CERTIFICATE OF APPROVAL

Comparative Structural Analysis for Multistorey Building

by

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A project dissertation submitted to the

Civil Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CIVIL ENGINEERING)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January, 2012

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.

(NOR ANIS MUNIRAH BT HAFENDI)

ACKNOWLEDGEMENTS

All praises go to Allah, our sustainer, without His grace and guidance, no effort could attain success.

Deepest gratitude to the author's supervisor, Dr. Noor Amila Bt Wan Abdullah Zawawi, who is willing to spend time to provide guidance to the author in completing this project. Also, special thanks to her for having given author the opportunity to proceed with her proposed project and with the trust such that the author is able to undertake the project to the very end.

Heartfelt appreciation goes to Engr. Ayu Fatma, Engr. Siti Norliza, and Engr. Nor Zahra from the author's internship company for their invaluable advice, guidance, support as well as encouragement throughout the project.

Not forgetting, the author's family and colleagues, no words can ever express her gratitude for the love, support, encouragement for the successful of this project. Thank you.

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 is a number of software in the market for a solution of similar problem. However, there is no existing comparative analysis among commercially available software for tall building design. Therefore, this research aims to perform comparative analysis of different software. The comparison was made in terms of efficiency, ease in modeling and economy of design. Throughout this project, the structural members of a multistorey building were analyzed using different approaches which are by manual calculation and chosen softwares: ESTEEM and ORION. At first, the comparison was made to the building which was subjected to only vertical loading. Then the building was simulated by dynamic loading such as wind loading. Lastly, the result outputs from the comparison was used to validate the efficiency of the chosen software in producing the most economical and optimum structural design with respect to manual calculation. Based on the analytical and structural design results, ORION software is found to be more superior to ESTEEM software in terms of producing the most efficient, economical and optimum structural design with respect to manual calculation.

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CHAPTER 1:

INTRODUCTION

1.1 BACKGROUND OF STUDY

Structure is a system formed from the interconnection structural members or the shape or form that prevents buildings from being collapsed. A structure supports the building by using a framed arrangement known as Superstructure. There are two important steps for the construction of a building, (i) Structural Analysis and (ii) Structural Design. Structural analysis is the force acting on different parts of the structure that can be determined through structural analysis. The most common forces calculated are movements and shear forces.

Complicated formula and charts will be used in the calculation works and this requires the use of computer software as well as trained and experienced engineers. However, basic understanding of the concept of the design and structural analysis is significantly required. Structural engineering software is introduced 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 design
- Geotechnical design

Structure engineering software program has substituted the manual method in design structure in construction industry. Design and analysis structure can be quickly and easily input and viewed on the screen in a various format. There are many structural engineering software introduced presently such as ESTEEM and ORION. This software can help difficult structures to be designed in a short time and reduced costs compared with traditional method.

In general, the efficiency of any structural design software is judged according to the competency of the design to fulfill 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. [2]

1.2 PROBLEM STATEMENT

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 ease engineer's work in many ways ranging from simple loading calculation to superstructure and substructure design and analysis. However, availability of so many software for the same purpose in the market raised a question to the end user: Which is the most competent software in terms of producing the most efficient, economical and optimum structural design?

1.3 OBJECTIVES

The main objective of this project is:

- To perform a comparative structural analysis for the software.

In order to achieve the main objective, this study must achieve the following sub-objectives:

- To identify the parameters for evaluation.
- To evaluate structure using different approach which by manual calculation and software.
- To perform sensitivity analysis/validate against different loading conditions.

1.4 SCOPE OF WORK

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

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

2. Study an architectural drawing of multistorey building and analyzed by using chosen softwares. At first, the analysis was made to the building which was subjected to only vertical loading. Then the building was simulated by dynamic loading such as wind loading.

3. Comparison of computational result output. The result output were studied and compared within the chosen softwares and also compared with the manual calculation in order to determine the competence software in producing an economical and optimum structural design.

CHAPTER 2:

LITERATURE REVIEW

This literature review covers six different sections. Section 2.1 focuses on the literature review of the published work on structural engineering software. Section 2.2 will discuss on the behavior of high rise building while section 2.3 focuses on standard computer analysis and application. Proceed with section 2.4 and 2.5 which will discuss on the review of software and criteria for case study respectively. Lastly section 2.5 focuses on the summary of the whole literature review.

2.1 LITERATURE REVIEW OF RESEARCHER ON STRUCTURAL ENGINEERING SOFTWARE

2.1.1 Research on Application of Structure Engineering Software

A study by Tuan Yusof and Faizah[3] review how far the application of structure engineering software in construction's company nowadays and the type of software usually used by local organization in the structure engineering especially in the study area, Ipoh.

This study acquires information in two ways through the literature study and case study. For case study method, analysis of data made based on form of questionnaires and discussion acquired from the party respondent such as contractor's company, consultant's company and local authority. The first analysis was made by referred to the outlook for software application in structure engineering. Further, analysis made based on the types of software which are used, frequency of application software and the reason of each software that have been used in construction industry in Malaysia.

STAAD Pro, ESTEEM, PROKON, ORION, EXCEL and SAP 2000 are the six popular types and frequently used in structural engineering. STAAD Pro occupies uppermost place in this frequency of use. According to respondent, STAAD Pro is the best method for the construction steel structure, it is very user friendly and no detail rebar needed, that mean this software only produce result that are required only. Second highest placed is ESTEEM's software that give faster and accurate result in the production structure design. Followed also by PROKON's software at third place of the frequent used. PROKON's software also provided accurate result and faster in the design structure engineering. ORION's software is in the forth place in the frequency of use. According to respondent, ORION's software can produce better and faster 3D. EXCEL occupies in fifth position frequency of percentage of using software although it only normal computer software not structure engineering software. SAP's software 2000 took the last place in frequency of use structure engineering software. Although it is sit under and lowest place popularity over other software but it still also popular used in structure design because it can help in generating fast data in the structure design.

The results from the study revealed that the software application in structure engineering is widely used, helps a lot and make it easy for design especially structure engineering in construction industry in Malaysia.

2.1.2 Comparison between Ribbed Slab Structure using Lightweight Foam Concrete and Solid Slab Structure using Normal Concrete

A study by Rana, Norizal, Ethar and Zailan[1] review the potential of Lightweight concrete in reducing of dead load on slab concrete structure, so that it would allow the structural designer to reduce the size of columns, footings and other load bearing.

Esteem® software is used throughout this study in order to design one-way ribbed slab and two-way solid slab. The first part of this study is conducting the Lab tests for the density and compression strength while the second part is the analysis of the data made by using the ESTEEM® software. ESTEEM® software is selected because of its efficiency in producing accurate values and also easy to use. The data was collected from the result of the density and compression tests for the concrete and were fed to the software. This software was designed according to British standard. It can analyze and calculate the volume of concrete, amount of steel and formwork, and produce the drawing of the sections and amounts of shears, moments and deflections. Furthermore, this software is able to calculate the raw cost and placement cost for the floor plan.

The result of the analysis, which was done by using the ESTEEM® software, shows that Foam concrete can be designed to meet the criteria of compressive strength of load bearing concrete and Foam concrete is a suitable solution in the construction of multi-storey buildings. Besides, foamed concrete has been identified as a suitable material to replace the normal concrete used for this purpose. At the same time, the density of foamed concrete can be designed and controlled according to the ratio of the mixture and the stability of the foam used. Furthermore, the construction cost of one-way ribbed slab with beams is more economical than that of the two- way solid slabs with beams. Lastly, the ESTEEM® software appears to be an efficient and accurate instrument that is reliable to be used in making the analysis and calculations.

2.1.3 Comparison of Different Structural Software for Multistorey Building Design in Terms of Concrete Column Reinforcement

A study by Chaw Kit Teng[2] compares the differences and effectiveness of different structural software available for the design of Reinforced Concrete Columns for multistorey building with variation of building height and bay framing width. Besides, this studies also intent to compare the competence of the difference structural software in producing the most economical and feasible column design.

Structure model with different combination of building height and bay width were used to carry out the analytical study. Column sizes were kept constant for all the models in order to maintain the consistency and accuracy of the results output. 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.

On the whole analysis, STAAD Pro 2002 is more suitable for tall building modeling as compare to PROKON VersionW1.1.02. 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 modeled either in three dimensional structure or two dimensional structure. On the contrary, PROKON software only allows a module of the entire structure to be modeled at any instant. 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.

The results from the study revealed that STAAD Pro's software proved to be highly efficiency software, which produced more economical design as compared to PROKON software.

2.2 BEHAVIOR OF HIGH RISE BUILDING

From the structural engineer's point of view, a high rise building can be defined as one that, because of its height, is affected by lateral forces due to wind or earthquake actions to an extent that they play an important role in the structural design [4].

The two primary types of vertical load-resisting elements of high rise building are columns and wall, the latter acting either independently as shear walls or in assemblies as shear wall cores. The building function will lead naturally to the provision of walls to divide and enclose space, and of cores to contain and convey services such as elevators. Columns will be provided, in otherwise unsupported regions, to transmit gravity loads and, in some types of structure, horizontal loads also.

The inevitable primary function of the structural elements is to resist the gravity loading from the weight of the building and its contents. Since the loading on different floors tends to be similar, the weight of the floor system per unit floor area is approximately constant, regardless of the building height. Because the gravity load on columns increases down the height of a building, the weight of columns per unit area increases approximately linearly with the building height.

The highly probable second function of the vertical structural elements is to resist also the parasitic load caused by wind and possibly earthquakes, whose magnitudes will be obtained from National Building Codes or wind tunnel studies. The bending moments on the building cause by these lateral forces increase with at least the square of the height, and their effects will become progressively more important as the building height increases.

Loading on high rise building differs from loading on low rise buildings in its accumulation into much larger structural forces, in the increased significant of wind loading, and in the greater importance of dynamics effects. The collection of gravity loading over a large number of stories in a high rise building can produce column loads of an order higher than those in low-rise buildings. Wind loading on a high rise building acts not only over a very large building surface, but also with greater intensity at the greater heights and with a larger moment arm about the base than a low rise building. Although wind loading on a low rise usually has an insignificant influence on the design of the structure, wind on a high rise building can have a dominant influence on its structural arrangement and design. In an extreme case of a very slender and flexible structure, the motion of the building in the wind may have to be considered in assessing the loading applied by the wind [2].

