DEVELOPMENT AND COST ANALYSIS OF A NEW IBS SYSTEM

by

KAREN CHIN MAY LIN
24527

Dissertation submitted in partial fulfilment of
the requirements for the

BACHELOR OF ENGINEERING (Hons)
(CIVIL)

JANUARY 2021

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Development and Cost Analysis of a New IBS System

by

Karen Chin May Lin

24527

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)
(CIVIL)

Approved by,

____

IR. DR. MUBARAK BIN ABDUL WAHAB

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2021

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.

Karen.

KAREN CHIN MAY LIN

ABSTRACT

Conventional in-situ construction has indeed been one of the most common construction methods till date, and is being adopted in most of the construction projects in Malaysia. Despite its familiarity among designers, contractors and labours, there are many disadvantages of it, including time consuming, labour intensive, dangerous site condition and many more. Cost and time overrun due to the usage of unskilled foreign worker proves the need of shifting to a more organized method of construction, which is the Industrialized Building System (IBS).

In this project, studies were done to develop an improved method of construction using IBS components for critical elements of a two-storey residential building. The goal is to achieve a lightweight structure, with possible reduction in labour usage, shorter construction time, and also overall cost reduction. After an extensive literature review, the system was proposed to be made up of structural steel framing, composite slab and lightweight concrete block wall. The structure was analyzed using Software A and was verified to be structurally stable under the loading combinations as indicated by Eurocode. Comparison on the material and labour costs of both the proposed method and conventional method of construction had shown that the proposed system is able to reduce the material costs, labour costs, and shorten the construction time. These results aligned with the previous literature stating that IBS enhances the productivity and duration of a construction project, and will help to increase the confidence of contractors and developers in transforming into IBS with the proven overall cost saving.

ACKNOWLEDGEMENT

I would like to express my utmost gratitude to several individuals for supporting me throughout my four-year degree studies. First and foremost, I would like to thank my parents and family for their constant support and concern on my well-being and education. They have provided me with a conducive learning environment which I am really grateful of.

Next, I wish to express my deepest gratitude to my supervisor, Ir. Dr. Mubarak for his valuable guidance, advice and encouragement throughout the project. His professional expertise has greatly helped in preparing me for my future career as an engineer. My greatest appreciation to all the lecturers from the Civil and Environmental Engineering Department of Universiti Teknologi PETRONAS (UTP), who has taught me with their dedication.

Special thanks to the local IBS manufacturers who have spent their precious time in providing information and consultations to answer my queries. I have gained much insight on the design of IBS components from them.

Last but not least, I would like to thank my friends who have ever provided supports and encouragement to me throughout my studies in UTP. They have made my university life a memorable one and these friendships are invaluable to me. Without the support from all of these parties, I would not be able to complete my degree and accomplish this project successfully.

TABLE OF CONTENTS

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Background Study

Industrialized Building System (IBS) is a term specifically used in Malaysia to represent the type of construction method where structural components like beams and columns are manufactured in a controlled environment either on or off site, and then being transported, positioned and assembled into the desired structure (CIDB, 2016). This construction system is better known worldwide as pre-fabricated, Off-Site Manufacture (OSM), modular construction or Modern Method of Construction (MMC). With this technique, site works like bar bending and formwork placing are being greatly minimized, and the quality of the components is constantly high.

According to Construction Industry Development Board (CIDB, 2016), IBS systems in Malaysia can be classified into five main groups:

(a) Precast concrete framing, panel and box systems

This is the most common group of IBS products used. Frame system involves the load transfer from precast concrete beams or girders, to the columns and eventually to the ground. In panel system, loads are being transferred through large floor and wall panels. While for box system, 3D modules are being fabricated which can be transported at one time.

(b) Steel formwork system

Othuman Mydin, Sani and Taib (2014, p. 1002) states that steel formwork system is the least pre-fabricated types of IBS. In this method, concrete is being placed on site into steel formwork, resulting in high quality finish and reduced construction time.

(c) Steel framing system

Steel trusses, beams, and portal frame system are some examples of this IBS category. They are mainly used for high rise or long span structures.

(d) Prefabricated timber framing system

This system comprises of pre-fabricated timber trusses, beams and columns. Its market demand lies on buildings requiring high aesthetical values like chalets.

(e) Block work system

Components like interlocking Concrete Masonry Unit (CMU) and lightweight concrete blocks are developed to replace the tedious work from traditional bricklaying.

Pre-fabricating structural elements in the factory brings a lot of advantages over conventional wet construction. By mass producing in the factory, quality is being closely monitored and controlled. Less waste is being generated as the components are manufactured in the desired dimension and with high precision. Timber formwork is also being replaced with reusable concrete or steel mould, saving on the Earth's natural resources. The construction time is significantly reduced as there will be mostly installation of pre-fabricated panels onto the load bearing frame at the construction site. This can be done by purely a few labours and this indirectly saves on the labour cost. Less machineries and cranes are required, allowing the site condition becomes tidier and more organized, resulting in a safer site condition. Off-site construction is also less influenced by the weather, significantly enhancing the quality of work, for instance concrete curing (Othuman Mydin et al., 2014, p.1002). The overall cost can be reduced especially when similar units are being mass produced. Repetitive designs like residential housings will definitely benefit from this advantage brought by IBS system. All in all, IBS system is said to be able to boost sustainability of the construction industry.

One of the downfalls of pre-fabricated construction is that there is less flexibility in the design of structural members as the specifications and dimensions are taken directly from the manufacturer, and customization will be required for special designs, inducing extra cost on the project. However, with the increasing number of manufacturers in the market, designers are given more options to select the components based on their needs.

1.2 Problem Statement

Construction industry has been long identified as 3D (Dirty, Dangerous and Difficult) and labour-intensive. In Malaysia, construction industry is still mainly focusing on traditional method of construction, for example reinforced concrete framing which involves timber formwork and in-situ placing of concrete elements like columns, slabs and beams, and brick wall construction. This type of construction method is time consuming, producing more waste, and is susceptible to more reworks due to its complexity and various uncertainties throughout the construction process.

Moreover, finding for inheritance of skilled labours for this job has also been and will still be a real challenge as millennials and generation Z's are unwilling to take up the jobs. Due to the tiring nature of work and low wages provided with a limited career development opportunity, construction sector in Malaysia is very much dependent on cheap migrant labours. However, most of the foreign workers are unskilled, which leads to low productivity and poor quality of work, not to mention the social problems that were also created (Iskandar Zulkarnain et al., 2019, p. 1007). Often, projects face with time and cost overruns due to the needs for rework. This indirectly leads to the reduction in quality of work.

All of these issues urge the need of shifting to a better construction method, particularly the Industrialized Building System (IBS). Despite the various benefits that IBS offer, its implementation in Malaysia is still not as encouraging. One of the reasons lies in the perception that IBS is expensive due to the higher material cost and cost for labour training. Thus, this project will work on developing an improved method of construction which suits the needs and expectations of the local communities and construction industry players, together with evaluating its economic feasibility in order to achieve a system which is lightweight in nature, with fewer labours required, and reduces time and overall cost.

1.3 Objectives

The objectives of this project are as follows:

i. To develop a new IBS system for low-rise residential building in a tropical country which fulfils the parameters of light weight, minimized labour usage, overall cost-saving and also time saving.
ii. To evaluate the proposed system in terms of structural performance and cost.

1.4 Scope of study

In this project, the scope of work will be focusing on the following:

i. Perform structural analysis on the elements including structural framing, slab, and foundation for the proposed IBS system.
ii. Perform cost analysis for the proposed method of construction.

A 2-storey residential housing located in Malaysia will be utilized as the project model to facilitate the analysis.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 Overview of Malaysian Construction Industry

Construction industry has been a major contributor to the country's economy and Gross Domestic Product (GDP) as it helps to provide for other sectors as well. With an increasing population, the demand for construction sector increases as well, be it a residential housing, commercial, institutional, or an infrastructure project like highway. Unlike manufacturing sector, every construction project is unique. Construction projects are fragmented and involve a number of parties. Construction projects are resource oriented; among the resources is money, machineries, materials and manpower. Construction site is often perceived as 'dirty, dangerous and difficult' (3D), and the constraints of project include quality, time and cost. Thus a successful project can be indicated by several factors: good quality of work, completion of project on time, and within budget.

Construction industry in Malaysia has been facing with several issues. Firstly, the shortage of skilled labour. In fact, Malaysia has established Technical and Vocational Education Training (TVET) institutions which aimed to provide skilled workers for construction sector; however, there is still a shortage of local skilled workers to meet the demand (Salleh et al., 2020, p. 620). This is because the locals are unwilling to take up the job due to the low wage rates and negative perception on the job (Ang et al., 2018; Salleh et al., 2020, p. 626). With the abundance of a cheaper alternative, which is the foreign labour, employers are often not willing to increase the wage for local workers, or to adopt new construction technologies as they are already used to the conventional method of construction. This results in an over reliance on migrant labour, which can be seen from the statistics from Department of Statistics Malaysia, stating that 22.4% of employment in construction sector in the year 2016 was taken up by foreigners (Ang et al., 2018). This is worsened by the fact that most of the foreign labours are unskilled, which is one of the main causes of low productivity and quality of work (Durdyev & Ismail, 2016, p. 453; Yap et al., 2017). The use of unskilled labour leads to the need of frequent reworks in order to improve quality of work done. Not only that, foreign workers can precipitate economic and social problems (Abdul Kadir et al., 2006, p. 416; Ang et al., 2018).

Other than unskilled workers, Yap et al. (2017) found out that poor coordination between parties, and poor quality of construction technology leads to reworks as well. In traditional contract model, contractors are often not involved during the planning or design stage, causing the lack of constructability consideration in the early stage. This leads to design error being identified during construction stage and reworks has to be done to mitigate the problem. With this, reworks bring negative impacts to both the cost and schedule of project. It incurs an additional cost of about 3-6% of contract sum, and 5-10% of schedule delay (Yap et al., 2017, p. 602). Quality of work will be affected as well. As a consequence of all these issues, construction projects in Malaysia often face with time and cost overrun. Another reason to low productivity that is worth mentioning is the poor weather conditions as stated by (Durdyev & Ismail, 2016). Activities like concrete casting and curing are weather dependent, thus poor weather conditions might lead to the delay of project if cast-in-situ method is utilized. Hence, all of these issues imply the need of shifting to a more systematic and organized method of construction.

2.2 Implementation of IBS in Malaysia

In Malaysia, introduction of Industrialized Building System (IBS), which is a form of off-site manufacturing and prefabrication, is said to be a measure to increase productivity, and to reduce over dependency of construction sector on foreign labours (Mohd Amin et al., 2017). It has been introduced in Malaysia since decades ago, during the early 1960's. Modern prefabrication was first introduced in Europe after the World War 2 which caused a lot of destructions and people were in desperate need of accommodations. CIDB (2016) believes that IBS is able to reduce the number of workers required by half and also the construction costs by 14%, which is beneficial especially when mass production of components is applicable.

In line with the effort of transforming construction process to a mechanized or industrialized approach, Construction Industry Master Plan (CIMP) 2006-2015 was established under CIDB. Through IBS Roadmaps, it is anticipated for IBS implementation in construction projects to increase. The effort is continued through the initiation of Construction Industry Transformation Programme (CITP) 2016-2020. The goal is to transform the construction industry through four strategic thrusts, which are Quality, Safety and Professionalism; Environmental Sustainability; Productivity; and Internationalization (CIDB, 2016). IBS is classified as one of the technologies under the effort to enhance productivity, though it contributes to other goals as well.

Despite the various benefits that IBS offers, its implementation in Malaysia is still low (Mohd Amin et al., 2017; CIDB, 2016). From the survey conducted by Md. Ali et al. (2018), and Razak and Awang (2014), it was found that the low adoption of IBS system is mainly due to two reasons, which are the insufficient knowledge on this system, and the higher initial cost required. Skilled workers are required in IBS to ensure project quality. This causes the contractors and developers to be reluctant to transform into IBS system despite its higher productivity, because they are already used to the conventional construction methods, and transformation will mean additional trainings for the workers and a higher upfront cost.

The problem associated with IBS also includes the technical and quality problems of the prefabricated components. A few researchers agree that connections and jointing methods is one of the aspects that require further Research and Development (R&D) activities (Md. Ali et al., 2018; Razak & Awang, 2014). Innovative approaches are needed to tackle issues like cracks and leakage in the building. It will be essential too for the designers to be well versed in the design using this relatively new method of construction.

2.3 Comparison between Conventional Method of Construction and IBS

Past research papers on the comparison between conventional method of construction and IBS were being studied, where most of the researches were based on case studies and questionnaires. From the studies done, it was found that most of the projects including residential and school projects are still utilizing traditional method of construction, which is cast-in-situ method (Abdul Kadir et al., 2006, p. 417; Haron & Abd. Mutalib, 2012, p. 48; Md. Rahim & Haron, 2013, p. 24).

In terms of construction time, it is agreed that IBS enables a faster construction as labour productivity is higher, and it involves mostly skilled workers. Thus IBS requires a smaller crew size as well. Not to forget the site overhead costs in a construction project, which includes site staff wages, labour accommodation, utilities, labours' insurance and so on. With a shorter construction time, cost saving can be obtained through reduction in overhead costs.

