42.37	293.36	52.96	458.36
11	1.16	27.54	144.15	41.31	324.34	51.64	506.78
10	1.12	26.72	157.51	40.08	354.40	50.10	553.74
9	1.08	25.78	170.40	38.67	383.40	48.34	599.06
8	1.03	24.73	182.76	37.09	411.22	46.36	642.53
7	0.99	23.67	194.60	35.51	437.85	44.39	684.14
6	0.94	22.62	205.91	33.93	463.30	42.41	723.90
5	0.89	21.45	216.63	32.17	487.43	40.21	761.60
4	0.83	20.16	226.71	30.24	510.11	37.79	797.03
3	0.76	18.63	236.03	27.95	531.07	34.94	829.78
2	0.67	16.76	244.41	25.14	549.92	31.42	859.24
1	0.62	15.12	251.97	22.68	566.93	28.35	885.82

Table 3.4: Results of the wind load calculation and maximum column-end moment for a 20 storeys building

Floor level	C_e	8 m		12 m		15 m	
		Wind load per level (kN)	**Max. col. moment (kNm)**	**Wind load per level (kN)**	**Max. col. moment (kNm)**	**Wind load per level (kN)**	**Max. col. moment (kNm)**
30	1.62	18.99	9.50	28.48	21.36	35.60	33.38
29	1.60	37.74	28.37	56.60	63.81	70.76	99.71
28	1.58	37.27	47.00	55.90	105.74	69.88	165.23
27	1.56	36.80	65.40	55.20	147.14	69.00	229.91
26	1.54	36.33	83.57	54.49	188.00	68.12	293.78
25	1.52	35.86	101.50	53.79	228.35	67.24	356.81
24	1.50	35.39	119.19	53.09	268.16	66.36	419.03
23	1.48	34.92	136.65	52.39	307.46	65.48	480.41
22	1.45	34.34	153.82	51.51	346.09	64.38	540.77
21	1.43	33.75	170.70	50.63	384.06	63.28	600.09
20	1.41	33.28	187.34	49.92	421.50	62.41	658.60
19	1.38	32.70	203.69	49.05	458.29	61.31	716.08
18	1.36	32.11	219.74	48.17	494.42	60.21	772.53
17	1.33	31.52	235.50	47.29	529.88	59.11	827.94
16	1.30	30.82	250.91	46.23	564.56	57.79	882.12
15	1.28	30.24	266.03	45.35	598.57	56.69	935.27
14	1.25	29.65	280.86	44.47	631.92	55.59	987.38
13	1.22	28.95	295.33	43.42	664.49	54.28	1038.27
12	1.19	28.24	309.45	42.37	696.26	52.96	1087.92
11	1.16	27.54	323.22	41.31	727.25	51.64	1136.33
10	1.12	26.72	336.58	40.08	757.31	50.10	1183.30
9	1.08	25.78	349.47	38.67	786.31	48.34	1228.62
8	1.03	24.73	361.84	37.09	814.13	46.36	1272.08
7	0.99	23.67	373.67	35.51	840.76	44.39	1313.70
6	0.94	22.62	384.98	33.93	866.21	42.41	1353.46
5	0.89	21.45	395.71	32.17	890.33	40.21	1391.16
4	0.83	20.16	405.79	30.24	913.01	37.79	1426.58
3	0.76	18.63	415.10	27.95	933.98	34.94	1459.34
2	0.67	16.76	423.48	25.14	952.83	31.42	1488.80
1	0.62	15.12	431.04	22.68	969.84	28.35	1515.38

Table 3.5: Results of the wind load calculation and maximum column-end moment for a 30 storeys building

Floor level	C_e	8 m		12 m		15 m	
		Wind load per level (kN)	**Max. col. moment (kNm)**	**Wind load per level (kN)**	**Max. col. moment (kNm)**	**Wind load per level (kN)**	**Max. col. moment (kNm)**
40	1.79	20.98	10.49	31.47	23.60	39.33	36.87
39	1.77	41.72	31.35	62.58	70.54	78.23	110.21
38	1.76	41.37	52.04	62.05	117.08	77.57	182.93
37	1.74	41.02	72.55	61.53	163.22	76.91	255.04
36	1.72	40.55	92.82	60.82	208.84	76.03	326.32
35	1.71	40.20	112.92	60.30	254.06	75.37	396.98
34	1.69	39.85	132.85	59.77	298.89	74.71	467.02
33	1.67	39.38	152.54	59.07	343.19	73.83	536.23
32	1.66	39.03	172.05	58.54	387.10	73.17	604.83
31	1.64	38.67	191.39	58.01	430.61	72.51	672.81
30	1.62	38.20	210.49	57.31	473.59	71.63	739.96
29	1.60	37.74	229.36	56.60	516.04	70.76	806.30
28	1.58	37.27	247.99	55.90	557.96	69.88	871.81
27	1.56	36.80	266.39	55.20	599.36	69.00	936.50
26	1.54	36.33	284.56	54.49	640.23	68.12	1000.36
25	1.52	35.86	302.49	53.79	680.57	67.24	1063.40
24	1.50	35.39	320.18	53.09	720.39	66.36	1125.61
23	1.48	34.92	337.64	52.39	759.68	65.48	1187.00
22	1.45	34.34	354.81	51.51	798.32	64.38	1247.35
21	1.43	33.75	371.69	50.63	836.29	63.28	1306.68
20	1.41	33.28	388.33	49.92	873.73	62.41	1365.19
19	1.38	32.70	404.68	49.05	910.52	61.31	1422.67
18	1.36	32.11	420.73	48.17	946.64	60.21	1479.11
17	1.33	31.52	436.49	47.29	982.11	59.11	1534.53
16	1.30	30.82	451.90	46.23	1016.78	57.79	1588.71
15	1.28	30.24	467.02	45.35	1050.80	56.69	1641.85
14	1.25	29.65	481.85	44.47	1084.15	55.59	1693.97
13	1.22	28.95	496.32	43.42	1116.71	54.28	1744.86
12	1.19	28.24	510.44	42.37	1148.49	52.96	1794.51
11	1.16	27.54	524.21	41.31	1179.47	51.64	1842.92
10	1.12	26.72	537.57	40.08	1209.53	50.10	1889.89
9	1.08	25.78	550.46	38.67	1238.54	48.34	1935.21
8	1.03	24.73	562.83	37.09	1266.35	46.36	1978.67
7	0.99	23.67	574.66	35.51	1292.99	44.39	2020.28
6	0.94	22.62	585.97	33.93	1318.43	42.41	2060.04
5	0.89	21.45	596.70	32.17	1342.56	40.21	2097.74
4	0.83	20.16	606.78	30.24	1365.24	37.79	2133.17
3	0.76	18.63	616.09	27.95	1386.20	34.94	2165.93
2	0.67	16.76	624.47	25.14	1405.06	31.42	2195.38
1	0.62	15.12	632.03	22.68	1422.07	28.35	2221.96

Table 3.6: Results of the wind load calculation and maximum column-end moment for a 40 storeys building

3.3.11 Load Combination

The following load combination for the ultimate limit state is applied in the column design of the structure models.

1.2 (Dead Load + Imposed Load + Wind Load)

In general, all columns are designed according to the ultimate limit state and those that are subjected to the maximum axial load and moment about the critical axis.

3.3.12 Minimum Percentage of Reinforcement

The minimum area of reinforcement for grade 460 should not be less than 4 % of the gross cross-sectional area of the column.

3.3.13 Maximum Percentage of Reinforcement

The maximum area of reinforcement should not exceed 6 % of the gross cross-sectional area of the vertically cast column.

3.4 TOOLS REQUIRED

The software which was used in this final year project includes Prokon Version W1.1.02 and STAAD Pro 2002.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 RESULTS

Table 4.1, 4.2, 4.3 and 4.4 illustrate the amount of reinforcement required in the columns of the multistory building modelled by STAAD Pro 2002 and Prokon Version W1.1.02 software. The results of the manual calculation are also being included in the tables. The 'N.A.' abbreviation in Table 4.4 denotes that there is no result output being generated by the corresponding software. This signifies that the Prokon software is unable to generate any results for the assigned column dimension due to the limitation of the program. This constraint is further discussed in the following section.

Storey	Bay Size											
	8 m				12 m				15 m			
	Column	% of reinforcement, A_{sc}			Column	% of reinforcement, A_{sc}			Column	% of reinforcement, A_{sc}		
	Size	Staad Pro	Prokon	Manual	Size	Staad Pro	Prokon	Manual	Size	Staad Pro	Prokon	Manual
6 - 10	300 x 550	[redacted]	[redacted]	1.40	550 x 750	[redacted]	[redacted]	1.00	650 x 1350	[redacted]	[redacted]	0.40
1 - 5	350 x 600	[redacted]	[redacted]	4.44	600 x 800	[redacted]	[redacted]	4.90	700 x 1400	[redacted]	[redacted]	4.20

Table 4.1: Amount of reinforcement required in the columns of a 10 storeys building with different bay width

Storey	Bay Size											
	8 m				12 m				15 m			
	Column	% of reinforcement, A_{sc}			Column	% of reinforcement, A_{sc}			Column	% of reinforcement, A_{sc}		
	Size	Staad Pro	Prokon	Manual	Size	Staad Pro	Prokon	Manual	Size	Staad Pro	Prokon	Manual
16 - 20	375 x 725	[redacted]	[redacted]	0.40	625 x 1325	[redacted]	[redacted]	0.40	825 x 1725	[redacted]	[redacted]	0.40
11 - 15	400 x 750	[redacted]	[redacted]	2.06	650 x 1350	[redacted]	[redacted]	0.76	850 x 1750	[redacted]	[redacted]	1.13
6 - 10	425 x 775	[redacted]	[redacted]	4.31	675 x 1375	[redacted]	[redacted]	3.00	875 x 1775	[redacted]	[redacted]	3.63
1 - 5	450 x 800	[redacted]	[redacted]	5.63	700 x 1400	[redacted]	[redacted]	4.94	900 x 1800	[redacted]	[redacted]	5.81

Table 4.2: Amount of reinforcement required in the columns of a 20 storeys building with different bay width

Storey	Bay Size											
	8 m				12 m				15 m			
	Column Size	% of reinforcement, A_{sc} Staad Pro	Prokon	Manual	Column Size	% of reinforcement, A_{sc} Staad Pro	Prokon	Manual	Column Size	% of reinforcement, A_{sc} Staad Pro	Prokon	Manual
26 - 30	475 x 775	[redacted]	[redacted]	**0.40**	775 x 1675	[redacted]	[redacted]	**0.40**	975 x 2175	[redacted]	[redacted]	**0.40**
21 - 25	500 x 800	[redacted]	[redacted]	**0.40**	800 x 1700	[redacted]	[redacted]	**0.40**	1000 x 2200	[redacted]	[redacted]	**0.40**
16 - 20	525 x 825	[redacted]	[redacted]	**2.19**	825 x 1725	[redacted]	[redacted]	**0.46**	1025 x 2225	[redacted]	[redacted]	**1.13**
11 - 15	550 x 850	[redacted]	[redacted]	**3.63**	850 x 1750	[redacted]	[redacted]	**1.88**	1050 x 2250	[redacted]	[redacted]	**2.75**
6 - 10	575 x 875	[redacted]	[redacted]	**4.94**	875 x 1775	[redacted]	[redacted]	**3.13**	1075 x 2275	[redacted]	[redacted]	**4.19**
1 - 5	600 x 900	[redacted]	[redacted]	**6.00**	900 x 1800	[redacted]	[redacted]	**4.25**	1100 x 2300	[redacted]	[redacted]	**5.56**