2.3 STANDARD COMPUTER ANALYSIS AND APPLICATION

Computer application in daily use is essentially for 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 test, 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 application in concrete engineering is continually expanding. New program are being developed for problem 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).

Most standard computer programs are based on the matrix method of structural analysis. Commercially available interactive computer programs demand few of the structural engineers for 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 analyzed 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 elements, i.e. the beam elements, 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 into the computer and so reference should be made to the respective program guidelines [6].

2.4 REVIEW OF SOFTWARE

ESTEEM [7]	ORION [8]	STAAD Pro [9]
	Differences	
• Suitable method for designing reinforced concrete structure	• Suitable method for designing reinforced concrete structure	• Best method for the construction of steel structure
• Only modeled for concrete design	• Only modeled for concrete design	• Also modeled for concrete and timber design
• Apply additional lateral loads including wind load	• Apply additional lateral loads including wind load	• Apply additional lateral loads including wind and seismic load
• Useful software in design any shaped of building	• Very useful software in design shaped square building	• Useful software in design any shaped of building
• Quantity take-off and costing of concrete, reinforcement and formwork for all structural elements	• Acquire full quantity take-off for concrete, reinforcement and formwork	• Produce clear and concise documentation including drawings and quantities
	Similarities	
	• Easy to understand, control in the short time and user friendly	
	• Complete with analysis, design and drawing	
	• Work in 2D or 3D views to create any building structure quickly	
	• Design and optimize the complete concrete building structure to British Standard	
	• Speed up modeling by copying and linking floors	
	• Import AutoCAD DXF files	

2.5 CRITERIA FOR CASE STUDY

Throughout this project, a software comparison was made to the building which was subjected to gravity load and also additional wind load. Therefore, 13 storeys office building was chosen as a case study. This is because dynamic effect such as wind loading will be dominant when the building height is more than 10 storeys. Furthermore, based on literature review, passed researchers have only focuses on specific studies of individual structural member such as slab [1] and column [2]. This study attends to do evaluation for all structural members of the building. It is a concern that complexity of the design will complicate the assessment and such that may not be accomplished within the FYP timeframe. Therefore, this project is only considered multistorey building with a simple design as a case study.

2.6 SUMMARY

Nowadays, there are several published works on structural engineering software that have been done by the researchers [1, 2, 3]. One of it is on the type of software usually used by the local organization and frequency of application [2]. This study revealed that STAAD Pro occupies uppermost place in the frequency of use followed by ESTEEM, PROKON, ORION, EXCEL and SAP 2000. This proved that the software application in structure engineering is widely used in construction industry in Malaysia. Another research focuses on application of software in designing the structural members such as slab [1]. ESTEEM software is selected because of its efficiency in producing accurate values and also easy to be used. There is also a research on application of different software such as STAAD Pro and PROKON but it only focuses on specific elements, not the whole members of the building [3]. Therefore, this project 'Comparative Structure Analysis for Multistorey Building' is focuses on the analyzing and designing all structure members of superstructure using different software. ESTEEM and ORION software is chosen because it is widely used to design reinforced concrete structure. In addition, multistorey building is chosen as a case study because the wind loading is dominant. Structural comparison can be made efficiently with the simulation of different loading.

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 PROCEDURE IDENTIFICATION

The multistorey building model was analyzed using ESTEEM software, ORION software and manual calculation. In order to carry out this study systematically, the project work was divided into 6 steps which could be summarized as following:

Step 1: Research on the published work was carried out to identify the most common structural engineering software used by the engineer in construction industry.

Step 2: The parameters for the case study was identified. The multistorey building was chosen to perform sensitivity analysis and validate against different loading conditions.

Step 3: Structural calculation was performed by manual calculation and chosen softwares. At this stage, the analysis was made to the building which was subjected to gravity loading. The slab, beam and column sizes were kept at constant value throughout the entire modeling analysis. These fixed sizes were determined using manual calculation since it employed the most conventional design approaches. The amount of reinforcement required in the slabs, beams and columns for each level was determined.

Step 4: The result outputs were compared between the manual calculation and chosen softwares.

Step 5: Sensitivity analysis was performed to the structure model to validate against different loading condition. Also, structural calculation was performed by manual calculation and chosen softwares.

Step 6: The result output were studied and comparison were made between the chosen softwares and manual calculation in order to determine the most competence software in producing an economical and optimum structural design.

The procedure and stage of the entire project was also shown in the flowchart below:

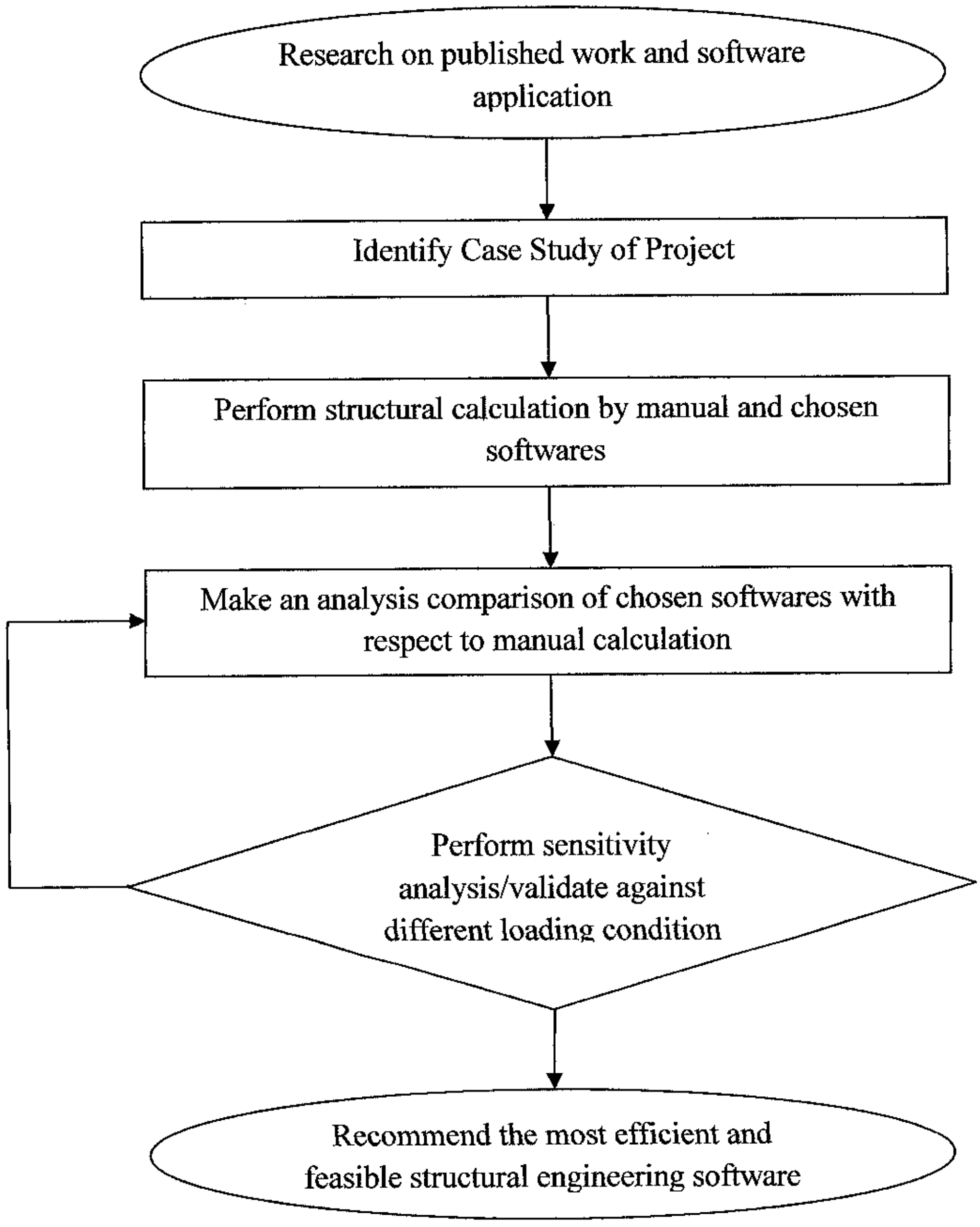

Figure 3.1: Flowchart of Methodology for FYP

3.2 STRUCTURE MODEL

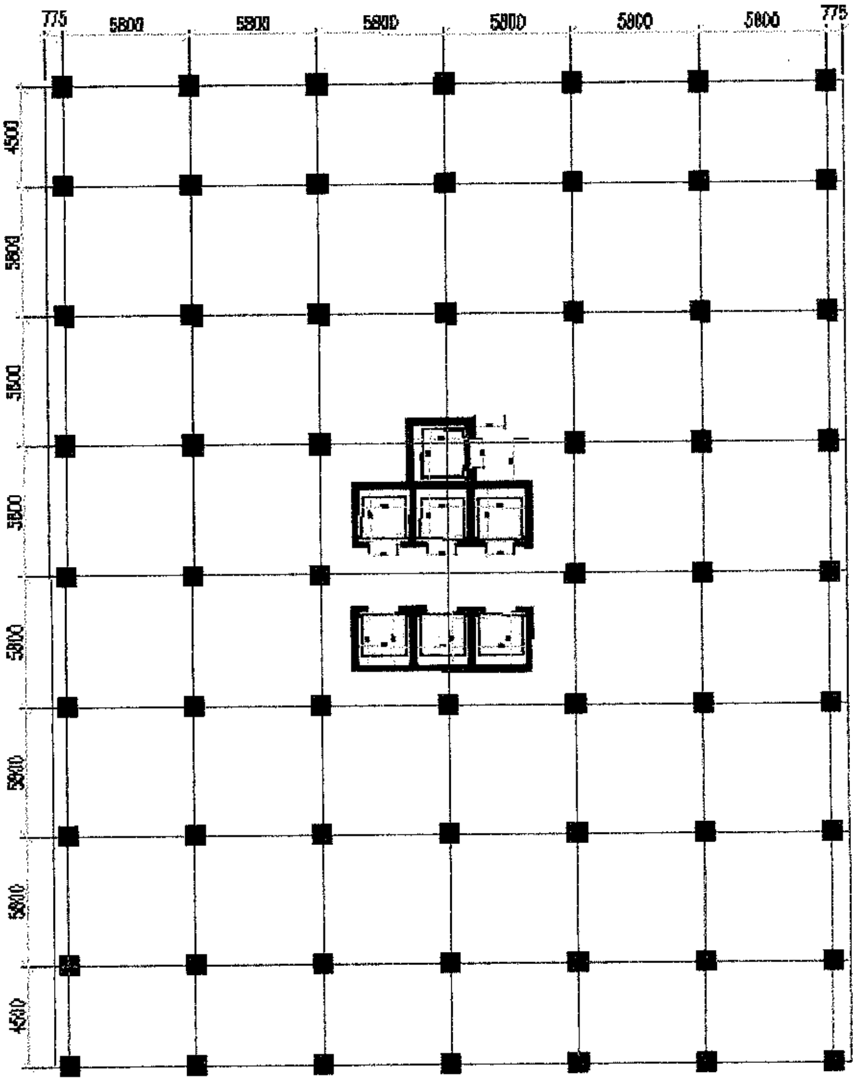

Figure 3.2: Typical floor framing and column layout plan

Figure 3.2 shows the typical floor framing and column layout plan of the multistorey model. The shape of the external and internal columns would be rectangular. Most of the columns were spaced 5.8 m apart while others were spaced 4.5 m apart. The height of the structure model was 13-storeys tall with a common storey height of 4 m. The structure model consists of several beams and also uniformly thick one-way slab as a floor system. The thickness of the slab used for every floors were 200 mm think. Meanwhile, the size of the beams used was 230 x 450 mm.