There are a few contradictions when it comes to cost comparison between conventional and IBS system. From the survey done by Ramli et al. (2016), most respondents agree that IBS enables a cost reduction of 6 to 10%, and the case study result also indicates that there is a 11.9% reduction in the cost of half slab as compared to traditional cast-in-situ slab. Case study on a condominium project has found to achieve a lower tender price when the project is switched to IBS formwork system (Md. Rahim & Haron, 2013). On the other hand, Haron et al. (2005), and Haron and Abd. Mutalib (2012) who performed case studies on school project realized that conventional system is more cost saving. This is because IBS is costly in terms of the components due to limited number of manufacturers and specialized contractors. Transportation may also contribute to a higher cost.

Although both Haron et al. (2005) and Md. Rahim and Haron (2013) were comparing the same methods which are conventional system and IBS formwork system, they got a different finding. This might be due to Haron et al. (2005) only considered the material costs, while Md. Rahim and Haron (2013) also took into consideration the labour costs, equipment costs, and overhead costs. This can be verified by the study conducted by CIDB (n.d.), in which the cost comparison has included structural costs, costs for finishes and also site overhead costs, and the result indicates that project utilizing full IBS system is obtained to be the most cost saving as compared to partial IBS system and conventional system. Besides, it may be deduced that cost reduction depends on the different types of IBS system being utilized. As an example, since formwork system contributes to only partial IBS Factors in IBS Scoring System, it might not be able to achieve a significant cost saving as compared to components that contribute full IBS Factors such as precast concrete columns. Conclusively, cost is still an issue that hinders the contractors from shifting to IBS due to the fact that there isn't a definite saving in IBS as compared to traditional method of construction in terms of materials.

2.4 Lightweight Construction

Apart from utilizing IBS, another criterion for the proposed system in this project is lightweight construction due to the various benefits it offers. Lightweight construction generally composed of a timber or light steel framing which acts as structural support for the building, and non-structural claddings made from lightweight materials are being attached to it, acting as wall components. Dorr and Stark (2018) perceive lightweight construction as an effort to improve the useful weight to dead weight ratio of the structure without affecting its structural functionality. Some examples of these innovative lightweight materials are lightweight concrete, structural insulated panels and polystyrene building products. These lightweight components often come in the forms of panels or blocks, where panels may contribute to a relatively shorter construction time.

While the most common method of construction for walls in Malaysia is the brick and mortar due to it being readily available and that the communities are very much comfortable with it, this kind of heavyweight construction might pose some disadvantages over lightweight construction. Due to their larger weight, they have greater thermal mass, which is undesirable in tropical countries as high thermal mass materials tend to store heat during the day and release heat at night. They also have a higher embodied energy as compared to lightweight materials, and require higher construction costs, specifically in the site preparations and materials transportation (Kelly, 2017).

In contrast, lightweight materials tend to save on construction materials, for example by achieving smaller column and foundation sizing due to lower self-weight of structure. They have a more rapid response towards temperature change, thus is able to cool more quickly. With this, the energy required for cooling is drastically reduced. They can also help in saving transportation cost and crane for handling, enhancing the building's overall sustainability. Lightweight construction can save on construction time as well especially when the components are pre-fabricated off site. Most importantly, handling lightweight elements greatly reduces workplace hazard, which assures workers' safety. Residential houses usually share common designs across the whole domestic area, thus mass production is possible, results in greater savings in terms of materials' unit price and transportation cost.

Development of a lightweight construction requires the designer to be equipped with knowledge on the material properties, production technology and also the costs (Dorr & Stark, 2018). It will not be beneficial if the advantages brought by lightweight construction require a very high cost to implement. Unfortunately, from the past researches, there are insufficient studies done on the development of lightweight construction together with the cost aspect. Hence, this project will focus not only on the development of lightweight construction methods, but also the economic requirements for the implementation.

2.5 Gap of Research

From the studies, we can conclude that there is a need for a simple and innovative way of construction which is able to reduce the construction time, cost and labours required, with improved quality and durability. It would be best too to adopt lightweight construction, and also putting effort on environmental sustainability through lesser waste production. Although IBS is identified as one of the solutions, it is seemed that the implementation in Malaysia is still low. It is well acknowledged that utilization of IBS saves construction time, enhances project quality, and reduces reliance on foreign labours; however, cost impact appears to be the barrier to adoption of IBS in construction projects. There is still insufficient research available on the cost comparison between conventional system and different types of IBS. Thus, this project will work on developing a prefabricated system with the aforementioned properties and lightweight property to improve on construction productivity. Cost comparison will be done utilizing the same building layout to ensure uniformity and to ensure that a cost-effective system can be introduced.

CHAPTER 3

METHODOLOGY

3. METHODOLOGY

Figure 1 shows the flow of work throughout this project in order to achieve the objectives in an organized manner.

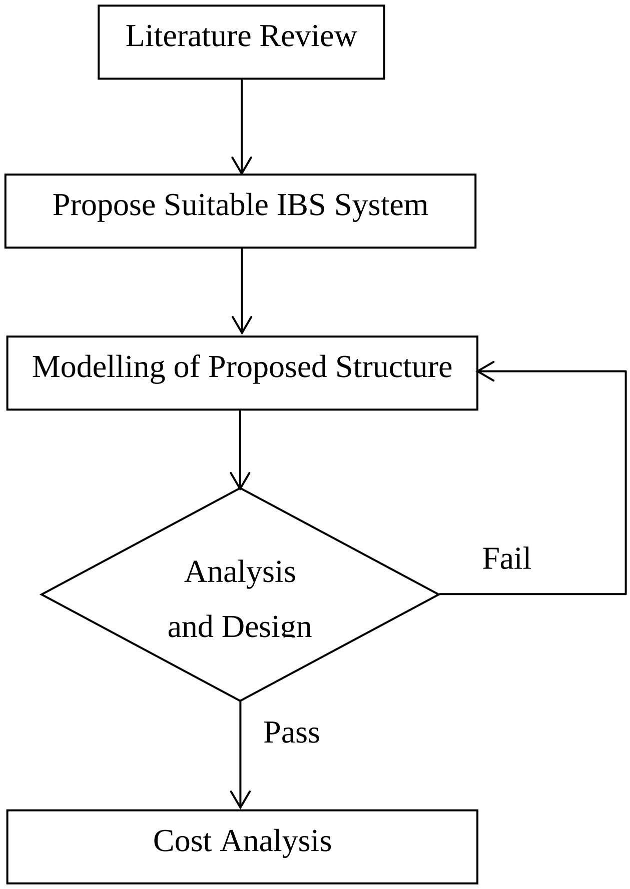


FIGURE 1 Flow of Work

Steps 1 and 2 aimed to solve problems related to the first objective, while the following steps are taken to achieve the second objective.

3.1 Project Activities

1. **Literature Review**

To start off with the project, an extensive literature review was done to research on past articles and materials on the topic of Industrialized Building System (IBS) and lightweight construction method. Various techniques specifically methods of construction for structural framing, wall and slab systems available in the South East Asia were being explored and studied.

2. **Development of Suitable IBS System**

After knowledge on the various methods of construction has been established, the work progressed with the development of suitable IBS system for the low-rise residential project. The proposed system is a steel framed housing with composite deck as flooring system. While for wall components, lightweight concrete blocks, particularly Autoclaved Aerated Concrete (AAC) block is utilized. A common roofing and foundation method were adopted, which are light weight roof truss and raft foundation respectively.

3. **Modelling of Proposed Structure**

Next, the proposed system was modelled using Software A, where floor plan of a two-storey residential house was used as a reference for the layout of structural and wall components. The properties of materials were defined accordingly, while the dimensions of members were assigned starting from the smallest possible dimension to perform iterations in order to obtain the optimum sizing required for the structure. The types of members being utilized are listed in Table 1.

TABLE 1 Materials Type

Structural Members	**Type of Materials**
Column	Square Hollow Section
Beam	Rectangular Hollow Section
Joist	Rectangular Hollow Section
1st Floor Slab	Composite slab (Structural Steel Deck + Concrete Top)

Figure 2 shows the 3D model prior to structural analysis.

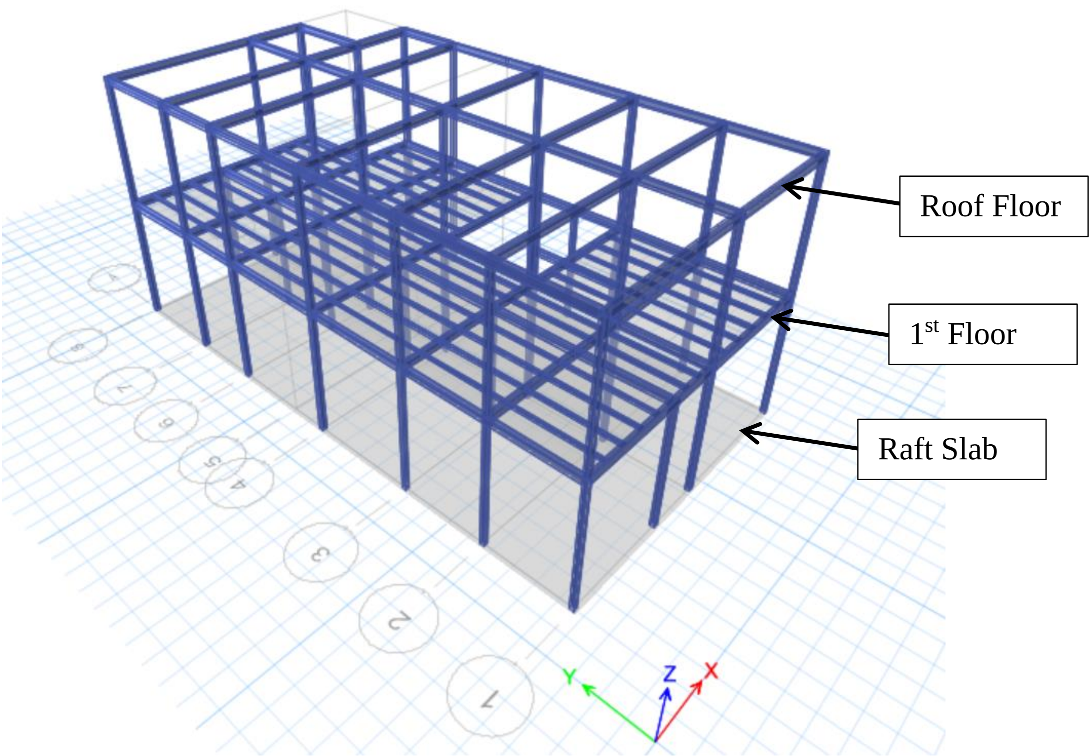


FIGURE 2 3D Model

In this project, the code of practice being referred to is Eurocode. Loadings were being assigned onto the structure as tabulated below. Superimposed Dead Load (SDL) refers to the weight of floor finishes and mechanical wirings, while Live Load (LL) constitutes the movable loads that the structure may carry.

TABLE 2 Loadings Implied on Structure

Loading Type	**Loading Values**
Floor Loading	SDL = 1.2 kN/m^2 LL = 1.5 kN/m^2
Roof Loading (Light steel truss)	DL = 0.8 kN/m^2 LL = 0.25 kN/m^2
AAC Block Wall - Exterior - Interior	DL = 6 kN/m^3 x 0.125m thick x 3m height = 2.25kN/m DL = 6 kN/m^3 x 0.1m thick x 3m height = 1.8kN/m
Staircase Loading on Beam	DL = 2.45 kN/m

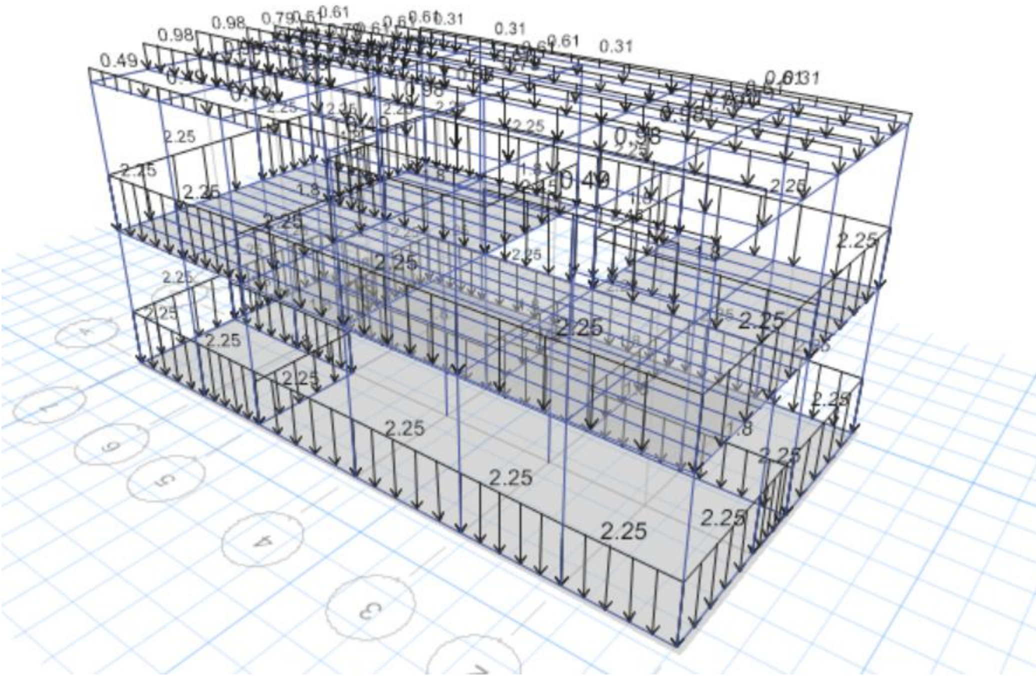


FIGURE 3 Applied Loadings on Structural Model

Load combinations are defined based on Eurocode 1990, which includes:

Case 1 (Ultimate Limit State):	1.35DL + 1.5LL
Case 2 (Ultimate Limit State):	1.35DL
Case 3 (Ultimate Limit State):	1.1DL + 1.5LL
Case 4 (Ultimate Limit State):	1.1DL
Case 5 (Service Limit State):	1.0DL + 1.0LL
Case 6 (Service Limit State):	1.0DL

4. Structural Analysis and Design

Structural analysis of steel frames and raft foundation was performed with the aid of Software A. Optimization of the structural members was done to minimize the dimension of members and to obtain a cost-effective design. In this phase, the bending moment and shear stresses acting on each frame were examined so that they do not exceed the design resistance of the members' sections.

