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THESIS

Comparative Analysis of Structural Steel and Reinforced Concrete Construction for Sustainable Development

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F56/87946/2016

Thesis submitted for the Degree of Master of Science in Civil Engineering (Structural Engineering) in the

Department of Civil Engineering of the University of Nairobi

SEPTEMBER 2023

DECLARATION AND APPROVAL

I, Dyna Gakii Kaaria, hereby declare that this thesis is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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This Thesis is submitted for examination with our approval and knowledge as university supervisors.

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DEDICATION

To my parents, the late Mr. Obadiah Kaaria, and Ms. Prudence Mbuthu, My Husband Paul Wanyama and My children Jeremy and Juliette without whom the motivation to do this would be lacking. This effort is for and because of you.

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May God bless you all abundantly.

ABSTRACT

Current discussions on Africa's Development revolves around positioning itself as an economic hub. Economic report on Africa, 2015 recognizes that there is potential for Africa to experience greater growth than East Asia countries through industrialization. To aid in this industrial growth, there needs to be corresponding construction development in industrial buildings, rail and roads and housing. This development needs to be environmentally, socially, and economically sustainable.

Choice of building material accounts for over 80% of the Greenhouse gas emissions during construction. Studies have sought to determine the performance of newer sustainable building materials like cross-laminated timber, recycled-aggregate concrete, alkali-activated concrete and concrete with reduced cement quantities and use of limestone powder in greenhouse gas emission. To do this however, study of conventional construction material has to be done to determine their contribution to global warming. The study therefore sought to identify the most economical, environmentally friendly, and least time-consuming material for construction.

The overall objective of the study involved employing structural design principles of a typical Industrial project to determine the most economical, environmentally friendly and most time efficient building material.

A cost-benefit analysis, carbon print analysis, and construction time evaluation of structural steel and reinforced concrete were conducted. A comprehensive design approach was developed with two designs of the same structure using the two materials. The methodology had a simple model structure for comparison. It comprised of a portal frame industrial shed of 60m x 20m in plan, and a double volume height of 7.73m. In addition, an overhead crane to account for abnormal loads was considered. This model structure was large enough to consider large-span design complexities. Two target construction materials (structural steel and reinforced concrete) were used to create the model structure. The two design structures were tested under the same loads. Results showed that embedded carbon for concrete was 149,179.85 KgCo2e/kg, and for steel was 167,193.57 KgCo2e/kg. This study demonstrates that concrete is sustainable in terms of embedded carbon emissions. Its universality is undisputed, making it a more sustainable construction material. The bills of quantities show that concrete construction costs Ksh. 21,542,870.00 while Steel construction costs Ksh. 26,903,320.00. The difference is Ksh. 5,360,450.00. Concrete construction therefore costs 19.92% lower, making it cheaper than steel construction.

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1 INTRODUCTION

1.1 Background of the Study

Concrete is preferred as a building material because of its high strength and compression characteristics. It is incorporated with steel to compensate for its tensile strength weaknesses. Its manufacturing requires the mining and transportation of limestone, which results in high equipment and fuel costs. The addition of limestone to cement requires large amounts of energy, and consequently, concrete production has contributed to environmental deterioration. Malhotra (2000) reiterated that the cement industry is responsible for the release of 7% of carbon dioxide (CO_2). Cement requires burning fossil fuels at temperatures over 1400 °C (Aziz, 1995) and is highly energy intensive.

The steel industry has promising prospects in terms of growth and profit. Steel is used in almost all types of structures. This provides designers with choices for developing fresh solutions. Its qualities, such as beauty, durability, adaptability, cost-effectiveness, and ductility, make it preferable for the construction industry (Duggal, 2000).

Sustainable development has been identified as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). The Africa manifesto for sustainable development showcases how Africa is responding to climate, economic, and social challenges, and opportunities for sustainable buildings and cities. Sustainable cities and communities are one of the seventeen sustainable development goals identified by the United Nations Member States in 2015 as part of the “The 2030 Agenda for Sustainable Development”. These goals are based on decades of work by countries and agencies to develop agendas and policies to foster sustainable development and reduce carbon emissions.

In line with this need for sustainable development, the construction industry which has a significant contribution to economic and social well-being and carbon emissions that contribute to global warming, has adjusted to conform to and reduce the impact of climate change. This includes the use of sustainable building materials and methods and immense research on the same for continued improvement.

In view of the above description, it is necessary to undertake research on the most sustainable material for construction with specific interest in cost-benefit analysis, carbon print analysis, and analysis of the overall time taken in construction.

This comparison is expected to provide the best image of the most appropriate material considering the type and size of the structure, expected use, and speed of the structure.

1.2 Problem Statement

Current discussions on Africa's development revolve around positioning Africa as an economic hub. *An economic report on Africa in 2015* recognised that Africa has the potential to experience greater growth than East Asian countries through industrialisation (UNECA, 2015). To aid industrial growth, there needs to be corresponding construction development in industrial buildings, railways, roads, and housing. Development must be Environmentally, Socially and Economically sustainable. There is deficient research on the specific contribution of conventional construction materials to global warming and sustainability. Therefore, this study seeks to identify the most economical, environmentally friendly, and least time-consuming material for construction.

1.3 Overall Objective

To determine the most economical, environmentally friendly, and time-efficient building material using the structural design principles of a typical industrial project.

1.3.1 Specific Objectives

1. To carry out a cost-benefit analysis of structural steel and reinforced concrete construction.
2. To carry out a Carbon print analysis of Structural steel and reinforced concrete
3. To analyse overall time taken in construction for the two construction materials

1.4 Justification for the study

Sustainable development is defined as that which meets all needs of the present but does not compromise future generations from meeting their needs. This definition simply involves as many players as possible to incorporate sustainable development decisions in the everyday running of their institutions (Muigai, 2014). Therefore, it is prudent for Civil Engineers to identify the most suitable materials and forms of construction that will reduce carbon emissions and environmental degradation and still meet the functions for which they are constructed. Often, sustainability in construction has focused on the use of locally available, environmentally friendly materials and/or waste as a replacement for cement manufacturing. This is greatly encouraged and is going a long way to enhance environmental and economic sustainability. However, there needs to be a focus on design as a part of enhancing sustainability. As we focused on the material, we also focused on the overall application of this material in the overall construction. This ensures that every material is optimally paired with the requirements.

More than 10 billion tons of concrete is produced annually, accounting for 8% of global carbon emissions (Dias, 2019). Thus, it is the most consumed product after water, and the impact of its production on greenhouse gas emissions is immense. Concrete additives can be used to reduce the amount of cement required for concrete production, and consequently its carbon emissions, and at the same time produce a strong workable material. Even with these studies, it is necessary to determine the levels of carbon emissions from conventional concrete construction. Globally, 1.8 billion tonnes of crude steel is used annually. Steel production accounts for over 7% of the global greenhouse gas emissions, therefore, steel construction, which is a conventional construction method, contributes significantly to global warming.

Therefore, this study sought to quantify the levels of carbon emissions and sought to determine which of the two materials is more sustainable: structural steel and reinforced concrete.

1.5 Scope of work

The scope of this study involved the formulation of a model structure and proceeded with the design of the structural steel and reinforced concrete industrial structures. The model structure was of size 60m long by 20m wide, and 7.73m high double-volume industrial shed. The study also involved the formulation of detailed bills of quantities for each of the two designs which was then be used for cost-benefit analysis. The bill of quantities were also used to determine the carbon print of each of the two materials analysed.

2 LITERATURE REVIEW

2.1 Steel

Steel is an iron-carbon alloy. Carbon strengthens steel by hardening it and preventing dislocations within the crystal lattice (Salmon & Johnson, 1990). The use of iron ore can be traced back to 400 BC, when Africans and Asians used iron to make agricultural tools (Vaibhav B Chavan, 2014). It was not until 300 BC that crude steel was created by combining iron ore with other materials and then reheating it.

During the Industrial Revolution, train stations were among the first major uses of steel for construction. This was because of the requirement for a material that was strong in both tension and compression. Wrought iron fits the description and is reasonably priced and readily available. The advantages of steel cannot be overlooked; however, its production costs are significantly high. The Bessemer process, that was invented in 1856 enabled steel production in large quantities.

2.2 Concrete

Concrete is the most important building material, because it is used in almost all building structures. Its greatest strength is its adaptability (the ability to be moulded into the shapes required for various forms). It is fire resistant and durable when procedures and specifications are correctly adhered to. Therefore, concrete finds a wide application in single-story, multi-story, bridge, retaining walls, and containment structures.

2.3 Replacement of British Standards with Eurocodes

In 2010, ten Eurocodes superseded British standards (Vijay, 2010). They were intended to harmonise the structural standards across the European Union (EU). However, each country is free to add an annex that modifies codes to reflect local conditions and practices. These annexes are referred to as the Nationally Determined Parameters (NDPs).

2.4 Design to BS 5950 versus Eurocode 3

British Standard BS 5950 governs the structural use of steelwork in buildings. It is used in structural steelwork design, fabrication, and erection. This standard does not apply to bridges because they are covered by a different standard, BS 5400. BS 5950 employs limit state design criteria and replaced BS 449, which employed a permissible stress approach.

It was superseded by BS EN 1993 (Eurocode 3: Design of steel structures, general rules, and rules for buildings). The Eurocode provides basic design rules for steel structures with material thicknesses greater than 3 mm. The National Annex to BS EN 1993-1-1 includes all UK decisions regarding the permitted National Determined Parameters (NDPs).

Eurocode 3 consists of 20 documents that cover various aspects of steel structure design. Eurocode 3 offers a more cost-effective and less conservative design compared to BS 5950. Specifically, using a steel beam as an example, Eurocode 3 provides increased shear and moment capacities with increased load and longer beam length. Conversely, BS 5950 requires a larger beam size for the same design. Additionally, Eurocode 3 allows for better actual and allowable deflection compared to BS 5950.

Therefore, in keeping with the current design procedures, all designs in this study were in accordance with the Eurocode standards.

2.5 Limit State Design Procedure for Reinforced Concrete

A typical reinforced concrete building structure comprises of the following elements: (i) foundation bases, which may be anchored piles, pads, and strips to distribute loads from the superstructure to the ground without causing excessive settlement; (ii) vertical elements that resist lateral, vertical, or in-plane loads (referred to as walls); (iii) slabs, which are horizontal load-carrying plates that resist lateral loads; (iv) beams, which are horizontal members that are used to support lateral loads; and columns, (which are vertical members that can carry axial loads and moments).

The procedure for the design of a building structure involves the following steps:

i. Idealisation of the structure into load-bearing frames and elements for analysis and design.
ii. Estimation of the loads acting on the structure.
iii. Determination of maximum moments, shears, and thrusts through analysis.
iv. Design and reinforcement arrangements for the structural sections.
v. Preparation of detailed drawings and bar bending schedules.

Limit state design (Load and Resistance Factor Design (LRFD) is a method for designing structures. All the loads acting on the structure during its lifetime were designed using this method (Gupta, 2008). Safety and serviceability acceptable limits before failure occurs is called “limit state”. Design loads are obtained by multiplying working loads with partial factors of safety for loads and in similar manner, design strength of materials is obtained by dividing characteristic strength (ultimate strength) with respective partial factors of safety for materials.

Members are therefore proportioned to carry limit state design loads, and materials are stressed to limit design strengths (Pandit & Gupta, 1981).

The structure to be constructed must fulfil the following requirements: endure all loads, ensure reliability, and maintain integrity throughout construction and usage. During maintenance, the structure should be designed to be durable and prevent disproportionate collapse or damage from accidents such as vehicle impacts or explosions. The design should be such as to minimize hazards through appropriate design choices, such as efficiency in layouts and accuracy in the detailing. This is in order to limit exposure to potential risks.

Serviceability Limit States encompass deformations and deflections that impair the functionality or appearance of the structure, cause disruptions to services or equipment, or cause damage to the finishing. Additionally, vibrations in the structure or its components can reduce its effectiveness. Furthermore, repairable damage or cracks caused by fatigue, as well as corrosion, must be considered in the design for fire resistance.

Figure 2.1 and Figure 2.2 present the design procedures for limit state and serviceability limits.

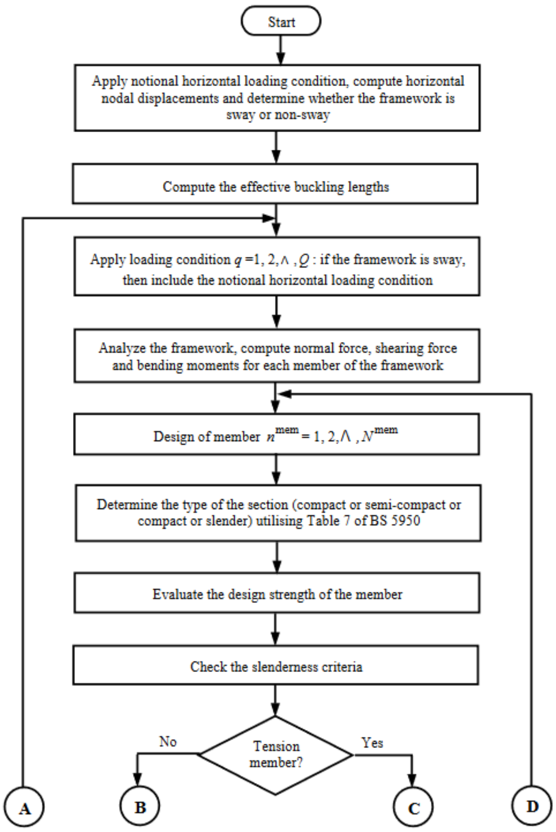


Figure 2.1: Limit state design procedure for structural steelwork (EN:1990;2002 Eurocode, Basis of Structural Design)

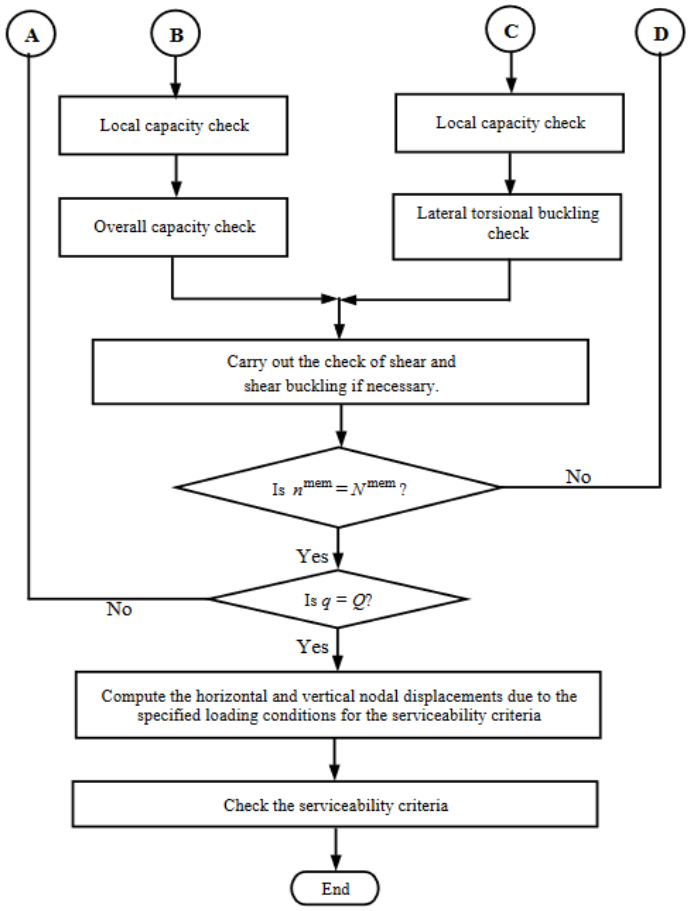


Figure 2.2: Limit state design procedure for structural steelwork contd, (EN:1990;2002 Eurocode, Basis of Structural Design)

2.5.1 Partial Safety Factors and Design Values

The characteristic values account for inherent fluctuations in loads and material strengths. Additionally, it's crucial to take into account other factors that may cause variations, and to allow for these uncertainties by incorporating appropriate partial safety factors (Syal & Goel, 2008). There may be uncertainties in the structural integrity of a building, which can be attributed to factors such as fatigue, long-term loading, weaker material than characteristic value, constructional faults including inadequate compaction or curing, impurities, and bad weather, repeated loading, corrosion during the lifetime of a structure, and excessive loading or stress, which can cause serious consequences.