Similar column sizes were used and they were extended up to 3 storeys before experienced any change in dimension. The dimensions of the columns were gradually being reduced from the lowest 3 storeys to the topmost 3 storeys.

The lift cores were located at the middle of the multistorey building. Hence, the structure model was considered as a braced framing system. Clause 3.8.1.5 (BS 8110:1:1997) [10] stated that " *a column may be considered braced in a given plane if lateral stability to the structure as a whole is provided by walls or bracing or buttressing designed to resist all lateral forces in that plane. It should otherwise be considered as unbraced.* "

3.3 DESIGN SPECIFICATION AND ASSUMPTIONS

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

3.1.1 Design Standard and Codes of Practices

The following codes of practices provide the general guide for the structural member design of the structure model.

- Uniform Building Code (UBC 1997) – Design Wind Pressure
- BS 8110: Part 1: 1997: Structural Use of Concrete
- BS 8110: Part 3: 1985: Structural Use of Concrete

3.1.2 Material Properties

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

Concrete	Grade 25 (25N/mm^2)
Reinforcement	Grade 460 (460N/mm^2)

3.1.3 Base Support

All base supports of the structure model are fully fixed.

3.1.4 Fire Resistance

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

3.1.5 Exposure Condition

All the structural members are considered to have a mild exposure condition.

3.1.6 Nominal Cover

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

3.1.7 Types of Occupancy

The multistorey building is designed for the office purposes.

3.1.8 Structural Form

The type of structural form used in this modeling analysis is a braced rigid frame.

3.1.9 Dead Load and Imposed Load

Dead Load	Self-weight of the reinforced concrete slab, beam and column.
Imposed Load	3.0 kN/m^2

3.1.10 Wind Load

The design wind pressure is computed based on UBC 1997 and subsequently used to calculate the wind load exerting at each level.

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

Where,

C_e is 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

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

Wind stagnation pressure, q_s (kN/m^2) = $0.0006126v^2$ (m/s)

Wind stagnation pressure, q_s (psf) = $0.00256v^2$ (mile/hour)

Where,

V is the basic wind speed

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 building has a height in excess of 70ft which is approximately 21m. Hence, the site is classified as Exposure B. Besides that, office buildings are typically assigned a Standard Occupancy of 1.00 (refer Appendix D).

Basically 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 C 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 E). Consequently, the value for the wind stagnation pressure, qs is 0.7497 kN/m^2.

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 column 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

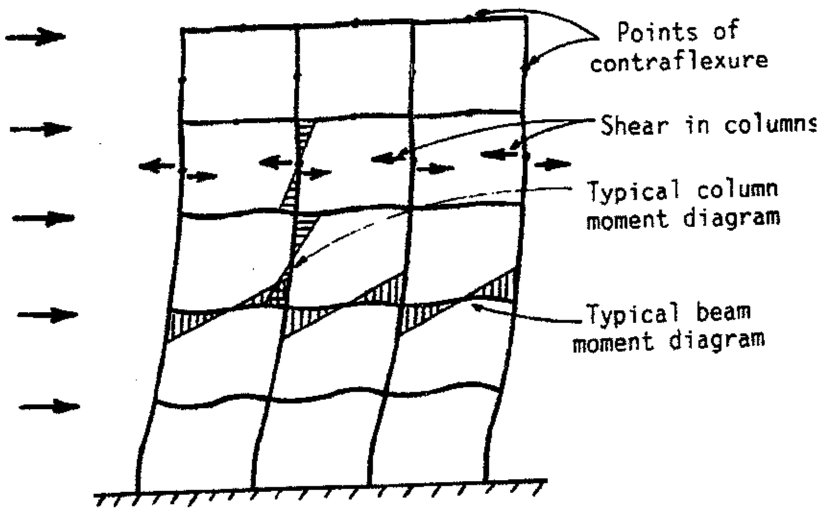

Figure 3.3: Forces and deformation cause by external shear

The results of the wind load calculation and maximum column-end moment for the structure model is displayed in Table 3.1.

Floor Level	q_s (kN/m^2)	C_e		C_q		Wind Load Per Level (kN)	Max. Column moment (kNm)
		WW	LW	WW	LW		
13	0.7497	1.340	1.340	0.8	- 0.5	15.15	5.2
12	0.7497	1.304	1.340	0.8	- 0.5	29.80	15.0
11	0.7497	1.268	1.340	0.8	- 0.5	29.30	24.8
10	0.7497	1.232	1.340	0.8	- 0.5	28.80	34.4
9	0.7497	1.194	1.340	0.8	- 0.5	28.27	43.8
8	0.7497	1.148	1.340	0.8	- 0.5	27.63	53.0
7	0.7497	1.094	1.340	0.8	- 0.5	26.88	62.0
6	0.7497	1.035	1.340	0.8	- 0.5	26.05	70.8
5	0.7497	0.976	1.340	0.8	- 0.5	25.23	79.2
4	0.7497	0.909	1.340	0.8	- 0.5	24.30	87.2
3	0.7497	0.836	1.340	0.8	- 0.5	23.29	95.0
2	0.7497	0.731	1.340	0.8	- 0.5	21.82	102.2
1	0.7497	0.620	1.340	0.8	- 0.5	20.28	109.0

Table 3.1: Result of the wind load calculation and maximum column-end moment for a 13 storeys building

3.1.11 Load Combination

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

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.

3.1.12 Minimum Percentage of Reinforcement

The minimum area of reinforcement for grade 460 should not be less than 0.4% of the gross cross-sectional area of the column.

The minimum area of reinforcement for grade 460 should not be less than 0.13% of the gross cross-sectional area of the slab and beam.

3.1.13 Maximum Percentage of Reinforcement

The maximum area of reinforcement for grade 460 should not exceed 6% of the gross cross-sectional area of the vertically cast column.

The maximum area of reinforcement for grade 460 should not exceed 4% of the gross cross-sectional area of the slab and beam.

3.4 TOOLS REQUIRED

The softwares which were used in this final year project include ESTEEM and ORION.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Slab

Figure 4.1 shows the plan view of the slab. Table 4.1, Figure 4.2, 4.3 and 4.4 illustrate the amount of reinforcement required in the slab Line 2 – 3 modeled by ESTEEM, ORION software and manual calculation respectively.

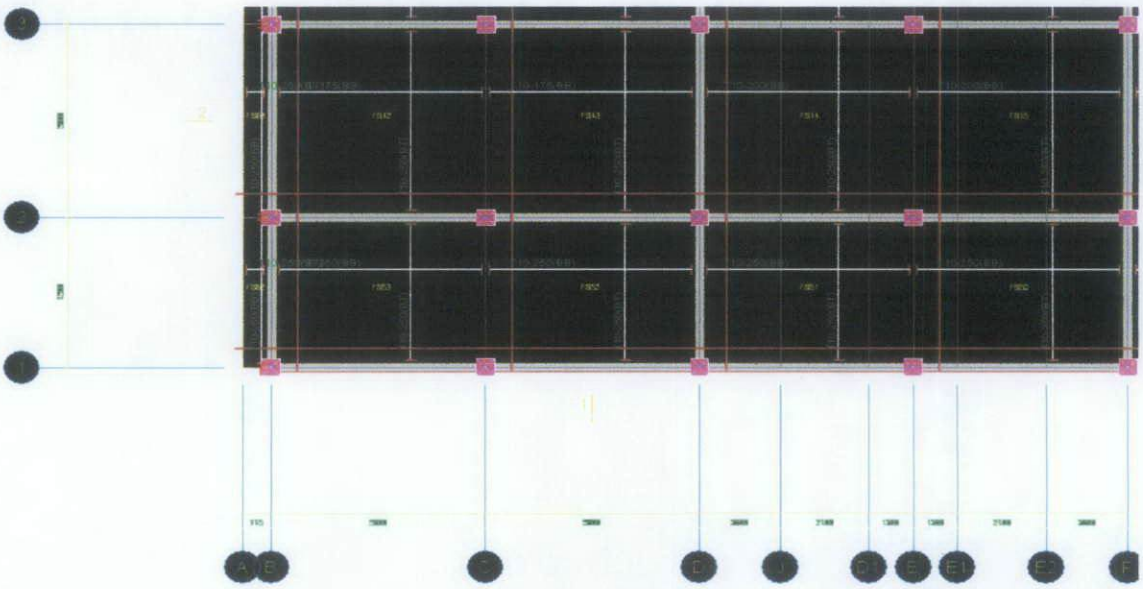

Figure 4.1: Plan view of slab Line 2 – 3

Result	**Main Bar Size**		**Distributional Bar Size** (mm²)
	Side Slab (mm²)	**Middle Slab** (mm²)	
Esteem	T16 – 200 (805)	T16 – 200 (805)	T16 – 200 (805)
Orion	T12 – 150 (754)	T10 – 125 (629)	T10 – 175 (449)
Manual	T12 – 150 (754)	T10 – 125 (629)	T10 – 175 (449)