For steel frames, the design check was based on the demand/capacity ratio (or PMM ratio), which is the ratio of design force over the resistance capacity of the member section. PMM ratio is the sum of the axial force demand/capacity ratio and the bending moment demand/capacity ratio. PMM ratio of greater than 1 indicates that the steel frame is overstressed.

Specifications for composite slab as shown in Figure 4 were taken from the manufacturer. Design tables and software from the manufacturer were being utilized to ensure the steel deck has sufficient capacity to withstand the loading on top.

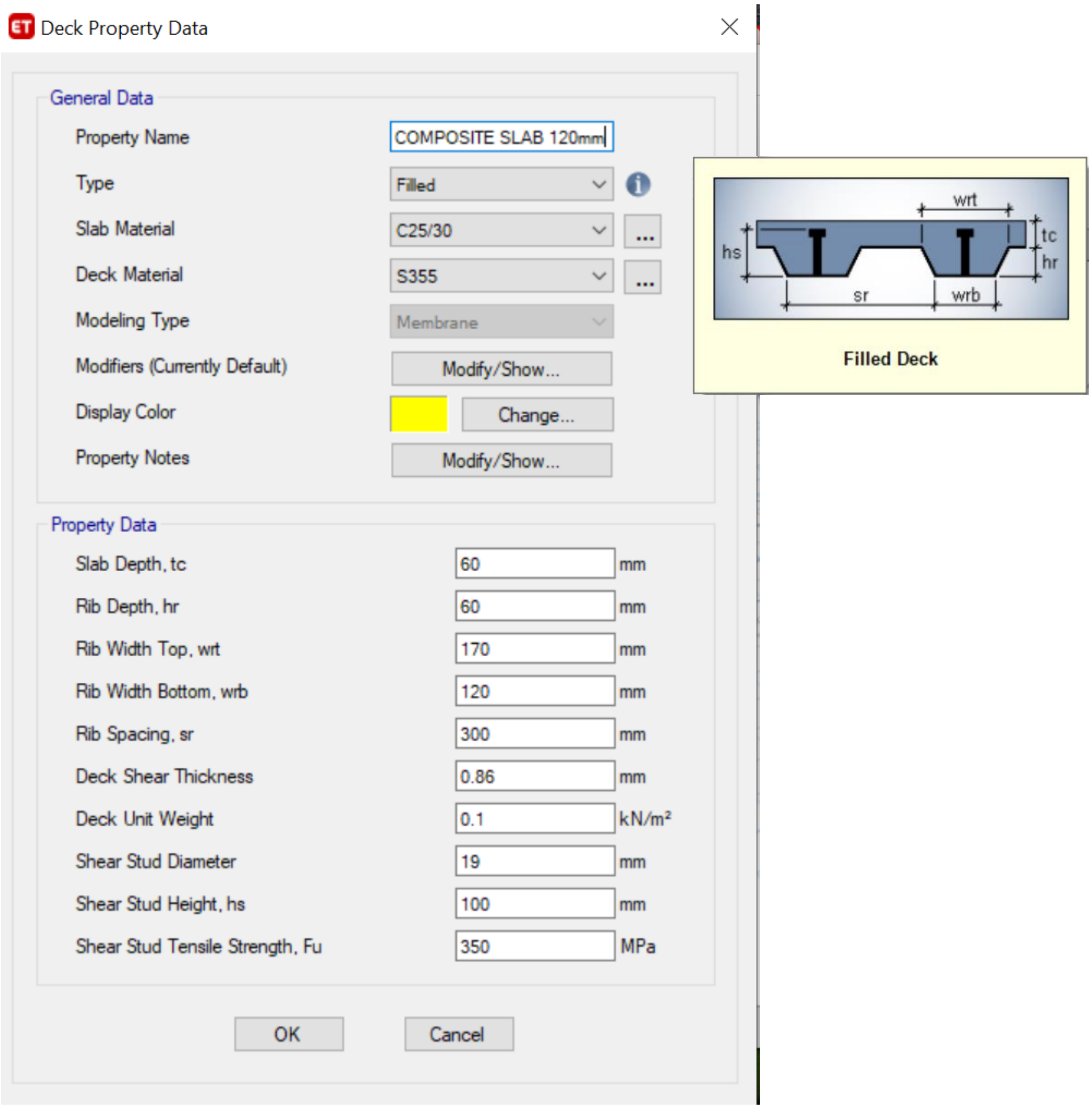


FIGURE 4 Deck Properties

For the design of raft foundation, checks for soil bearing capacity and settlement were performed using load combinations for Serviceability Limits State, while punching shear ratio and bending moment were obtained using Ultimate Limit State load combinations.

Raft slab was designed using strip based method, where design strips consisting of column strip and middle strip were modelled as shown in Figure 5 to obtain the maximum bending moment per unit width, and consequently to obtain the required area of reinforcement.

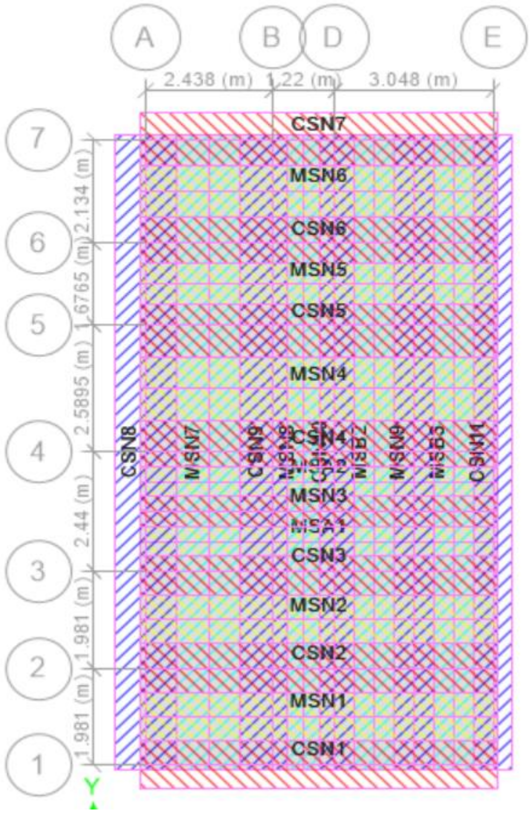


FIGURE 5 Design Strips Modelled on Raft Foundation

For conventional method of construction, design of concrete slabs and beams were performed using design spreadsheets, while columns were designed using Software B. The design for column structure was then being input into Software A for verification and followed by the design of raft foundation.

5. Cost Analysis

After the structural system was confirmed to be feasible under the various load combinations, cost analysis was performed to examine the economic viability of the system proposed. The analysis had included the material and labour costs for the specific elements, namely the steel frame, composite deck, raft foundation, and wall system. Bill of Quantities (BQ) was prepared in order to quantify and tabulate the price for the elements. The costs and labour productivity rate were obtained through sources like manufacturers, websites, and published cost data from Construction Industry Development Board (CIDB Malaysia) and Building Cost Information Services Malaysia (BCISM Sdn. Bhd.). Comparison was performed for the same layout of building using different methods of construction, which are the new proposed system and conventional system.

CHAPTER 4

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

4.1 Proposed Methods of Construction

4.1.1 Structural Framing

As compared to heavier concrete members like beams and columns, steel framing is relatively lighter, easier to handle, and enables a faster installation. Steel framing system has been widely used in commercial structures, warehouses, long span structures and so on. Structural steel is proposed to be the structural framing system of this structure due to its high strength-to-weight ratio and quick construction as compared to reinforced concrete frame. Steel construction also enhances the sustainability of the structure by eliminating the carbon emission from concrete production. In steel structures design, it is important to include the design for connections, corrosion resistance and fire protection despite the typical structural strength design. Methods of jointing between dissimilar materials require equal attention so that the building will be functional without occurrence of problems like leakage and cracks.

In this project, hollow sections were being selected over I beam sections due to the relatively lighter weight and overall constant stiffness on both axes of the section. Hollow sections require a lower finishing cost, which includes fire proofing treatment and painting due to lesser surface area. The method of construction for steel frame involves on-site assembly through welding process, while the connection between steel frame and concrete foundation involves base plate connection as shown in Figure 6. The end of column section is welded with a base plate which is then bolted to the raft foundation using anchor bolts that is being casted in the concrete. The interface between concrete and base plate is then filled with non-shrink grout.

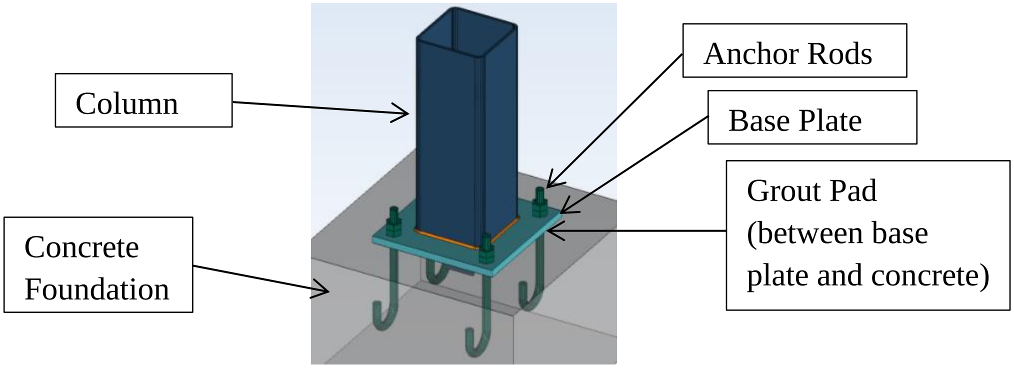


FIGURE 6 Base Plate Connection (Graitec, n.d.)

Corrosion resistance of steel can be obtained by applying anti-corrosion paint, or performing hot-dip galvanizing. Appropriate fire protection like coatings should be applied to provide a sufficient fire rating in order to ensure steel integrity in the event of fire.

4.1.2 Slab System

According to Ahmed and Tsavdaridis (2019, p. 287), composite construction is defined as the combination of steel and concrete into a component which functions as a single unit, with a better performance than the two materials being utilized separately. The principle lies in the fact that concrete is strong in compression but weak in tension, hence it relies on steel to take on the tensile forces in any structural component. Some major benefits of composite construction are the reduced self-weight of the elements, and the speed of construction. While flooring system contributes the most to the overall weight of a building, a lightweight floor slab will bring substantial benefits to the project. Composite slab comprising of a profiled steel deck with an in-situ concrete topping is thus introduced. This combination has gained increasing popularity in residential buildings as they are able to provide acoustically excellent and fire resistant construction.

FIGURE 7 Composite Slab (Tata Steel Europe, n.d.)

Profiled steel decking is made by cold-forming structural steel sheet into corrugated profiles, which helps increasing the bending capacity and results in a high strength-to-weight ratio. In some cases, embossments are provided for interlocking between the decks with the concrete for better shear resistance. Based on Steelconstruction.info (n.d.-c), there are two classes of profiled sheeting, which are shallow profiles and deep decking, for short span and long span applications respectively. Shallow profiles are of trapezoidal or "re-entrant" shapes, while deep decking is in trapezoidal shape. They are laid transverse to the secondary beams, and connected to the steel beams by shear studs, where shear studs enable the transfer of shear stress between the concrete slab and steel beam. These connections are the most critical parts for the system in order to achieve composite action between the two different materials.

The steel decking serves two purposes. Firstly, it acts as a permanent formwork for the slab and also as a working platform for the construction workers, which eliminates the need for temporary formwork. Special edge forms are used to close off the ends of concrete slab. Since the decking is light and able to be stacked in bundles, crane lifts are greatly reduced when compared to heavy precast slabs, as the bundles of decking can be lifted onto the working platform and then carried by hand (Ahmed & Tsavdaridis, 2019, p. 288; Steelconstruction.info, n.d.-b). However, the decking should be refrained from pounding of concrete pour to prevent deflection. In addition, steel deck acts as tensile reinforcement, thus only upper layer of steel mesh is required for cracks control, to resist longitudinal shear, and to act as tensile reinforcement in case of fire (Steelconstruction.info, n.d.-a). Additional bars may be placed in the troughs if the slab is subjected to heavy loads or designed for longer period of fire resistance (SteelConstruction.info, n.d.-b). A nominal mesh reinforcement of 0.2% of cross sectional area of slab will be sufficient to achieve 90 minutes fire resistance (Steel Construction Institute, 2008). The profile of steel deck also results in a saving in concrete required. The profiled section eliminates the unnecessary concrete, thus reducing the self-weight of slab without compromising its structural integrity. With this, services can be easily accommodated into the decking profile.