2.5.2 Actions, Characteristic and Design Values of Action

The actions (loads) are classified as follows:

i. Permanent actions (G): These are the fixed values such as the self-weight of the structure and the weight of finishes, ceilings, services, and partitions.

ii. Variable actions (Q): These are the imposed loads on floors caused by people, furniture, equipment, and wind and snow loads.

iii. Accidental actions (A): These are the loads caused by vehicle crashes, bomb blasts, and other forces.

The characteristic value of an action (load) is its main representative value defined by a nominal value which is normally expected to have a 95% probability of not being exceeded (CEN, 2002) The characteristic loads used in design are as follows:

The permanent actions (G_k) of a structure are assigned a single value due to its insignificant fluctuation over the structure's lifespan (CEN, 2002).

For irreversible final limit states, the variable action (Q_k) is characterized by a combination value of $\Psi_0 Q_k$. For reversible limit states, the frequent value of $\Psi_1 Q_k$ is used. The quasi-permanent value of $\Psi_2 Q_k$ is used for the deflection and other aspects of the structural appearance. The combination factor Ψ reduces the design value of variable loads when they act in tandem (CEN, 2002).

The design value is the product of the representative value and a load factor, while partial safety factors account for unforeseen increases in load, incorrect evaluation of the load effect, overlooked member stress distribution, the magnitude of values of the limit state in question. Characteristic wind action, W_k, is determined by the building shape, dimension, and location. Characteristic earth loads are also considered in a design, and they are specified in the EN 1990 and EN 2002 Load combinations standards.

2.6 Advantages and disadvantages of Steel

Steel is used to build large structures, such as industrial buildings, residential buildings, and bridges. Steel construction offers numerous advantages over concrete construction.

In contrast to concrete, the properties of steel remain unchanged. Steel is pliable, and it follows Hooke’s law very accurately. However, steel has numerous disadvantages that render reinforced concrete preferable. Steel columns are susceptible to buckling whereas RC columns are sturdy and massive. Steel is susceptible to corrosion when exposed to air, water, and humidity. Therefore, its maintenance costs are high because it has to be painted periodically.

Steel requires high-level fireproofing techniques because its strength is significantly reduced at high temperatures. Steel underperforms under fatigue conditions.

2.7 Widespread Uses of Steel as Opposed to Concrete

Although steel is gaining momentum as a construction material owing to its flexibility and reduced construction time, concrete has been conventionally used as a construction material over time. Both materials have high embodied energy in their manufacturing.

Steel allows fast erection on-site, irrespective of its high lead time. It needs fire protection whereas this is inherent in the design of reinforced concrete (Dabhade, Hedaoo, Gupta, & Ronghe, 2009).

Thin-film intumescent coatings can be applied offsite because they allow the prefabrication of steel. Reduced labour costs and ease of erection allowing sooner occupation are some of the benefits of steel.

A Steel Frame can be up to sixty percent lighter than a comparable Reinforced Concrete frame, making it what can be referred to as "lightweight". This allows a less expensive foundation system for the steel frame. During service, modifications can be easily made by the removal of structural steel members if necessary.

Reinforced concrete is water-resistant and does not corrode when built and properly maintained. However, precautions should be taken to avoid exposing the steel reinforcement, which could compromise the strength of the structure owing to corrosion.

2.8 Design Using Open Sections Versus Closed Sections

Open steel sections have a bent or formed shape with a starting end and a non-connected end. This include I, C, W, L, Z among others (Chavan, Nimbalkar, & Jaiswal, 2014). The closed steel sections indicate that the sidewalls are continuous. Closed sections are those with all sides closed, such as Hollow Structural Sections, HSS, or two channels joined with webs facing outwards, thus forming a tubular structure (Chavan, Nimbalkar, & Jaiswal, 2014).

Hollow Structural sections offer several benefits, including their excellent static properties. They also provide better performance in buckling and torsion compared to open members, and have economic advantages in that they have the capacity to reduce the cost of corrosion protection due to their closed shape and changeover at sections. Additionally, their strength can be increased by filling the section with concrete or by varying the wall thickness without changing the outside dimensions. Hollow sections can also be combined with other functions such as heating, ventilation, and fire protection, resulting in structures that are clean, functional, and spacious. Furthermore, drag coefficients for hollow sections are lower than those for sections with edges, which is beneficial for structures exposed to fluid flow.

2.9 Design of Cold-Formed Sections Versus Hot-Rolled Sections to BS 5950

Cold-formed steel sections are made by rolling or pressing steel into semi-finished or finished goods at relatively low temperatures.

Hot-rolled steel sections are made by passing industrial metals between work rolls at temperatures above the recrystallisation temperature. The primary goal of hot rolling is to manipulate the material shape and geometry, rather than the mechanical properties (Salmon & Johnson, 1990).

Cold forming increases the yield strength of the steel. This increase is due to cold working in the strain-hardening range. This increase was more pronounced when the metal was bent by folding. Consequently, cold working increased the mean yield stress by 15 to 30%. A minimum enhancement of 15% was assumed for the design. (Syal & Goel, 2008).

Cold-formed steel sections have several advantages over hot-rolled sections, including the ability to manufacture light members for short spans and light loads, the economical production of unusual configurations, and the resulting favourable strength-to-weight ratios. Cold-formed members also offer the possibility of close tolerances for cross-sectional shapes, consistency in formation and repetition, pre-galvanized and pre-coated metals for corrosion resistance and an appealing surface finish, and various joining methods such as welding, riveting, bolting, and adhesive joining. Additionally, cold-formed steel sections have high stiffness and strength, and the ability to produce long spans.

With cold-formed members, the load-carrying capacity, particularly in beams, can be enhanced by displacing the material away from the neutral axis. Infinite type of cross-sections can be formed (Salmon & Johnson, 1990)

2.10 Carbon Print Analysis and Sustainable Development

The carbon footprint is the total amount of carbon dioxide (CO_2) and greenhouse gas emissions emitted by a product over its lifetime (Goodier, 2010). Sustainable development aims to meet all needs of the present without compromising the needs of future generations (Brundtland, 1987). Based on the foregoing, a sustainable structure can be defined as one that is designed to meet specific needs while minimising environmental impacts and costs through: (i) efficient construction technologies and production; (ii) use of materials with optimum properties for durability and minimal environmental impact; (iii) optimising and using appropriate structural layouts and volume; and (iv) Material recycling. (Muigai, 2014).

Sustainable development aims at mitigation of environmental degradation and offers one of the solutions to the economic and social impacts on the environment.

2.10.1 Carbon Footprint Analysis

Human activities produce greenhouse gas (GHG) emissions, which have a negative impact on the environment. Most important of the emissions is Carbon dioxide (CO_2). Emissions, in turn, have a negative impact on the environment, leading to climate change. Dealing with these impacts is crucial in mitigating these changes. Therefore, Carbon Footprint Analysis is used as a metric in construction studies. It is a life-cycle analysis of emissions that have an impact on GWP (Muigai, 2014).

Carbon Footprint Analysis gives the amount of equivalent carbon dioxide emissions (kg CO_2-eq) that are caused directly or indirectly by an activity or are accumulated by stages of a product as demonstrated in Figure 2.3: Carbon dioxide emissions associated with UK household consumption in 2001 (Weidmann & Minx, 2008). The carbon dioxide emissions shown in the figure is quantified in Kiloton (kt).

The energy embodied in a product is closely related to its carbon footprint. This describes the amount of energy used in the production (Muigai, 2014). When conducting Carbon Footprint Analysis, this embodied energy can be used in the life cycle analysis (LCA) of a product. The lifecycle models are shown in Figure 2.4 and Figure 2.5.

Embodied energy measures the gross energy requirement of a material, structure, and/or structural component (Ashley & Lemay, 2008).

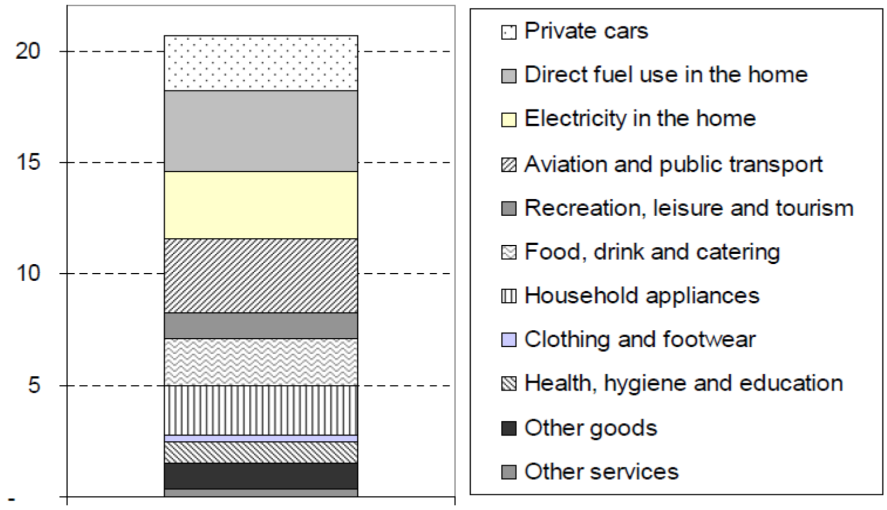


Figure 2.3: Carbon dioxide emissions associated with UK household consumption in 2001 (Weidmann & Minx, 2008).

The ordinates in Figure 2.3 are carbon dioxide in Kiloton (kt).

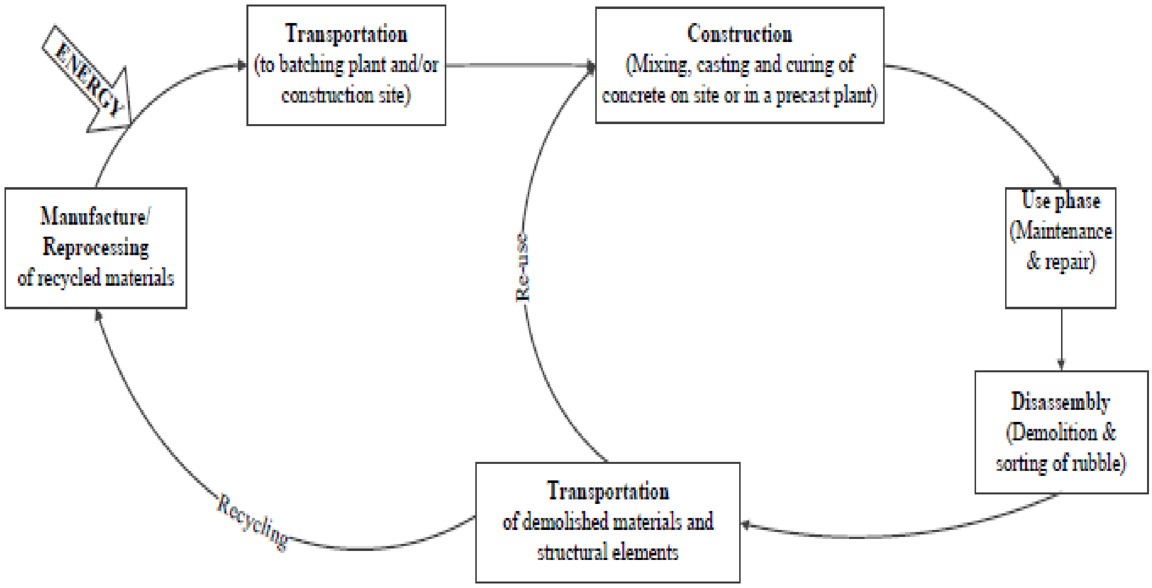


Figure 2.4: Circular lifecycle of construction material model (Muigai, 2014)

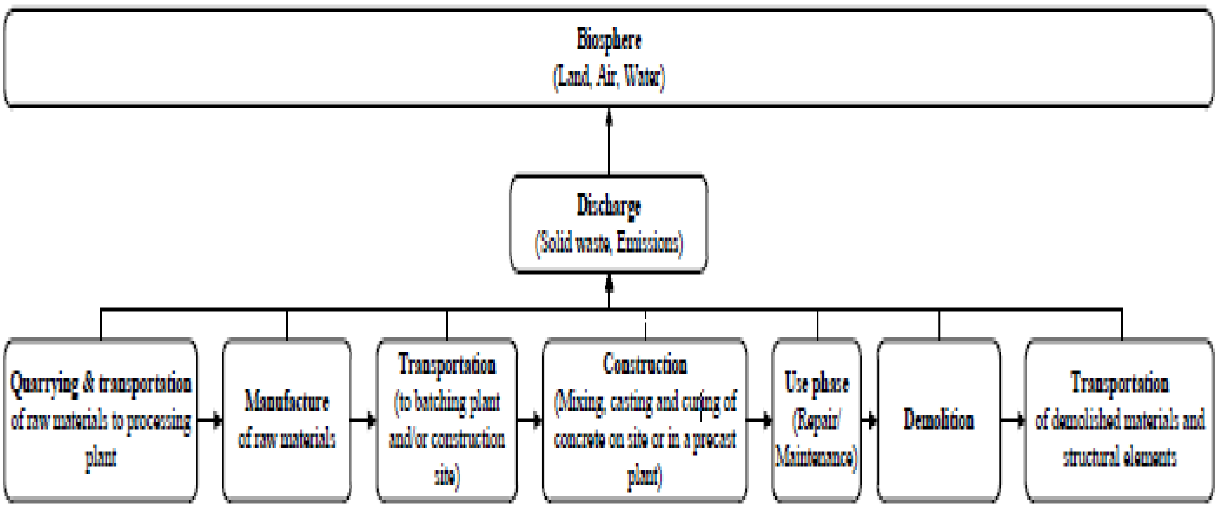


Figure 2.5: Linear lifecycle model of a construction material (Muigai, 2014)

2.10.2 Sustainable Development History

Scientists agree that, beginning in the second half of the twentieth century, anthropogenic activities have caused climate change at a much faster rate than any other time in human history. (Solomon, Qin, Manning, Averyt, & Marquis, 2007).

Human activities impacting the ecosystem include those reported by Duraiappah et al. (2005), such as the increased use of non-renewable resources, technological progress based on resource exploitation, and the loss of biodiversity caused by the extinction or introduction of animal and plant species. Land use has also evolved over time. Environmental changes are expected to increase until 2050, as the human population grows. (Muigai, 2014).

Solow's (1974) theory of neoclassical economic growth distinguishes between natural, human, and manufactured capital regarding sustainability. It reasons "Natural capital scarcity because of increased use will push for technological advancement hence leading to more efficiency for use of scarce resources. It relies on technological advancement to guarantee infinite substitution of natural capital with manufactured or human capital and in turn mitigate scarcity/limit constraints" (Turner, Pearce, & Bateman, 1994)

The substitution has certain limitations (Pearce, Markanday, & Barbier, 2013). For instance, less affluent populations are disproportionately affected by environmental degradation, and some natural capital, like ozone, cannot be replaced once it's depleted. Additionally, the loss of biodiversity due to extinct plant or animal species is irreversible. Moreover, there are uncertainties regarding the reliability of technological advancements.