Table 4.1: Comparison of the amount of reinforcement in the slab

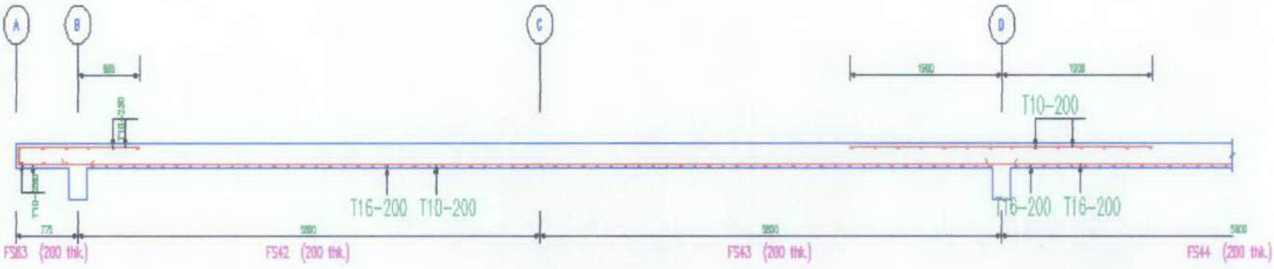

Figure 4.2: Reinforcement bar size in slab results from Esteem software analysis

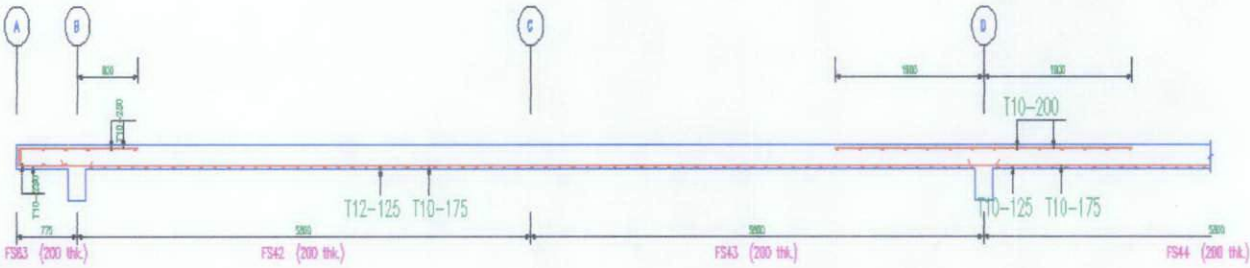

Figure 4.3: Reinforcement bar size in slab results from Orion software analysis

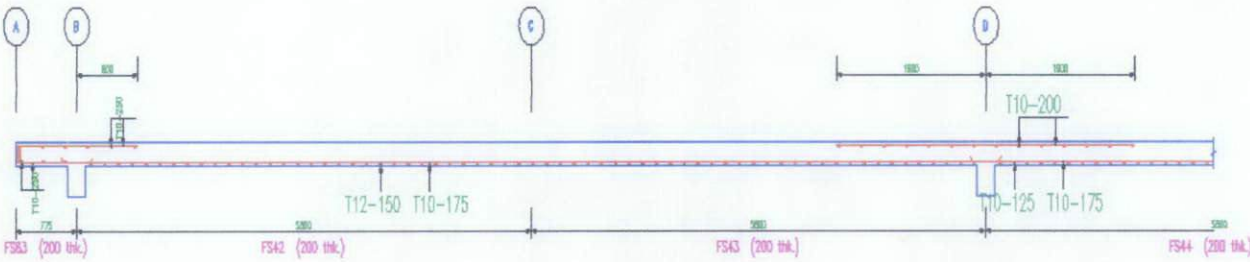

Figure 4.4: Reinforcement bar size in slab results from manual calculation

4.1.2 Beam

Figure 4.5 and 4.6 illustrate the plan view and cross section of the beam respectively. Table 4.2 and 4.3 show the amount of reinforcement required in the beam for middle frame modeled by ESTEEM, ORION software and manual calculation.

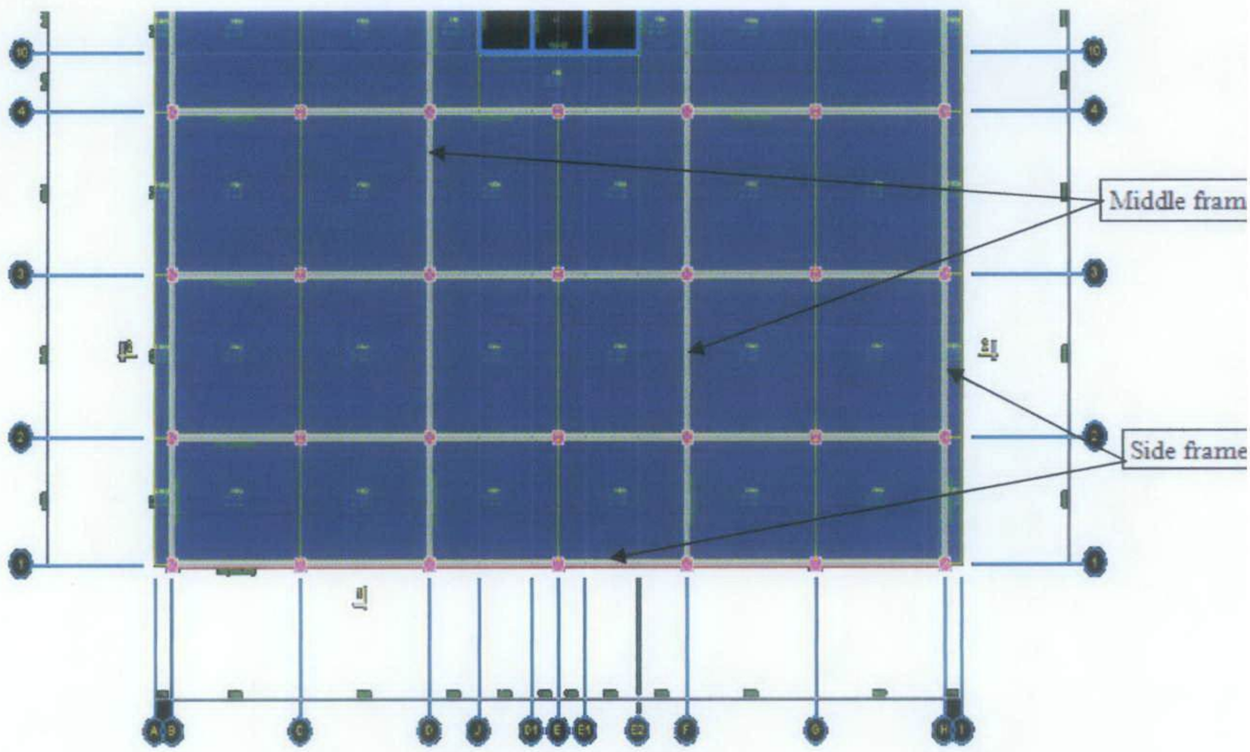

Figure 4.5: Plan view of Beam Line 3

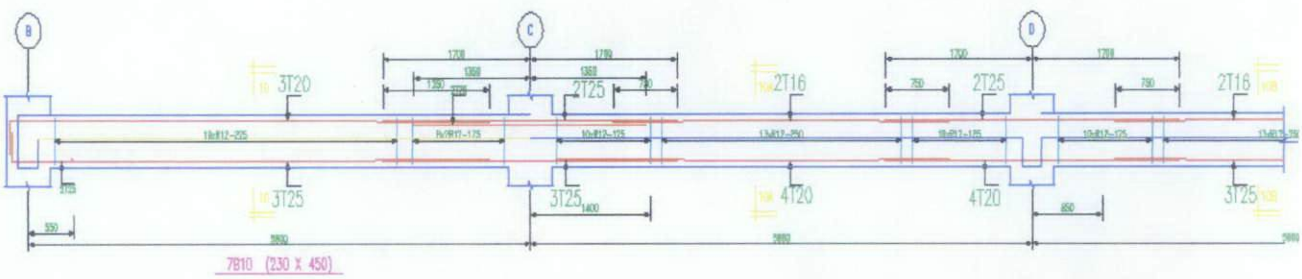

Figure 4.6: Cross section of the beam Line 3

Result	Without wind loading		
	Left hand side (mm^2)	Middle (mm^2)	Right hand side (mm^2)
Esteem	3T25 (1473)	4T20 (1257)	4T20 (1257)
Orion	3T20 (943)	4T16 (805)	4T16 (805)
Manual	3T25 (982)	4T16 (805)	3T20 (943)

Table 4.2: Comparison of beam for middle frame before wind simulation

Result	With wind loading		
	Left hand side (mm^2)	Middle (mm^2)	Right hand side (mm^2)
Esteem	4T25 (1964)** 3T25 (1473)*	4T20 (1257)	3T25 (1473)** 4T20 (1257)*
Orion	4T20 (1257)** 2T25 (982)*	3T20 (943)	3T25 (1473)** 3T20 (943)*
Manual	3T25 (1473)** 4T20 (1257)*	2T25 (982)	3T25 (1473)** 2T25 (982)*

In each row, **shows top reinforcement and * shows bottom reinforcement of the beam

Table 4.3: Comparison of beam for middle frame after wind simulation

4.1.3 Column

Table 4.4 and 4.5 show the amount of reinforcement required in the columns of the multistorey building modeled by ESTEEM V6.6.3.3 and ORION R14 software. The results of the manual calculation are also being included in the tables. The comparison is narrowed to a specific column location which designated as column 3D. Column 3D is classified as a side column located at the middle frame. Figure 4.7 illustrate the location of column 3D.