4.1.3 Lightweight Wall System

Types of lightweight wall system compatible with structural steel framing include lightweight concrete panels or blocks. As compared with normal concrete with a density of 2200 to 2500kg/m^3, concrete having a density ranging from 300 to maximum of 2000kg/m^3 can be classified as lightweight concrete (Hedjazi, 2019). Production of conventional concrete creates a huge environmental footprint, and even increases when take into account the fuel consumption for its transportation. Lightweight concrete is therefore introduced to reduce these footprints. There are three generally acknowledged methods for mixing lightweight concrete namely, lightweight aggregate concrete, aerated concrete and no fines concrete.

In the proposed system, Autoclaved Aerated Concrete (AAC) will be utilized as the wall component. AAC is one of the lightweight wall construction materials that is getting popular in countries like Malaysia, Singapore and Australia. It falls into the category of aerated concrete. AAC was invented by Dr. Axel Eriksson from Sweden in the year 1924, to cater for the shortage of timber in Europe. It has been widely used in Europe for various types of construction. According to Building Green (2012), AAC has been used in 60% of Germany's development in 2006. AAC is made by including an expanding agent like aluminium paste into the concrete mix, where aluminium paste reacts with the alkaline elements in the cement and form hydrogen gas. This induces air bubbles or voids in the concrete mix. These air pockets help in contributing to the insulating properties such as thermal and acoustic insulation. They also attribute to its light weight property. A typical AAC block has the dimension of 600mm length with 200mm width, and a thickness ranging from 50mm to 300mm (which is equivalent to almost 7 bricks); whereas AAC panel has a typical dimension of 3m to 6m height, 600mm width and thickness ranging from 100mm to 300mm. AAC is said to possess a weight of 1/5 of the weight of normal concrete. The concrete then achieves its extraordinary strength through steam curing in an autoclave machine. Because of its lightweight properties, transportation is less costly. Building Green (2012) also stated that even after the intensive autoclaving process, the production energy is at approximately 50% of regular concrete due to the reduced cement usage in AAC, which contributes to the sustainability criteria of AAC.

Apart from that, AAC is also incombustible and does not produce toxic fumes, thus is suitable for fire rated usage. According to Downton (2013), the fire rating of AAC can be up to 4 hours depending on the thickness of the concrete block. As compared to bricks, AAC blocks have a lower thermal conductivity, or a higher R value. R value implies the thermal resistance of the blocks, thus its thermal insulation property enables the house to stay cool and reduces the air-conditioning requirements especially in a hot climate country. In terms of sound insulation, AAC block provides Sound Transmission Class (STC) of 40dB and above, thus it is able to provide a comfortable living condition for residential housing. Finally, AAC blocks were also highly workable as it can be cut into desired dimension by using hand tools. They come with a better surface finish, thus enable an easier and thinner application of plaster or render as compared to bricks. However, working with AAC blocks requires more precise and accurate mortar application due to the low dimensional tolerance of thin bed mortar (Building Green, 2012; Downton, 2013). Thus, additional trainings should be provided for the construction workers.

In the proposed system, AAC blocks will be utilized as the non-load bearing external and internal wall to replace the traditional bricks. AAC blocks enable an easier renovation by home owners as compared to panels which come with tongue and groove. AAC block is preferred also because it allows a relatively easier placement by workers due to its lightweight property, and the workers are already familiar with the block laying method; whereas a panel trolley will be required for AAC panel installation.

Another feasible solution to lightweight wall is the lightweight aggregate concrete. It is a mix that uses organic or artificial lightweight aggregates as a substitute for coarse aggregates. Since organic lightweight aggregates are porous, it tends to absorb more water from the mix, which will result in less workable concrete. To compensate that, more water was added into the mix, which in turn increasing cement usage to maintain adequate W/C ratio, which is uneconomical, less environmental friendly and less efficient as this extra cement does not enhance the mechanical properties of the concrete. This problem can be solved by using artificial lightweight aggregates, for instance expanded polystyrene (EPS) beads. EPS has been used extensively in construction field as means of heat isolation. It is important to note that large quantity of unused EPS was being disposed either legally or illegally after construction projects. Therefore, by introducing EPS into the concrete mix, this helps the environment not only by preserving natural resources but also reducing wastes. According to the research done by Shi, Miao, Luo, Wang and Chen (2016), EPS concrete is more durable than regular concrete. It provides excellent heat and sound insulation as well. EPS concrete often comes in the form of wall panel with fiber cement board attached on both side of the concrete for additional protection towards moisture, heat and impact. The surface boards eliminate the needs for plastering works as well. Table 3 illustrates the comparison between common clay brick, AAC block and EPS panel.

TABLE 3 Comparison between Clay Brick, AAC Block and EPS Panel

	Clay Brick	**AAC Block**	**EPS Panel**
Typical Dimension	215mm x 96mm x 70mm	600mm x 200mm x 50-300mm	2.4-3m x 610mm x 75-200mm
Weight	~2.5kg/pcs (1700-1900kg/m^3)	1/5 of normal concrete (550-650 kg/m^3)	600-800 kg/m^3
Cost	RM28.89/m^2	RM35.00/m^2	~RM40/m^2
Productivity	10 m^2/man-day	22 m^2/man-day	-
Performance	- Fire rating up to 2 hours for 100mm brick - Thermal conductivity: 0.6W/mK and above	- Fire rating up to 4 hours for 100mm block - Thermal conductivity: 0.16 W/mK and above - Certified by CIDB with IBS factor of 0.5	- Fire rating up to 4 hours for 100mm panel - Thermal conductivity: <0.4 W/mK - IBS factor of 1.0

4.1.4 Jointing and Waterproofing

To ensure a watertight connection of the entire structure, jointing methods between AAC block wall and steel frame were studied and illustrated in figure below. Consultation with AAC block manufacturer was done to ensure feasibility of the system.

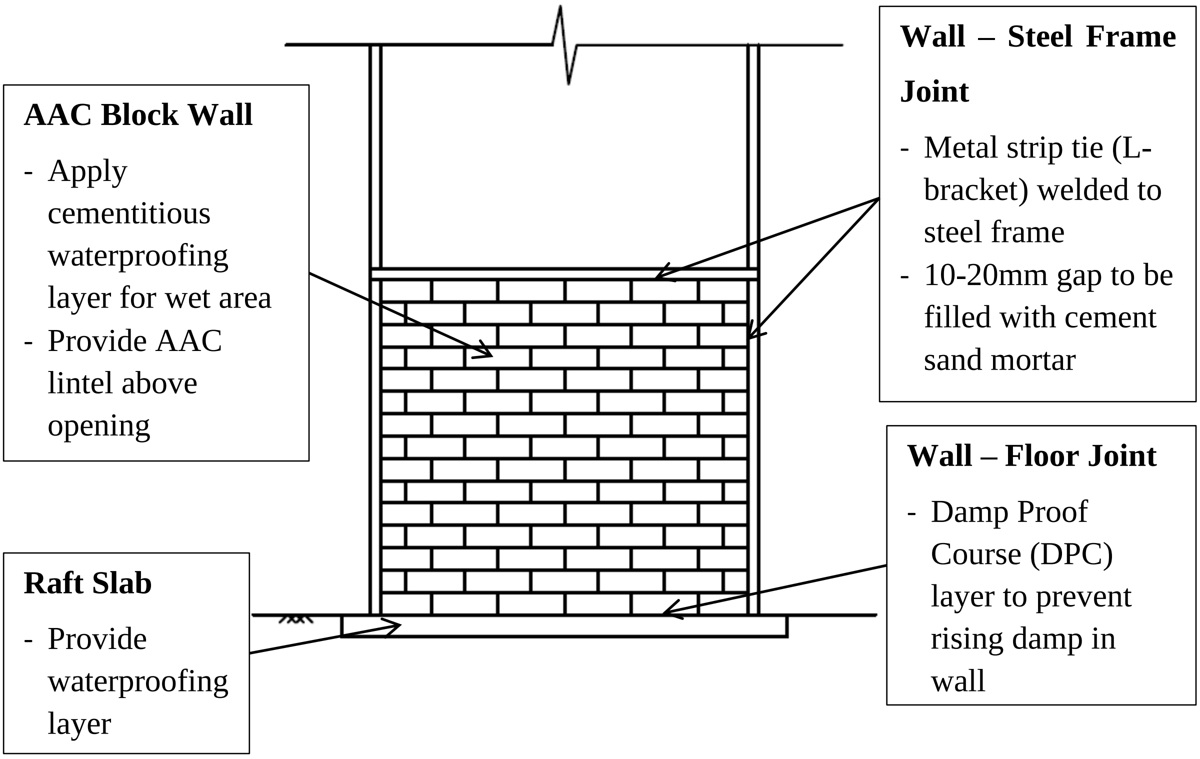


FIGURE 8 Side View Showing Joints between Dissimilar Materials

4.2 Structural Analysis

Based on the analysis performed using Software A, the design and optimum sizes for each element are illustrated in the following sections.

A balance between the structural layout and sizing of members is to be achieved such that the weights of each structural member are light enough to be able to be carried by 1 to 2 persons for ease of installation.

4.2.1 New Method of Construction

Steel Frame

From the analysis, the steel members adequately provide support for the imposed static loads as their utilization ratio is less than 1. Refer to Appendix A to E for the values of utilization ratio for the steel members.

A summary of structural steel sections and their weight is tabulated in Table 4.

TABLE 4 Summary of Structural Steel Section Properties

Element	Section Property	Section Weight (kg/m)	Maximum Length of Member (m)	Weight per element (kg)
Roof Floor Column	75x75x2.3mm (S275)	5.143	3.00	15.43
1st Floor Column	100x100x3mm (S275)	8.955	3.00	26.90
Roof Floor Beam	75x100x2.3mm (S275)	6.046	3.66	22.20
1st Floor Beam	100x100x3mm (S275)	8.955	3.66	32.78
Steel Joist	50x75x1.6mm (S275)	3.008	2.60	7.82

Composite Slab

The maximum unity factors as seen from Figure 9 were extracted from software from the manufacturer. The values are lower than 1, which indicates that the design deck is sufficient in its construction stage, normal stage, fire condition, and serviceability.

Full Output

Note: Section Designed to Eurocodes, UK National Annex

Construction Stage:	PASS	Max Unity Factor:	0.40
Normal Stage:	PASS	Max Unity Factor:	0.27
Fire Condition:	PASS	Max Unity Factor:	0.62
Serviceability:	SATISFACTORY	Max Unity Factor:	0.53

*** Section Adequate ***

FIGURE 9 Output from Manufacturer's Software

Raft Foundation

Four checks were performed in the design for raft foundation:

- Soil bearing capacity check
- Settlement check
- Punching shear check
- Bending moment capacity

Figure 10 illustrates the soil bearing capacity below the raft slab. Maximum soil pressure is obtained to be 25.63kN/m^2, which is smaller than the allowable bearing capacity of 100kN/m^2.

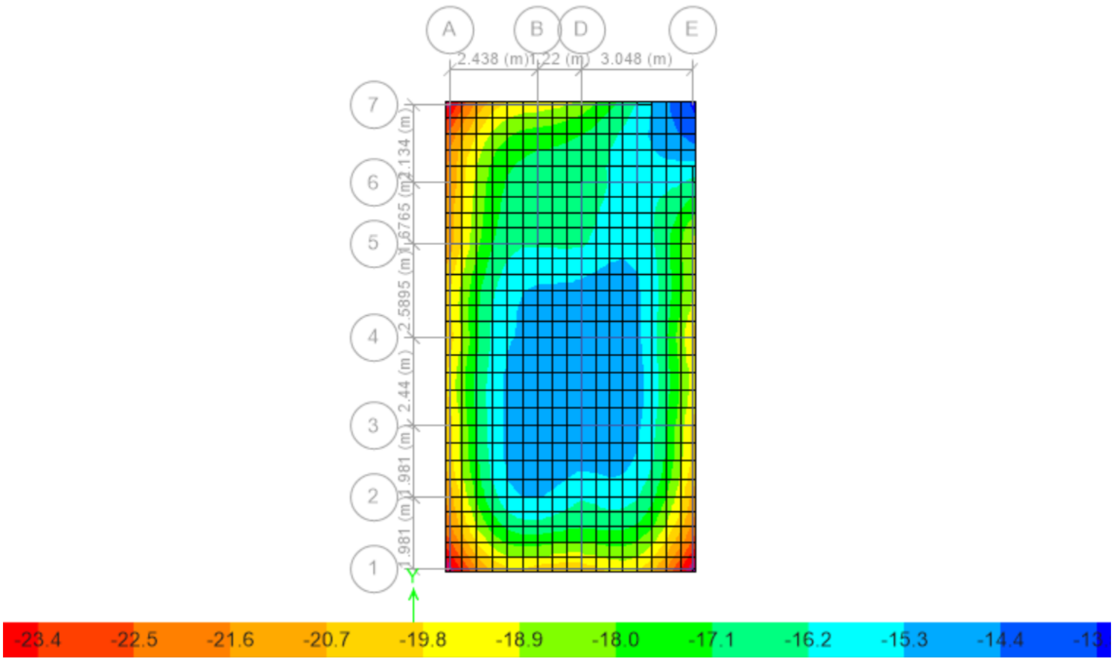


FIGURE 10 Soil Pressure Check for New Method of Construction

Figure 11 indicates the settlement of foundation with the imposed load from the structure above. The maximum settlement is obtained to be 4.3mm which is within the allowable settlement of 50mm.