Sustainable development therefore is described as "Ecosystem and human interaction with the environment being able to maintain or support each other even if at a minimal level." (Muigai, 2014). Figure 2.6. Schedule of international stakeholder engagements on sustainable development (Muigai, 2014) shows the international workshops or conferences undertaken from the 1970s to 2010 showing the growing interest in sustainable development.

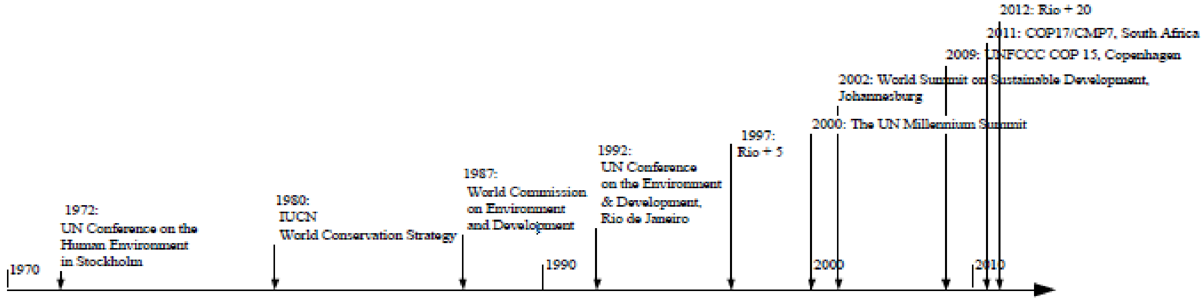


Figure 2.6.: Schedule of international stakeholder engagements on sustainable development (Muigai, 2014)

2.10.3 Conclusion of Literature Review

The Literature review focused on different aspects of Carbon Footprint Analysis, which was the main aim of this study.

Carbon footprint analysis is a lifecycle analysis of emissions that has an impact on the potential for global warming. It specifies the amount of (kg CO_2-eq) equivalent carbon dioxide emissions caused directly or indirectly by an activity or accumulated by the production stages. The energy embodied in a product is closely related to its carbon footprint. This describes the amount of energy consumed in the product. When conducting carbon footprint analysis, this embodied energy can be used in the life cycle analysis (LCA) of a product. Embodied energy measures the gross energy requirement of a material, structure, and/or structural component. This was the basis for the analysis of the two designs in this study.

In line with the objectives of the study, the literature elaborated the use of conservative construction material of reinforced concrete and steel, their usage and historical use and hence helped give guidance on how to determine the most sustainable of the two most common materials for construction, namely, Structural Steel, and Reinforced Concrete. There was a focus on their advantages and disadvantages.

The study elaborated on this in the discussion and conclusion. The review also touched on the principles of design, especially the limit state design, which was employed in the design calculations.

3 RESEARCH METHODOLOGY

3.1 Introduction

A comprehensive design approach was adopted to undertake two separate designs of the same structure, using structural steel and reinforced concrete.

The methodology included a straightforward model structure, which made it possible to formulate a comparison. The model structure was a 60m by 20m, 7.73m high, double volume portal frame industrial shed with provision for an overhead crane to provide an opportunity to introduce abnormal loads. The structure was also sufficiently large to allow for the complexities of large-span design considerations. The model structure was designed using both of the target construction materials (structural steel and reinforced concrete). The two model structures were the research samples with the capacity to resist the same loads. The parameters used as data for the analysis and drawing conclusions were as follows:

i. Sizes of foundation bases (from the weight of the structure)

ii. Shear resistance capacity

iii. Construction cost (generated bill of quantities for each of the two designs)

iv. Construction period

v. Carbon Footprint which was calculated from the material quantities generated from the bill of quantities.

Carbon footprint analysis methodologies could be performed in two different ways: The Process Analysis method focusing on the environmental impacts of a product from cradle to grave, or the Environmental Input-Output (EIO) analysis, which focuses on a top-down approach using input-output tables as economic accounts (Weidmann & Minx, 2008).

3.2 Design Criteria

3.2.1 Structural Designs

This Section described the criteria for the structural design of this project. This design procedure was compiled from the Kenyan Standards, British Standards, Eurocode and other International Standards and Codes of Practice.

3.3 Design Objective

The primary design criteria for a structure focus on strength requirements, which protect the structure against collapse, and meets the serviceability requirements. The latter focus on the functional performance of the structure. The structural integrity of any structure is guaranteed not only by structural calculations, but also by the materials specifications, quality control, and workmanship.

Limit state design has the limitation that a structure can become unsatisfactory in a variety of ways, each of which must be considered independently against defined limits of satisfactory behaviour. Limit state design recognises that loads, materials, and design and construction methods are subject to inherent variability, making complete safety against any potential flaws impossible. As a result, by providing adequate margins of safety, the Limit State Method provides a probabilistic approach for designing a structure that will remain usable over its entire life span.

There are two (2) major categories of limit-state designs.

i. For adequate safety provisions (Life Safety), the ultimate limit state (ULS) is used (Normal Occupancy).
ii. The serviceability limit state (SLS) is used for durability provisions. Serviceability entails Deflection and Cracking (for reinforced concrete structures).

The objectives and performance at the different limit states used in the reinforced concrete designs in this study as shown in Table 3.1 Limit state design for reinforced concrete.

Table 3.1: Limit state design for reinforced concrete

	Ultimate Limit State	Serviceability Limit State	
		Deflection	Cracking
Objective	Provision of adequate Safety	Structure not to deflect so as to impair use	
Load	Design Ultimate Loads	Design Service Loads	Design Service
Performance Limit	Structure not to fail	Deflection not to exceed specified limits	Crack width not to exceed 0.3mm

3.4 Material & Loading Characteristic Values

As previously stated in section 3.3, variations within materials are analysed statistically. The test results were assumed to follow a normal or Gaussian distribution curve, and a characteristic value was selected using Equation 3.1 below which indicates that no more than 5% of the test results were expected to lie.

$$\boldsymbol{Characteristic\ strength\ = Average\ strength - 1.64\ \times standard\ deviation}$$ *Equation 3.1*

Characteristic Loading was similarly defined as a load within 5% probability of being exceeded during the lifetime of the structure. However, it is not yet possible to express loading in statistical terms; therefore, the design uses the load defined in BS 6399: Parts 1, 2 and 3 as shown below.

Steel: Q235 ($Minimum\ yield\ stress\ F_y\ =\ 235\ N/mm^2$)

Bolt: 10.9 grade high-strength bolts (equal to A325M bolts)

3.4.1 Design Loading:

The design loading is given by Equation 3.2.

$$\boldsymbol{Design\ Load\ = Characteristic\ load\ \times Y_r}$$ *Equation 3.2*

Where: $Y_r = Load\ safety\ factor$

The design takes into consideration the Load Safety Factor. This factor considers the possibility of the loads acting on the structure exceeding the characteristic values. It also takes care of the assumptions used in the analysis as well as the severity of any failure to meet the design criteria for a specific limit state. Table 3.2: Ultimate Load Factors, lists the combinations of the ultimate load factors for the ultimate limit state. Recommended in the code (Eurocode 1)

Table 3.2: Ultimate load factors

Combination of Loads	Partial safety factor to be applied to;				
	Dead Load		Imposed Load		Wind Load/ Seismic Load
	When Effect of Load is;				
	Adverse	Beneficial	Adverse	Beneficial	
Dead & Imposed	1.4	1.0	1.6	0	-
Dead & Wind/Seismic	1.4	1.0	-	-	1.4
Dead & Wind/Seismic with Imposed	1.2	1.2	1.2	1.2	1.2

3.4.2 Design Strengths:

The characteristic strength of the materials to be used for the construction are based on a 50-year design life (Eurocode 2). The design strength is related to the design strength by Equation 3.3.

$$\boldsymbol{Characteristic\ load/Y_m = Design\ strength} \qquad \textit{Equation 3.3}$$

Where Y_m denotes the partial safety factor for material strength. This factor considers the variation in workmanship and quality control that can be expected during material manufacturing. Table 3.3: Ultimate yield strength factors shows Ym values which were used for determination of the ultimate limit state as recommended by the code (Eurocode 1).

Table 3.3: Ultimate yield strength factors

Values of Y_m for the Ultimate Limit State	
1. Reinforcement	1.05
2. Concrete	
- Flexure or Axial Load	1.5
- Shear Strength without Shear Reinforcement	1.25
- Bond strength	1.4
- Others (e.g. Bearing Stress)	≥ 1.5

3.4.3 Structural System

The model structure was a 60m by 20m, 7.73m high, double volume portal frame industrial shed with an overhead crane to allow for the introduction of abnormal loads. The structure was also sufficiently large to accommodate the complexities of large-span design considerations.

3.4.4 Basic Parameters

The design parameters were summarized in Table 3.4: Basic parameters for design that follows.

Table 3.4: Basic parameters for design

	BASIC PARAMETERS	
Item	**Description**	**Reference**
	3.4.4.1 *Dead Load* *(i) Self-weight* Roof sheet + 100mm mineral wool insulation layer = 0.08 KN/m^2 Roof support system = 0.02 KN/m^2 Purlin = 0.05 KN/m^2 The total self-weight of the roof system = 0.15 KN/m^2 Dead load, D = 0.15x6 = 0.9 KN/m *(ii) Roof Live Load* Using the method 1 (Normal Force Method) Tributary loaded area A= 20m x 6m =120 m^2 > 600 m^2 (55.74m^2), and roof slope = 26.8% < 33.3%, Lr =0.575 KN/m^2 Roof live load R L = Lr x e W = 0.575x 6 =3.45 KN/m *(iii) Wind Load Analysis* 10-minute mean wind speed of 24.3m/s was adopted for the design. The basic wind speed was defined as at 10 metres above a flat and open terrain, and the maximum average velocity was reached in three seconds and was expected to be exceeded once every 50 years. The transformation formula used for design wind speed was defined by Equation 3.4. $\mathbf{69/10min, 100 = 24.3/0.69 = 35.2m/s}$ *Equation 3.4* $pressure\ q = 0.762\ KN/m2$ $The\ mean\ height\ of\ store\ house\ h = 6.67m$ $The\ plant\ site\ was\ categorized\ as\ Exposure\ C, therefore, C = 1.15$ $pressure\ coefficient\ q\ C = 0.8\ inward\ (windward\ wall),$ $q\ C = 0.5\ outward\ (leeward\ wall),$ $q\ C = 0.7\ outward\ (leeward\ roof\ or\ flat\ roof$ $q\ C = 0.9\ outward\ (windward\ roof\ for\ slope\ 2:12\ (16.7\%)\ toless\ than\ 9:12\ (75\%))$	According to the Table 16-C of UBC 97 IBC-2009 Table 16-F of UBC 97 Table 16-G of UBC 97, Table 16-H of UBC 97, Table 16-K of UBC 97, formula (20-1) of UBC 97

Because of store house belong to standard occupancy category 4, wind importance factor $w\,I = 1.0$

Design wind pressures for the key locations on the structure (P) were determined using the information provided for "Wind perpendicular to ridge", hence the following values were obtained:

$P1 = 1.15x0.8x0.762x1 = 0.70\ KN/m2 \quad for\ windward\ wall$

$P2 = 1.15x0.9x0.762x1 = 0.79\ KN/m2 \quad for\ windward\ roof$

$P3 = 1.15x0.7x0.762x1 = 0.61\ KN/m2 \quad for\ leeward\ roof$

$P4 = 1.15x0.5x0.762x1 = 0.44\ KN/m2 \quad for\ leeward\ wall$

(iv) Wind load

$W1 = e\,WP\,1 = 0.70x6 = 4.20\ KN/m$

$W2 = e\,WP\,2 = 0.79x6 = 4.74\ KN/m$

$W3 = e\,WP\,3 = 0.61x6 = 3.66\ KN/m$

$W4 = e\,WP\,4 = 0.44x6 = 2.64\ KN/m$

$W\ --Effective\ load\ width$

Seismic data from the authoritative meteorological agency.

(v) Seismic Load Analysis

Figure 3.1 shows the seismic zoning (using peak ground acceleration (PGA) in m/s^2), where zoning had been characterized into high and medium based on earthquake magnitude distribution. Yellow areas had PGA ranging from 0.8 – 1.6 and light green areas had PGA ranging from 0.2 – 0.8. The PGA provided in Figure 3.1 showed areas with 10% chance that the peak ground acceleration will be exceeded in the next 50 years.

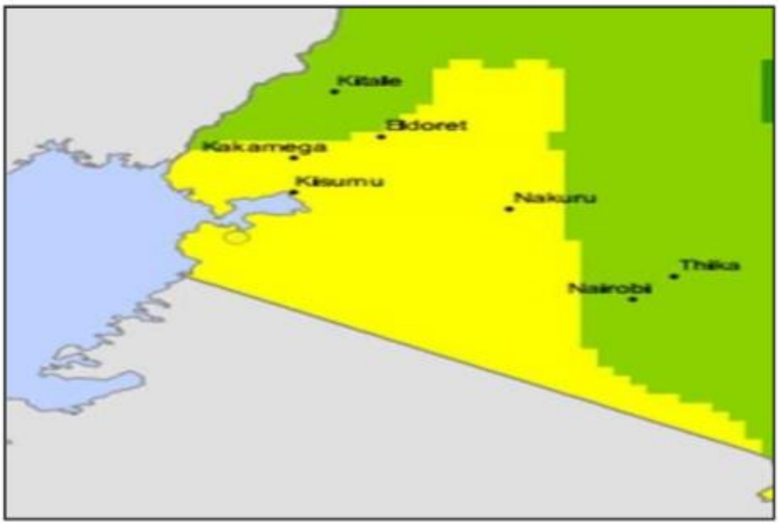


Figure 3.1: Code of Practice for the design and construction of buildings and other structures in relation to Earthquakes (1973)

As shown in the Appendix in Chapter 16 of UBC 97, Kenya is located in seismic zone designated 2A. Specifically, Kisumu, the study area, is located in the yellow seismic zone as shown in Figure 3.1. Therefore, the maximum ground acceleration (PGA) used for the analysis was 1.6 m/s^2 (equivalent to 0.16g).

According to the geotechnical investigation report, the standard penetration test N = 20 (15 to the type of 50), which belongs to soil profile D S (Table 16-J). The other parameters used for seismic design were:

$Seismic\ zone\ factor\ Z = 0.15\ in\ Table\ 16 - I$

$Seismic\ importance\ factor\ I = 1.0\ in\ Table\ 16 - K$

$R = 5.6\ 0 = 2.2\ (Building\ frame\ system - Ordinary\ braced\ frames)\ Table\ 16 - N$

$Seismic\ coefficient\ a\ C = 0.22\ (Z = 0.15, soil\ profile\ type\ D\ S)\ in\ Table\ 16 - Q$

$Seismic\ coefficient\ v\ C = 0.32\ (Z = 0.15, soil\ profile\ type\ D\ S)\ in\ Table\ 16 - R$

The occupancy category 4 store house used the static lateral force procedure.

(vi) Base Shear Design

The total design base shear in a given direction was calculated using the following formula:
$W\ RT\ IC\ v = V\ (30 - 4)$

The total design base shear did not exceed the following: $V = W\ RT\ IC\ a\ 5.2\ (30 - 5)$

The total design base shear was not to be less than the following:

$V = IWC\ 4/3\ t(\ nhCT\ \ (30 - 8)\ \ t\ C\ (30 - 5) = 0.0488$

3.4.4.2 *Structural Concrete*

Structural Concrete Class chosen for the design was as follows (Eurocode 2):

a) Columns C25
b) Beams C25
c) Slabs C25

3.4.4.3 *Blinding Concrete*

Blinding concrete chosen for the design was Class C15 (Eurocode 2).