Table 4.3: Amount of reinforcement required in the columns of a 30 storeys building with different bay width

Storey	Bay Size											
	8 m				12 m				15 m			
	Column Size	% of reinforcement, A_{sc} Staad Pro	Prokon	Manual	Column Size	% of reinforcement, A_{sc} Staad Pro	Prokon	Manual	Column Size	% of reinforcement, A_{sc} Staad Pro	Prokon	Manual
36 - 40	625 x 825	[redacted]	[redacted]	**0.40**	825 x 1725	[redacted]	[redacted]	**0.40**	925 x 3025	[redacted]	[redacted]	**0.40**
31 - 35	650 x 850	[redacted]	[redacted]	**0.40**	850 x 1750	[redacted]	[redacted]	**0.40**	950 x 3050	[redacted]	[redacted]	**0.40**
26 - 30	675 x 875	[redacted]	[redacted]	**0.40**	875 x 1775	[redacted]	[redacted]	**0.40**	975 x 3075	[redacted]	[redacted]	**0.40**
21 - 25	700 x 900	[redacted]	[redacted]	**1.63**	900 x 1800	[redacted]	[redacted]	**1.44**	1000 x 3100	[redacted]	[redacted]	**1.13**
16 - 20	725 x 925	[redacted]	[redacted]	**2.69**	925 x 1825	[redacted]	[redacted]	**2.63**	1025 x 3125	[redacted]	[redacted]	**2.38**
11 - 15	750 x 950	[redacted]	[redacted]	**3.57**	950 x 1850	[redacted]	[redacted]	**3.69**	1050 x 3150	[redacted]	[redacted]	**3.50**
6 - 10	775 x 975	[redacted]	[redacted]	**4.38**	975 x 1875	[redacted]	[redacted]	**4.69**	1075 x 3175	[redacted]	[redacted]	**4.50**
1 - 5	800 x 1000	[redacted]	[redacted]	**5.06**	1000 x 1900	[redacted]	[redacted]	**5.57**	1100 x 3200	[redacted]	[redacted]	**5.50**

Table 4.4: Amount of reinforcement required in the columns of a 40 storeys building with different bay width

4.2 DISCUSSION

Theoretically, larger column size or higher amount of reinforcement or both are required as the height and floor span of a building increase. This statement is clearly being exemplified by the result output displayed in the preceding tables.

On the whole, columns designed by STAAD Pro 2002 required the least amount of reinforcement followed by the manual calculation and Prokon Version W1.1.02 disregard the building height and bay width. There is also a large deviation in the result outputs produced by Prokon software as compare to the result outputs produced by STAAD Pro software and manual calculation. This deviation is even more apparent as the height of the building increases as refer to Figure 4.4, 4.5 and 4.6. Basically, the deviation is greater towards the base of the building or at lower floor columns according to Figure 4.1, 4.2 and 4.3. In general, the deviation between the result output produced by Prokon software and hand calculation method is the most significant and noticeable.

Typically, lower floor columns experience drastic increment in the required amount of reinforcement as the building height increases especially those columns that are design by Prokon software. However, there are also only slight deviations among the result output for higher floor columns. The amount of reinforcement required in the columns seems to be reducing in an almost exponential like manner as the height of the building increase. For instance, the 15 topmost floor columns acquire almost similar result outputs as refer to Figure 4.1, 4.2 and 4.3.

The following Figure 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 displayed some of the result outputs in graphical form for different structure models.

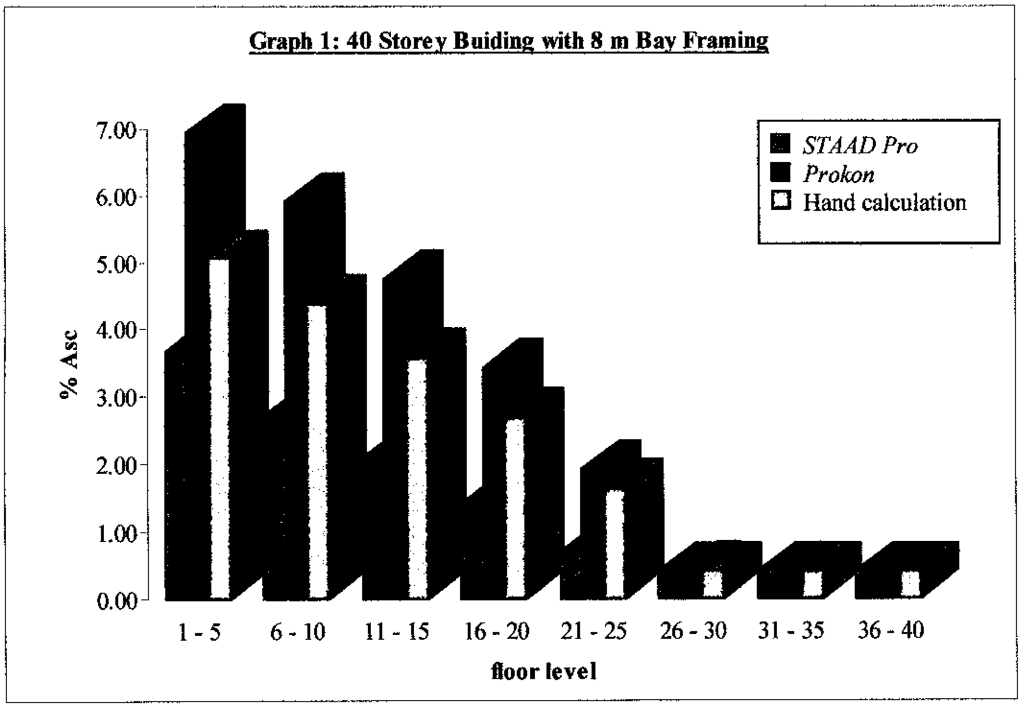

Figure 4.1: Graph showing the amount of reinforcement required in the columns of a 40 storeys building with 8 m bay width

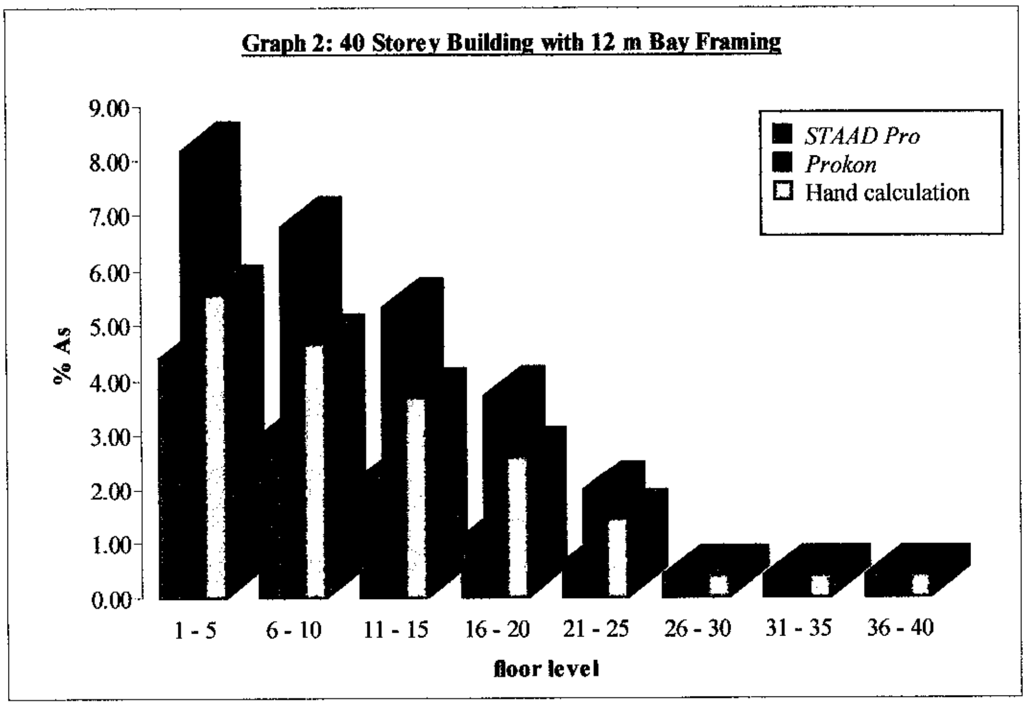

Figure 4.2: Graph showing the amount of reinforcement required in the columns of a 40 storeys building with 12 m bay width

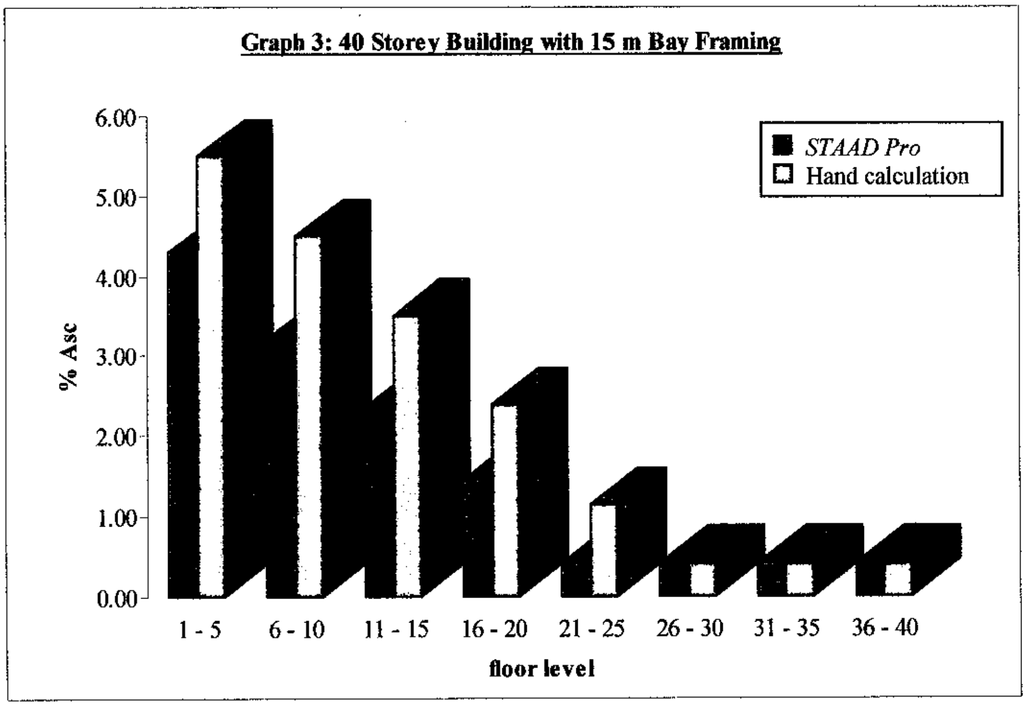

Figure 4.3: Graph showing the amount of reinforcement required in the columns of a 40 storeys building with 15 m bay width