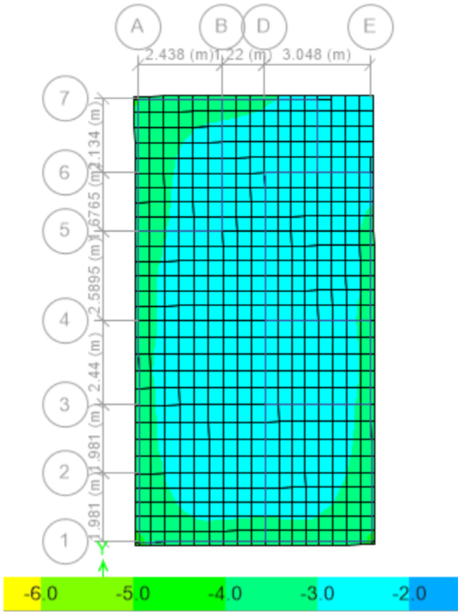


FIGURE 11 Settlement Check for New Method of Construction

Punching shear ratio shown in Figure 12 is the ratio of maximum design shear stress over concrete shear stress capacity. Ratio of less than 1 indicates that the concrete has sufficient shear capacity.

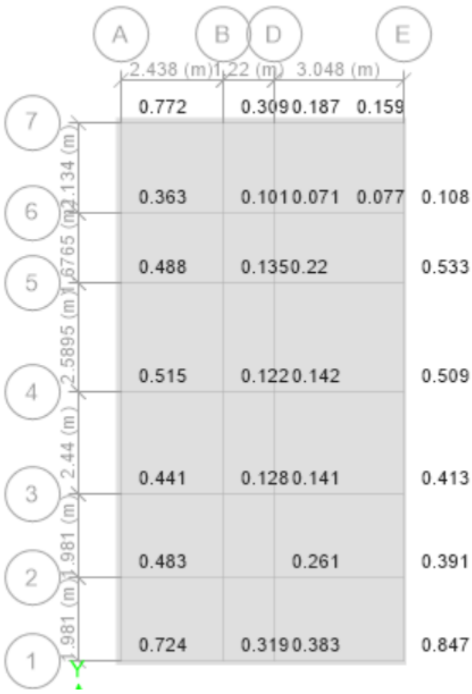
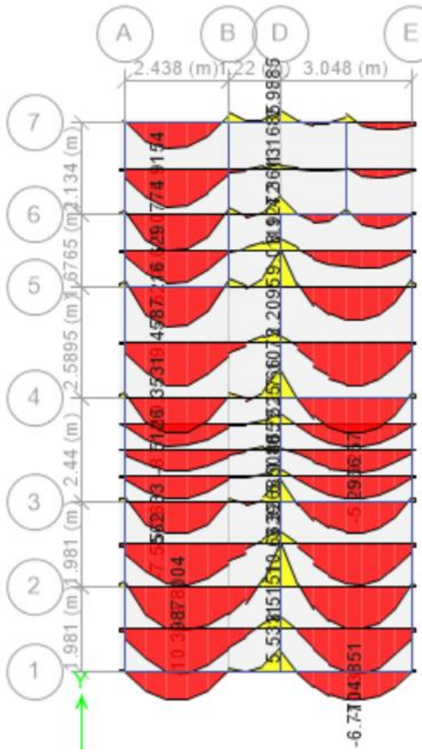
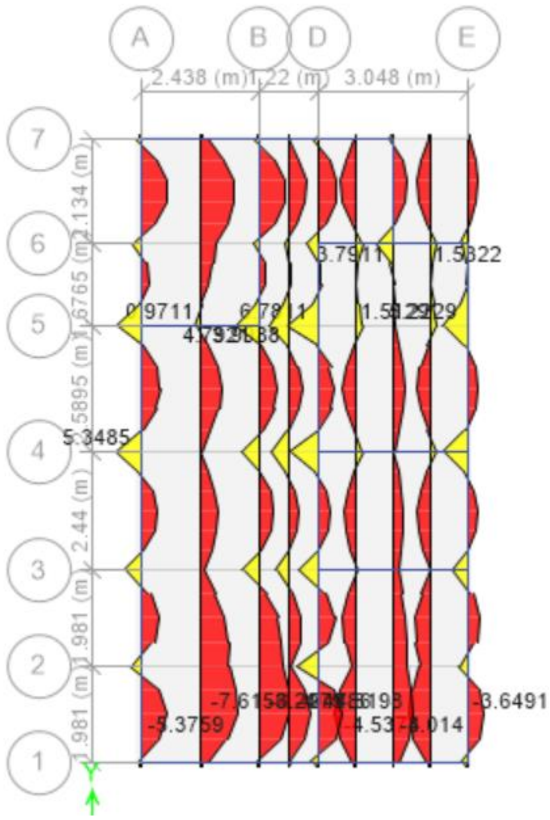


FIGURE 12 Punching Shear Check for New Method of Construction

Figures 13 show the bending moment per unit width acting on the design strips for both x and y directions.



(a)



(b)

FIGURE 13 (a), (b) Bending Moment Acting on Design Strips for New Method of Construction

From the analysis, the thickness of raft foundation is governed by punching shear check. Thickness of 225mm is obtained to be sufficient.

The maximum positive and negative bending moment per unit width of the strip are tabulated in Table 5. Maximum negative bending moment is used for the design of top reinforcement while maximum positive bending moment is used for the design of bottom reinforcement. Similar arrangement of reinforcement is provided throughout the foundation length for simplicity.

TABLE 5 Maximum Bending Moment and Minimum Reinforcement for Raft Foundation in New Method of Construction

Design Strip	X direction (Layer A)	Y direction (Layer B)
Maximum +ve moment (kNm/m)	10.67	6.78
Maximum –ve moment (kNm/m)	-10.40	-7.62
Minimum area of reinforcement required (mm^2/m)	409.59	368.36
Reinforcement provided	T12-250mm c/c	T12-300mm c/c

4.2.2 Conventional Method of Construction

Reinforced Concrete Frame

The dimension and reinforcement design for the reinforced concrete members are illustrated in Table 6. Same design was taken for similar elements for simplicity.

TABLE 6 Summary of Concrete Members Design

Element	Dimension / Properties	Design Reinforcement	Design Shear Link
Roof Floor & 1st Floor Column	200mm x 200mm Concrete C25/30	4T12 (1.13%)	T6-200mm c/c
Roof Floor & 1st Floor Beam	200mm x 200mm Concrete C25/30	4T12 (1.13%)	T8-100mm c/c
1st Floor Slab	100mm thick Concrete C20/25	T10-300mm c/c each way	-

The columns in Figure 14 are shown in blue which indicates that the reinforcement design for columns is sufficient.

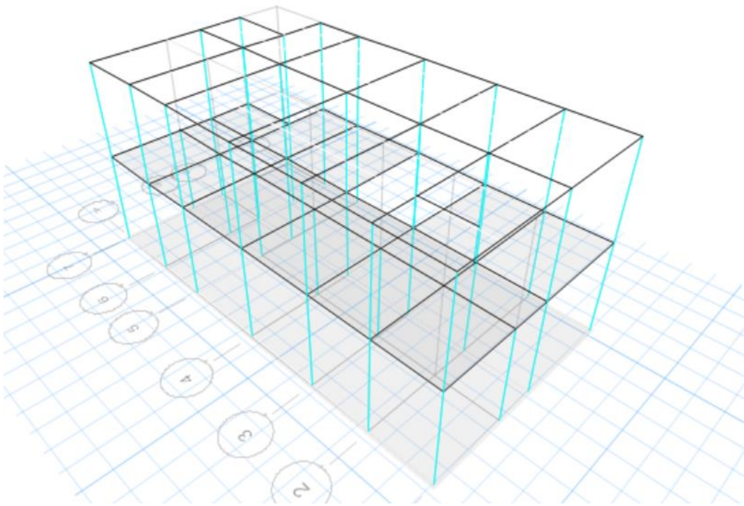


FIGURE 14 Verification of Column Design in Software A

Raft Foundation

From Figure 15 and 16, it is shown that the settlement and soil bearing capacity checks are within allowable limit where the maximum settlement is obtained to be 6.3mm and maximum soil pressure is 37.4kN/m^2.

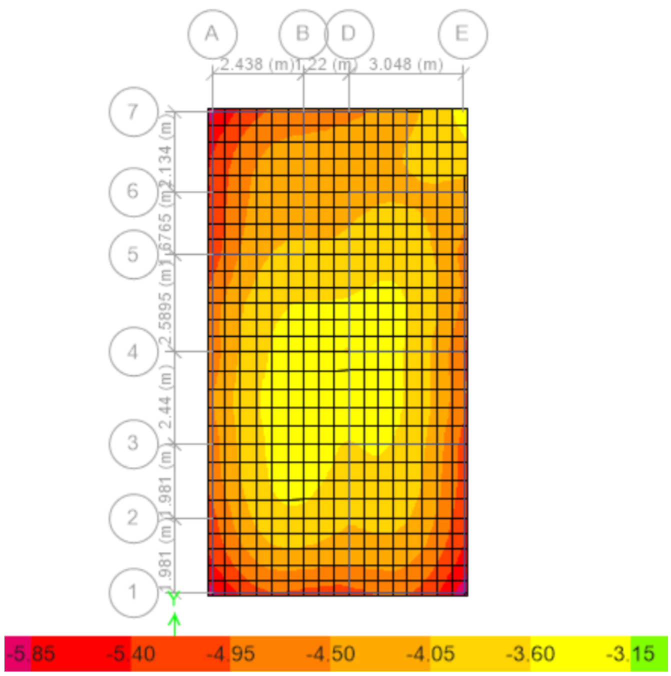


FIGURE 15 Settlement Check for Conventional Method of Construction

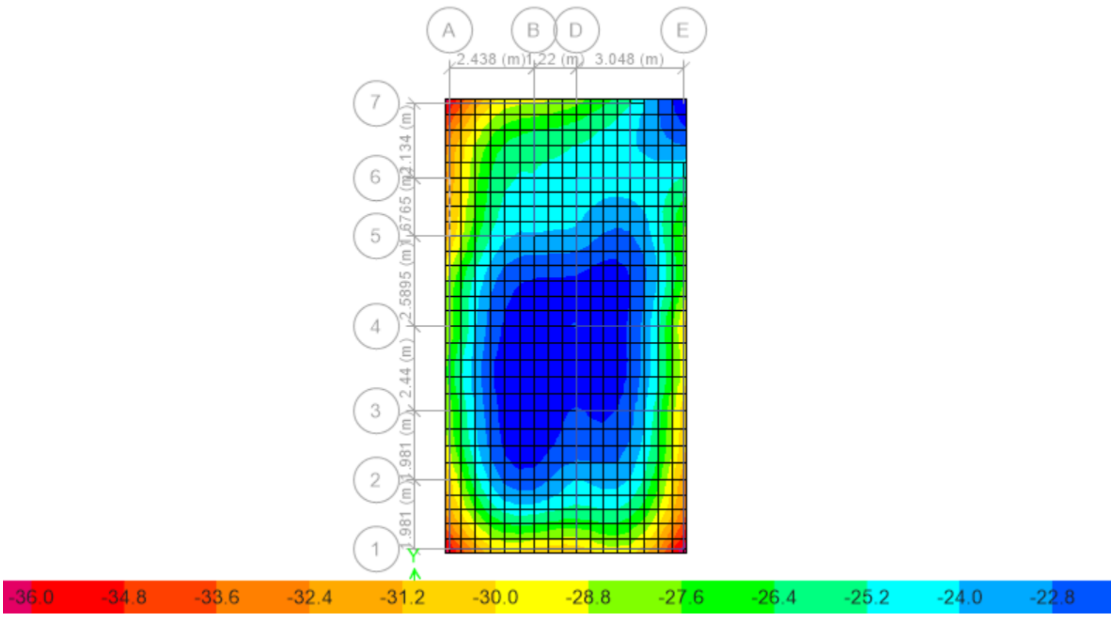


FIGURE 16 Soil Pressure Check for Conventional Method of Construction

Figure 17 shows that punching shear ratio is within the limit of 1. From the analysis, the thickness of raft slab is governed by punching shear.

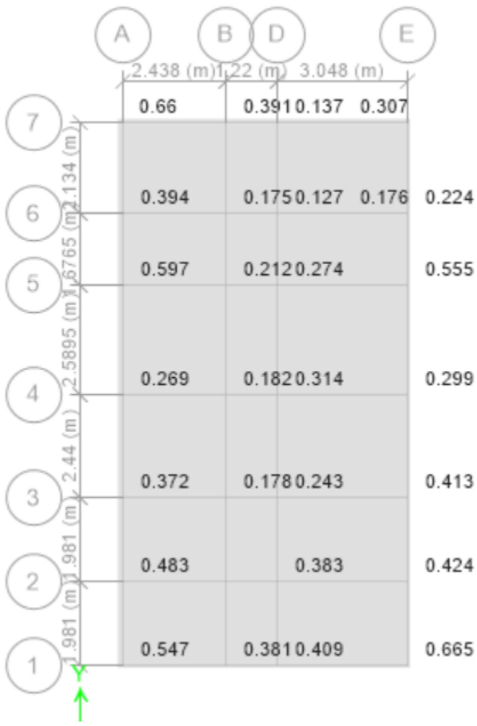


FIGURE 17 Punching Shear Check for Conventional Method of Construction

The maximum bending moment acting on each design strip is tabulated in Table 7.