3.4.4.4 *Reinforcement*

a) High Yield Rebar: fy = 460 N/mm^2 (type 1 bond characteristics)

Allowable design steel stress for liquid retaining structures where required.

$= 130\ N/mm^2$

b) Mild steel rebar: $f_y = 250\ N/mm2$

$$f_y = 115\ N/mm2\ for\ liquid\ retaining\ structures\ where\ required$$

3.4.4.5 *Structural timber*

Where structural timber was to be employed for the works, it was to be seasoned cypress grade II (structural) or better (Eurocode 5).

In particular, the following stresses for Cypress timber were used for the design:

a) Bending stress parallel to grain (//g) fb = 5N/mm2
b) Compression //g fc = 6N/mm2
c) Tension //g ft = 3N/mm2
d) Shear //g fv = 1.1N/mm2
e) The values of Modulus of Elasticity (E) chosen for the design were (cite).:

$$Emax = 7400N/mm^2$$

$$Emin = 3600N/mm^2$$

3.4.4.6 *Durability Requirements*

i. Fire

Fire resistance for structural elements was based on 2 hours generally. The minimum width of structural concrete to meet the 2 hours fire resistance was to be as follows:

B.S. 4449

a) Beams: 200mm.
b) Floor Slab: 125mm.
c) Column 50% exposed (with plaster): 200mm

BS-8007-87

ii. Minimum Cover to Main Reinforcement

a) Columns 40 mm; Beams 30 mm (bottom and sides) and 30 mm (top); Foundations 50 mm (with blinding) and 75 mm (without blinding);
b) Solid slabs and stairs 25 mm (bottom and sides) and 20 mm (top).

KS02-771:

1991

3.5 Preparation of Bills of Quantities

After the designs and drawings were completed, bills of quantities were prepared for each of Reinforced Concrete and Steel Structure designs. The rates used were from the prevailing unit rates provided by various construction institutions (construction cost handbook). The sections considered for taking off the quantities were: (i) substructure, (ii) superstructure, (iii) walling, (iv) roof construction, (v) finishes, (vi) windows, (vii) doors, (viii) mechanical installation, and (ix) electrical installation.

3.6 Carbon Analysis: Estimation of Embedded Carbon (EC)

The carbon footprint was used as a metric in these studies.

The amounts specified in the Bill of Quantities were converted to kilogrammes. Conversion rates and references were calculated using the Carbon and Energy (ICE) summary. The ICE database has boundaries from start to finish (as earlier captured in the Literature Review in section two. Even with these limits, numerous variations affected the absolute study boundaries. Variable boundaries were part of the main issues in using secondary data resources because they could cause significant differences in the results. The ICE database had ideal boundaries that it strived to adhere to consistently. However, owing to the limitations of secondary data resources, changes to these boundaries were not possible in some cases, such as bush clearing, excavation etc.

4 RESULTS AND DISCUSSION

4.1 Overall Model and Load Inputs-Structural Steel

The analysis was implemented in Staad Pro. A typical section of the steel frame with member labels is shown in Figure 4.1, and the sizes for the respective members are shown in Table 4.1.

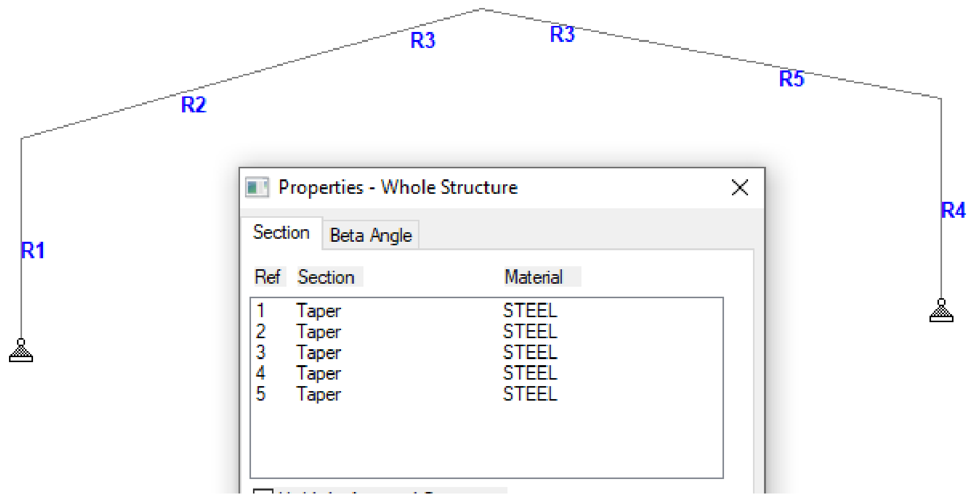


Figure 4.1: Steel structural model

Table 4.1: Member sizes -Steel Design

Member No.	Size (mm)
R1 = 4	300-600 x 200 x 6 x12 (5000mm)
R2	600-300 x 200 x 6 x12 (6000mm)
R3	300 x180 x 6 x 8 (4000mm)
R5	600-300 x 200 x 6 x12 (6000mm)

The conventional X-Y axes of the loaded structural steel frame are shown in Figure 4.2. The actual values of dead, roof live, wind, and seismic loads are shown in Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6 and Figure 4.7 respectively.

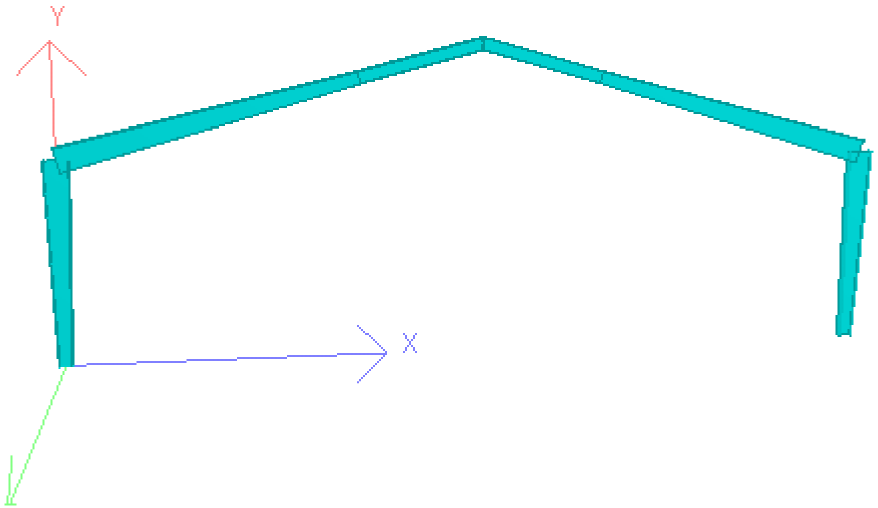


Figure 4.2: Loaded structural steel model

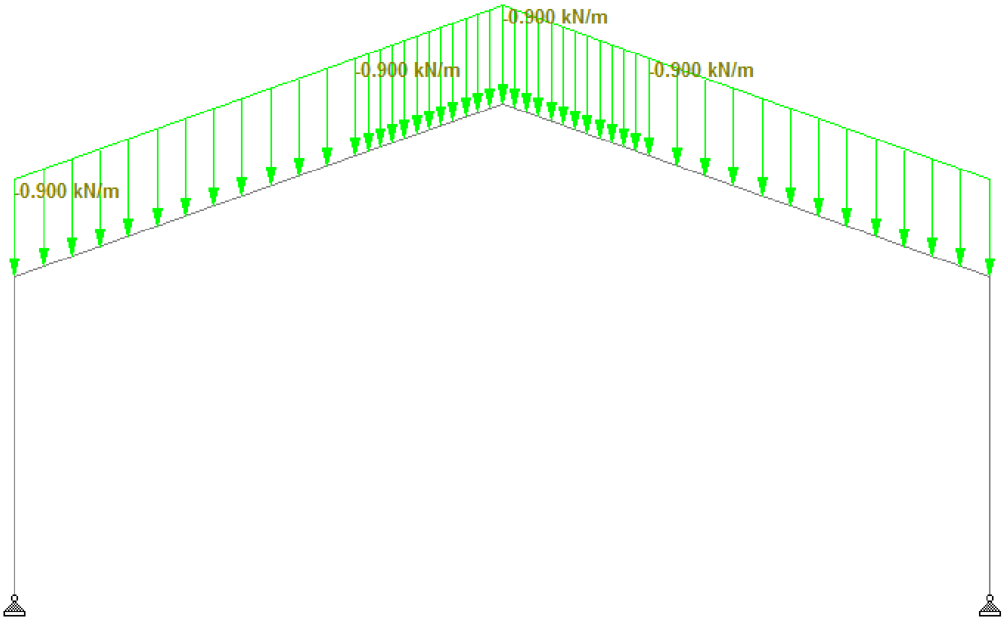


Figure 4.3:Dead load input

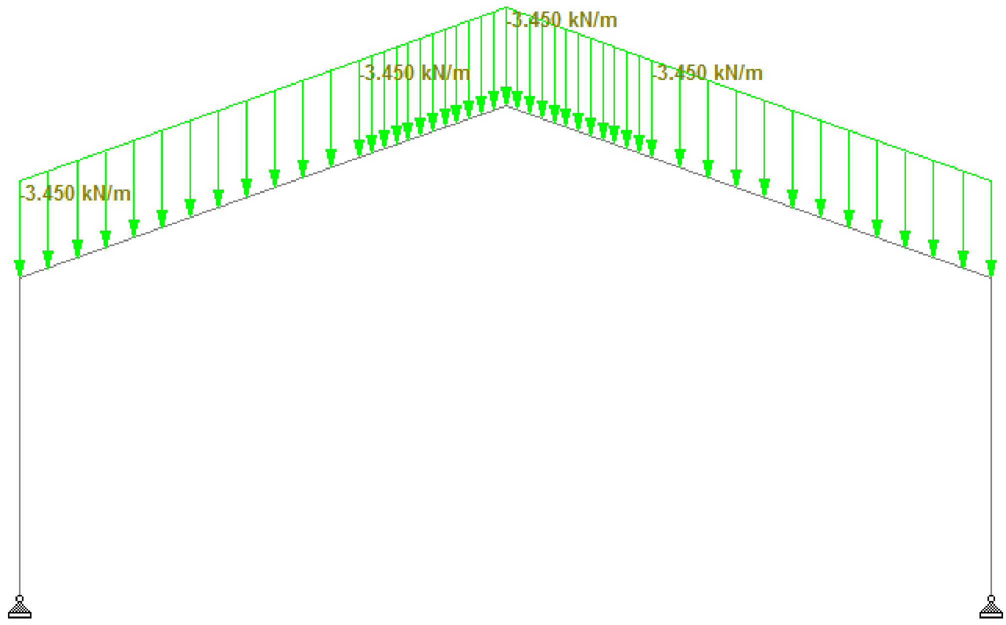


Figure 4.4: Roof live load

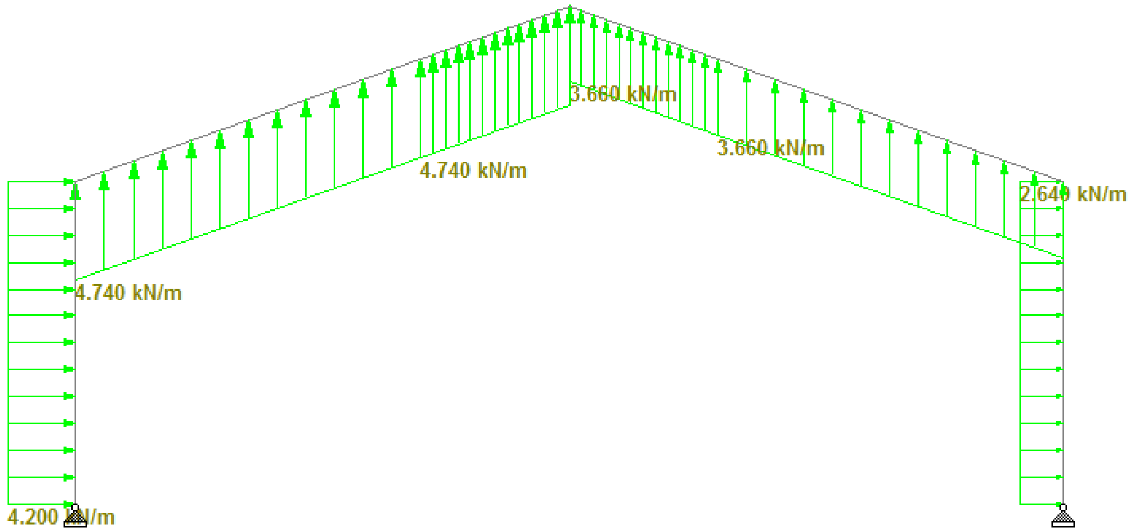


Figure 4.5: Wind load input (W+)

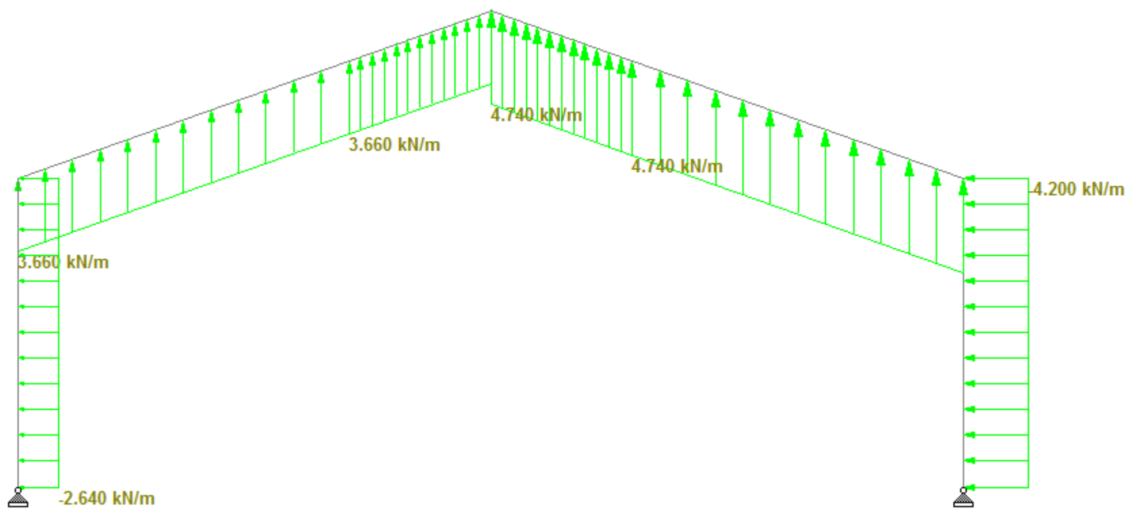


Figure 4.6: Wind load input (W-)