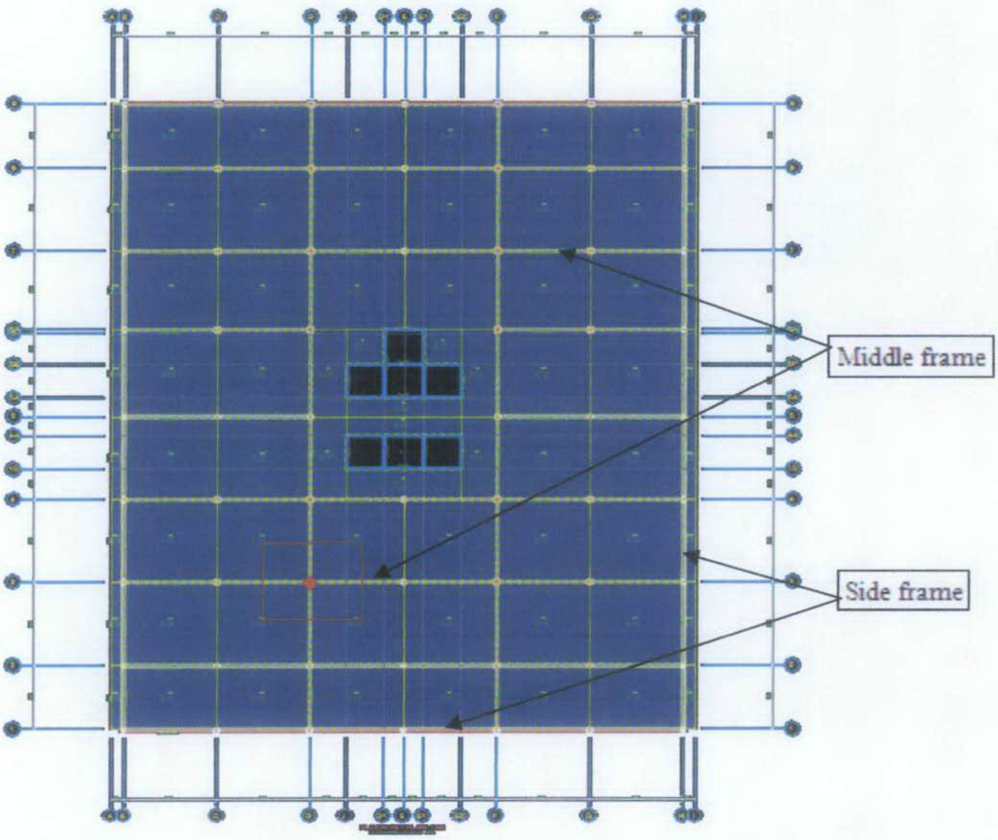

Figure 4.7: Location of side column for middle frame

Floor Level	Column Size (mm)	Side column without wind loading		
		Esteem (mm^2)	**Orion** (mm^2)	**Manual** (mm^2)
11th Floor	400 x 400	5T25 (2455)	7T20 (2200)	12T16 (2413)
7th Floor	500 x 500	12T20 (3770)	10T20 (3142)	7T25 (3428)
4th Floor	700 x 700	8T25 (3929)	11T20 (3456)	11T20 (3456)
Ground Floor	900 x 900	12T25 (5890)	10T25 (4909)	11T25 (5400)

Table 4.4: Comparison of side column for middle frame before wind simulation

Floor Level	Column Size (mm)	Side column with wind loading		
		Esteem (mm^2)	**Orion** (mm^2)	**Manual** (mm^2)
11th Floor	400 x 400	14T20 (4398)	11T20 (3456)	12T20 (3770)
7th Floor	500 x 500	11T25 (5400)	14T20 (4398)	10T25 (4909)
4th Floor	700 x 700	14T25 (6872)	14T20 (4398)	12T25 (5890)
Ground Floor	900 x 900	16T25 (7854)	12T25 (5890)	14T25 (6872)

Table 4.5: Comparison of side column for middle frame after wind simulation

4.2 DISCUSSION

Basically, the structure model of the multistorey building is analyzed for two different loading conditions. For the first part, the structure model is only subjected to gravity loading which consists of live load and dead load. Then, the simulation of the wind loading is taking place in the second part of the analysis.

Slab Line 2-3 has been chosen to evaluate the amount of reinforcement modeled by ESTEEM, ORION software and manual calculation. The slab is design as one-way continuous slab and the result output in Table 4.1 summarize the amount of reinforcement required in the main bars and distribution bars of the slab.

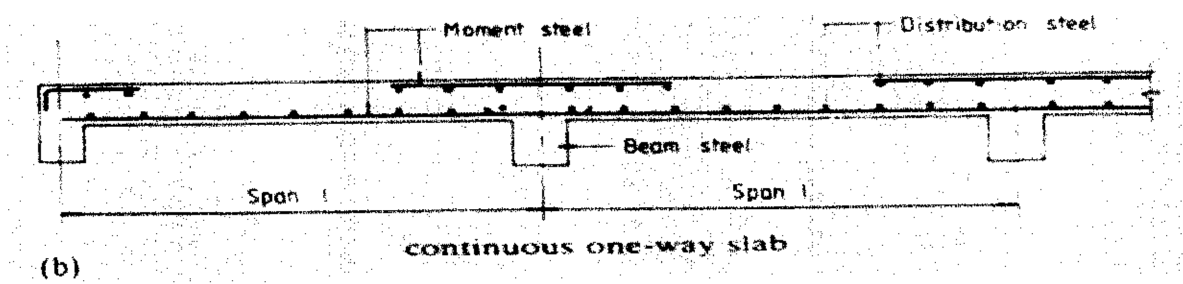

Figure 4.8: Illustration of continuous one-way slab

The deviation in the amount of reinforcement between the side slab and middle slab are due to the different in the amount of bending moment. Theoretically, the bending moment at the side slab is greater than middle slab. Table 4.6 shows the coefficient used to calculate the bending moment in the slab.

	End support/slab connection				At first interior support	Middle interior spans	Interior supports
	Simple		Continuous				
	At outer support	Near middle of end span	At outer support	Near middle of end span			
Moment	0	0.086Fl	− 0.04Fl	0.075Fl	− 0.086Fl	0.063Fl	− 0.063Fl
Shear	0.4F	—	0.46F	—	0.6F	—	0.5F
NOTE F is the total design ultimate load ($1.4G_k + 1.6Q_k$); l is the effective span							

Table 4.6: Ultimate bending moment and shear forces in one-way spanning slabs

The amount of reinforcement in the slab does not change after the wind simulation. This is because, large amount of axial load from load combination of 1.4 Dead Load + 1.6 Imposed Load is governing rather than the load combination of 1.2 Dead Load + 1.2 Imposed Load + 1.2 Wind Load [10], [11]. In another word, wind loading combination is not very significant. For beams and columns, the design must consider wind loading to resist sway in building [13].

Based on the result output in Table 4.1, the amount of reinforcement produced by ORION software is least as compared to ESTEEM software with respect to manual calculation. ESTEEM software produce greater amount of reinforcement because the minimum percentage of reinforcement area fixed by its program is greater than ORION software. The minimum percentage of reinforcement area specified by ESTEEM, ORION and manual calculation are 0.4%, 0.13% and 0.13% respectively.

Usually, the amount of reinforcement required in the slab is small because it only carried the loads from its own floor level. Since the design needs to follow the minimum percentage of reinforcement area specified by the programs, therefore there is a slight deviation in result output evaluated by the chosen softwares.

For the beam analysis, the comparison is specified to the beam for the middle frame located at the ground floor since it takes large amount of bending moment from the effect of wind loading. As shown in Table 4.2 and 4.3, the amount of reinforcement has increased significantly between the case before the wind simulation and after the wind simulation. This happened because beam needs to resist the wind loading and greater amount of reinforcement is required.

In addition, from table 4.3, it can be seen that extra amount of reinforcement has provided in the left and right hand side of the beam. This happened so to develop the necessary moment of resistance because the moment has increased significantly (approximately 20% to 40%) due to wind loading.

The deviation in the amount of reinforcement produced by the chosen softwares is due to uniform consideration of the parameter in the softwares itself. Like slab, the minimum percentage of reinforcement area fixed by the programs influence the amount of reinforcement required in the structural member. The minimum percentage of reinforcement area fixed by ORION software is least as compared to ESTEEM software which is 0.40% and 1.00% respectively. For instance, for a 230 x 450 mm beam, the minimum percentage of reinforcement area required for ORION and ESTEEM software are 414mm^2 and 1035mm^2 respectively. To follow this minimum specification, ESTEEM software tends to produce greater amount of reinforcement rather than ORION software. Hence, ORION software is considered as competent software in producing the optimum structural design with respect to manual calculation.

Furthermore, side column for middle frame is chosen to demonstrate the results output from the column analysis. This is because, the load combination of 1.2 Dead Load + 1.2 Imposed Load + 1.2 Wind Load is more governed. This statement is vise versa to the middle column for middle frame in which the load combination of 1.4 Dead Load + 1.6 Imposed Load is governed.

Based on the results output displayed in Table 4.4 and 4.5, as the storey level decrease the column size require is increased. The column sizes were kept at constant value for different cases so that amount of reinforcement in the column can be differentiated effectively. From the tables, it can be found that the amount of reinforcement has increased significantly after the wind simulation. The deviation is more apparent for the column at the lower floor. The change in the amount of reinforcement before and after wind simulation is approximately 20% to 50%.

Generally, the deviation in the amount of reinforcement for the case before and after wind simulation is not really big. This is because the structure model is designed as a braced framing system with the existence of the lift cores which act as a shear walls. Shear walls are very rigid in their own plane and hence are effective in limiting deflections [4].

On the whole, columns designed by ORION software required the least amount of reinforcement as compared to ESTEEM software. This comparison is made with respect to manual calculation. The deviation in the amount of reinforcement between chosen software and manual calculation is approximately 5% to 25%. Esteem software tends to produce greater amount of reinforcement because its program has specified 10% of the load allowance as the additional loading on top of the reaction loads. This value is multiplied to the loads from the column reaction.

ESTEEM software produced heavy column design as compared to the ORION software and manual calculation in the lowest 3 storeys columns. Since the horizontal wind loading are being assigned manually to the ESTEEM 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. Subsequently, this will cause the columns to be overstressed and thus, higher amount of reinforcement is required.

Based on the results and the above discussion, ORION software proved to produce the most optimum design as compared to ESTEEM software with respect to manual calculation. This is mainly due to the ability of ORION software to analyze the structure by its own features. However, ESTEEM software requires the lateral loads to be inserted manually.

4.3 COST ESTIMATION

The cost estimation for this project is focused on concrete and steel cost only. Table 4.7 and Table 4.8 show the total cost estimate before wind simulation and after wind simulation respectively. The comparison of the total cost estimate is made between chosen softwares and manual calculation. On the whole, the total cost estimate after the wind simulation is higher as compared to before the wind simulation. The different is roughly about 8.3%. This is because the amount of reinforcement in the structural members has increased in order to withstand the lateral loading.

The concrete cost for the structural members do not change since the dimension is still the same for different cases. Nevertheless, the steel cost is change because the amount of reinforcement has increased. Beams and columns give the most significant change for the steel cost. Both of these structural members are important in resisting the building from the wind loading. Moreover, floor slab is the most costly because the amount of reinforcement and concrete used are greatest as compared with other structure members. Floor slab takes approximately 43.5% of the total cost estimate for the superstructure.