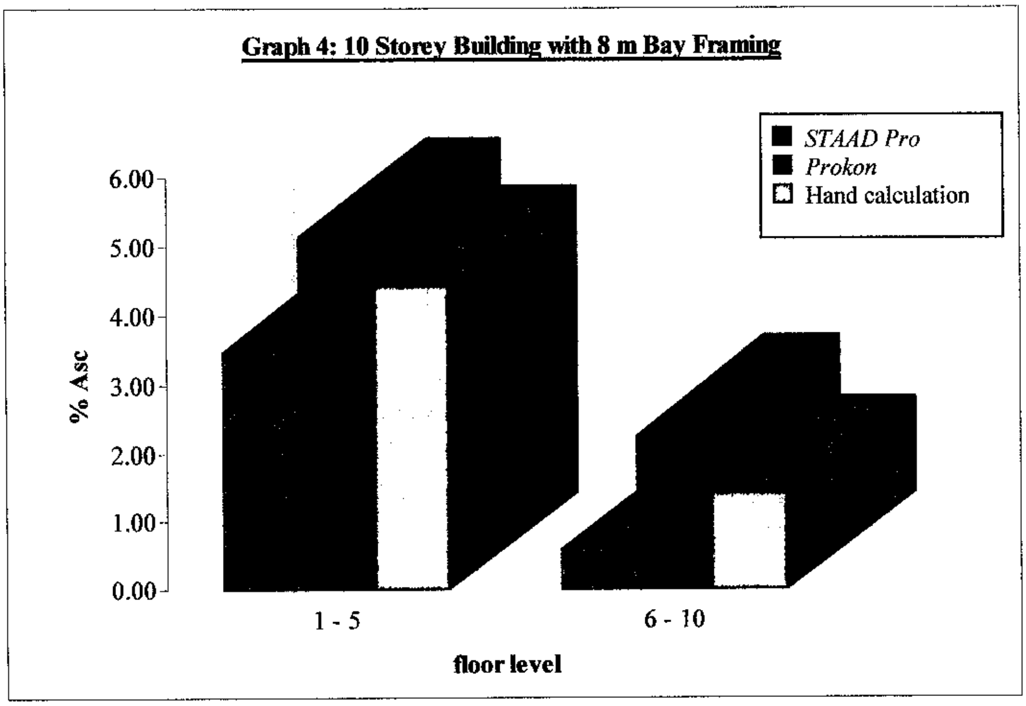

Figure 4.4: Graph showing the amount of reinforcement required in the columns of a 10 storeys building with 8 m bay width

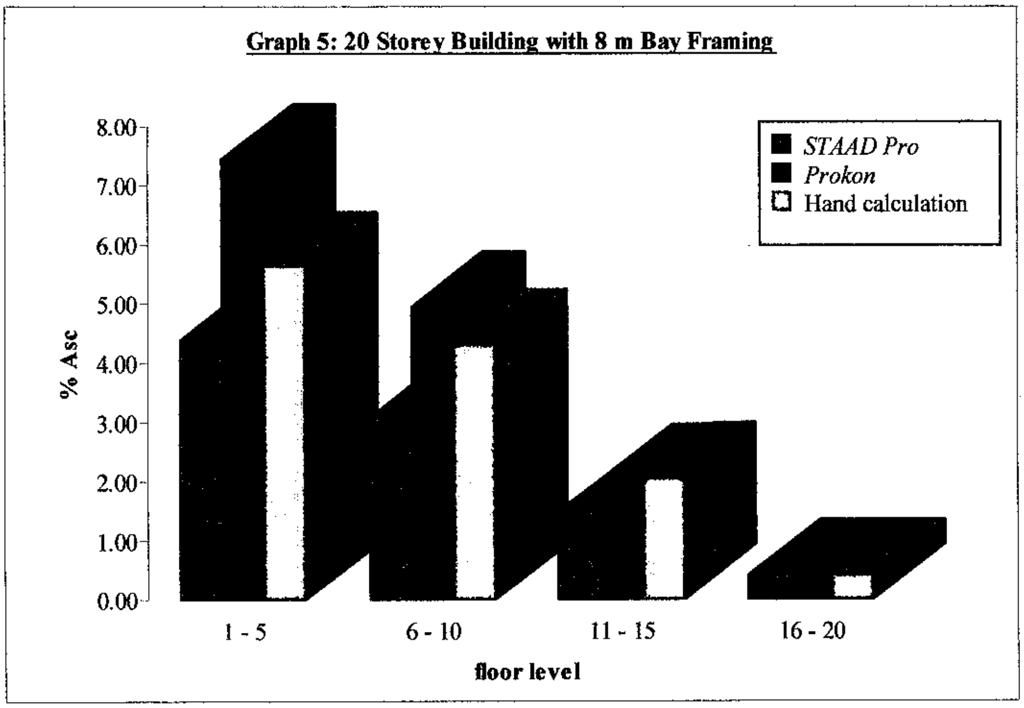

Figure 4.5: Graph showing the amount of reinforcement required in the columns of a 20 storeys building with 8 m bay width

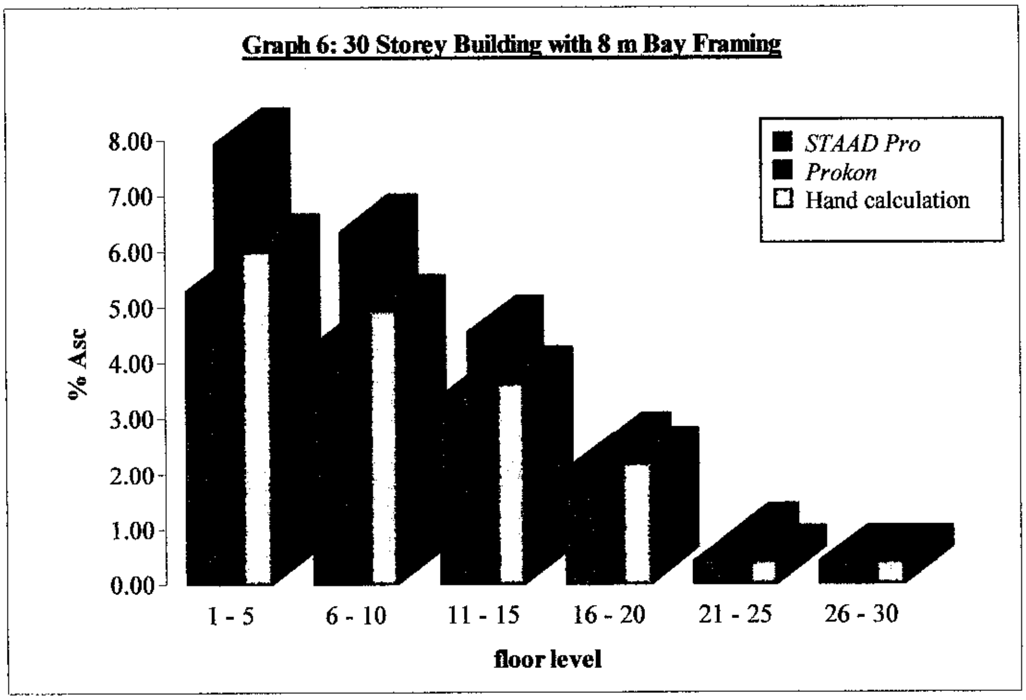

Figure 4.6: Graph showing the amount of reinforcement required in the columns of a 30 storeys building with 8 m bay width

Figure 4.7, 4.8, 4.9 and 4.10 show the amount of reinforcement required in the lowest 5 storeys columns in graphical form. Based on the pie charts, Prokon software produced rather heavy column design as compared to the STAAD Pro software and manual calculation in the lowest 5 storeys columns. Since the columns are being design as a module by the Prokon software, there is a high tendency that some of the columns especially the lower floor columns will be subjected to enormous amount of loading as a result of load accumulation from each storey.

Besides that, Prokon software does not provide any stress redistribution feature in the program since the columns are being design as a module. Subsequently, this will cause some of the columns to be overstressed and thus, higher amount of reinforcement is required in those columns. In actual fact, redistribution of stresses and moment is a common practice in the design of tall building. This can be done if the building is being modelled as a complete three dimensional structure. Structural software that is developed for tall building purposes are normally incorporated with stress redistribution feature and other advanced functions to suit the purposes. Hence, the design of tall building should be carried out by using more advanced and sophisticated software such as STAAD Pro, E-Tabs, or a newer version of Prokon software such as Prokon Version 2.1, which provide modelling solution, in order to achieve the desire objective of this project. Normally, these advance structural software obtain a pretty complex program layout as compare to the Prokon Version W1.1.02.

The overstressing of column is also depend on the correctness of the load taking method since Prokon software does not automatically compute the overall design load for each column design. Hence, the overall design load and moment need to be hand calculated and manually included in the program. Simplified calculations are usually being adopted in the manual load taking method and it is always a very conservative approach in order to encounter for the most unfavourable structure conditions. Hence the final design load applied to each column will normally be quite high and subsequently lead to heavier column design.

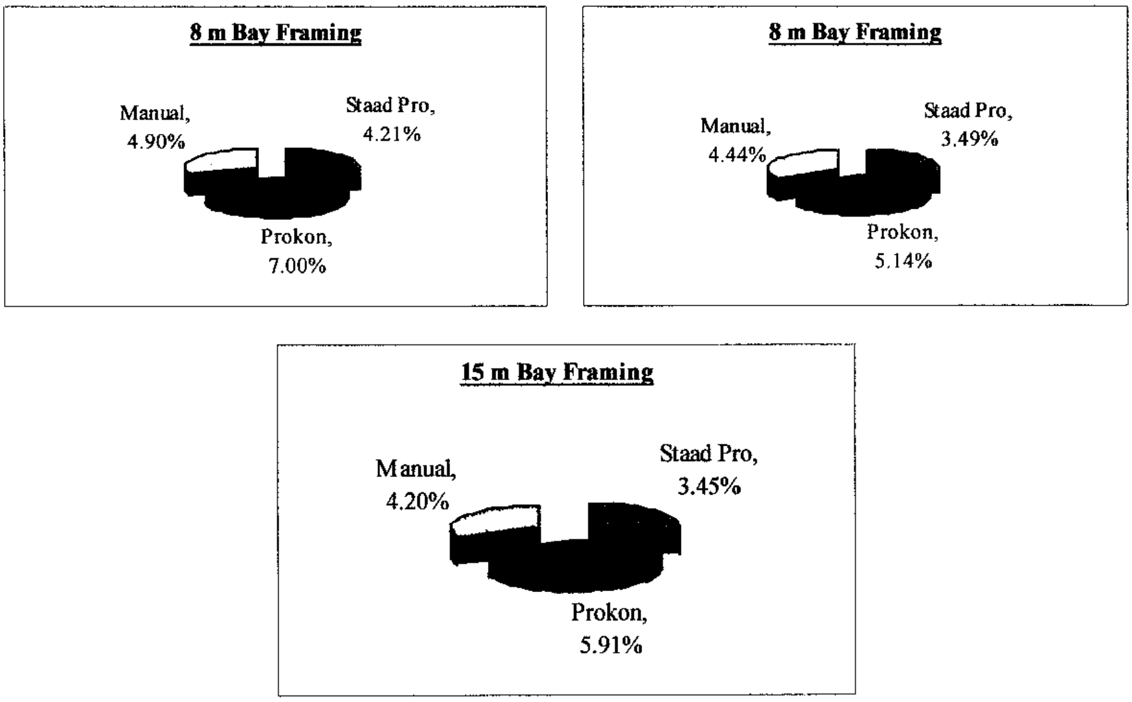

Figure 4.7: Pie charts showing the amount of reinforcement required in the lowest 5 storeys columns for a 10 storeys building with different bay width