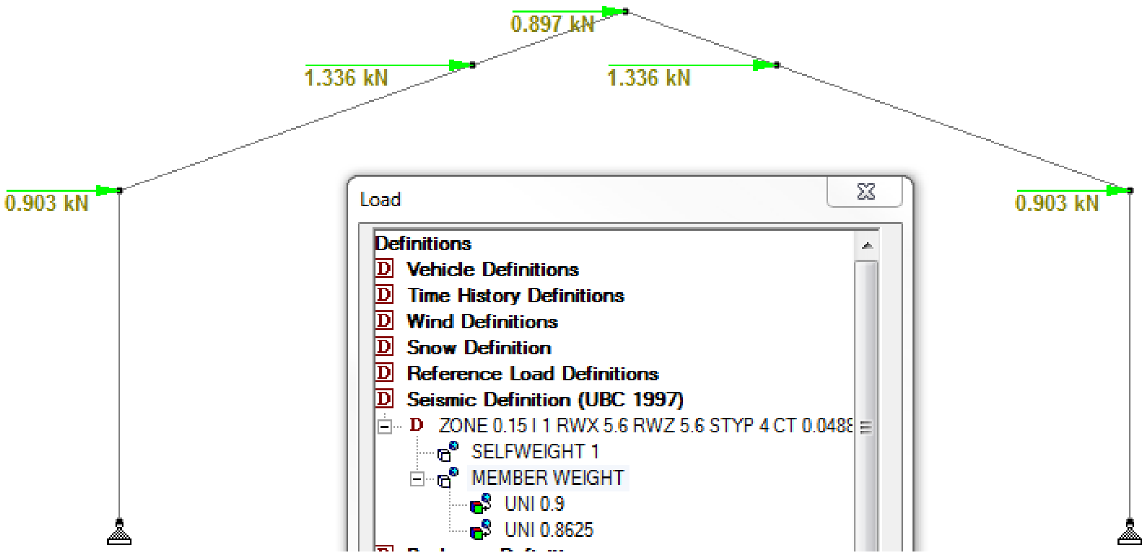


Figure 4.7: Seismic load input

4.2 Internal Force Output

4.2.1 Internal force under Dead Load

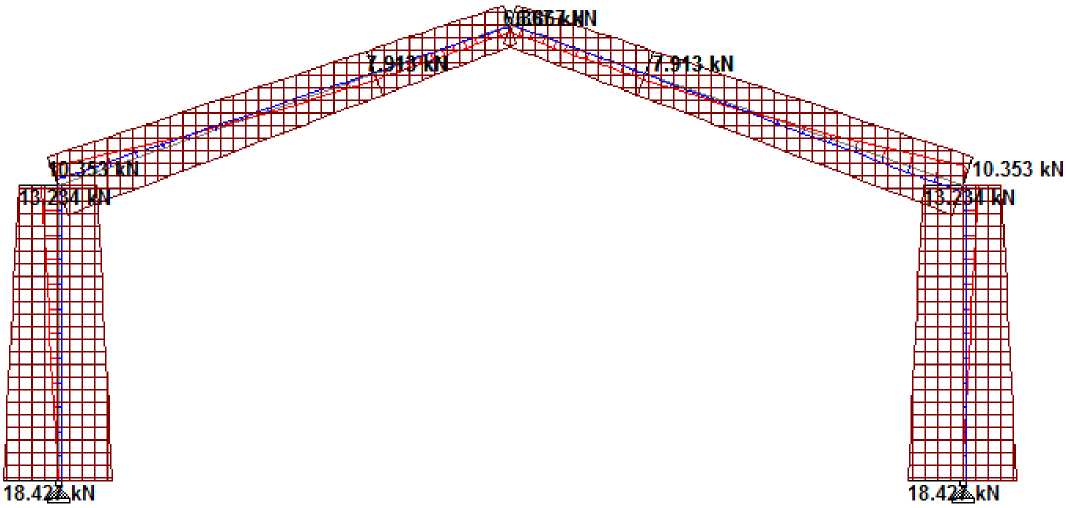


Figure 4.8: Axial force output

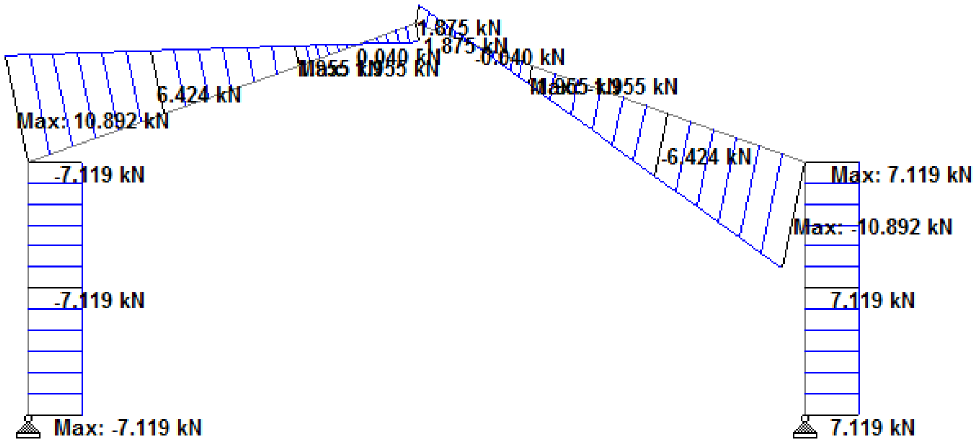


Figure 4.9: Shear force output

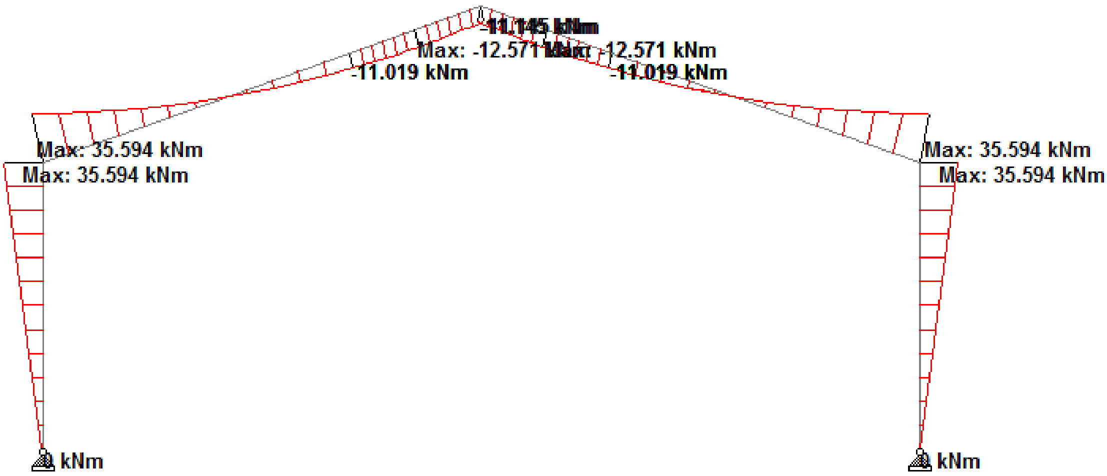


Figure 4.10: Moment output

4.2.2 Internal force under Roof Live Load

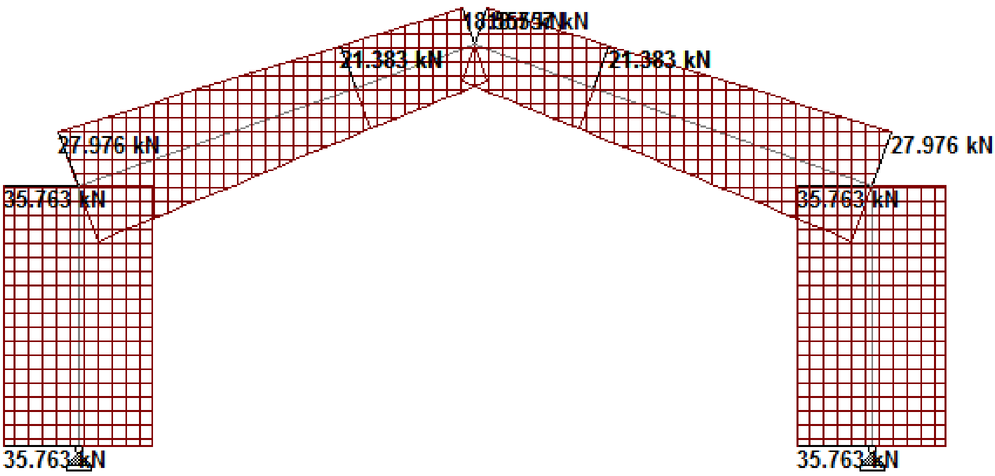


Figure 4.11: Axial force under roof live load

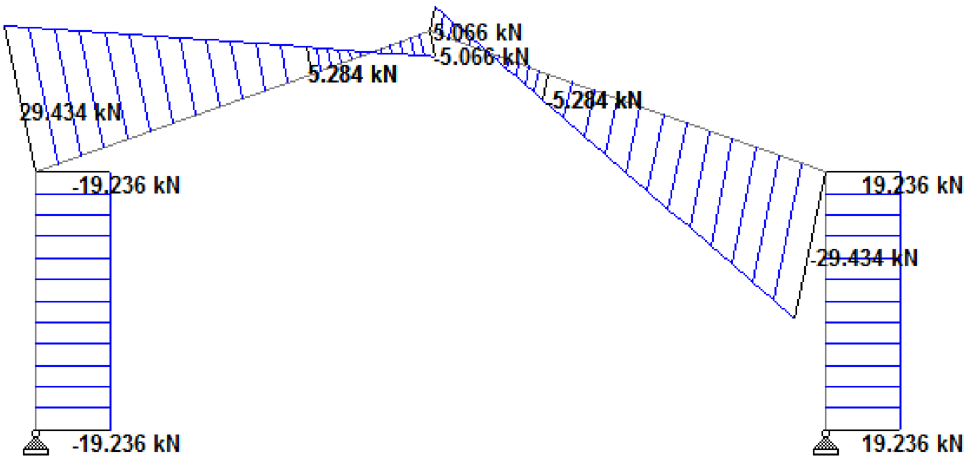


Figure 4.12: Shear force under roof live load

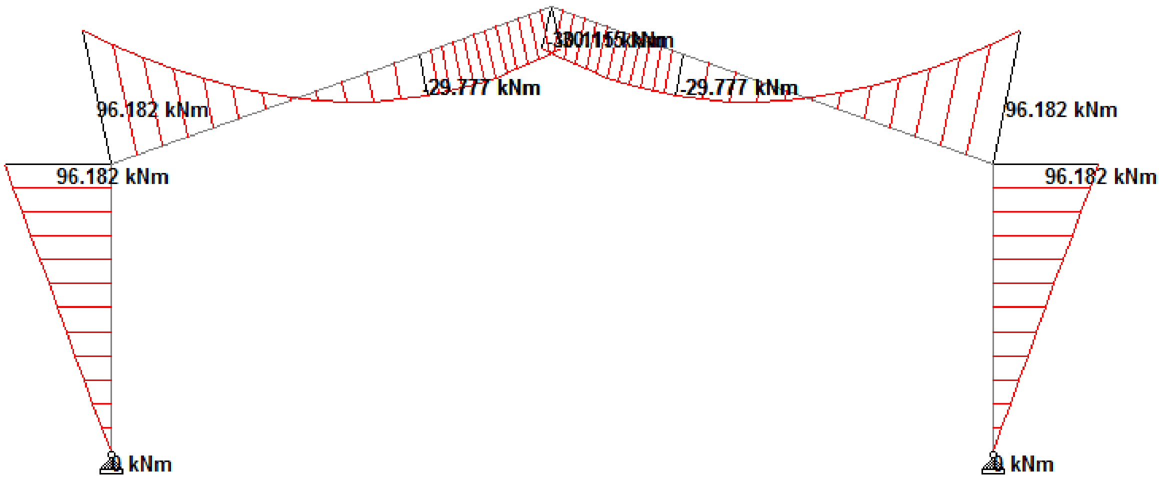


Figure 4.13: Moment under roof live load

4.2.3 Internal force under Wind Load (W+)

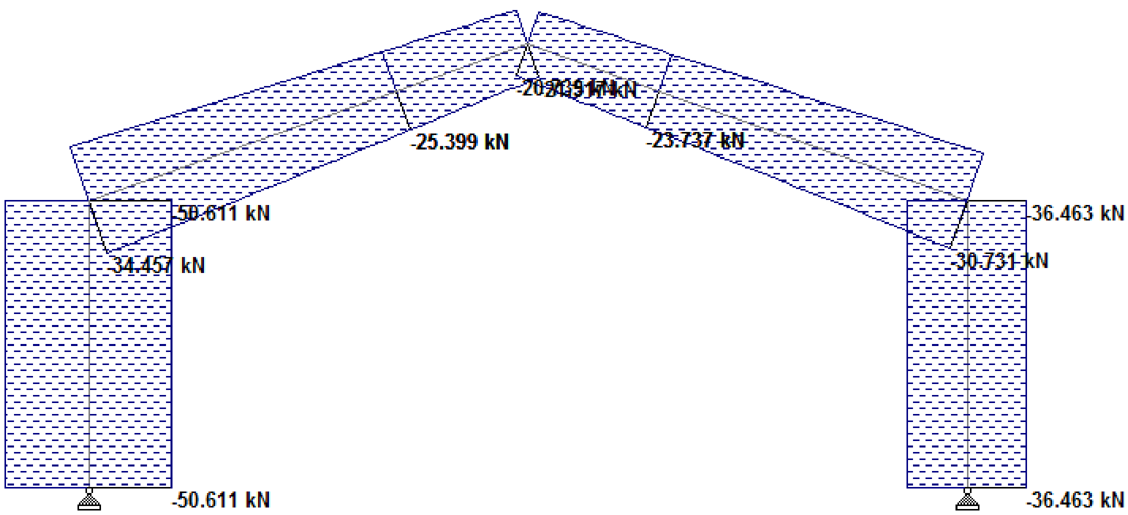


Figure 4.14: Axial force under wind load (W+)

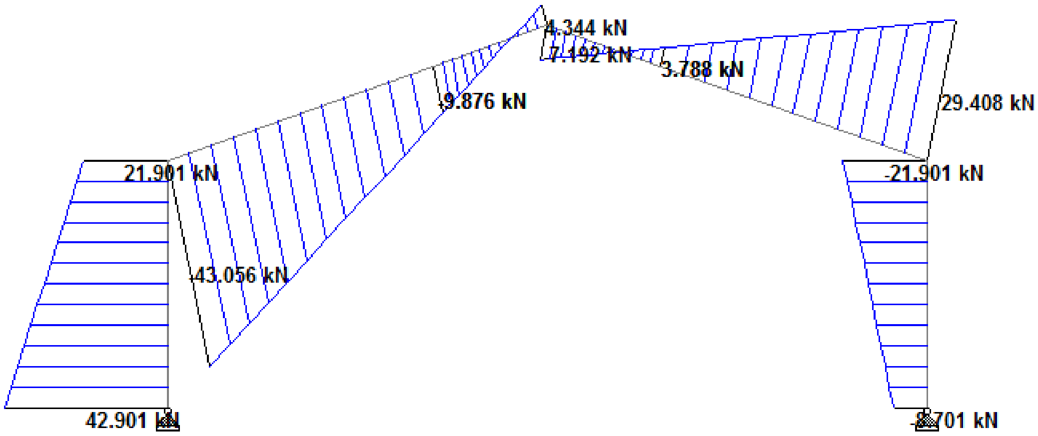


Figure 4.15: Shear force under wind load (W+)