TABLE 7 Maximum Bending Moment and Minimum Reinforcement for Raft Foundation in Conventional Method of Construction

Design Strip	**X direction (Layer A)**	**Y direction (Layer B)**
Maximum +ve moment (kNm/m)	20.73	11.15
Maximum –ve moment (kNm/m)	-17.17	-11.64
Minimum area of reinforcement required (mm^2/m)	409.59	368.36
Reinforcement provided	T12-250mm c/c	T12-300mm c/c

4.2.3 Discussion

From the analysis output, both the structure utilizing the proposed IBS system and conventional system are in their optimal sections and dimensions, in which they are verified to be structurally sound against the static load imposed on the structure.

By referring to Table 5 and 7, it is shown that the maximum positive and negative moment acting on the raft slab in the conventional system is higher than that in the proposed IBS system due to the larger weight of traditional reinforced concrete frame. This is proven by the greater soil pressure under the raft foundation for conventional system, which is 37.4kN/m^2 as compared to the proposed system with a soil pressure of 25.63kN/m^2. Thus, we can conclude that the proposed steel structure is lighter than the conventional reinforced concrete framed structure.

Although the thickness of raft slab and the minimum reinforcement required do not differ much between the two systems, the lightweight IBS system still bring advantages in terms of ease and speed of construction, and also reduction of labours required, as discussed in Chapter 4.3.

4.3 Cost Analysis

4.3.1 Material Cost

1. **New Method of Construction**

Quantity take-off is performed for each of the components as tabulated below.

Steel Frame

TABLE 8 Quantity Take-Off for Steel Frame

Section Property	Total Length (m)	Weight per meter (kg/m)	Total Quantity (kg)
Joist			
50x75x1.6mm (S275)	122.22	3.008	367.64
Beam			
75x100x2.3mm (S275)	83.83	6.046	506.84
100x100x3mm (S275)	96.63	8.955	865.32
Column			
75x75x2.3mm (S275)	66.00	5.143	339.44
100x100x3mm (S275)	84.00	8.955	752.22

Composite Slab

TABLE 9 Quantity Take-Off for Composite Slab

Material	Weight	Total Quantity	Total Weight (kN)
S355, 0.9mm Metal Deck	0.11 kN/m^2	75.16 m^2	8.27
Edge Form for 120mm slab	0.11 kN/m^2	49.10m	0.65
C25/30 Concrete	24 kN/m^3	0.088 m^3/m^2 x 75.16 m^2 = 6.62 m^3	158.88
BRC A6	2.22 kg/m^2	75.16 m^2	1.66

Raft Foundation

Quantity of reinforcement was calculated by assuming reinforcement bar to be placed across the whole length of slab for both top and bottom bars, without taking into account the bend length and lap length.

TABLE 10 Quantity Take-Off for Raft Foundation in New Method of Construction

Material	Volume / Area	Total Quantity
C30/37 Concrete	89.79 m^2 225mm thickness	20.21 m^3
Main bar (top & bottom): T12-250mm c/c	Number of bars = 12802/250 x 2 = 104 bars Total length = 104 x 6.706 = 697.43m Volume = 697.43 x (1.13×10^{-4}) = 0.0788 m^3	618.58 kg
Distribution bar (top & bottom): T12-300mm c/c	Number of bars = 6706/300 x 2 = 46 bars Total length = 46 x 12.706 = 584.48m Volume = 584.48 x (1.13×10^{-4}) = 0.0660 m^3	518.10 kg

AAC Block Wall

TABLE 11 Quantity Take-Off for AAC Block Wall

Material	Length (m)	Total Quantity (m^2)	Total Weight (kN)
AAC Block (interior wall) 600mm x 200mm x 100mm	41.61	124.83	74.90
AAC Block (exterior wall) 600mm x 200mm x 125mm	78.05	234.15	175.61

Bill of Quantity (BQ)

TABLE 12 Bill of Quantity for New Method of Construction

Element	Material	Unit	Quantity	Unit Price	Price (RM)
Steel Frame	**Steel joist**				
	50x75x1.6mm (S275)	kg	367.64	RM4,362/mt	1,603.65
	Steel beam				
	75x100x2.3mm (S275)	kg	506.84	RM4,114/mt	2,085.15
	100x100x3mm (S275)	kg	865.32	RM4,100/mt	3,547.80
	Steel column				
	75x75x2.3mm (S275)	kg	339.44	RM4122/mt	1,399.20
	100x100x3mm (S275)	kg	752.22	RM4,100/mt	3,084.10
Composite Slab	0.9mm metal deck	m^2	75.16	RM59/m^2	4,434.45
	Edge Form	m	49.1	RM16/m	785.60
	C25/30 concrete	m^3	6.62	RM208/m^3	1,377.00
	BRC A6	m^2	75.16	RM6.75/m^2	507.35
Raft Foundation	C30/37 concrete	m^3	20.21	RM218/m^3	4,405.80
	Rebar T12	kg	1136.68	RM3/kg	3,410.05
AAC Block Wall	600x200x100mm (int.)	m^2	124.83	RM22.50/ m^2	2,808.70
	600x200x125mm (ext.)	m^2	234.15	RM28.17/ m^2	6,596.00
TOTAL					**RM 36,044.85**

2. **Conventional Method of Construction**

Quantity take-off is performed for each of the materials as tabulated below.

Formwork

TABLE 13 Quantity Take-Off for Timber Formwork

Element	Width	Total Length (m)	Total Quantity (m^2)
Roof Floor & 1st Floor Column	0.2m * 4	150.00	120.00
Roof Floor & 1st Floor Beam	0.2m * 3	180.45	108.27
1st Floor Slab	0.1m	49.10	4.91 + 75.16 (slab soffit) = 80.07

Concrete

Bar Bending Schedule (BBS) as shown in Appendix F to H were prepared for columns, beams and slab to tabulate the quantity of reinforcement required. Table 14 shows the volume of concrete needed for each structural element.

TABLE 14 Quantity Take-Off for Concrete Material

Element	Dimension	Total Length / Area	Total Quantity (m^3)
Roof Floor & 1st Floor Column	200mm x 200mm	150m	6.00
Roof Floor & 1st Floor Beam	200mm x 200mm	180.45m	7.22
1st Floor Slab	100mm thickness	75.16 m^2	7.52
Raft Foundation	225mm thickness	89.79 m^2	20.21

Bill of Quantity (BQ)

TABLE 15 Bill of Quantity for Conventional Method of Construction

Element	Material	Unit	Quantity	Unit Price	Price (RM)
Reinforced Concrete Frame	**Column**				
	Formwork	m^2	120.00	RM31.65/m^2	3,798.00
	C25/30 Concrete	m^3	6.00	RM208/m^3	1,248.00
	Reinforcement (12mm)	kg	619.30	RM3/kg	1,857.90
	Shear link (6mm)	kg	115.54	RM3/kg	346.60
	Beam				
	Formwork	m^2	108.27	RM31.65/m^2	3,426.75
	C25/30 Concrete	m^3	7.22	RM208/m^3	1,501.75
	Reinforcement (12mm)	kg	668.79	RM3/kg	2,006.40
	Shear link (8mm)	kg	461.31	RM3/kg	1,383.90
Concrete Slab	Formwork	m^2	80.07	RM31.65/m^2	2,534.20
	C20/25 Concrete	m^3	7.52	RM198/m^3	1,489.00
	Reinforcement (8mm)	kg	357.04	RM3/kg	1,071.10
Raft Foundation	C30/37 Concrete	m^3	20.21	RM218/m^3	4,405.80
	Reinforcement (12mm)	kg	1136.68	RM3/kg	3,410.05
Brick Wall	Clay brick	m^2	358.98	RM28.89/m^2	10,370.90
TOTAL					**RM 38,850.35**

4.3.2 Labour Cost

1. New Method of Construction

Labour cost was calculated using labour productivity per man-hour and wage rate per unit work performed. The number of days required per work element is tabulated as below.

TABLE 16 Labour Cost Calculation for New Method of Construction

	Work Element	Unit	Total Quantity	Labour productivity (unit/man-hour)	Required man-hour	Required man-day	Labour Wage Rate	Labour Cost (RM)
1	**Raft Foundation**							
	bar bender	kg	1136.68	44.84	25.35	3.17	RM 0.45/kg	511.50
	concreter	m^3	20.21	1.41	14.33	1.80	RM 30.00/m^3	606.30
				SUBTOTAL	**39.68**			**1,117.80**
2	**Steel Frame**							
	skilled labour	kg	2831.46	18.80	150.61	18.83	RM 95.00/day	1,788.85
3	**Composite Slab**							
	skilled labour	m^2	81.06	2.22	36.52	4.57	RM 95.00/day	434.15
	BRC bar bender	m^2	75.16	6.30	11.93	1.50	RM 2.15/m^2	161.60
	concreter	m^3	6.62	1.41	4.70	0.59	RM 30.00/m^3	198.60
				SUBTOTAL	**53.15**			**794.35**
4	**AAC Block Wall**							
	IBS block wall installer	m^2	358.98	2.75	130.54	16.32	RM 14.50/m^2	5,205.20
TOTAL					**373.98**	**46.78**		**8,906.20**

2. Conventional Method of Construction

TABLE 17 Labour Cost Calculation for Conventional Method of Construction

	Work Element	Unit	Total Quantity	Labour Productivity (unit/man-hour)	Required man-hour	Required man-day	Labour Wage Rate (RM/unit)	Labour Cost (RM)
1	**Raft Foundation**							
	bar bender	kg	1136.68	44.84	25.35	3.17	0.45	511.50
	concreter	m³	20.21	1.41	14.33	1.80	30.00	606.30
				SUBTOTAL	**39.68**			**1,117.80**
2	**RC Column & Beam**							
	carpenter	m²	228.27	3.72	61.36	7.67	23.00	5,250.20
	bar bender	kg	1864.94	44.84	41.60	5.20	0.45	839.20
	concreter	m³	13.22	1.41	9.38	1.18	30.00	396.60
				SUBTOTAL	**112.34**			**6,486.00**
3	**Slab**							
	carpenter	m²	80.07	3.72	21.53	2.70	23.00	1,841.60
	bar bender	kg	357.04	44.84	7.97	1.00	0.45	160.70
	concreter	m³	7.52	1.41	5.34	0.67	30.00	225.60
				SUBTOTAL	**34.84**			**2,227.90**
4	**Brick Wall**							
	bricklayer	m²	358.98	1.38	260.13	32.52	12.00	4,307.80
TOTAL					**446.99**	**55.91**		**14,139.50**

4.3.3 Discussion

In terms of material cost, the proposed IBS system is obtained to be slightly cheaper than the conventional method, which is around 7.22%. The proposed system achieves cost savings mostly through its steel frame. The total cost for steel frame is calculated to be RM 11,719.90 while reinforced concrete (RC) frame requires RM 15,569.30. Timber formwork contributes to almost half of the RC frame's cost, which is RM 7,224.75. The use of timber formwork does not only increase the time required for construction, it is also not environmentally sustainable as timber formwork has to be disposed after several uses.

In the aspect of manpower, comparison of the two systems can be done on the structural framing, slab system and wall system. The proposed IBS system shows a reduction in labour cost of around RM5,000, or equivalent to a percentage of 37. A significant saving is again obtained from the steel frame. This is because steel frame only requires on-site erection through welding or bolting, while RC frame involves three processes on site, which are formwork erection, bar fixing, and concrete casting. Although RC frame shows a relatively shorter construction time which is around 5 days ahead of steel frame, RC frame will require additional time for concrete curing, which has not been taken into account in Table 17. In addition, productivity for RC frame construction is greatly affected by the weather condition, whereas structural steel as a factory pre-fabricated component is less likely to be affected by poor weather condition.

In the design of slab, composite slab requires a higher cost of RM7,104.40 as compared to RC slab of RM5,094.30. As a substitute to the traditional temporary formwork system and tensile reinforcement, the metal decking is much more expensive to be an economically feasible alternative for the contractors. Its higher price might be due to the limited amount of suppliers within the country, which was agreed by Haron et al. (2005), and Haron and Abd. Mutalib (2012). Furthermore, nominal wire mesh is still required for cracks prevention and fire performance. There is an insignificant saving in concrete volume as well.

Composite slab and RC slab are having similar manpower requirements for steel reinforcement and concrete placing. However, they differ in their formwork placement where RC slab requires a higher labour cost for timber formwork erection.

There is a huge difference of RM1,433.55 between composite slab and RC slab in terms of their total labour costs, where RC slab requires RM2,227.90 while composite slab requires only RM794.35. This value has helped to even out the difference between the two slab systems from the material cost aspect. Despite the higher labour cost of RC slab, a slightly shorter installation time is needed. This might be due to the familiarity towards timber formwork among labourers. Besides, installation of metal decking requires the use of lorry crane due to its large size and heavy weight. Given a rate of RM550 per day for the crane with operator, an installation period of 5 days will require an additional machineries cost of RM2,750, which further increases the overall costs of composite slab.