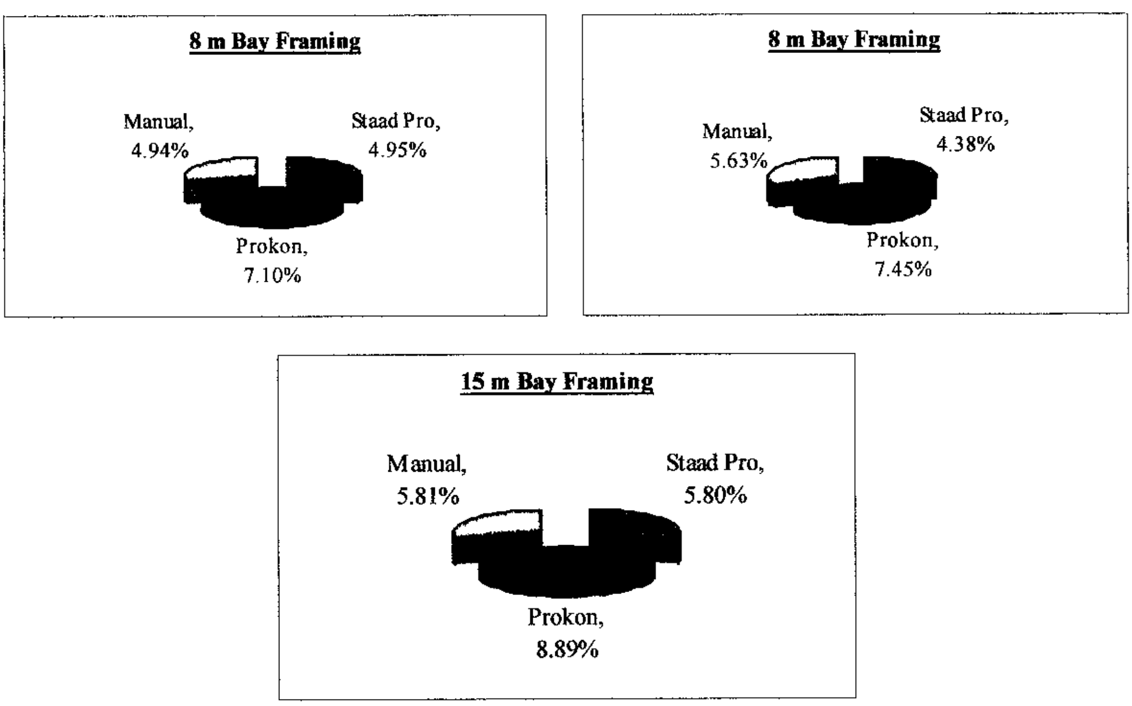

Figure 4.8: Pie charts showing the amount of reinforcement required in the lowest 5 storeys columns for a 20 storeys building with different bay width

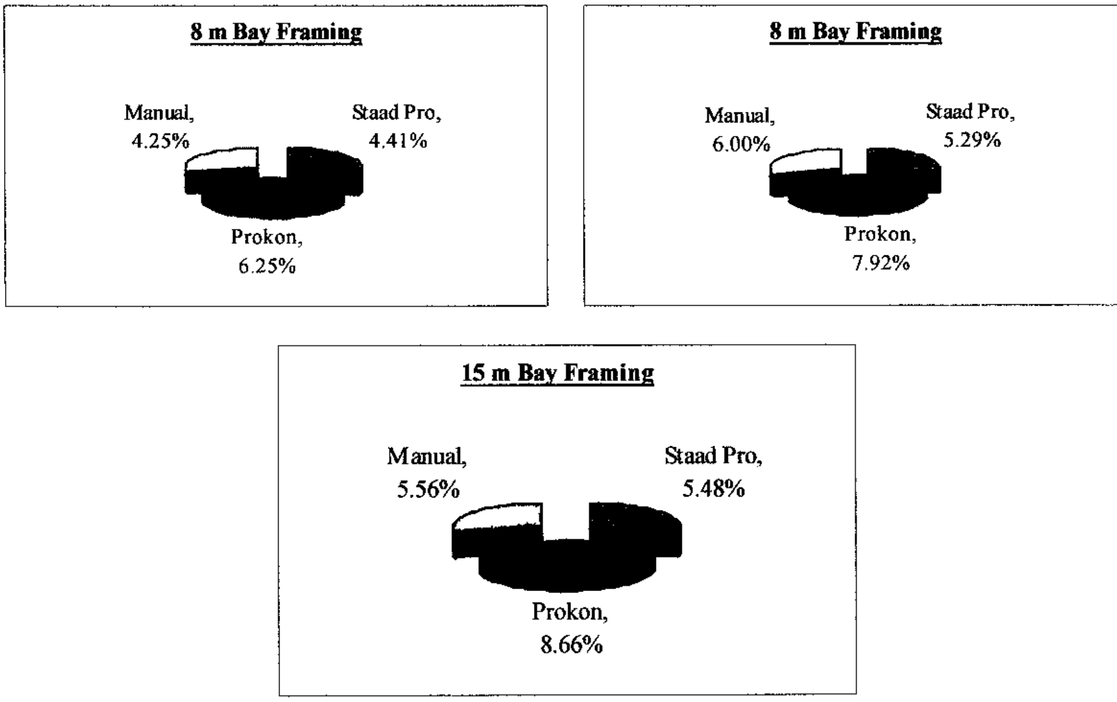

Figure 4.9: Pie charts showing the amount of reinforcement required in the lowest 5 storeys columns for a 30 storeys building with different bay width

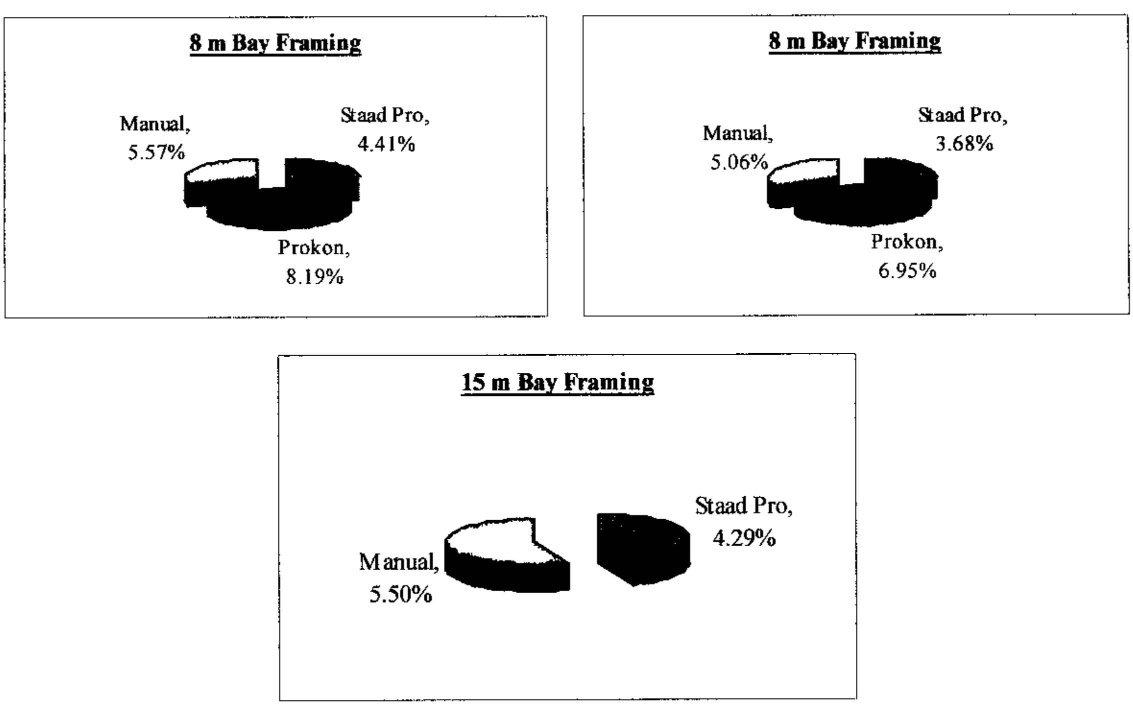

Figure 4.10: Pie charts showing the amount of reinforcement required in the lowest 5 storeys columns for a 40 storeys building with different bay width

Based on the results and the above discussion, STAAD Pro software proved to be more superior to Prokon software in term of producing a more economical and feasible column design for multistory building. This is mainly due to the ability of STAAD Pro software to model the entire building as three dimensional structure which offers a greater advantage in certain aspects. Basically loads and stresses are being equally distributed throughout the entire three dimensional structure, thus reducing the likelihood of overstressing among the columns. Subsequently, this would lead to a more economical column design without neglecting the safety concern.

4.3 COMPARISON OF THE DIFFERENT STRUCTURAL SOFTWARE

4.3.1 Differences of the Structural Software

On the whole, STAAD Pro 2002 is more suitable for tall building modelling as compare to Prokon Version W1.1.02. Prokon software is commonly recommended as useful in column design for structures up to 10 storeys only. Moreover STAAD Pro software allows the entire building to be modelled either as three dimensional structure or two dimensional structure. On the contrary, Prokon software only allows a module of the entire structure to be modelled at any instant. Basically the result output would be different depending whether the structures are modelled as three dimensional, two dimensional or as a module. This is because each design mode would exhibit different structural behaviour with respect to the applied loads.

Besides that, any rectangular column dimensions are acceptable by the STAAD Pro software whereas Prokon software only allow rectangular column dimensions of which the ratio of the larger to the smaller does not exceed 1:4. Hence, this has become the main constraint that causes the program to be unable of generating any results for the assigned column dimension as shown in Table 4.4.

Basically, the overall design load is automatically computed by the STAAD Pro software according to the load condition that is being inserted. Unlike STAAD Pro software, the overall design load and moment need to be hand calculated and manually included in the Prokon program. This will eventually lead to over-design or under-design since it largely depends on the correctness and accuracy of the manual load taking methods. Furthermore, all entered loads should be factored as ultimate loads since the program does not include any partial factors of safety into it. The program also does not automatically include the self-weight of the column. Thus, the self-weight should be calculated and manually included into the applied loads as well.

Although STAAD Pro 2002 is more superior to Prokon Version W1.1.02 in terms of efficiency and economy, Prokon software generally requires less amount of time to execute a design project. This is mainly due to the less sophisticated and complexity of the program when weigh against STAAD Pro software. Unlike STAAD Pro software, Prokon software is capable of generating structural detailing drawing which can be further improved into a construction drawing with detail editing. For example, adding bars and construction notes to the drawing.

4.3.2 Similarities of the Structural Software

In general, both programs have employed the finite element analysis as a practical solution for all structural analysis and design problem. Besides that, both software also capable of preparing calculation reports which are totally customisable by the user. They include tables, diagrams and maps of results, plus any view of the structure. The report always keeps track of any changes made to the structural model, thereby ensuring that the calculations and results are always associated with the current structural model.

4.3.3 Limitation of the Structural Software

All structural software has limitation in certain aspects. Both the STAAD Pro 2002 and Prokon Version W1.1.02 have a certain degree of limitation in reinforced concrete design. For instance, the properties of the structural members especially the dimensions need to be clearly defined. Unlike reinforced concrete design, both programs are capable of generating the most optimum member's cross section without having to define the member's dimension in steel design.

Basically, trial and error is the only method that can be used in order to achieve optimisation in reinforced concrete design. Consequently, this has created a significant drawback in reinforced concrete design for both programs. For instance, both programs are unable to perform under the condition that requires them to produce the most optimum column sizes at maximum percentage (6%) of steel reinforcement.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The conclusion of this research is:

1. STAAD Pro 2002 is more superior to Prokon Version W1.1.02 in term of producing a viable column design especially for structures up to 40 storeys. Hence, Prokon software is commonly recommended as useful in column design for structures up to 10 storeys only.