On the whole, ORION software gives the least total cost estimate followed by manual calculation and ESTEEM software. ORION software gives less 4.8% of the total cost estimate from manual calculation while ESTEEM software gives additional 6.9% of the total cost estimate from manual calculation. Therefore, ORION software can produce economical design rather than ESTEEM software.

Structure	Esteem	Orion	Manual
Slab	934,752.92	878,811.17	878,811.17
Beam	254,427.52	200,958.35	232,363.29
Column	345,120.76	298,063.44	328,317.85
TOTAL	**1,534,301.20**	**1,377,832.96**	**1,439,492.31**

Table 4.7: Total Cost estimate before wind simulation

Structure	Esteem	Orion	Manual
Slab	934,752.92	878,811.17	878,811.17
Beam	304,049.12	234,730.80	270,991.34
Column	455,223.11	371,023.94	409,576.05
TOTAL	**1,694,025.15**	**1,484,565.91**	**1,559,369.65**

Table 4.8: Total Cost estimate after wind simulation

4.4 COMPARISON OF DIFFERENT STRUCTURAL SOFTWARE

4.4.1 Differences of the Structural Software

On the whole, ORION software is more suitable for tall building modeling as compare to ESTEEM software. This is because ORION software is able to produce optimum structural design without the needs to assign the horizontal wind loading manually. However, ESTEEM software requires the horizontal wind loading to be inserted manually to its program.

Besides, ORION software can produce the design in a short time because its program allows the user to insert the total number of storeys at the start of the program. Then, the design status (whether fail or pass) can be known immediately after the structural member's dimension is assigned. However, ESTEEM software requires the storeys level to be inserted after the precedence storeys have been analyzed. Meanwhile, the design status can be known after the whole structural members have been analyzed and such method is time consuming.

4.4.2 Similarities of the Structural Software

In general, both programs have employed the finite element analysis (FEA) as a practical solution for all structural analysis and design problem. FEA is based on the idea of building a complicated object with simple blocks, or, dividing a complicated object into small and manageable pieces. The procedure of FEM in structural analysis is as following [14]:

- Divide structure into pieces (elements with nodes)
- Describe the behavior of the physical quantities on each element
- Connect (assemble) the elements at the nodes to form an approximate system of equations for the whole structure.

- Solve the system of equations involving unknown quantities at the nodes (e.g., displacements)
- Calculate desired quantities (e.g., strains and stresses) at selected elements

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.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusion can be made based on the analysis of multistorey building using ESTEEM, ORION software and manual calculation:

1. ORION software is the most competent software in term of producing the most optimum structural design with respect to manual calculation.
2. ORION software is capable in producing the economical structural design since the amount of reinforcement required is nearest to the manual calculation rather than ESTEEM software.
3. ORION software is more efficient because its program can produce a design status in a short time as compared to ESTEEM software which is time consuming.
4. There is also a tendency for over-design or under-design to occur in the used of ESTEEM software since the program required to assigned wind load manually and which mainly depends on the accuracy and correctness of the manual method.
5. ORION software is a more advance program in terms of tall building modeling as limitation is encountered in using ESTEEM software.
6. 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 RECOMMENDATIONS

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.
- The multistorey building should be increased in height so that the large deviation in terms of dimension, amount of reinforcement and cost can be validated effectively by the chosen softwares.
- Civil engineering students of UTP should be exposed to structural engineering 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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APPENDICES

APPENDIX A: Gantt Chart FYP 1

	DETAILS	WEEK NO/DATE													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project topic														
2	Research on published work and software application														
3	Submission of Extended Proposal Defence						●								
4	Study the architecture drawing of multistorey building														
5	Proposal Defence										●				
6	Make general assumption of multistorey structural members design													●	
7	Submission of Interim Draft Report														●
8	Submission of Interim Report														

Progress

● Suggested milestone

APPENDIX B: Gantt Chart FYP 2

	DETAILS	WEEK NO/DATE														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Workout a few reinforced concrete examples of respective software	■														
2	Perform structural analysis by chosen software		■	■	■											
3	Perform structural calculation by manual					■	■	■								
4	Submission of Progress report								●							
5	Simulate different loading condition and run the software									■	■					
6	Repeat manual calculation for loading simulation										■	■				
7	Perform structural comparison and recommend the competence software												■			
8	Pre-EDX											●				
9	Submission of Draft Report												●			
10	Submission of Dissertation (Soft Bound)													●		
11	Submission of Technical Paper													●		
12	Oral Presentation														●	
13	Submission of Project Dissertation (Hard Bound)															●

■ Progress ● Suggested milestone

APPENDIX C: Combined Height, Exposure and Gust Factor Coefficient, C_e (UBC

TABLE 16-G—COMBINED HEIGHT, EXPOSURE AND GUST FACTOR COEFFICIENT (C_e)[1]

HEIGHT ABOVE AVERAGE LEVEL OF ADJOINING GROUND (feet) × 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	1.45	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

[1]Values for intermediate heights above 15 feet (4572 mm) may be interpolated.

APPENDIX D: Occupancy Category (UBC 1997)

TABLE 16-K—OCCUPANCY CATEGORY

OCCUPANCY CATEGORY	OCCUPANCY OR FUNCTIONS OF STRUCTURE	SEISMIC IMPORTANCE FACTOR, I	SEISMIC IMPORTANCE[1] FACTOR, I_p	WIND IMPORTANCE FACTOR, I_w
1. Essential facilities[2]	Group I, Division 1 Occupancies having surgery and emergency treatment areas Fire and police stations Garages and shelters for emergency vehicles and emergency aircraft Structures and shelters in emergency-preparedness centers Aviation control towers Structures and equipment in government communication centers and other facilities required for emergency response Standby power-generating equipment for Category 1 facilities Tanks or other structures containing housing or supporting water or other fire-suppression material or equipment required for the protection of Category 1, 2 or 3 structures	1.25	1.50	1.15
2. Hazardous facilities	Group H, Divisions 1, 2, 6 and 7 Occupancies and structures therein housing or supporting toxic or explosive chemicals or substances Nonbuilding structures housing, supporting or containing quantities of toxic or explosive substances that, if contained within a building, would cause that building to be classified as a Group H, Division 1, 2 or 7 Occupancy	1.25	1.50	1.15
3. Special occupancy structures[3]	Group A, Divisions 1, 2 and 2.1 Occupancies Buildings housing Group E, Divisions 1 and 3 Occupancies with a capacity greater than 300 students Buildings housing Group B Occupancies used for college or adult education with a capacity greater than 500 students Group I, Divisions 1 and 2 Occupancies with 50 or more resident incapacitated patients, but not included in Category 1 Group I, Division 3 Occupancies All structures with an occupancy greater than 5,000 persons Structures and equipment in power-generating stations, and other public utility facilities not included in Category 1 or Category 2 above, and required for continued operation	1.00	1.00	1.00
4. Standard occupancy structures[3]	All structures housing occupancies or having functions not listed in Category 1, 2 or 3 and Group U Occupancy towers	1.00	1.00	1.00
5. Miscellaneous structures	Group U Occupancies except for towers	1.00	1.00	1.00

[1]The limitation of I_p for panel connections in Section 1633.2.4 shall be 1.0 for the entire connector.
[2]Structural observation requirements are given in Section 1702.
[3]For anchorage of machinery and equipment required for life-safety systems, the value of I_p shall be taken as 1.5.

APPENDIX E: Pressure Coefficient, C_p (UBC 1997)

TABLE 16-H—PRESSURE COEFFICIENTS (C_q)

STRUCTURE OR PART THEREOF	DESCRIPTION	C_q FACTOR
1. Primary frames and systems	**Method 1** (Normal force method) Walls: Windward wall Leeward wall Roofs[1]: Wind perpendicular to ridge Leeward roof or flat roof Windward roof less than 2:12 (16.7%) Slope 2:12 (16.7%) to less than 9:12 (75%) Slope 9:12 (75%) to 12:12 (100%) Slope > 12:12 (100%) Wind parallel to ridge and flat roofs	 0.8 inward 0.5 outward 0.7 outward 0.7 outward 0.9 outward or 0.3 inward 0.4 inward 0.7 inward 0.7 outward
	Method 2 (Projected area method) On vertical projected area Structures 40 feet (12 192 mm) or less in height Structures over 40 feet (12 192 mm) in height On horizontal projected area[1]	 1.3 horizontal any direction 1.4 horizontal any direction 0.7 upward
2. Elements and components not in areas of discontinuity[2]	Wall elements All structures Enclosed and unenclosed structures Partially enclosed structures Parapets walls	 1.2 inward 1.2 outward 1.6 outward 1.3 inward or outward
	Roof elements[3] Enclosed and unenclosed structures Slope < 7:12 (58.3%) Slope 7:12 (58.3%) to 12:12 (100%) Partially enclosed structures Slope < 2:12 (16.7%) Slope 2:12 (16.7%) to 7:12 (58.3%) Slope > 7:12 (58.3%) to 12:12 (100%)	 1.3 outward 1.3 outward or inward 1.7 outward 1.6 outward or 0.8 inward 1.7 outward or inward
3. Elements and components in areas of discontinuities[2,4,5]	Wall corners[6] Roof eaves, rakes or ridges without overhangs[5] Slope < 2:12 (16.7%) Slope 2:12 (16.7%) to 7:12 (58.3%) Slope > 7:12 (58.3%) to 12:12 (100%) For slopes less than 2:12 (16.7%) Overhangs at roof eaves, rakes or ridges, and canopies	1.5 outward or 1.2 inward 2.3 upward 2.6 outward 1.6 outward 0.5 added to values above
4. Chimneys, tanks and solid towers	Square or rectangular Hexagonal or octagonal Round or elliptical	1.4 any direction 1.1 any direction 0.8 any direction
5. Open-frame towers[7,8]	Square and rectangular Diagonal Normal Triangular	 4.0 3.6 3.2
6. Tower accessories (such as ladders, conduit, lights and elevators)	Cylindrical members 2 inches (51 mm) or less in diameter Over 2 inches (51 mm) in diameter Flat or angular members	 1.0 0.8 1.3
7. Signs, flagpoles, lightpoles, minor structures[8]		1.4 any direction

[1]For one story or the top story of multistory partially enclosed structures, an additional value of 0.5 shall be added to the outward C_q. The most critical combination shall be used for design. For definition of partially enclosed structures, see Section 1616.