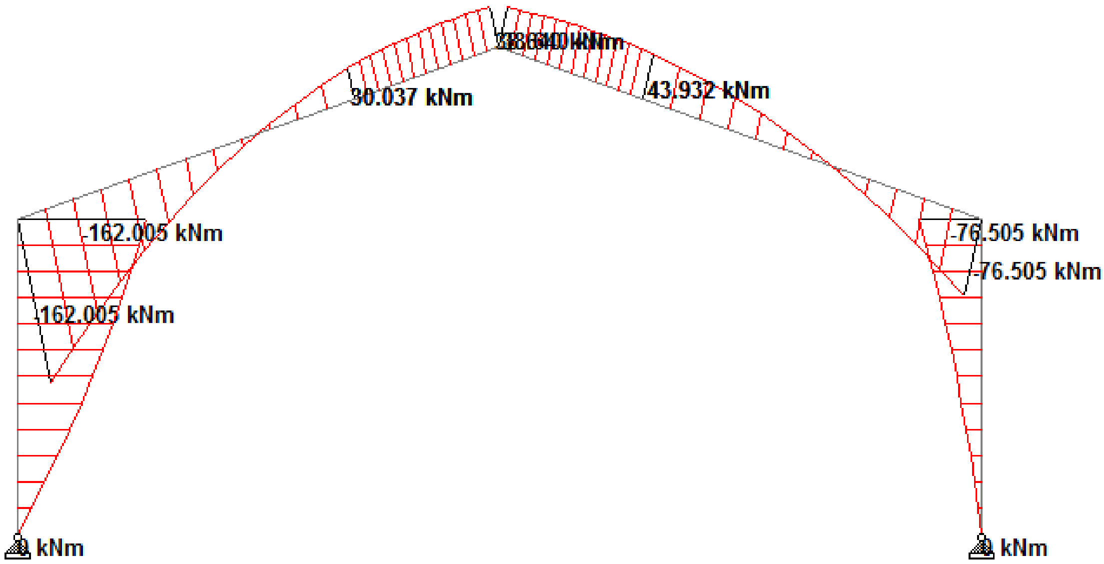


Figure 4.16: Moment under wind load (W+)

4.2.4 Internal force under Wind Load (W-)

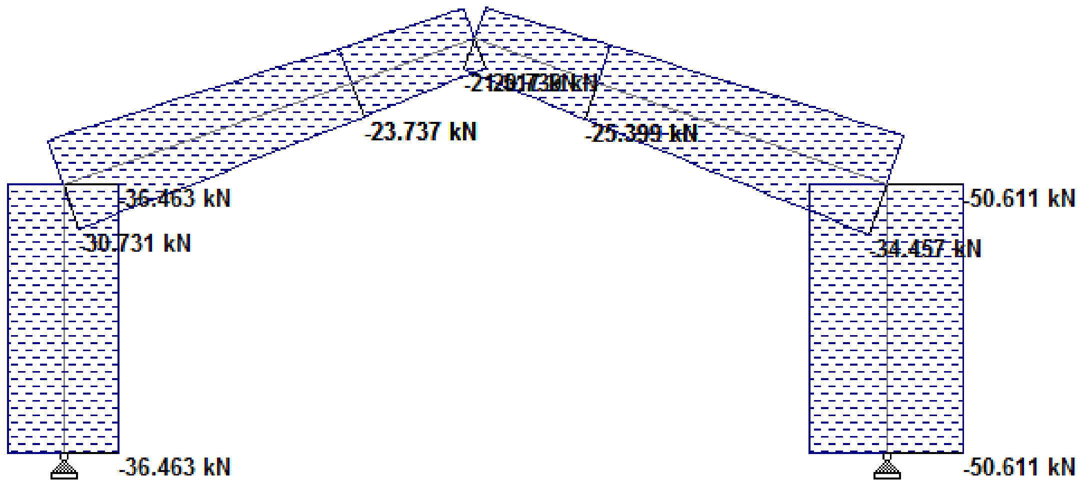


Figure 4.17: Axial force under wind load (W-)

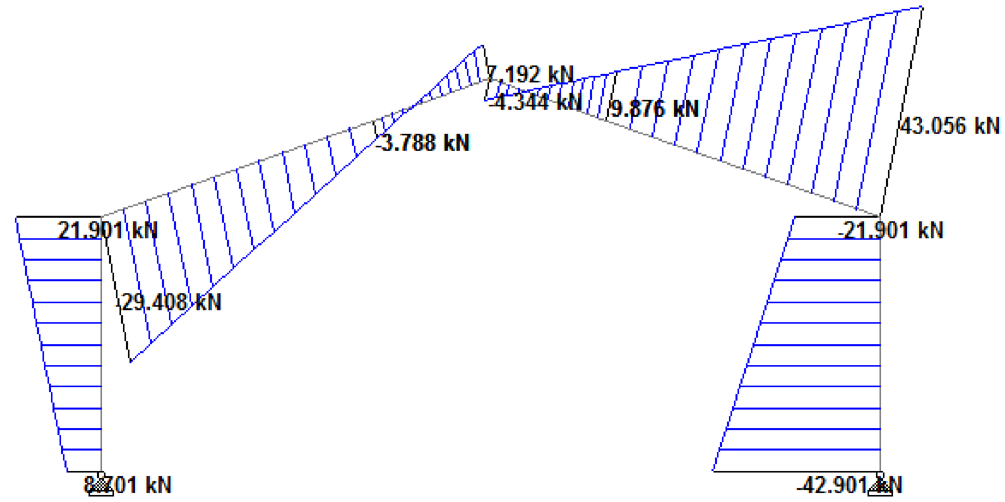


Figure 4.18: Shear force under wind load (W-)

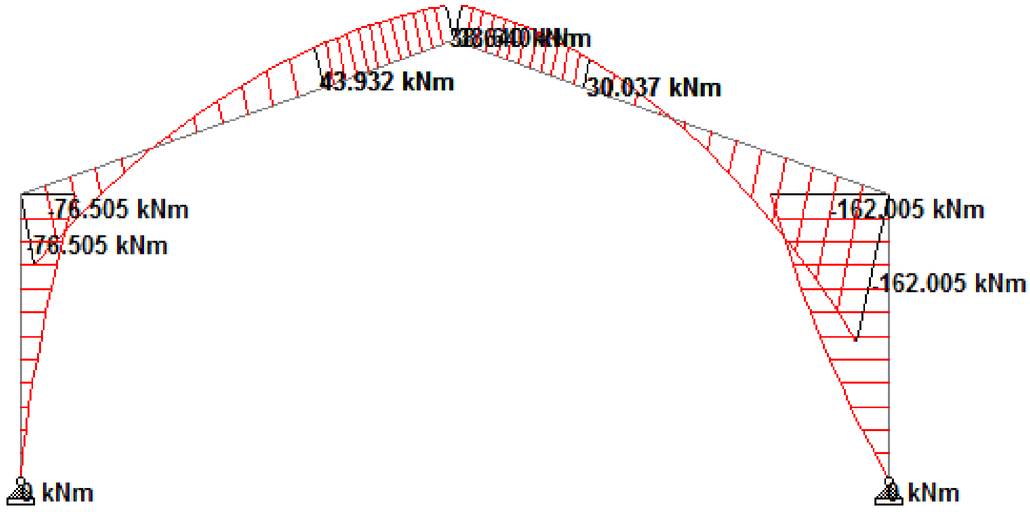


Figure 4.19: Moment under wind load (W-)

4.2.5 Internal force under Seismic Load

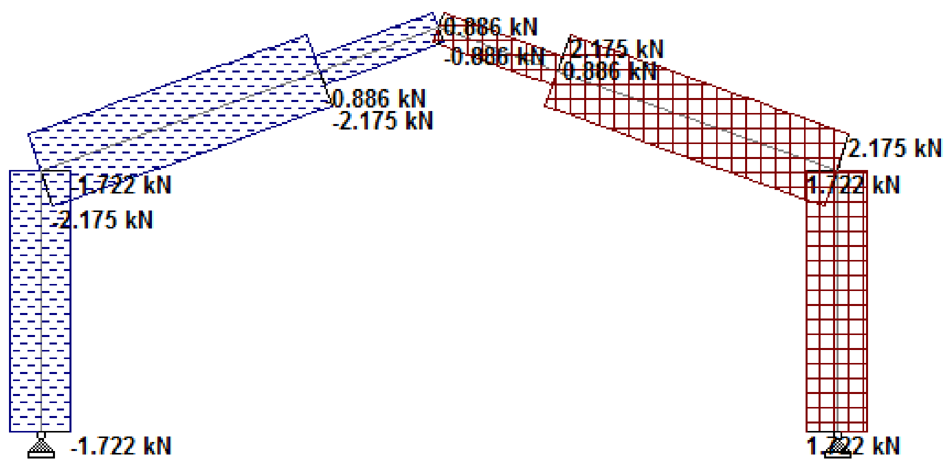


Figure 4.20: Axial force under seismic load

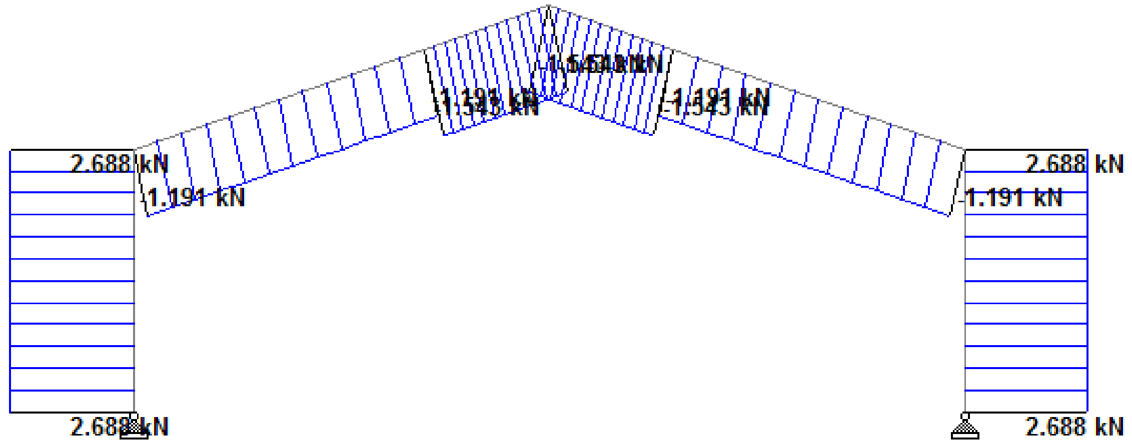


Figure 4.21: Shear force under seismic load

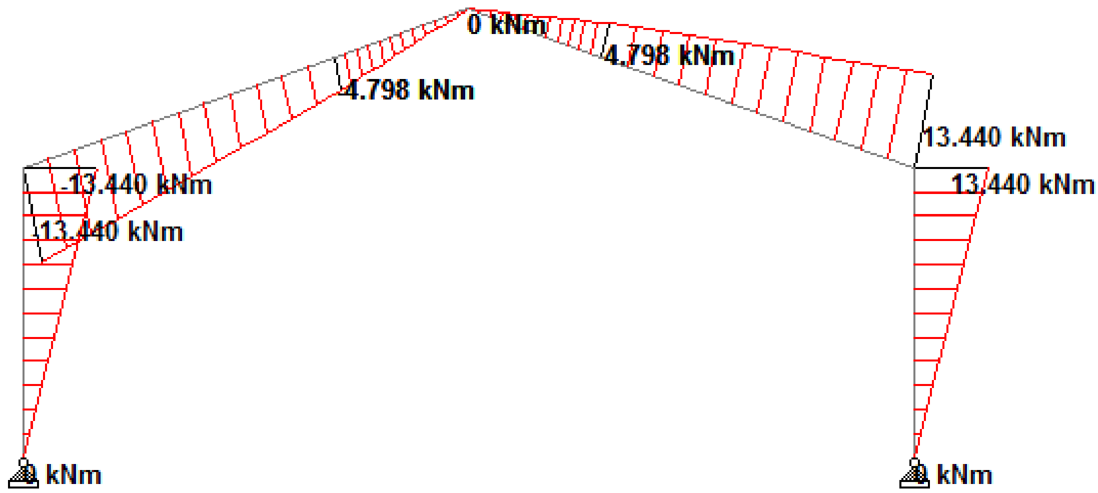


Figure 4.22: Moment under seismic load

4.2.6 Most severe load case (0.9DL+1.3 W+)

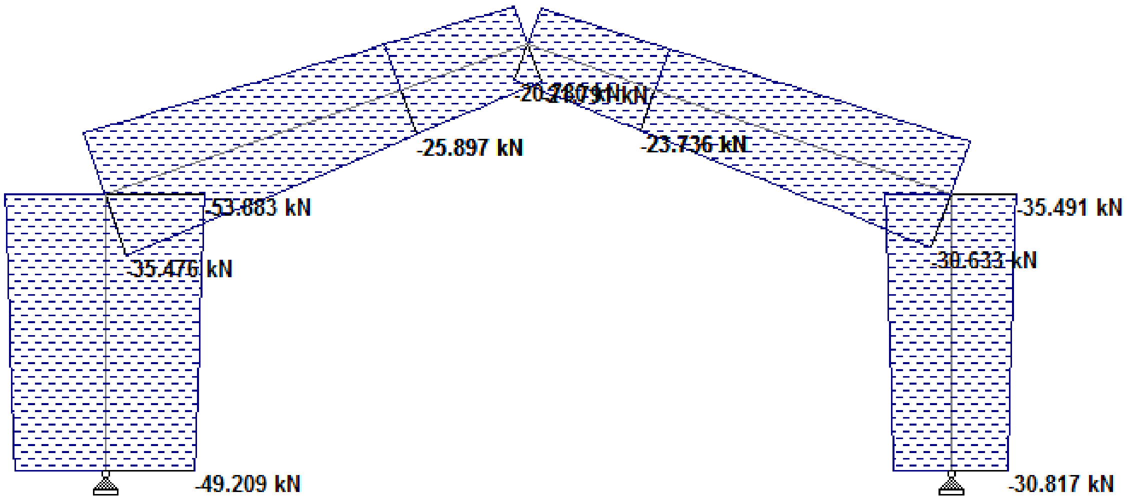


Figure 4.23: Axial force for severe load case

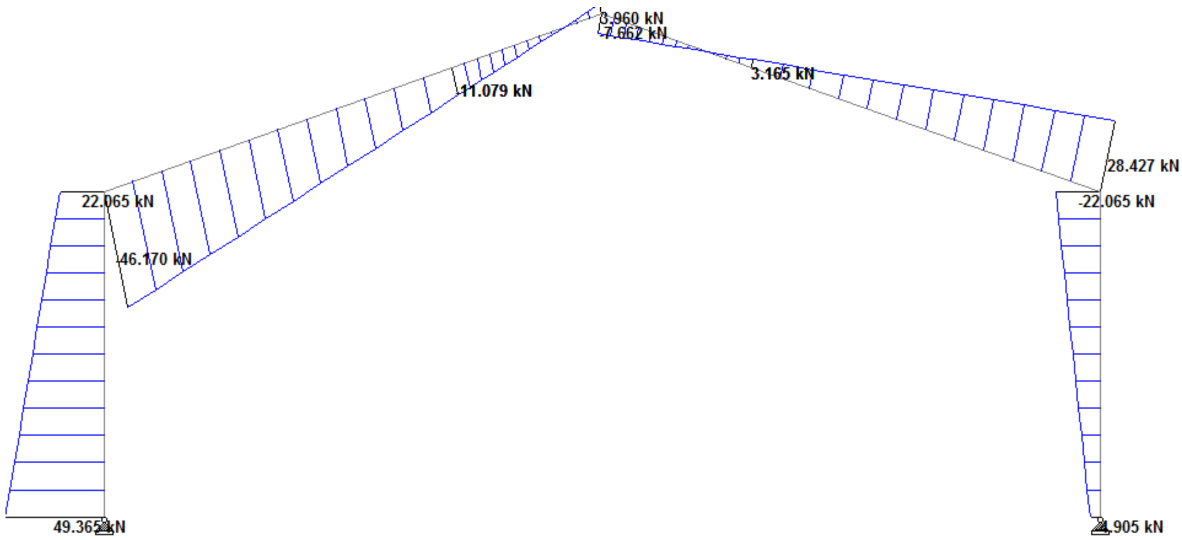


Figure 4.24: Shear Force for severe load case

4.3 Analysis Results – Concrete Columns & Steel Roof

4.3.1 Overall Model

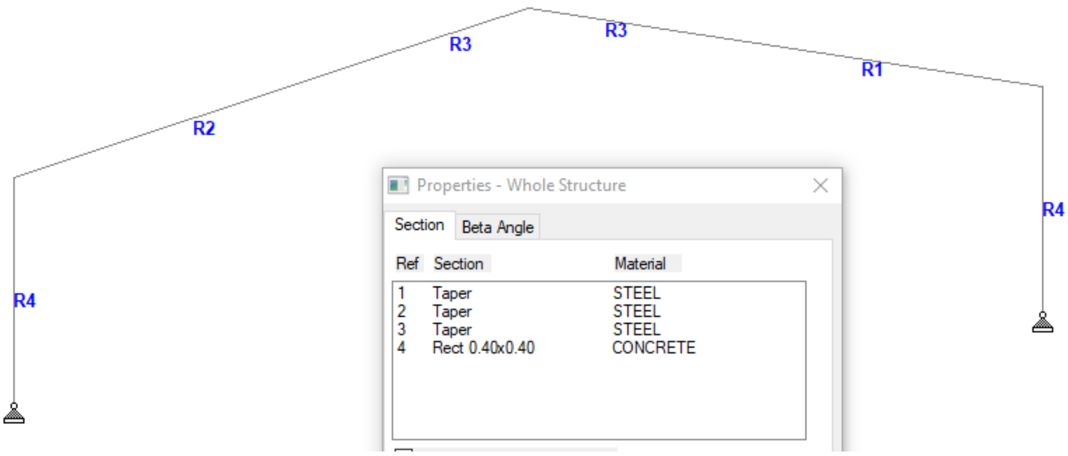


Figure 4.25: Concrete structural model

Table 4.2: Member Sizes-Concrete Design

Member.	Size (mm)
R4	400 x 400 (5000mm)
R1 = R2	600-300 x 200 x 6 x12 (6000mm)
R3	300 x 180 x 6 x 8 (4000mm)