2. The design of rectangular column for Prokon software is constraint by the column dimension of which the larger column dimension must not exceed four times the smaller dimension.

3. There is also a tendency for over-design or under-design to occur in the used of Prokon software since the program does not automatically compute the design loads which mainly depends on the accuracy and correctness of the manual load taking method.

4. STAAD Pro 2002 is a more advance program in terms of tall building modelling as many limitations are encountered in using Prokon Version W1.1.02.

5. Although every effort has been made to ensure the correctness of both programs, any mistake, error or misrepresentation in or as a result of the usage of the programs is able to cause a great problem to the design output. Hence, superfluous attentions are required in order to ensure the correctness as well as the accurateness of the data input.

5.2 RECOMMENDATION

The recommendations derived from this project include:

- The investigation should be done using more variety of software in order to further validate the accuracy of the results output.
- Instead of self learning, student should be taught or given brief description on the application and function of the available structural software in order to avoid unnecessary waste of time or misinterpretation of the program.
- Civil engineering students of UTP should be exposed to structural software at earlier stage with the intention that students will be more prepared for their future final year projects as well as for future working purposes.

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[9] <http://www.staadpro.co.uk>

[10] <http://www.prokon.com>

[11] STAAD Pro 2002: American Examples Manual

[12] STAAD Pro 2002: Technical References Manual

APPENDICES

APPENDIX A: Combined Height, Exposure and Gust Factor Coefficient, C_e* (UBC 1994)

Height Above Average Level of Adjoining Ground (feet) x 304.8 for mm	Exposure D	Exposure C	Exposure B
0 - 15	1.39	1.06	0.62
20	1.45	1.13	0.67
25	1.50	1.19	0.72
30	1.54	1.23	0.76
40	1.62	1.31	0.84
60	1.73	1.43	0.95
80	1.81	1.53	1.04
100	1.88	1.61	1.13
120	1.93	1.67	1.20
160	2.02	1.79	1.31
200	2.10	1.87	1.42
300	2.23	2.05	1.63
400	2.34	2.19	1.80

**Values for intermediate heights above 15 feet (4572 mm) may be interpolated.*

APPENDIX B: Pressure Coefficient, C_q for Primary Frames and systems (UBC 1994)

Description	C_q
Method 1 (Normal force method)	
Walls:	
Windward wall	0.8 inward
Leeward wall	0.5 outward
Roofs:	
Wind perpendicular to ridge	
Leeward roof or flat roof	0.7 outward
Windward roof	
Less than 2:12 (16.7%)	0.7 outward
Slope 2:12 (16.7%) to less than 9:12 (75%)	0.9 outward or 0.3 inward
Slope 9:12 (75%) to 12:12 (100%)	0.4 inward
Slope > 12:12 (100%)	0.7 inward
Wind parallel to ridge and flat roofs	0.7 outward
Method 2 (Project area method)	1.3 horizontal any direction
On vertical projected area	
Structures 40 feet (12192 mm) or less in height	1.3 horizontal any direction
Structures over 40 feet (12,192mm) in height	
On horizontal projected area	0.7 upward

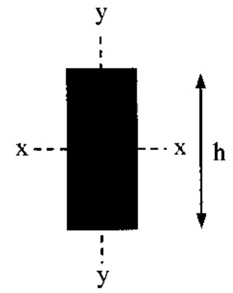
APPENDIX C:

Example of Unbraced Slender Design Spreadsheet Developed for Manual Calculation

Project	: Comparison of Different Structural Software for Mulitstory Building Design in Terms of Concrete Columns Reinforcement	Date :	6/Jun/2005
		Designed by :	CKT
		Checked by :	

Reference	Calculation	Output

Column width, b = 350 mm
Column height, h = 600 mm
Flat plate thickness = 225 mm
Original column height, l = 3000 mm
End condition for top = 2 } β = 1.3
End condition for bottom = 1 }
Clear column height, l_o = 2775 mm
Effective length, l_e = 3608 mm



Slenderness ratio:

$\frac{l_{ex}}{h} = \frac{3608}{600} = 6.01 \quad < 10$

$\frac{l_{ey}}{b} = \frac{3608}{350} = 10.31 \quad > 10$

Thus, the column is considered as slender with respect to both axes

Provisions for slender columns:

$\frac{h}{b} = \frac{600}{350} = 1.71 \quad < 3$

$\frac{l_{ex}}{h} = \frac{3608}{600} = 6.01 \quad < 20$

$\frac{l_{ey}}{b} = \frac{3608}{350} = 10.31 \quad < 20$

Thus, the slender column will bent about a single axis

Column Load Take-Down (Approximate Method)

Width of aisle each column supports, l_a = 8 m
Flat plate thickness, thk = 0.225 m
No.of storey considered, n = 10 m

Dead load at each floor, DL = $24 \times l_a^2 \times thk$
= 24 x 8 ^2 x 0.225
= 345.60 kN

Live load at each floor, LL = $3 \times l_a^2$
= 3 x 8 ^2
= 192 kN

Project	: Comparison of Different Structural Software for Mulitstory Building Design in Terms of Concrete Columns Reinforcement	Date : 6/Jun/2005 Designed by : CKT Checked by :

Reference	Calculation	Output

Column selfweight, SW = 24 x h x b x l / 1000000

$= \frac{24 \times 350 \times 600 \times 3000}{1000000}$

= 15.12 kN

Design axial load, N = 1.2 x (DL + LL + SW) x n

= 1.2 x [345.60 + 192 + 15.12] x 10

= 6632.64 kN

Max column-end moment, M = 101.03 kNm (obtain from portal method)

Design moment, M_i = 1.2 x M

= 121.24 kNm

Unbraced Slender Column Design (with respect to minor axis y-y)

$M_{add} = \frac{NKb}{2000} \times \left(\frac{le}{b'}\right)^2$ Assume factor K = 1.0

$= \frac{6632.64 \times 1.0 \times 350/1000}{2000} \times \left(\frac{3608}{350}\right)^2$

= 123.31 kNm

$M_T = M_i + M_{add}$

= 244.55 kNm

$\frac{N}{bh} = \frac{6632.64 \times 10^3}{350 \times 600}$ = 31.58 N/mm2

$\frac{M}{b^2h} = \frac{244.55 \times 10^6}{350^2 \times 600}$ = 3.33 N/mm2

d = b - 50 = 300 mm (the cover for the reinforcement is taken as 50 mm)

$\frac{d}{b} = \frac{300}{350}$ = 0.86 mm

Use design chart where,

f_{cu} = 40 N/mm^2

f_y = 460 N/mm^2

d/b = 0.90 (round-up of the computed d/b value)

Project	: Comparison of Different Structural Software for Mulitstory Building Design in Terms of Concrete Columns Reinforcement	Date	: 6/Jun/2005
		Designed by	: CKT
		Checked by	:

Reference	Calculation	Output

K	M_{add}	M_T	M/b^2h	$100A_{sc}/bh$	$K_{corrected}$
1.0	123.31	244.55	3.33	5.38	0.27
0.27	33.29	154.53	2.10	4.63	0.19
0.19	6.33	127.56	1.74	4.44	0.17
0.17	1.08	122.31	1.66		
0	0.00	121.24	1.65		

The above iterations are continued until the value of $K_{corrected}$ in the last column of the table are in reasonable agreement with the value of K in the first column

Thus, the final value of the K = 0.17 and $100A_{sc}/bh$ = 4.44 %

As a check on the final value of K interpolated from the design chart:

$$\frac{100A_{sc}}{bh} = 4.44\ \%$$

$$A_{sc} = \frac{4.44 \times 350 \times 600}{100} = 9324\ mm^2$$

$$N_{uz} = 0.45\ f_{cu} A_c + 0.87\ f_y A_{sc}$$

$$= \frac{0.45 \times 40 \times (350 \times 600 - 9324) + 0.87 \times 460 \times 9324}{1000}$$

$$= 7343.63\ kN$$

$$N_{bal} = 0.25\ f_{cu} hd$$

$$= \frac{0.25 \times 40 \times 600 \times 300}{1000}$$

$$= 1800.00\ kN$$

$$K = \frac{N_{uz} - N}{N_{uz} - N_{bal}} = 0.13 \quad < 1$$

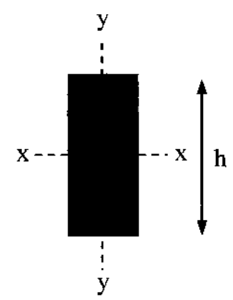
(Determine whether the computed K value agrees with the final value of K interpolated from the design chart.)

Notes:
(i) All columns will be designed with respect to the minor axis, y-y which is the most critical axis.
(ii) All slender columns bent about a single axis.

Project	: Comparison of Different Structural Software for Mulitstory Building Design in Terms of Concrete Columns Reinforcement	Date	:	6/Jun/2005
		Designed by	:	CKT
		Checked by	:	

Reference	Calculation	Output

Column width, b = 450 mm
Column height, h = 800 mm
Flat plate thickness = 225 mm
Original column height, l = 3000 mm
End condition for top = 2
End condition for bottom = 1 } β = 1.3
Clear column height, l_o = 2775 mm
Effective length, l_e = 3608 mm



Slenderness ratio:

$$\frac{l_{ex}}{h} = \frac{3608}{800} = 4.51 \quad < 10$$

$$\frac{l_{ey}}{b} = \frac{3608}{450} = 8.02 \quad < 10$$

Thus, the column is considered as short with respect to both axes

Column Load Take-Down (Approximate Method)

Width of aisle each column supports, l_a = 8 m
Flat plate thickness, thk = 0.225 m
No.of storey considered, n = 20 m

Dead load at each floor, DL = $24 \times l_a^2 \times thk$
= 24 x 8 ^2 x 0.225
= 345.60 kN

Live load at each floor, LL = $3 \times l_a^2$
= 3 x 8 ^2
= 192 kN

Column selfweight, SW = 24 x h x b x l / 1000000

$$= \frac{24 \times 450 \times 800 \times 3000}{1000000}$$

= 25.92 kN

Design axial load, N = 1.2 x (DL + LL + SW) x n
= 1.2 x { 345.60 + 192 + 25.92} x 20
= 13524.5 kN

Max column-end moment, M = 101.03 kNm (obtain from portal method)
Design moment, M_i = 1.2 x M
= 121.24 kNm

Project	: Comparison of Different Structural Software for Mulitstory Building Design in Terms of Concrete Columns Reinforcement	Date : 6/Jun/2005 Designed by : CKT Checked by :

Reference	Calculation	Output

Unbraced Short Column Design (with respect to minor axis y-y)

$$\frac{N}{bh} = \frac{13524.5 \times 10^3}{450 \times 800} = 37.57 \text{ N/mm2}$$

$$\frac{M}{b^2h} = \frac{121.24 \times 10^6}{450\text{ ^2} \times 800} = 0.75 \text{ N/mm2}$$

$d = b - 50 = 400$ mm (the cover for the reinforcement is taken as 50 mm)

$$\frac{d}{b} = \frac{400}{450} = 0.89 \text{ mm}$$

Use design chart where,

$f_{cu} = 40$ N/mm^2
$f_y = 460$ N/mm^2
$d/b = 0.90$ (round-up of the computed d/b value)

$$\frac{100A_{sc}}{bh} = 5.63 \ \%$$

$$A_{sc} = \frac{5.63 \times 450 \times 800}{100} = 20268 \text{ mm}^2$$

Notes:
All columns will be designed with respect to the minor axis, y-y which is the most critical aixs.