On the other hand, AAC blocks appear to be cheaper when it is bought in bulk. AAC block installation has a slightly higher labour wage rate due to the higher productivity. AAC block installation is quite similar to the traditional brick wall laying, but it comes with a bigger dimension and lighter weight. From the analysis, AAC block is able to reduce the required man-day by half from the clay brick laying. AAC block may result in further saving if finishing cost is being considered. This is because the blocks have a better surface finish from common clay brick, thus a thinner coating will be required. A summary of cost comparison for the structural framing, slab and wall systems of both systems is illustrated in Table 18.

TABLE 18 Summary of Cost Comparison for Structural Framing, Slab and Wall Systems

Proposed IBS System		Conventional System	
Steel frame	(RM)	**RC Frame**	(RM)
Material	11,719.90	Material	15,569.30
Labour	1,788.85	Labour	6,486
TOTAL	**13,508.75**	**TOTAL**	**22,055.30**
Composite slab	(RM)	**RC Slab**	(RM)
Material	7,104.40	Material	5,094.30
Labour	794.35	Labour	2,227.90
Lorry crane	2,750		
TOTAL	**10,648.75**	**TOTAL**	**7,322.20**
AAC Block wall	(RM)	**Brick**	(RM)
Material	9,404.70	Material	10,370.90
Labour	5,205.20	Labour	4,307.80
TOTAL	**14,609.90**	**TOTAL**	**14,678.70**

In Table 16 and 17, the labour cost output was based on one crew size. A shorter man-day required indicates that a smaller crew size is required. With a smaller crew size, the site becomes less congested, and this helps to reduce the safety hazards and risks. Besides, it should be noted that the material costs calculated have not included the percentage for wastage. As compared to traditional method of construction, IBS construction such as steel frame is able to reduce the construction waste as they often come in precise dimension and better surface finish, thus minimum cutting works is required on site. This reduces the possibility of errors which lead to reworks. This means that the conventional system will have a much higher material costs if wastage is being accounted for.

In overall, from the cost analysis performed, the new IBS system is proved to be lighter, is able to shorten the time for construction by approximately 9 days, and provide an overall cost saving of up to RM 8,000, which is equivalent to 18.25%. These findings are in accordance with previous studies that IBS offers a faster construction time, better productivity, and a smaller crew size. The result also proves that the proposed IBS structure has advantage over conventional method of construction in terms of material costs and labour costs.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the first objective of developing a new method of construction which is light weight, reduces labour usage, time saving and overall cost saving has been achieved. Extensive researches were done on the existing techniques available in South East Asia. The proposed structural framing was decided to be utilizing structural steel, whereas the flooring and wall systems will be utilizing composite slab and lightweight concrete blocks respectively. The method of connection between structural steel members, and between dissimilar materials such as steel to concrete slab, and lightweight concrete block to steel, has been established to provide a watertight jointing to ensure occupants' comfort and the structure's durability.

In addition, the second objective of examining the proposed system's structural integrity and cost has been achieved as well. Through the analysis output from Software A, the steel framed structure was able to withstand the loading combinations as indicated in the Eurocode standards. Comparison between the proposed system and conventional method of construction using the same building layout has proven that the proposed system results in savings in material costs and labour costs by around 7.22% and 37% respectively. It has also achieved reduction in the total time required to perform the work elements by 16.33%. In overall, the proposed IBS system enables a saving in material and labour costs by 18.25%. These findings have justified the potential implementation of the proposed system in terms of strength and economics, especially when used in mass production for structure with typical design.

5.2 Recommendation

It is acknowledged that IBS system is able to bring substantial benefits to the building construction in terms of productivity and quality; however it is still difficult to quantify the benefits just by looking into the costs requirement for materials and manpower. Further research work can be performed to establish work schedule for both the proposed system and conventional in-situ construction, and include all the necessary costs throughout construction stage, for instance transportation and machineries cost for a more comprehensive comparison. A detailed design comprising the design for connections should also be performed.

Considering the time constraint and limited funding, the possible future work for this study mainly pertains to the fabrication and construction of an actual model structure using the improved IBS system. With this, experimental testing against the materials' strength and behaviours can be conducted. This will also ensure a more refined cost and construction time analysis with a more accurate labour productivity rate. Besides, it is with hope that this improved method of construction can be presented to the industry players like designers, contractors and government authorities to obtain constructive feedback on the system's constructability and potential implementation in the Malaysian construction sector.

Lastly, the research should continue with analysis utilizing different IBS components as opposed to the commonly used materials like concrete and bricks to keep up with the constantly changing technologies. This is to support the purpose of IBS adoption in Malaysia which is to enhance construction productivity and reduce dependency on foreign labour.

REFERENCES

Abdul Kadir, M. R., Lee, W. P., Jaafar, M. S., Sapuan, S. M., & Ali, A. A. A. (2006). Construction performance comparison between conventional and industrialised building systems in Malaysia. *Structural Survey*, *24*(5), 412–424. https://doi.org/10.1108/02630800610712004

Ang, J. W., Athreya, M., & Chai, Y. W. (2018). *Low-Skilled Foreign Workers' Distortions to the Economy*. Bank Negara Malaysia.

BCISM. (n.d.). *Pocket Costbook 2020*. http://www.bcism.org.my/pocket-costbook-2020/

CIDB Malaysia. (2016). Industrialised Building System: The Path to Enhanced Productivity. *Heights*, *3*, 1–27. https://www.cidb.gov.my/sites/default/files/2020-03/Heights3-compressed.pdf.

CIDB. (2007). *Labour Costs and Labour Output Information for Building Construction*. http://n3c.cidb.gov.my/n3c/product_labour_cost.php

CIDB. (n.d.). A Study on Cost Comparison between IBS and Conventional Construction.

Dorr, J., & Stark, A. (2018, June 20). *Possibilities of Lightweight Material Construction*. SPOTLIGHTMETAL. https://www.spotlightmetal.com/possibilities-of-lightweight-material-construction-a-721959/

Durdyev, S., & Ismail, S. (2016). On-site construction productivity in Malaysian infrastructure projects. *Structural Survey*, *34*(4/5), 446–462. https://doi.org/10.1108/ss-12-2015-0058

Endut, I. R., Akintoye, A., & Kelly, J. (2009). *COST AND TIME OVERRUNS OF PROJECTS IN MALAYSIA*. http://www.irbnet.de/daten/iconda/CIB10633.pdf

Graitec. (n.d.). *Base Plate Connection for Square Hollow Section* [Image]. Advance Design - Steel Connection. https://www.graitec.com/Help/Advance-BIM-Designers/Steel-Connection-Designer/desktop/Tubular_Base_Plate.htm

Haron, N. A., Hassim, I. S., Abd. Kadir, M. R., & Jaafar, M. S. (2005). Building Cost Comparison Between Conventional and Formwork System: A Case Study of Four-storey School Buildings in Malaysia. *American Journal of Applied Sciences*, *2*(4), 819–823. https://doi.org/10.3844/ajassp.2005.819.823

Haron, N. A. & Abd. Mutalib, Z. (2012). Construction Cost Variance for School Project in Malaysia. *European International Journal of Science and Technology*, *1*(3), 43–55.

Hendrickson, C., & Au, T. (2008). *Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects, and Builders* (2.2 ed.). Prentice Hall.

Iskandar Zulkarnain, M. N., Rumaizah, M. N., Ezlina, M. A., & Khalida, M. S. (2019). Malaysian as the Component of Labour Force for Construction Industry in Malaysia. *MATEC Web of Conferences* (p. 01007). EDP Sciences. https://doi.org/10.1051/matecconf/201926601007

Kelly, R. (2017, July 3). *The benefits of lightweight construction*. The West Australian. https://thewest.com.au/lifestyle/real-estate/the-benefits-of-lightweight-construction-ng-b88525455z

Materials Prices. (2021, January 18). QUANTITY SURVEYOR ONLINE. http://quantitysurveyoronline.com.my/materials-prices.html

Md. Ali, M., Haslinda Abas, N., Mohd Affandi, H., & Ain Abas, N. (2018). Factors impeding the industrialized building system (IBS) implementation of building construction in Malaysia. *International Journal of Engineering & Technology*, *7*(4), 2209–2212. https://doi.org/10.14419/ijet.v7i4.17863

Md. Rahim, M. S., & Haron, N. A. (2013). Construction Cost Comparison Between Conventional and Formwork System for Condominium Project. *International Journal Computer Science Engineering, 2*(5), 19–25.

Memon, A. H., Abdul Rahman, I., & Abdul Azis, A. A. (2012). Time and Cost Performance in Construction Projects in Southern and Central Regions of Peninsular Malaysia. *International Journal of Advances in Applied Sciences*, *1*(1), 45–52. https://doi.org/10.11591/ijaas.v1i1.537

Mohd Amin, M. A., Abas, N. H., Shahidan, S., Rahmat, M. H., Suhaini, N. A., Nagapan, S., & Abdul Rahim, R. (2017). A review on the current issues and barriers of Industrialised Building System (IBS) adoption in Malaysia's construction industry. *IOP Conference Series: Materials Science and Engineering*, 012031. https://doi.org/10.1088/1757-899x/271/1/012031

Othuman Mydin, M. A., Sani, N. M., & Taib, M. (2014). Industrialised Building System in Malaysia: A Review. *MATEC Web of Conferences*, 01002. EDP Sciences. https://doi.org/10.1051/matecconf/20141001002

Ramli, M. Z., Hanipah, M. H., Zawawi, M. H., Zainal Abidin, M. Z., Zainal, N. A., & Abdul Halim, N. S. (2016). Cost comparison on industrialized building system (IBS) and conventional method for school construction project. *Journal of Scientific Research and Development, 3*(4), 95–101.

Razak, F. M., & Awang, H. (2014). The Contractors' Perception of the Implementation of Industrialised Building System (IBS) in Malaysia. *MATEC Web of Conferences*, 04003. https://doi.org/10.1051/matecconf/20141004003

Salleh, N. M., Lop, N. S., Mamter, S., & Abidin, Z. Z. (2020). Preliminary Survey on Availability of Local Skilled Construction Workers at Construction Sites. *International Journal of Academic Research in Business and Social Sciences, 10*(3), 618–632.

Steelonstruction.info. (n.d.-a). *Design of composite steel deck floors for fire*. Retrieved December 2, 2020, from https://www.steelconstruction.info/Design_of_composite_steel_deck_floors_for_fire

Steelconstruction.info. (n.d.-b). *Floor systems*. Retrieved December 2, 2020, from https://www.steelconstruction.info/Floor_systems

Steelconstruction.info. (n.d.-c). *Steel construction products*. Retrieved December 2, 2020, from https://www.steelconstruction.info/Steel_construction_products#Decking_for_floors

Steel Construction Institute. (2008). *Best Practice in Steel Construction - Residential Buildings*.

Tata Steel Europe. (n.d.). *ComFlor 60* [Image]. https://www.tatasteelconstruction.com/en_GB/Products/structural-buildings-and-bridges/Composite-floor-deck/Comflor%C2%AE-60

Yap, J. B. H., Low, P. L., & Wang, C. (2017). Rework in Malaysian building construction: impacts, causes and potential solutions. *Journal of Engineering, Design and Technology*, *15*(5), 591–618. https://doi.org/10.1108/jedt-01-2017-0002

APPENDICES

APPENDIX A

PMM Ratio Table for Roof Floor Columns

TABLE: Steel Frame Design Summary - Eurocode 3-2005					
Story	Label	Design Type	Design Section	PMM Combo	PMM Ratio
Roof	C8	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.69
Roof	C11	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.504
Roof	C5	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.481
Roof	C28	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.463
Roof	C12	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.447
Roof	C24	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.436
Roof	C22	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.435
Roof	C7	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.406
Roof	C26	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.4
Roof	C6	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.377
Roof	C34	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.359
Roof	C20	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.276
Roof	C23	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.275
Roof	C9	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.274
Roof	C15	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.266
Roof	C25	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.259
Roof	C31	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.245
Roof	C27	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.223
Roof	C4	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.18
Roof	C17	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.176
Roof	C21	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.156
Roof	C18	Column	COL 75X75X2.3	1.35DL+1.5LL(C)	0.137

APPENDIX B

PMM Ratio Table for First Floor Columns

TABLE: Steel Frame Design Summary - Eurocode 3-2005					
Story	Label	Design Type	Design Section	PMM Combo	PMM Ratio
1st Floor	C31	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.815
1st Floor	C11	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.747
1st Floor	C25	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.745
1st Floor	C5	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.731
1st Floor	C9	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.692
1st Floor	C12	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.655
1st Floor	C7	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.629
1st Floor	C4	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.615
1st Floor	C28	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.602
1st Floor	C26	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.572
1st Floor	C22	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.554
1st Floor	C3	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.536
1st Floor	C24	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.528
1st Floor	C34	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.486
1st Floor	C13	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.484
1st Floor	C6	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.447
1st Floor	C2	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.446
1st Floor	C16	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.432
1st Floor	C20	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.411
1st Floor	C18	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.409
1st Floor	C15	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.402
1st Floor	C14	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.393
1st Floor	C23	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.387
1st Floor	C1	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.348
1st Floor	C27	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.28
1st Floor	C17	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.223
1st Floor	C21	Column	COL 100X100X3	1.35DL+1.5LL(C)	0.157