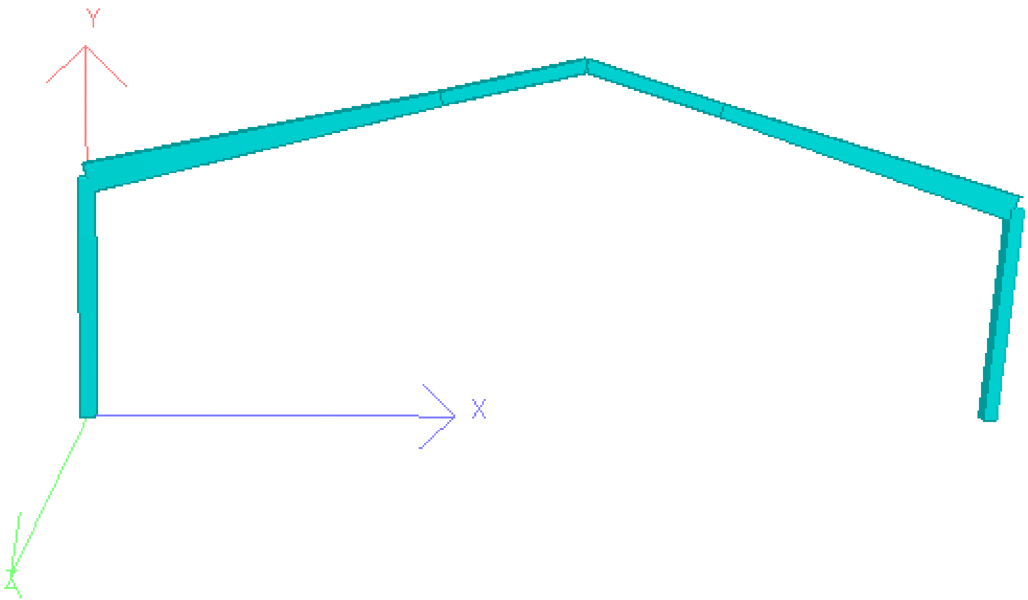
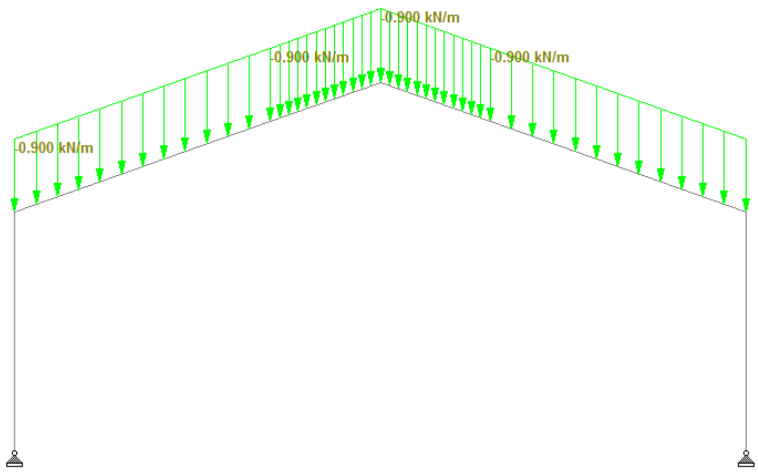


Figure 4.26: Dead load input

4.3.2 Dead Load Input (Self-weight and Superimposed Dead load 0.9 kN/m)



a) Roof Live Load

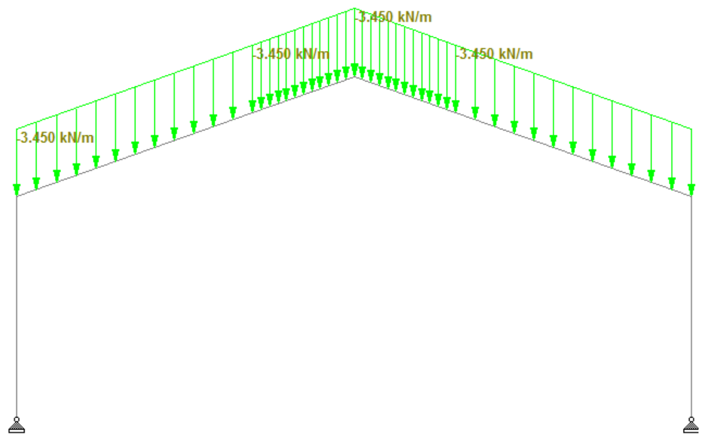


Figure 4.27: Roof live load

b) Wind Load Input (W+)

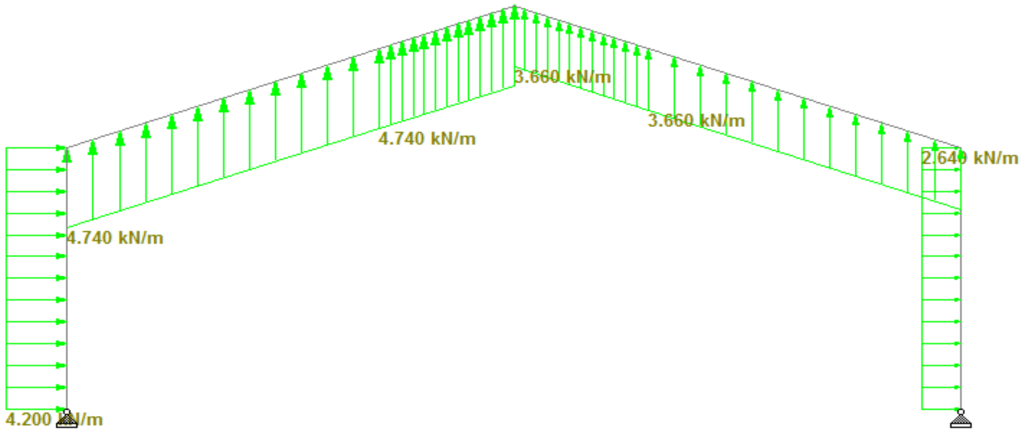


Figure 4.28: Wind load input (W+)

c) Wind Load Input (W-)

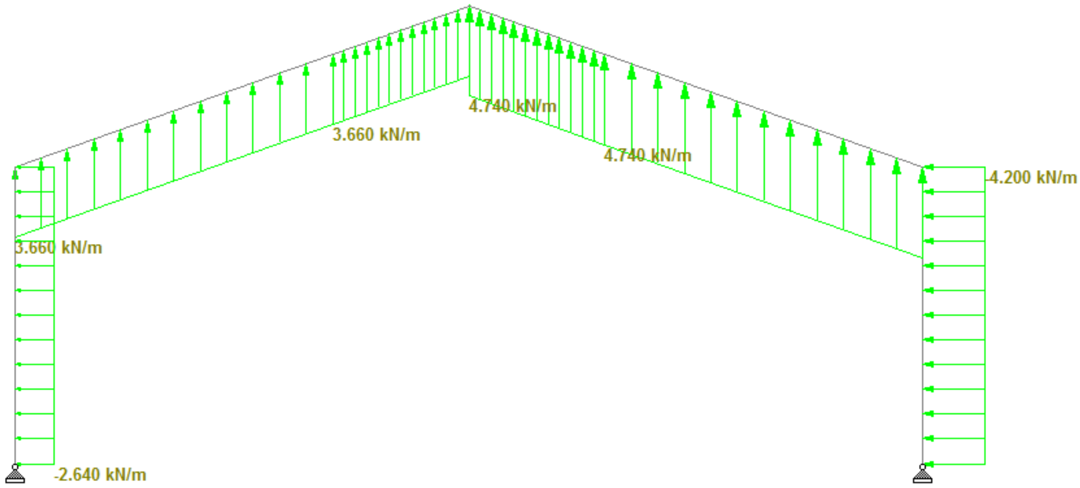


Figure 4.29: Wind load input (W-)