[2]C_q values listed are for 10-square-foot (0.93 m^2) tributary areas. For tributary areas of 100 square feet (9.29 m^2), the value of 0.3 may be subtracted from C_q, except for areas at discontinuities with slopes less than 7 units vertical in 12 units horizontal (58.3% slope) where the value of 0.8 may be subtracted from C_q. Interpolation may be used for tributary areas between 10 and 100 square feet (0.93 m^2 and 9.29 m^2). For tributary areas greater than 1,000 square feet (92.9 m^2), use primary frame values.

[3]For slopes greater than 12 units vertical in 12 units horizontal (100% slope), use wall element values.

[4]Local pressures shall apply over a distance from the discontinuity of 10 feet (3048 mm) or 0.1 times the least width of the structure, whichever is smaller.

[5]Discontinuities at wall corners or roof ridges are defined as discontinuous breaks in the surface where the included interior angle measures 170 degrees or less.

[6]Load is to be applied on either side of discontinuity but not simultaneously on both sides.

[7]Wind pressures shall be applied to the total normal projected area of all elements on one face. The forces shall be assumed to act parallel to the wind direction.

[8]Factors for cylindrical elements are two thirds of those for flat or angular elements.

APPENDIX F: Sectional Areas of Groups of Bars (mm^2)

Saiz Bar (mm)	Bilangan Bar								Ukur Lilit (mm)
	1	2	3	4	5	6	7	8	
6	28.3	56.6	84.9	113	141	170	198	226	*18.9*
8	50.3	101	151	201	251	302	352	402	*25.1*
10	78.6	157	236	314	393	471	550	629	*31.4*
12	113	226	339	453	566	679	792	905	*37.7*
16	201	402	603	805	1006	1207	1408	1609	*50.3*
20	314	629	943	1257	1571	1886	2200	2514	*62.9*
25	491	982	1473	1964	2455	2946	3438	3929	*78.6*
32	805	1609	2414	3218	4023	4827	5632	6437	*100.6*
40	1257	2514	3771	5029	6286	7543	8800	10057	*125.7*

APPENDIX G: Sectional Areas Per Metre Width for various Bar Spacing (mm^2)

Saiz Bar (mm)	Jarakantara Bar (mm)								
	50	75	100	125	150	175	200	250	300
6	566	377	283	226	189	162	141	113	94
8	1006	670	503	402	335	287	251	201	168
10	1571	1048	786	629	524	449	393	314	262
12	2263	1509	1131	905	754	647	566	453	377
16	4023	2682	2011	1609	1341	1149	1006	805	670
20	6286	4190	3143	2514	2095	1796	1571	1257	1048
25	9821	6548	4911	3929	3274	2806	2455	1964	1637
32	16091	10728	8046	6437	5364	4598	4023	3218	2682
40	25143	16762	12571	10057	8381	7184	6286	5029	4190

APPENDIX H: Average Price of Building Materials for Peninsular Malaysia

Table 1. Average Price of Building Materials for Peninsular Malaysia (BMDAM)

No.	Description	Unit	Credit Term	Del or Ex	October 2009 Selangor
1	Ordinary Portland Cement (50 kg)	bag	60	del	14.25
2	Ordinary Portland Cement (bulk)	MT	60	del	275.00
3	Granite Aggregate 3/4"	MT	60	ex	21.33
4	Normal River Sand	MT	30	ex	28.00
5	Fine River Sand for Plastering	MT	30	ex	32.00
6	Normal Mining Sand	MT	30	ex	28.00
7	Fine Mining Sand for Plastering	MT	30	ex	32.00
8	Mild Steel Round Bars - 10mm, MS146	MT	14	del	2,076.67
9	Mild Steel Round Bars - 12mm, MS146	MT	14	del	2,076.67
10	Mild Steel Round Bars - 16mm, MS146	MT	14	del	2,010.00
11	Mild Steel Round Bars - 20mm, MS146	MT	14	del	2,043.33
12	Mild Steel Round Bars - 22mm, MS146	MT	14	del	2,043.33
13	Mild Steel Round Bars - 25mm, MS146	MT	14	del	2,043.33
14	Mild Steel Round Bars - 32mm, MS146	MT	14	del	2,043.33
15	High Tensile Deformed Bars - 10mm, MS146	MT	14	del	2,076.67
16	High Tensile Deformed Bars - 12mm, MS146	MT	14	del	2,076.67
17	High Tensile Deformed Bars - 16mm, MS146	MT	14	del	1,976.67
18	High Tensile Deformed Bars - 20mm, MS146	MT	14	del	1,976.67
19	High Tensile Deformed Bars - 25mm, MS146	MT	14	del	1,976.67
20	High Tensile Deformed Bars - 32mm, MS146	MT	14	del	1,976.67
21	BRC Fabric - A6, MS145	m^2	30	del	5.60
22	BRC Fabric - A7, MS145	m^2	30	del	7.62
23	BRC Fabric - A8, MS145	m^2	30	del	9.97
24	BRC Fabric - A9, MS145	m^2	30	del	12.59
25	BRC Fabric - A10, MS145	m^2	30	del	15.53

Source of Data: This average price is compiled from data supplied by BMDAM.
MT = Metric Ton or Tonne, m^2 = Square Metre, m^3 = Cubic Metre, Del = Delivered, [illegible] Sand Pit

Table 1. Average Price of Building Materials for Peninsular Malaysia (BMDAM) (Continue...)

No.	Description	Unit	Credit	Del or Ex	October 2009

Table 1. Average Price of Building Materials for Peninsular Malaysia (BMDAM) (Continue...)

No.	Description	Unit	Credit Term	Del or Ex	October 2009 Selangor
26	Ready Mix Concrete - Normal Mix - Grade 10	m^3	30	del	186.00
27	Ready Mix Concrete - Normal Mix - Grade 15	m^3	30	del	191.00
28	Ready Mix Concrete - Normal Mix - Grade 20	m^3	30	del	196.00
29	Ready Mix Concrete - Normal Mix - Grade 25	m^3	30	del	203.00
30	Ready Mix Concrete - Normal Mix - Grade 30	m^3	30	del	212.33
31	Ready Mix Concrete - Normal Mix - Grade 35	m^3	30	del	222.00
32	Ready Mix Concrete - Normal Mix - Grade 40	m^3	30	del	233.67
33	Clay Brick - Pallet	piece	30	del	0.27
34	Smooth Face Facing Brick, Red	piece	30	del	0.79
35	Cement Sand Brick - Pallet	piece	60	del	0.20
36	Precast Concrete Hollow Block 90mm x 190mm x 390mm M.S 27 1996	piece	60	del	1.82
37	Plain Gypsum Partition Board, 1.2m x 2.4m x 12mm thick, Boral/Armstrong	sheet	30	del	27.30
38	Laminated Gypsum Partition Board, 1.2m x 2.4m x 12mm thick, Boral/Armstrong	sheet	30	del	40.33
39	Corrugated Roofing Sheet - 76mm Double Width, 1065mm x 2440mm x 4mm (Hume/ Malex/ UAC)	sheet	60	del	22.90
40	Interlocking Concrete Tiles - Standard Duotone Colour (Monier Elabana)	piece	60	del	1.62
41	MS Decking - Lysaght Clean Colorbond - Kliplok Hi-Ten 0.53mm TCT	m^2	60	del	60.93
42	MS Decking - Lysaght Clean Colorbond - Spandek Hi-Ten 0.47mm TCT	m^2	60	del	53.03
43	MS Decking - Lysaght Clean Colorbond - Trimdek Hi-Ten 0.47mm TCT	m^2	60	del	52.87
44	MS Decking - Ajiya AP Rib Hi-Tensile G28, 0.40mm TCT, Clean Colorbond (Commercial)	m^2	60	del	39.07
45	MS Decking - Ajiya AP Rib Hi-Tensile G26, 0.47mm TCT, Clean Colorbond (Commercial)	m^2	60	del	42.67

Source of Data: This average price is compiled from data supplied by BMDAM
MT = Metric Ton or Tonne, m^2 = Square Metre, m^3 = Cubic Metre, Del = Delivered, Ex = Ex-Factory, Ex-Quarry, Ex-Sand Pit

APPENDIX I: Building Material Cost Index by Category of Building and Region

Table 1. Building Material Cost Index by Category of Building and Region (Jul 2002 = 100)

Category of Building	Period	Region A	Region B	Region C	Region D	Region E
		Pulau Pinang, Kedah, Perlis	Perak	Kuala Lumpur, Selangor, Negeri Sembilan, Melaka	Johor	Pahang
(3) Hotel Building	Jan-10	144.9	140.7	148.0	145.2	149.8
	Feb-10	146.0	142.4	148.1	145.9	150.2
	Mar-10	150.6	146.5	152.8	149.9	155.3
	Apr-10	152.8	149.7	156.1	154.1	159.6
	May-10	154.5	151.0	157.0	155.1	161.9
	Jun-10	150.2	147.5	153.6	150.3	157.3
	Jul-10	149.8	146.1	153.2	150.8	156.2
	Aug-10	149.3	146.0	153.1	149.6	158.3
	Sep-10	149.4	146.0	153.1	149.6	158.5
	Oct-10	147.7	144.3	151.6	148.3	157.7
	Nov-10	147.0	143.7	151.9	147.6	158.4
	Dec-10	148.4	145.1	152.7	148.7	160.9
(4) Office Building	Jan-10	150.0	145.9	153.2	151.3	152.9
	Feb-10	151.5	148.1	153.6	152.3	154.7
	Mar-10	156.9	152.8	159.1	157.0	160.3
	Apr-10	161.2	156.9	163.4	162.4	164.7
	May-10	162.1	158.3	164.1	163.4	169.0
	Jun-10	156.2	153.7	159.5	157.2	161.9
	Jul-10	154.4	152.0	158.9	157.7	160.5
	Aug-10	154.9	151.7	158.6	156.1	162.2
	Sep-10	154.9	151.7	158.6	156.2	162.8
	Oct-10	152.7	149.6	156.8	154.4	161.3
	Nov-10	151.9	148.9	156.3	153.6	161.8
	Dec-10	153.8	150.6	158.0	155.1	164.4
(5) Commercial Building	Jan-10	147.9	144.5	150.8	149.6	151.4

Source of Data: This index is compiled from data supplied by Department of Statistics, Malaysia.