APPENDIX C

PMM Ratio Table for Roof Floor Beams

TABLE: Steel Frame Design Summary - Eurocode 3-2005					
Story	Label	Design Type	Design Section	PMM Combo	PMM Ratio
Roof	B30	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.769
Roof	B39	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.687
Roof	B31	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.678
Roof	B41	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.655
Roof	B87	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.625
Roof	B13	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.602
Roof	B42	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.579
Roof	B37	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.553
Roof	B88	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.514
Roof	B22	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.405
Roof	B85	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.317
Roof	B40	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.313
Roof	B1	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.289
Roof	B86	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.221
Roof	B43	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.147
Roof	B70	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.098
Roof	B2	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.097
Roof	B45	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.091
Roof	B47	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.089
Roof	B46	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.082
Roof	B29	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.07
Roof	B69	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.068
Roof	B81	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.066
Roof	B26	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.064
Roof	B83	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.063
Roof	B25	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.06
Roof	B77	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.05
Roof	B82	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.049
Roof	B33	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.046
Roof	B36	Beam	BEAM 75X100X2.3	1.35DL+1.5LL(C)	0.027

APPENDIX D

PMM Ratio Table for First Floor Beams

TABLE: Steel Frame Design Summary - Eurocode 3-2005					
Story	Label	Design Type	Design Section	PMM Combo	PMM Ratio
1st Floor	B30	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.72
1st Floor	B30	Beam	BEAM 100X100X3	1.35DL+1.5LL(T)	0.72
1st Floor	B31	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.662
1st Floor	B39	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.635
1st Floor	B39	Beam	BEAM 100X100X3	1.35DL+1.5LL(T)	0.635
1st Floor	B1	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.588
1st Floor	B37	Beam	BEAM 100X100X3	1.35DL+1.5LL(T)	0.574
1st Floor	B13	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.549
1st Floor	B37	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.463
1st Floor	B85	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.456
1st Floor	B85	Beam	BEAM 100X100X3	1.35DL+1.5LL(T)	0.456
1st Floor	B40	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.398
1st Floor	B40	Beam	BEAM 100X100X3	1.35DL+1.5LL(T)	0.398
1st Floor	B10	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.304
1st Floor	B9	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.3
1st Floor	B22	Beam	BEAM 100X100X3	(T)	0.237
1st Floor	B25	Beam	BEAM 100X100X3	(T)	0.21
1st Floor	B86	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.152
1st Floor	B32	Beam	BEAM 100X100X3	(T)	0.142
1st Floor	B27	Beam	BEAM 100X100X3	1.35DL(C)	0.134
1st Floor	B35	Beam	BEAM 100X100X3	(T)	0.132
1st Floor	B3	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.131
1st Floor	B19	Beam	BEAM 100X100X3	(T)	0.13
1st Floor	B23	Beam	BEAM 100X100X3	1.35DL(C)	0.128
1st Floor	B34	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.127
1st Floor	B77	Beam	BEAM 100X100X3	(T)	0.122
1st Floor	B69	Beam	BEAM 100X100X3	1.1DL+1.5LL(T)	0.121
1st Floor	B11	Beam	BEAM 100X100X3	(T)	0.108
1st Floor	B83	Beam	BEAM 100X100X3	(T)	0.103
1st Floor	B69	Beam	BEAM 100X100X3	1.1DL+1.5LL(C)	0.098
1st Floor	B70	Beam	BEAM 100X100X3	1.35DL(C)	0.097
1st Floor	B70	Beam	BEAM 100X100X3	1.35DL(T)	0.096
1st Floor	B82	Beam	BEAM 100X100X3	(T)	0.077
1st Floor	B26	Beam	BEAM 100X100X3	(T)	0.076
1st Floor	B36	Beam	BEAM 100X100X3	1.35DL(C)	0.076
1st Floor	B46	Beam	BEAM 100X100X3	1.35DL(C)	0.064
1st Floor	B47	Beam	BEAM 100X100X3	(T)	0.025
1st Floor	B84	Beam	BEAM 100X100X3	(T)	0.017
1st Floor	B14	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.01
1st Floor	B48	Beam	BEAM 100X100X3	1.35DL+1.5LL(C)	0.009

APPENDIX E

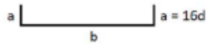
PMM Ratio Table for First Floor Joists

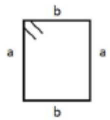
TABLE: Steel Frame Design Summary - Eurocode 3-2005					
Story	Label	Design Type	Design Section	PMM Combo	PMM Ratio
1st Floor	B90	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B91	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B92	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B93	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B94	Beam	JOIST 50X75X1.6	1.35DL(C)	0.015
1st Floor	B95	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.015
1st Floor	B96	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B97	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B98	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B99	Beam	JOIST 50X75X1.6	(T)	0.015
1st Floor	B100	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.015
1st Floor	B100	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(T)	0.015
1st Floor	B58	Beam	JOIST 50X75X1.6	(T)	0.013
1st Floor	B59	Beam	JOIST 50X75X1.6	(T)	0.013
1st Floor	B68	Beam	JOIST 50X75X1.6	(T)	0.013
1st Floor	B126	Beam	JOIST 50X75X1.6	(T)	0.013
1st Floor	B166	Beam	JOIST 50X75X1.6	1.35DL(C)	0.013
1st Floor	B167	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.013
1st Floor	B144	Beam	JOIST 50X75X1.6	(T)	0.01
1st Floor	B145	Beam	JOIST 50X75X1.6	(T)	0.01
1st Floor	B154	Beam	JOIST 50X75X1.6	(T)	0.01
1st Floor	B155	Beam	JOIST 50X75X1.6	(T)	0.01
1st Floor	B156	Beam	JOIST 50X75X1.6	(T)	0.01
1st Floor	B157	Beam	JOIST 50X75X1.6	(T)	0.01
1st Floor	B158	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.01
1st Floor	B158	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(T)	0.01
1st Floor	B159	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.01
1st Floor	B159	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(T)	0.01
1st Floor	B64	Beam	JOIST 50X75X1.6	1.35DL(C)	0.009
1st Floor	B64	Beam	JOIST 50X75X1.6	1.35DL(T)	0.009
1st Floor	B65	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B66	Beam	JOIST 50X75X1.6	1.35DL(C)	0.009
1st Floor	B71	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B72	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B121	Beam	JOIST 50X75X1.6	1.35DL(C)	0.009
1st Floor	B121	Beam	JOIST 50X75X1.6	1.35DL(T)	0.009
1st Floor	B122	Beam	JOIST 50X75X1.6	1.35DL(C)	0.009
1st Floor	B123	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B124	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.009
1st Floor	B125	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B15	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B16	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B17	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.009
1st Floor	B17	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(T)	0.009
1st Floor	B18	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.009
1st Floor	B21	Beam	JOIST 50X75X1.6	1.35DL+1.5LL(C)	0.009
1st Floor	B24	Beam	JOIST 50X75X1.6	(T)	0.009
1st Floor	B28	Beam	JOIST 50X75X1.6	(T)	0.009

APPENDIX F

Bar Bending Schedule for Beams

No.	Beam Marking	No. of Beams	B (mm)	x	D (mm)	L (mm)	Description	a (mm)	b (mm)	Total length (mm)	No. of bar/link	Bar diameter (mm)	Bar weight (kg/m)	Total bar weight (kg)
1	RB A-E/1	6	200	x	200	6706	Top bar	160	6636	6956	2	12	0.89	74.108
							Bottom bar	160	6636	6956	2	12	0.89	74.108
							Shear link	130	130	712	62	8	0.39	104.511
2	RB A-E/7	1	200	x	200	5182	Top bar	160	5112	5432	2	12	0.89	9.645
							Bottom bar	160	5112	5432	2	12	0.89	9.645
							Shear link	130	130	712	47	8	0.39	13.204
3	RB A,D/1-7	2	200	x	200	12802	Top bar	160	13157	13477	2	12	0.89	47.860
							Bottom bar	160	13157	13477	2	12	0.89	47.860
							Shear link	130	130	712	116	8	0.39	65.179
4	RB D/6-7	1	200	x	200	2134	Top bar	160	2064	2384	2	12	0.89	4.233
							Bottom bar	160	2064	2384	2	12	0.89	4.233
							Shear link	130	130	712	19	8	0.39	5.338
5	RB E/1-6	1	200	x	200	10668	Top bar	160	10598	10918	2	12	0.89	19.386
							Bottom bar	160	10598	10918	2	12	0.89	19.386
							Shear link	130	130	712	96	8	0.39	26.971
6	1B A-E/1	6	200	x	200	6706	Top bar	160	6636	6956	2	12	0.89	74.108
							Bottom bar	160	6636	6956	2	12	0.89	74.108
							Shear link	130	130	712	61	8	0.39	102.825
7	1B A-E/7	1	200	x	200	5182	Top bar	160	5112	5432	2	12	0.89	9.645
							Bottom bar	160	5112	5432	2	12	0.89	9.645
							Shear link	130	130	712	47	8	0.39	13.204
8	1B A,B,D/1-7	3	200	x	200	12802	Top bar	160	13157	13477	2	12	0.89	71.790
							Bottom bar	160	13157	13477	2	12	0.89	71.790
							Shear link	130	130	712	116	8	0.39	97.768
9	1B D/6-7	1	200	x	200	2134	Top bar	160	2064	2384	2	12	0.89	4.233
							Bottom bar	160	2064	2384	2	12	0.89	4.233
							Shear link	130	130	712	19	8	0.39	5.338
5	1B E/1-6	1	200	x	200	10668	Top bar	160	10598	10918	2	12	0.89	19.386
							Bottom bar	160	10598	10918	2	12	0.89	19.386
							Shear link	130	130	712	96	8	0.39	26.971



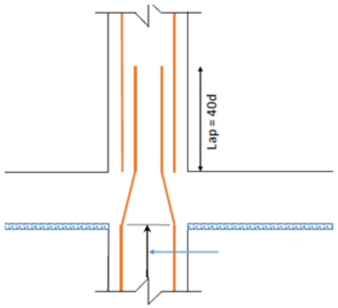


Bar (mm)	8	12
Total (kg)	461.31	668.79

APPENDIX G

Bar Bending Schedule for Columns

No.	Column Marking	No. of Columns	B (mm)	x	D (mm)	L (mm)	Description	a (mm)	b (mm)	Total length (mm)	No. of bar/link	Bar diameter (mm)	Bar weight (kg/m)	Total bar weight (kg)
1	Roof Column	22	200	x	200	3000	Main bar	-	-	3000	4	12	0.89	234.383
							Shear link	130	130	664	14	6	0.22	45.392
2	L1 Column	28	200	x	200	3000	Main bar	-	-	3871	4	12	0.89	384.914
							Shear link	130	130	664	17	6	0.22	70.152



Bar (mm)	6	12
Total (kg)	115.54	619.30

APPENDIX H

Bar Bending Schedule for Slab

Main bar

No.	Slab Marking	L (mm)	x	B (mm)	D (mm)	Description	Bar spacing	No. of bar	Total length (mm)	Bar diameter (mm)	Bar weight (kg/m)	Total bar weight (kg)
1	1S A-E/1-2	6706	x	1981	100	Top bar	T8-300	7	3850	8	0.39	10.63
						Bottom bar	T8-300	7	6656	8	0.39	18.38
2	1S A-E/2-3	6706	x	1981	100	Top bar	T8-300	7	3850	8	0.39	10.63
						Bottom bar	T8-300	7	6656	8	0.39	18.38
3	1S A-D/3-4	3568	x	2440	100	Top bar	T8-300	9	2800	8	0.39	9.94
						Bottom bar	T8-300	9	3518	8	0.39	12.49
4	1S A-E/4-5	6706	x	2590	100	Top bar	T8-300	10	4250	8	0.39	16.77
						Bottom bar	T8-300	10	6656	8	0.39	26.26
5	1S A-E/5-6	6706	x	1677	100	Top bar	T8-300	6	4250	8	0.39	10.06
						Bottom bar	T8-300	6	6656	8	0.39	15.76
6	1S A-E/6-7	5182	x	2134	100	Top bar	T8-300	6	3820	8	0.39	9.04
						Bottom bar	T8-300	6	5132	8	0.39	12.15

Distribution bar

No.	Slab Marking	L (mm)	x	B (mm)	D (mm)	Description	Bar spacing	No. of bar	Total length (mm)	Bar diameter (mm)	Bar weight (kg/m)	Total bar weight (kg)
7	1S A-B/1-7	12802	x	2438	100	Top bar	T8-300	9	8650	8	0.39	30.72
						Bottom bar	T8-300	9	13102	8	0.39	46.53
8	1S B-D/1-7	12802	x	1220	100	Top bar	T8-300	5	8650	8	0.39	17.07
						Bottom bar	T8-300	5	13102	8	0.39	25.85
9	1S D-E/6-7	2134	x	1524	100	Top bar	T8-300	6	1420	8	0.39	3.36
						Bottom bar	T8-300	6	2084	8	0.39	4.93
10	1S D-E/4-6	4266	x	3048	100	Top bar	T8-300	11	2690	8	0.39	11.68
						Bottom bar	T8-300	11	4216	8	0.39	18.30
11	1S D-E/1-3	3962	x	3048	100	Top bar	T8-300	11	2560	8	0.39	11.11
						Bottom bar	T8-300	11	3912	8	0.39	16.98

Total (kg)	357.04