APPENDIX E: Example of STAAD. Pro 2002 Input Codes

```
STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 14-Feb-05
END JOB INFORMATION
INPUT WIDTH 79
UNIT METER KN
JOINT COORDINATES
1 0 0 0; 2 0 0 8; 3 0 0 16; 4 0 0 24; 5 8 0 0; 6 8 0 8; 7 8 0 16; 8 8 0 24;
9 16 0 0; 10 16 0 8; 11 16 0 16; 12 16 0 24; 13 24 0 0; 14 24 0 8; 15 24 0 16;
16 24 0 24; 17 0 3 0; 18 0 3 8; 19 0 3 16; 20 0 3 24; 21 8 3 0; 22 8 3 8;
23 8 3 16; 24 8 3 24; 25 16 3 0; 26 16 3 8; 27 16 3 16; 28 16 3 24; 29 24 3 0;
30 24 3 8; 31 24 3 16; 32 24 3 24; 33 0 6 0; 34 0 6 8; 35 0 6 16; 36 0 6 24;
37 8 6 0; 38 8 6 8; 39 8 6 16; 40 8 6 24; 41 16 6 0; 42 16 6 8; 43 16 6 16;
44 16 6 24; 45 24 6 0; 46 24 6 8; 47 24 6 16; 48 24 6 24; 49 0 9 0; 50 0 9 8;
51 0 9 16; 52 0 9 24; 53 8 9 0; 54 8 9 8; 55 8 9 16; 56 8 9 24; 57 16 9 0;
58 16 9 8; 59 16 9 16; 60 16 9 24; 61 24 9 0; 62 24 9 8; 63 24 9 16;
64 24 9 24; 65 0 12 0; 66 0 12 8; 67 0 12 16; 68 0 12 24; 69 8 12 0; 70 8 12 8;
71 8 12 16; 72 8 12 24; 73 16 12 0; 74 16 12 8; 75 16 12 16; 76 16 12 24;
77 24 12 0; 78 24 12 8; 79 24 12 16; 80 24 12 24; 81 0 15 0; 82 0 15 8;
83 0 15 16; 84 0 15 24; 85 8 15 0; 86 8 15 8; 87 8 15 16; 88 8 15 24;
89 16 15 0; 90 16 15 8; 91 16 15 16; 92 16 15 24; 93 24 15 0; 94 24 15 8;
95 24 15 16; 96 24 15 24; 97 0 18 0; 98 0 18 8; 99 0 18 16; 100 0 18 24;
101 8 18 0; 102 8 18 8; 103 8 18 16; 104 8 18 24; 105 16 18 0; 106 16 18 8;
107 16 18 16; 108 16 18 24; 109 24 18 0; 110 24 18 8; 111 24 18 16;
112 24 18 24; 113 0 21 0; 114 0 21 8; 115 0 21 16; 116 0 21 24; 117 8 21 0;
118 8 21 8; 119 8 21 16; 120 8 21 24; 121 16 21 0; 122 16 21 8; 123 16 21 16;
124 16 21 24; 125 24 21 0; 126 24 21 8; 127 24 21 16; 128 24 21 24; 129 0 24 0;
130 0 24 8; 131 0 24 16; 132 0 24 24; 133 8 24 0; 134 8 24 8; 135 8 24 16;
136 8 24 24; 137 16 24 0; 138 16 24 8; 139 16 24 16; 140 16 24 24; 141 24 24 0;
142 24 24 8; 143 24 24 16; 144 24 24 24; 145 0 27 0; 146 0 27 8; 147 0 27 16;
148 0 27 24; 149 8 27 0; 150 8 27 8; 151 8 27 16; 152 8 27 24; 153 16 27 0;
154 16 27 8; 155 16 27 16; 156 16 27 24; 157 24 27 0; 158 24 27 8;
159 24 27 16; 160 24 27 24; 161 0 30 0; 162 0 30 8; 163 0 30 16; 164 0 30 24;
165 8 30 0; 166 8 30 8; 167 8 30 16; 168 8 30 24; 169 16 30 0; 170 16 30 8;
171 16 30 16; 172 16 30 24; 173 24 30 0; 174 24 30 8; 175 24 30 16;
176 24 30 24;
MEMBER INCIDENCES
1 1 17; 2 2 18; 3 3 19; 4 4 20; 5 5 21; 6 6 22; 7 7 23; 8 8 24; 9 9 25;
10 10 26; 11 11 27; 12 12 28; 13 13 29; 14 14 30; 15 15 31; 16 16 32; 17 17 33;
18 18 34; 19 19 35; 20 20 36; 21 21 37; 22 22 38; 23 23 39; 24 24 40; 25 25 41;
26 26 42; 27 27 43; 28 28 44; 29 29 45; 30 30 46; 31 31 47; 32 32 48; 33 33 49;
34 34 50; 35 35 51; 36 36 52; 37 37 53; 38 38 54; 39 39 55; 40 40 56; 41 41 57;
42 42 58; 43 43 59; 44 44 60; 45 45 61; 46 46 62; 47 47 63; 48 48 64; 49 49 65;
50 50 66; 51 51 67; 52 52 68; 53 53 69; 54 54 70; 55 55 71; 56 56 72; 57 57 73;
58 58 74; 59 59 75; 60 60 76; 61 61 77; 62 62 78; 63 63 79; 64 64 80; 65 65 81;
66 66 82; 67 67 83; 68 68 84; 69 69 85; 70 70 86; 71 71 87; 72 72 88; 73 73 89;
74 74 90; 75 75 91; 76 76 92; 77 77 93; 78 78 94; 79 79 95; 80 80 96; 81 81 97;
82 82 98; 83 83 99; 84 84 100; 85 85 101; 86 86 102; 87 87 103; 88 88 104;
89 89 105; 90 90 106; 91 91 107; 92 92 108; 93 93 109; 94 94 110; 95 95 111;
96 96 112; 97 97 113; 98 98 114; 99 99 115; 100 100 116; 101 101 117;
102 102 118; 103 103 119; 104 104 120; 105 105 121; 106 106 122; 107 107 123;
108 108 124; 109 109 125; 110 110 126; 111 111 127; 112 112 128; 113 113 129;
114 114 130; 115 115 131; 116 116 132; 117 117 133; 118 118 134; 119 119 135;
120 120 136; 121 121 137; 122 122 138; 123 123 139; 124 124 140; 125 125 141;
126 126 142; 127 127 143; 128 128 144; 129 129 145; 130 130 146; 131 131 147;
132 132 148; 133 133 149; 134 134 150; 135 135 151; 136 136 152; 137 137 153;
138 138 154; 139 139 155; 140 140 156; 141 141 157; 142 142 158; 143 143 159;
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144 144 160; 145 145 161; 146 146 162; 147 147 163; 148 148 164; 149 149 165;
150 150 166; 151 151 167; 152 152 168; 153 153 169; 154 154 170; 155 155 171;
156 156 172; 157 157 173; 158 158 174; 159 159 175; 160 160 176;
ELEMENT INCIDENCES SHELL
161 4 8 7 3; 162 8 12 11 7; 163 12 16 15 11; 164 3 7 6 2; 165 7 11 10 6;
166 11 15 14 10; 167 2 6 5 1; 168 6 10 9 5; 169 10 14 13 9; 170 20 24 23 19;
171 24 28 27 23; 172 28 32 31 27; 173 19 23 22 18; 174 23 27 26 22;
175 27 31 30 26; 176 18 22 21 17; 177 22 26 25 21; 178 26 30 29 25;
179 36 40 39 35; 180 40 44 43 39; 181 44 48 47 43; 182 35 39 38 34;
183 39 43 42 38; 184 43 47 46 42; 185 34 38 37 33; 186 38 42 41 37;
187 42 46 45 41; 188 52 56 55 51; 189 56 60 59 55; 190 60 64 63 59;
191 51 55 54 50; 192 55 59 58 54; 193 59 63 62 58; 194 50 54 53 49;
195 54 58 57 53; 196 58 62 61 57; 197 68 72 71 67; 198 72 76 75 71;
199 76 80 79 75; 200 67 71 70 66; 201 71 75 74 70; 202 75 79 78 74;
203 66 70 69 65; 204 70 74 73 69; 205 74 78 77 73; 206 84 88 87 83;
207 88 92 91 87; 208 92 96 95 91; 209 83 87 86 82; 210 87 91 90 86;
211 91 95 94 90; 212 82 86 85 81; 213 86 90 89 85; 214 90 94 93 89;
215 100 104 103 99; 216 104 108 107 103; 217 108 112 111 107;
218 99 103 102 98; 219 103 107 106 102; 220 107 111 110 106; 221 98 102 101 97;
222 102 106 105 101; 223 106 110 109 105; 224 116 120 119 115;
225 120 124 123 119; 226 124 128 127 123; 227 115 119 118 114;
228 119 123 122 118; 229 123 127 126 122; 230 114 118 117 113;
231 118 122 121 117; 232 122 126 125 121; 233 132 136 135 131;
234 136 140 139 135; 235 140 144 143 139; 236 131 135 134 130;
237 135 139 138 134; 238 139 143 142 138; 239 130 134 133 129;
240 134 138 137 133; 241 138 142 141 137; 242 148 152 151 147;
243 152 156 155 151; 244 156 160 159 155; 245 147 151 150 146;
246 151 155 154 150; 247 155 159 158 154; 248 146 150 149 145;
249 150 154 153 149; 250 154 158 157 153; 251 164 168 167 163;
252 168 172 171 167; 253 172 176 175 171; 254 163 167 166 162;
255 167 171 170 166; 256 171 175 174 170; 257 162 166 165 161;
258 166 170 169 165; 259 170 174 173 169;
ELEMENT PROPERTY
161 TO 259 THICKNESS 0.225
DEFINE MATERIAL START
ISOTROPIC CONCRETE
E 2.17185e+007
POISSON 0.17
DENSITY 23.5616
ALPHA 1e-005
DAMP 0.05
END DEFINE MATERIAL
CONSTANTS
MATERIAL CONCRETE MEMB 1 TO 259
MEMBER PROPERTY BRITISH
1 TO 80 PRIS YD 0.35 ZD 0.6
81 TO 160 PRIS YD 0.3 ZD 0.55
SUPPORTS
1 TO 16 FIXED
LOAD 1 WL + DL + LL
SELFWEIGHT Y -1.2
JOINT LOAD
161 TO 164 FX 13.13
145 TO 148 FX 25.78
129 TO 132 FX 24.73
113 TO 116 FX 23.67
97 TO 100 FX 22.62
81 TO 84 FX 21.45
65 TO 68 FX 20.16
49 TO 52 FX 18.63
33 TO 36 FX 16.76
17 TO 20 FX 15.12
ELEMENT LOAD
```

```
161 TO 259 PR GY -3.6
PDELTA ANALYSIS PRINT LOAD DATA
START CONCRETE DESIGN
CODE BS8110
FC 40000 MEMB 1 TO 160
FYSEC 460000 MEMB 1 TO 160
FYMAIN 460000 MEMB 1 TO 160
DESIGN COLUMN 1 TO 160
DESIGN ELEMENT 161 TO 259
END CONCRETE DESIGN
FINISH
```

APPENDIX F:

Example of Prokon Calculation Report

xample: Unbraced slender column with bi-axial bending

C11

ɛctangular column design by *PROKON*. (RecCol Ver W1.1.01 - 4 Feb 1999)