APPENDIX J: Example of ESTEEM software interface

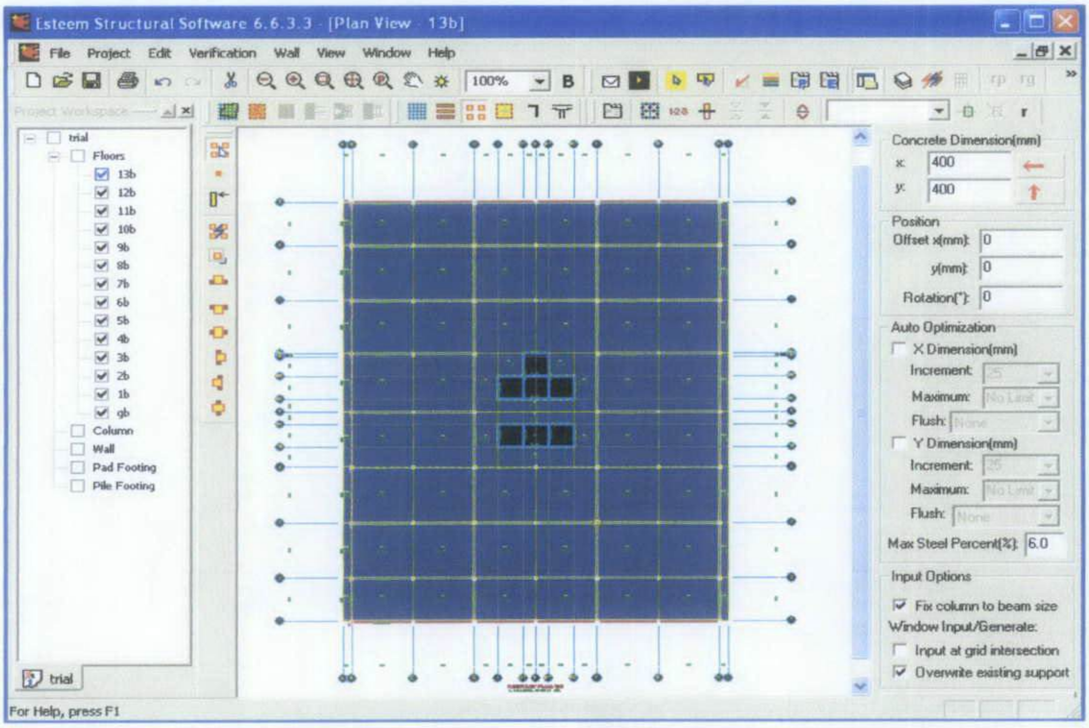

Figure J-1: Structural properties being assigned to the structure model

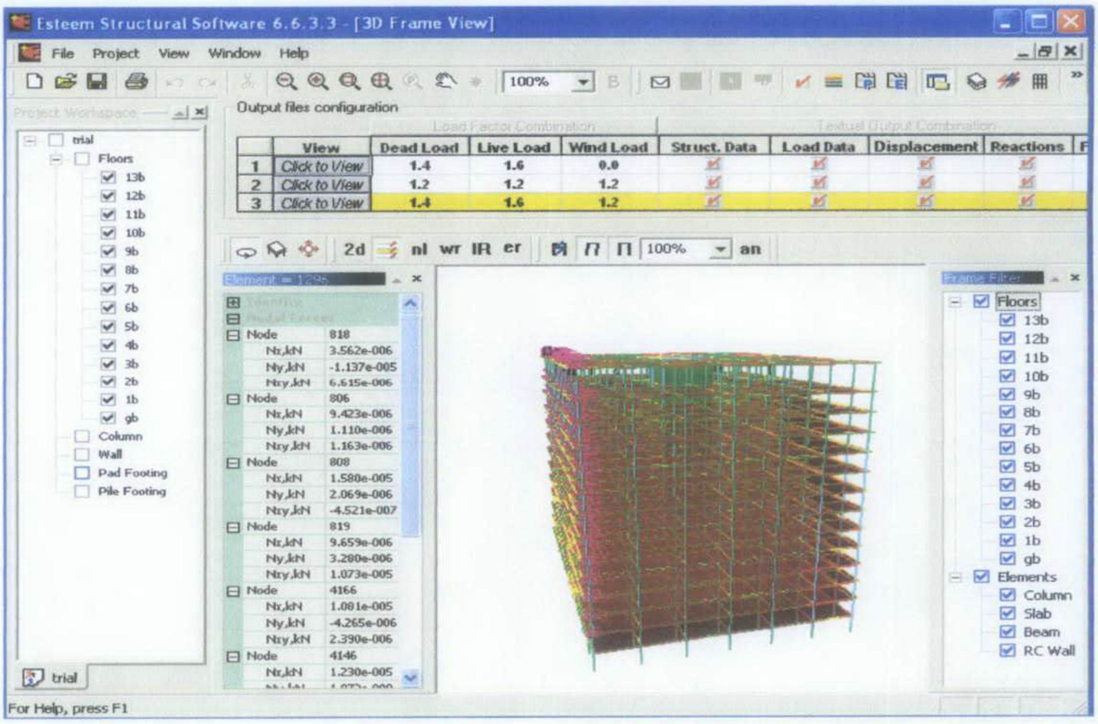

Figure J-2: Loads are being assigned to the structure model

APPENDIX K: Example of ORION software interface

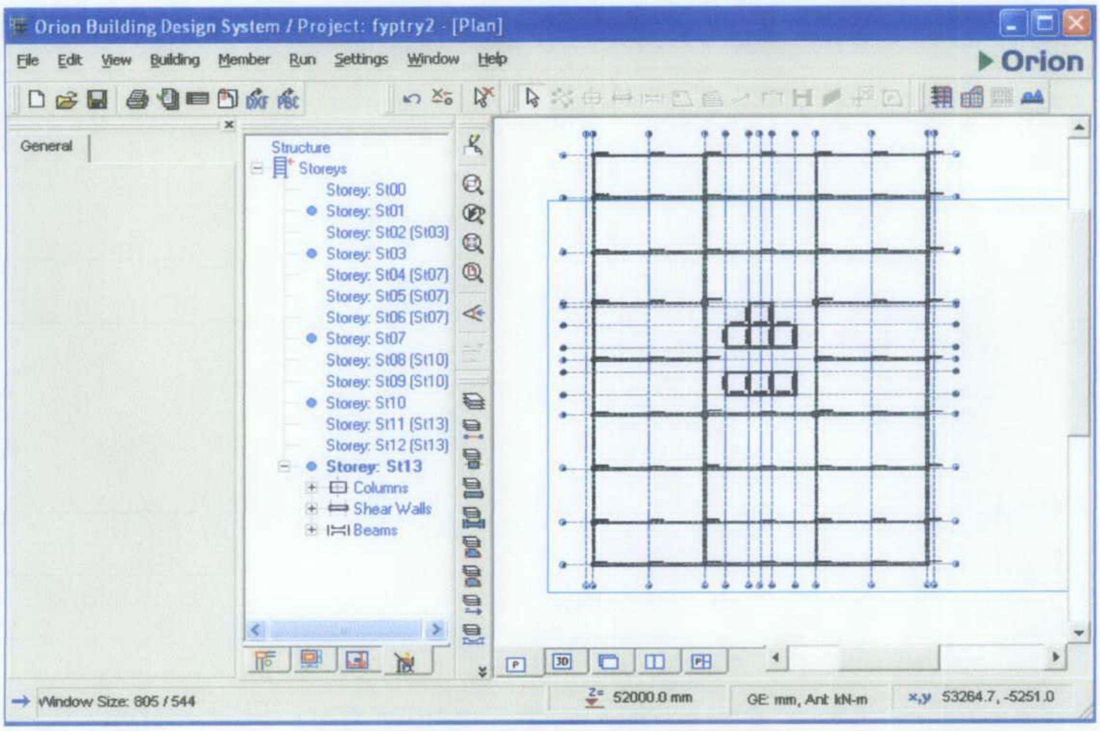

Figure K-1: Plan view of structure model

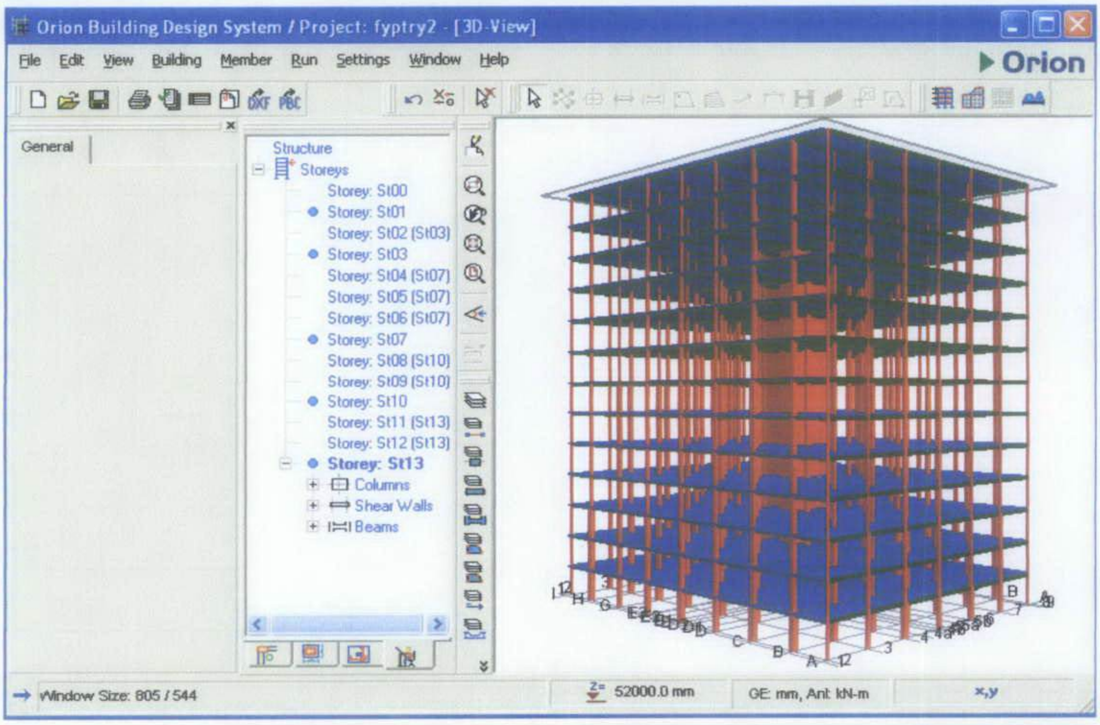

Figure K-2: Three dimensional rendered view of structure model