ɜsign code : BS8110-1997

put tables

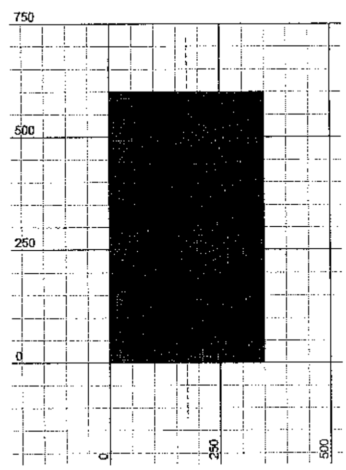
ɜneral design parameters and loads:

ı (mm)	600
ɔ (mm)	350
ɗ'x (mm)	50
ɗ'y (mm)	50
.o (m)	2.775
'cu (MPa	40
y (MPa)	460

Case no	Description	P (kN)	Mx top (kNm)	My top (kNm)	Mx bot (kNm)	My bot (kNm)
1	DL + LL	6586.20				
	WL			121.24		121.24

eneral design parameters:

ven:
ı = 600 mm
ı = 350 mm
l'x = 50 mm
l'y = 50 mm
.o = 2.775 m
ɔu = 40 MPa
y = 460 MPa



ıerefore:
\c = b· d = 210000.00 mm²
ı' = h - d'x = 550 mm
ɔ' = h - d'y = 300 mm

ɜsumptions:
1) The general conditions of clause 3.8.1is applicable.
2) The section is symmetrically reinforced.
3) The specified design axial loads include the self-weight of the column.
4) The design axial loads are taken constant over the height of the column.

esign approach:

ıe column is designed using an iterative procedure:
1) The column design charts are constructed.
2) An area steel is chosen.
3) The corresponding slenderness moments are calculated.
4) The design axis and design ultimate moment is determined .
5) The steel required for the design axial force and moment is read from the relevant design chart.
6) The procedure is repeated until the convergence of the area steel about the design axis.
7) The area steel perpendicular to the design axis is read from the relevant design chart.

ıeck column slenderness:

ıd fixity and bracing for bending about the X-X axis:
ıt the top end: Condition 2 (partially fixed).
ıt the bottom end: Condition 1 (fully fixed).
'he column is unbraced.
ßx = 1.30 *Table 3.22*

ıd fixity and bracing for bending about the Y-Y axis:
ıt the top end: Condition 2 (partially fixed).
ıt the bottom end: Condition 1 (fully fixed).
'he column is unbraced.
ßy = 1.30 *Table 3.22*

fective column height:
ɘx = ßx· Lo = 3.607 m
ɘy = ßy· Lo = 3.607 m

ıeck if the column is slender: *3.8.1.3*
ɘx/h = 6.0 < 10
ɘy/b = 10.3 > 10
The column is slender.

ıeck slenderness limit: *3.8.1.7*
.o = 2.775 m < 60· b' = 21.000 m
Slenderness limit not exceeded.

itial moments:

ıe initial end moments about the X-X axis:
/1 = Smaller initial end moment = 0.0 kNm
/2 = Larger initial end moment = 0.0 kNm

ıe initial moment near mid-height of the column : *3.8.3.2*
Mi = -0.4M1 + 0.6M2 ≤ 0.4M2 = 0.0 kNm

ıe column is bent in double curvature about the Y-Y axis:
/1 = Smaller initial end moment = 121.2 kNm
/2 = Larger initial end moment = 121.2 kNm

ıe initial moment near mid-height of the column : *3.8.3.2*
Mi = -0.4M1 + 0.6M2 ≤ 0.4M2 = 0.0 kNm

eflection induced moments: *3.8.3.1*

ɘsign ultimate capacity of section under axial load only:
ɴuz = 0.45· fcu· Ac + 0.95· fy· Asc = 0.0 kN

aximum allowable stress and strain:
\llowable compression stress in steel, fsc = 0.95· fy = 437.0 MPa
\llowable tensile stress in steel, fst = 0.95· fy = 437.0 MPa
\llowable tensile strain in steel, ey = fst/Es = 0.0022 m/m
\llowable compressive strain in concrete, ec = 0.0035 m/m

or bending about the Y-Y axis:
3alanced neutral axis depth, xb = ec/(ec+es)· b' =184.7 mm
ɴbal = 0.44· h· fcu· xbal + At/2· (fsd-fs) = 1773.1 kN
< = (Nuz - N) / (Nuz - Nbal) = 0.284 < 1.0
ßa = (1/2000)· (ley/b)² = 0.053
Madd = N· ßa· K· b = 34.8 kNm

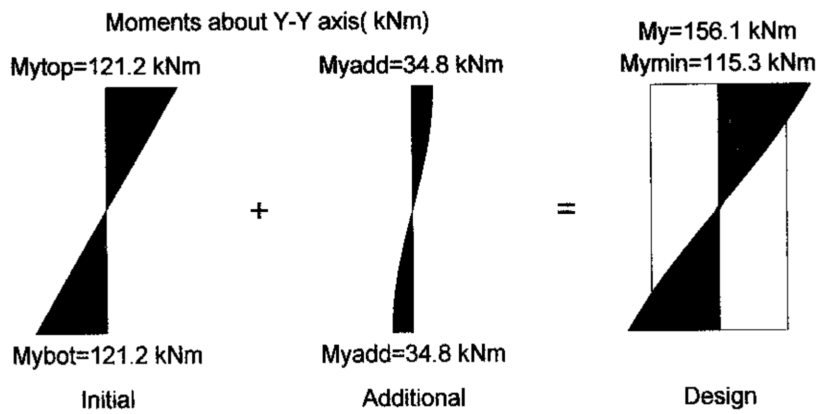
esign ultimate load and moment:

esign axial load:
P_u = 6586.2 kN

r bending about the X-X axis, the maximum design moment is the greatest of: 3.8.3.7
a) M2 + Madd = 0.0 kNm
b) emin· N = 131.7 kNm
Mx = 0.0 kNm

r bending about the Y-Y axis, the maximum design moment is the greatest of: 3.8.3.7
a) M2 + Madd = 156.1 kNm
b) emin· N = 115.3 kNm
My = 156.1 kNm

oment distribution along the height of the column for bending about the Y-Y:
At the top, Mx = 156.1 kNm
Near mid-height, Mx = 115.3 kNm
At the bottom, Mx = 156.1 kNm



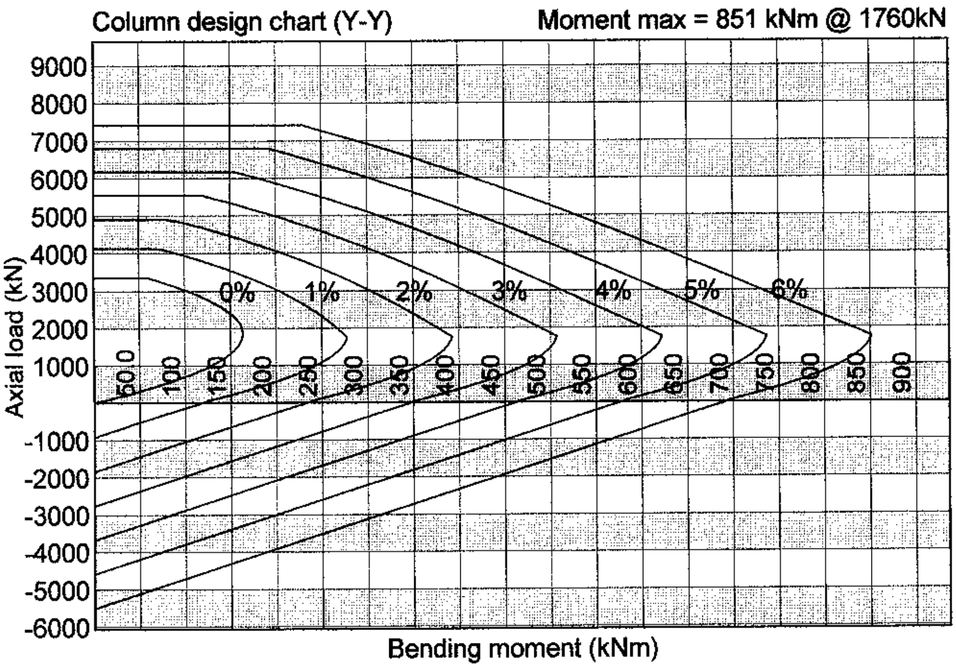
heck for miminum eccentricity: 3.8.2.4
Check that the eccentricity excceeds the minimum in the plane of bending:
Mmin = 115.3 kNm about the Y-Y axis.

esign of column section for ULS:

hrough inspection:
The critical section lies at the top end of the column.

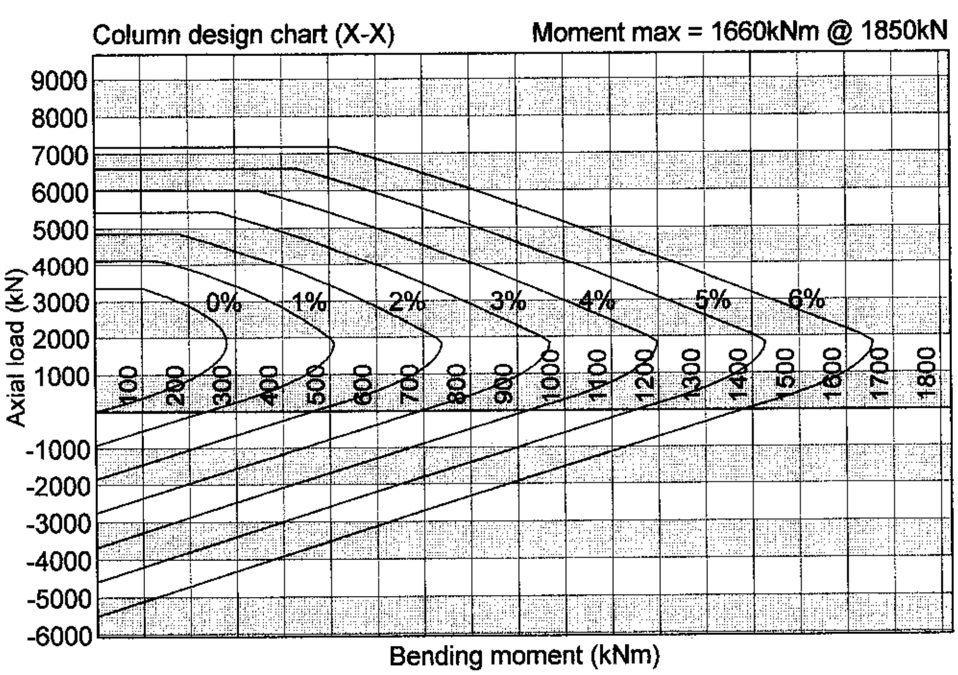
ne column is designed to withstand the uni-axially applied moment about e major axis.

or bending about the design axis:



einforcement required about the Y-Y axis:
From the design chart, Asc = 10799 mm² = 5.14%

or bending perpendicular to the design axis:



Reinforcement required about the X-X axis:
From the design chart, Asc = 8767 mm² = 4.17%

ummary of design calculations:

esign results for all load cases:

Load case	Axis	N (kN)	M1 (kNm)	M2 (kNm)	Mi (kNm)	Madd (kNm)	Design	M (kNm)	M' (kNm)	Asc (mm^2)
Load case 1 DL + LL + WL	X-X Y-Y	6586.2	0.0 121.2	0.0 121.2	0.0 48.5	0.0 34.8	Y-Y Top	0.0 156.1	0.0 156.1	8767 (4.2%) 10799 (5.1%)

APPENDIX G: Example of STAAD. Pro 2002 Software Interface

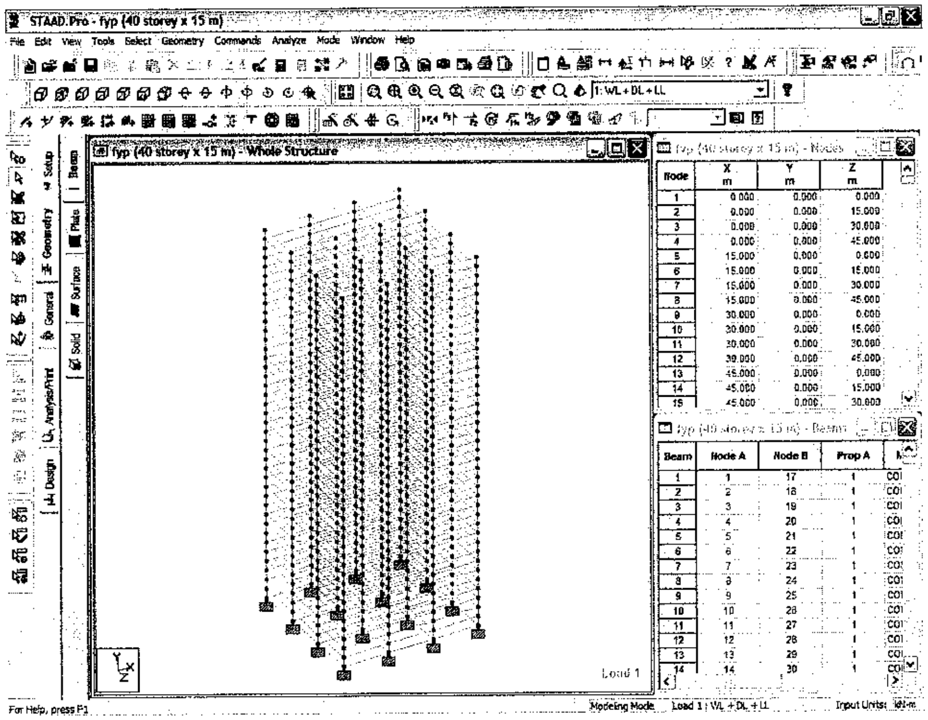


Figure G-1: Skeleton of the structure model built by assigning the geometry information

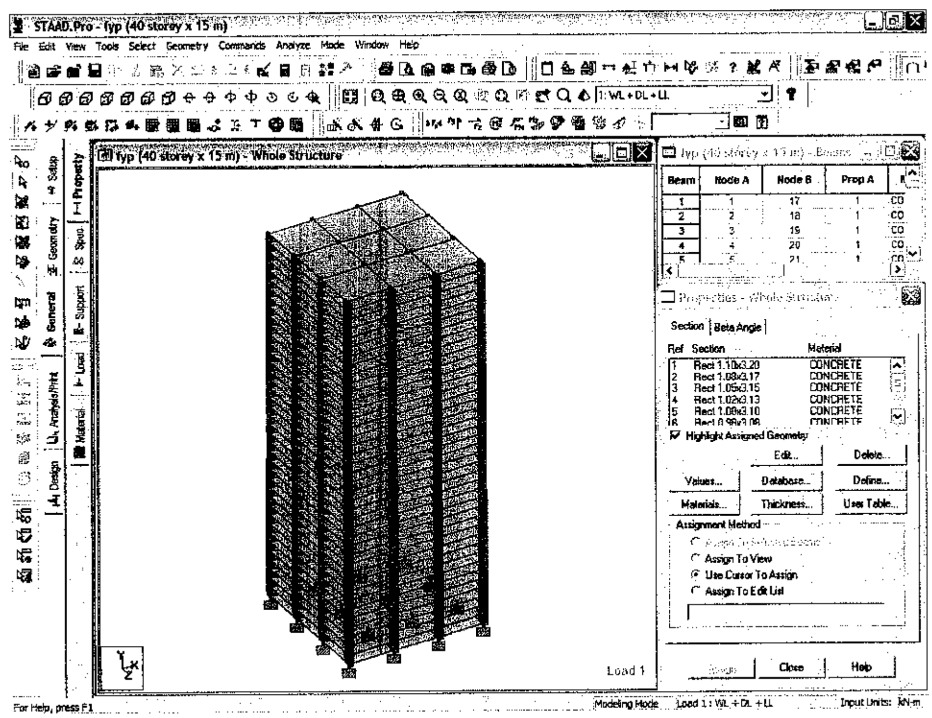


Figure G-2: Structural properties being assigned to the structure model

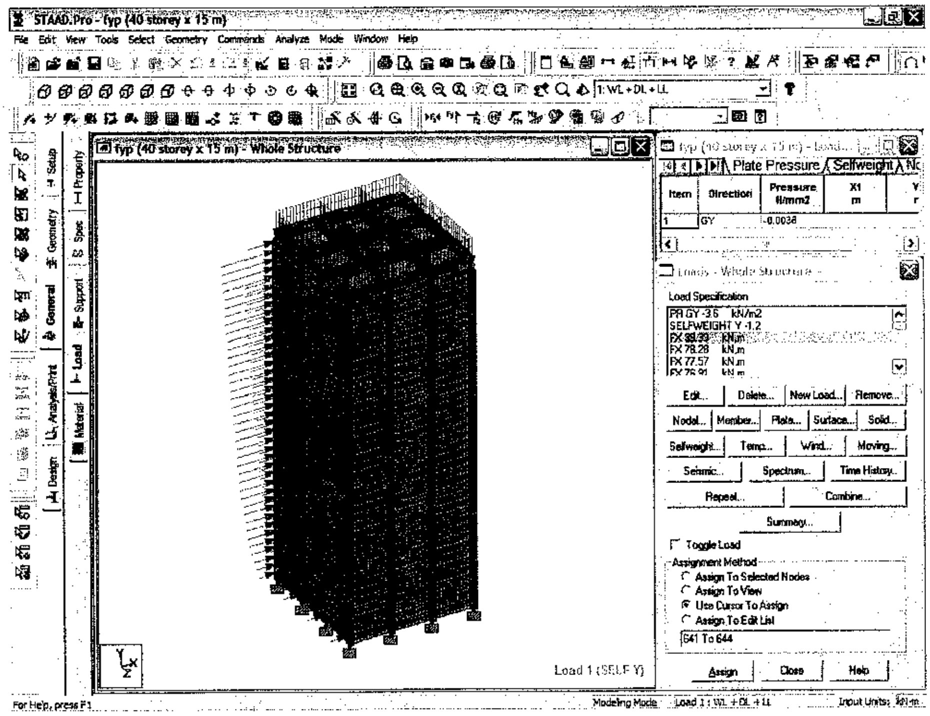


Figure G-3: Loads are being assigned to the structure model

APPENDIX H: Example of Prokon Software Interface

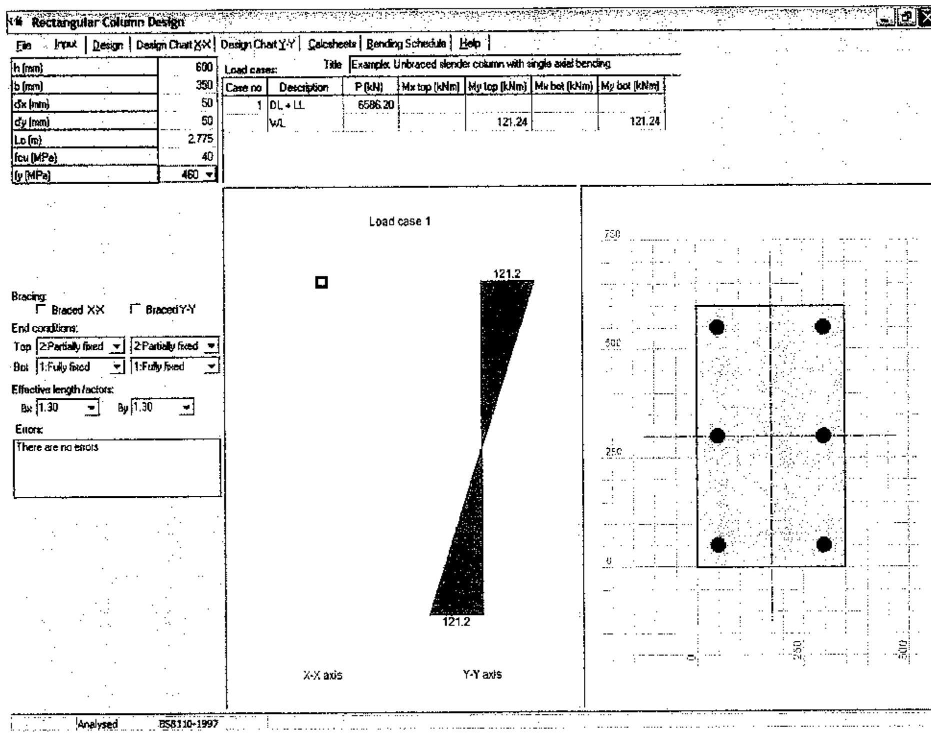


Figure H-1: Data input for the column section

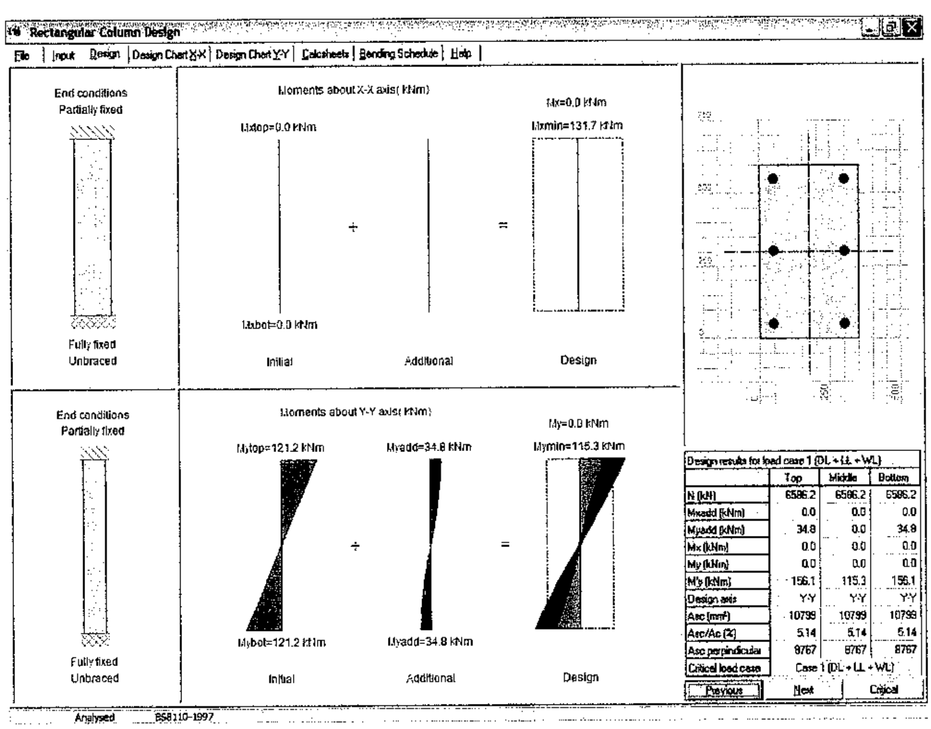


Figure H-2: Column design results