d) Seismic Load Input

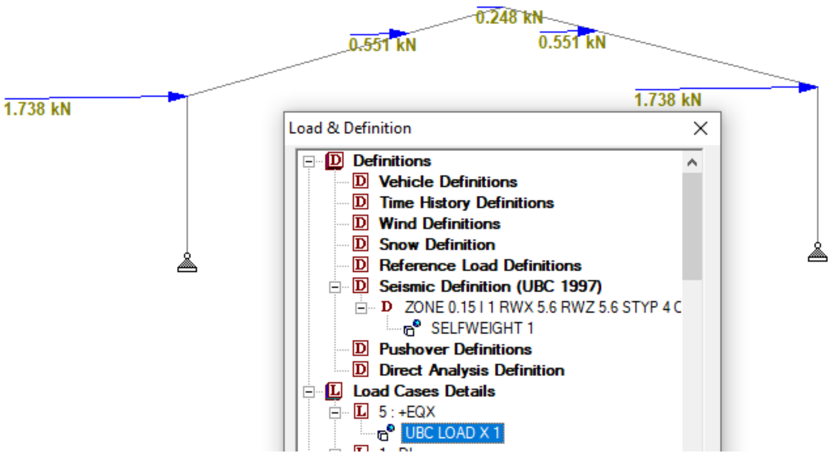


Figure 4.30: Seismic Load Input

4.3.3 Internal Force Output - Internal Force Under Dead Load

a) Axial Force

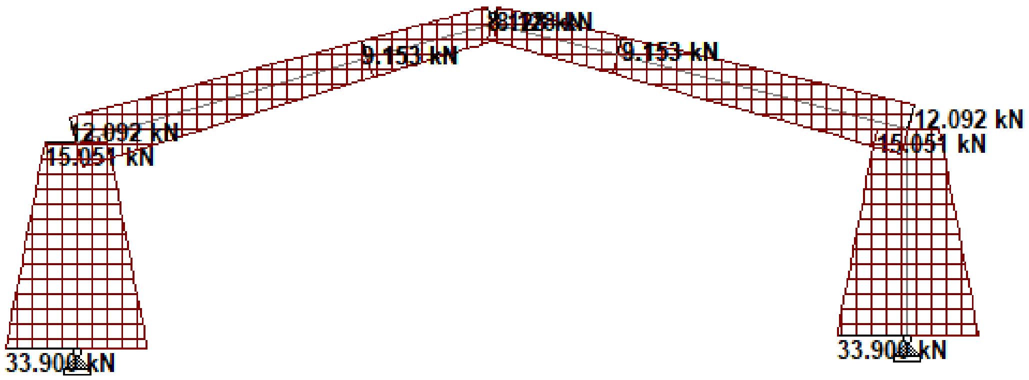


Figure 4.31: Axial Force output under dead load

b) Shear Force

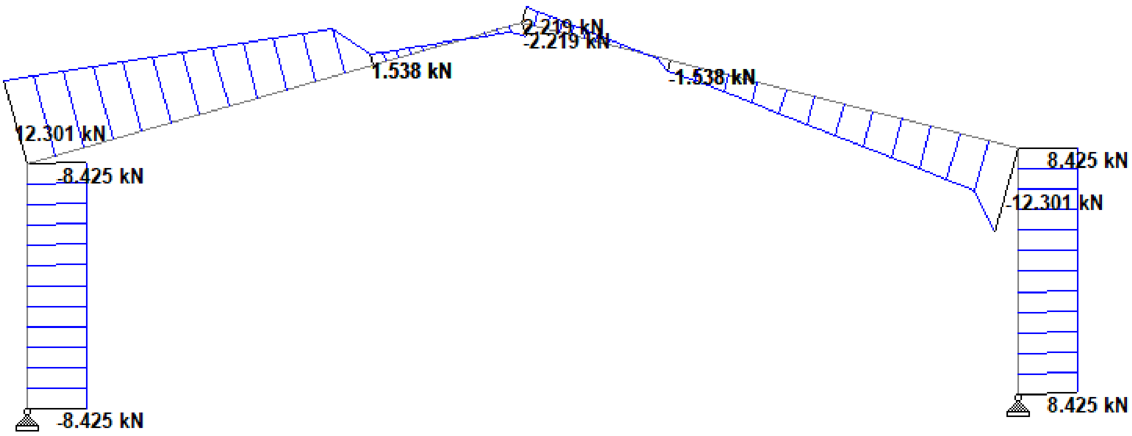


Figure 4.32: Shear Force output under dead load

c) Moment

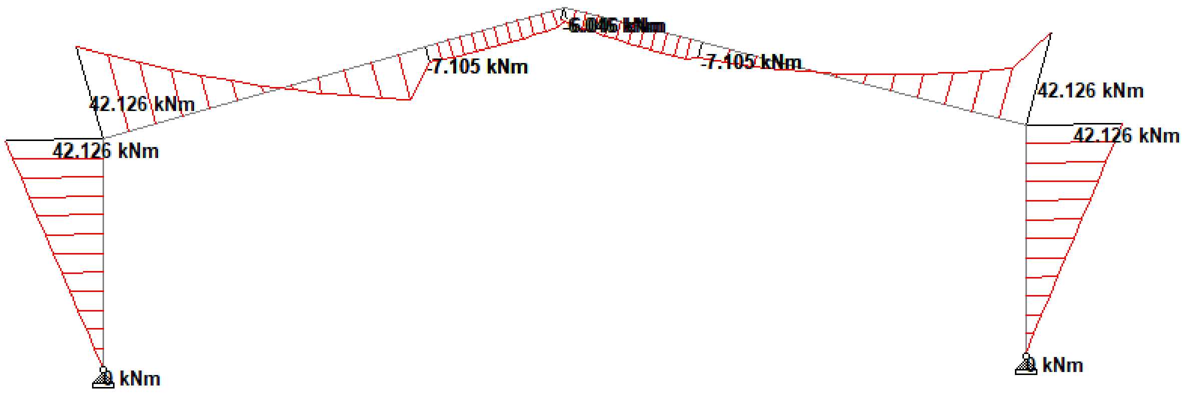


Figure 4.33: Moment under dead load

4.3.4 Internal force under Roof Live Load

a) Axial Force

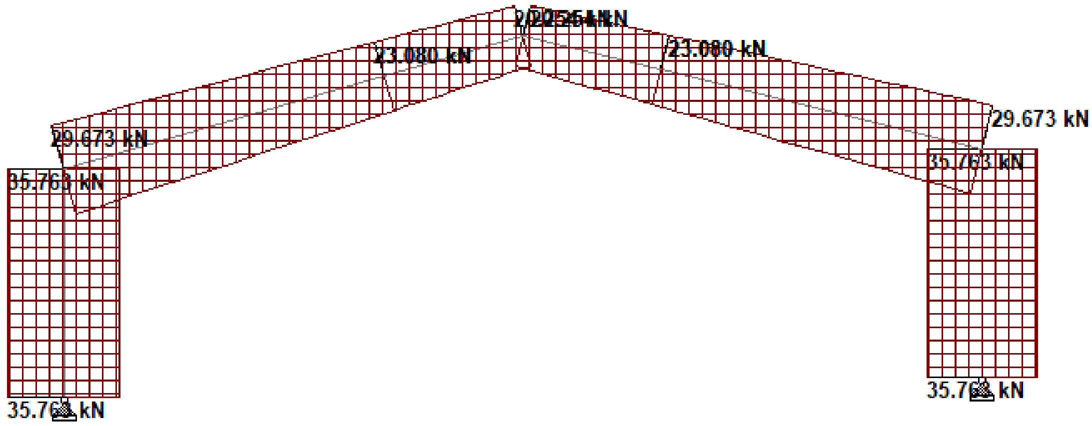


Figure 4.34: Axial force output under roof live load

b) Shear Force

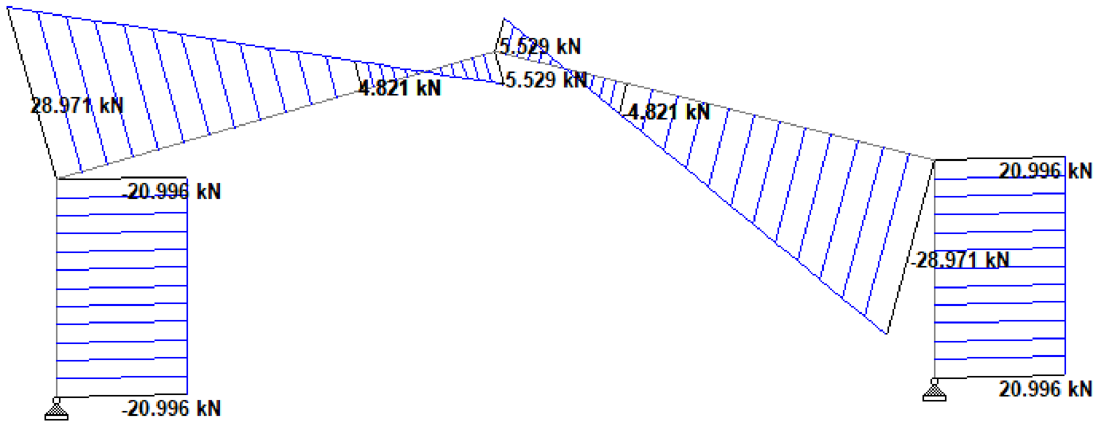


Figure 4.35: Shear force output under roof live load

c) Moment

Figure 4.36: Moment output under roof live load

4.3.5 Internal force under Wind Load (W+)

a) Axial Force

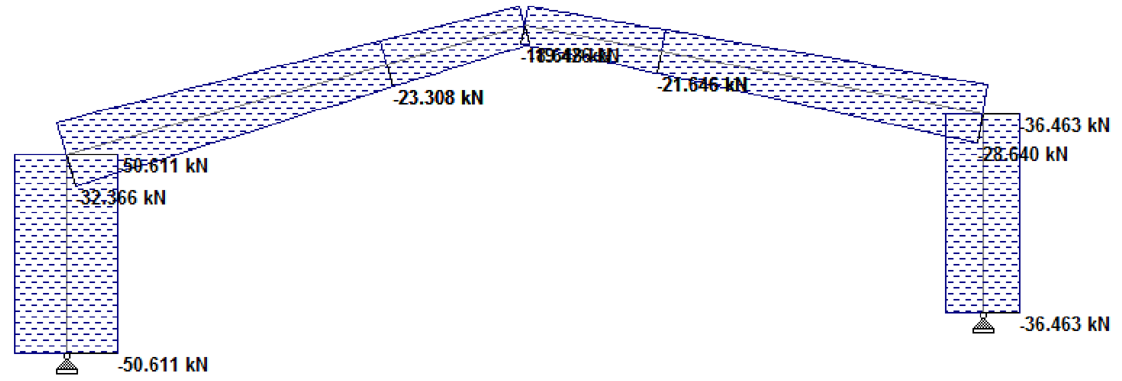


Figure 4.37: Axial force output under Wind Load (W+)

b) Shear force

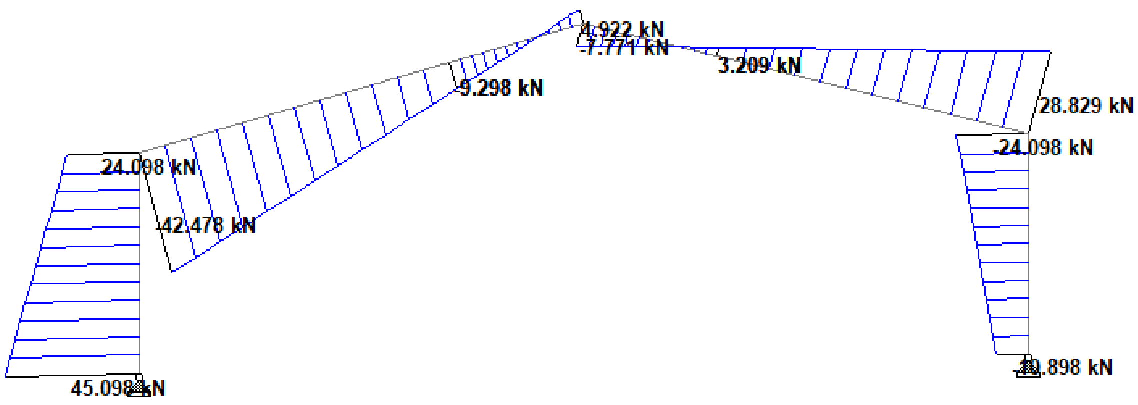


Figure 4.38: Shear force output under Wind Load (W+)

c) Moment

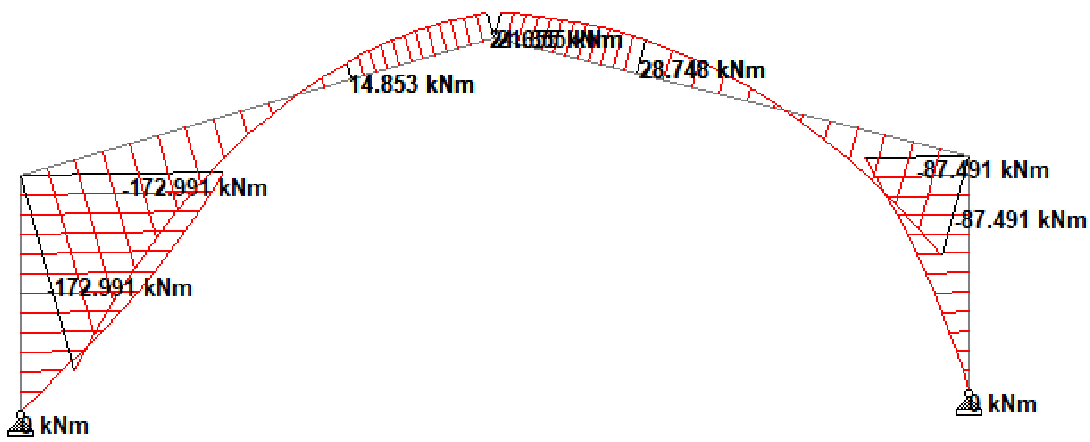


Figure 4.39: Moment output under Wind Load (W+)

4.3.6 Internal force under Wind Load (W-)

a) Axial Force

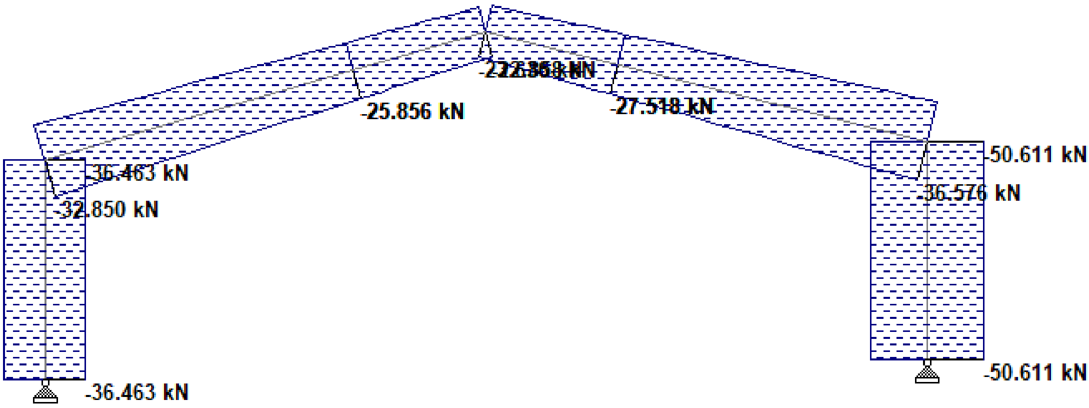


Figure 4.40: Axial force output under Wind Load (W-)

b) Shear Force

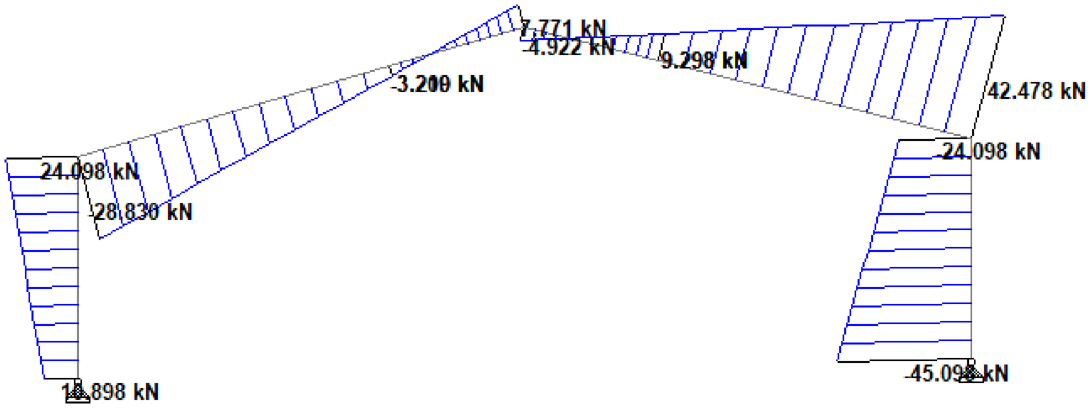


Figure 4.41: Shear force output under Wind Load (W-)

c) Moment

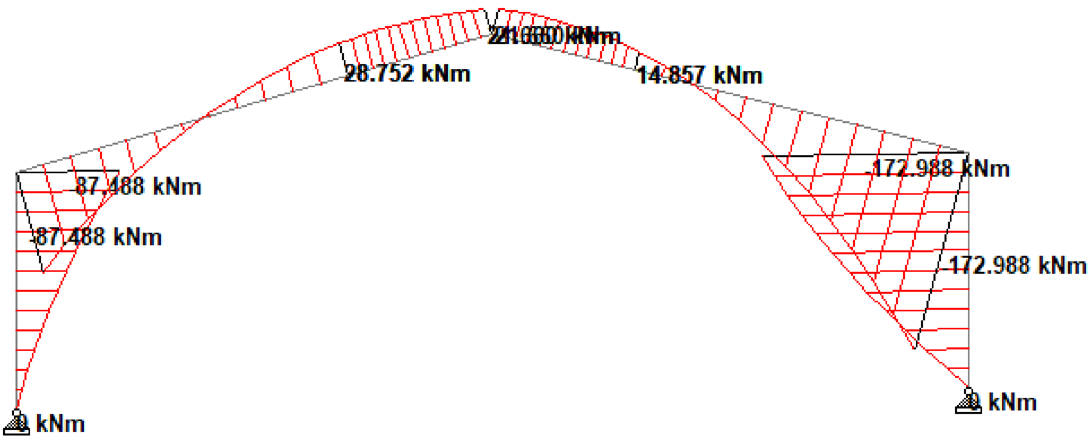


Figure 4.42: Moment output under Wind Load (W-)

4.3.7 Internal force under Seismic Load

a) Axial Force

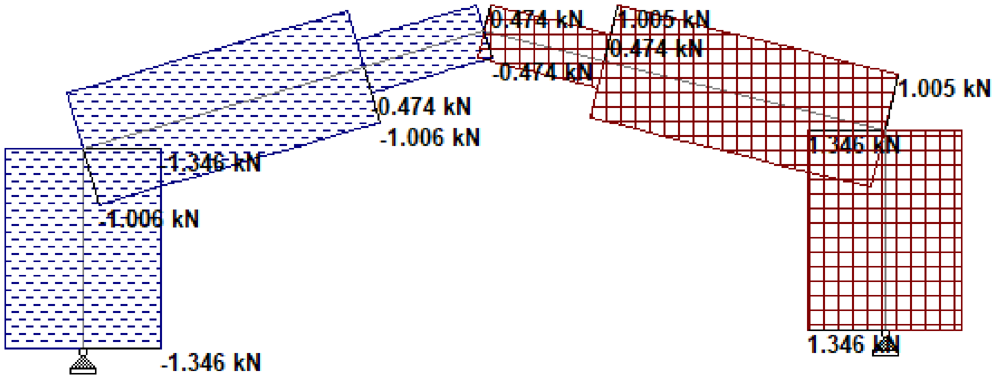


Figure 4.43: Axial force output under Seismic Load

b) Shear Force

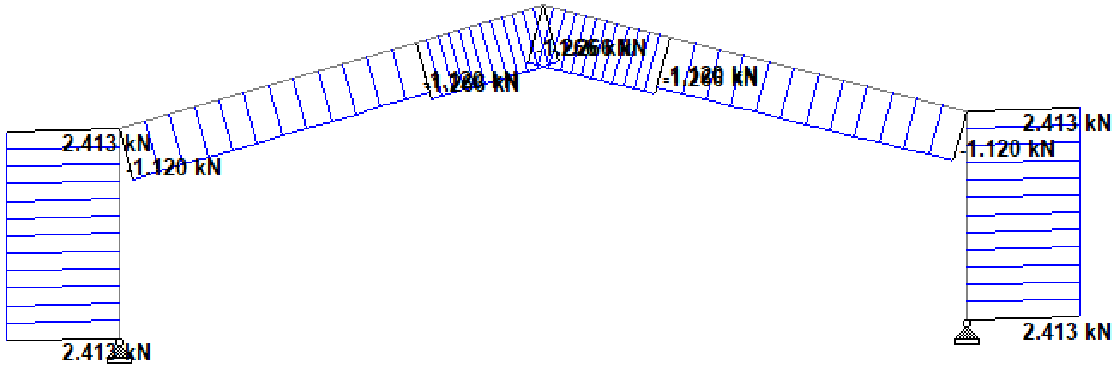


Figure 4.44: Shear force output under Seismic Load

c) Moment

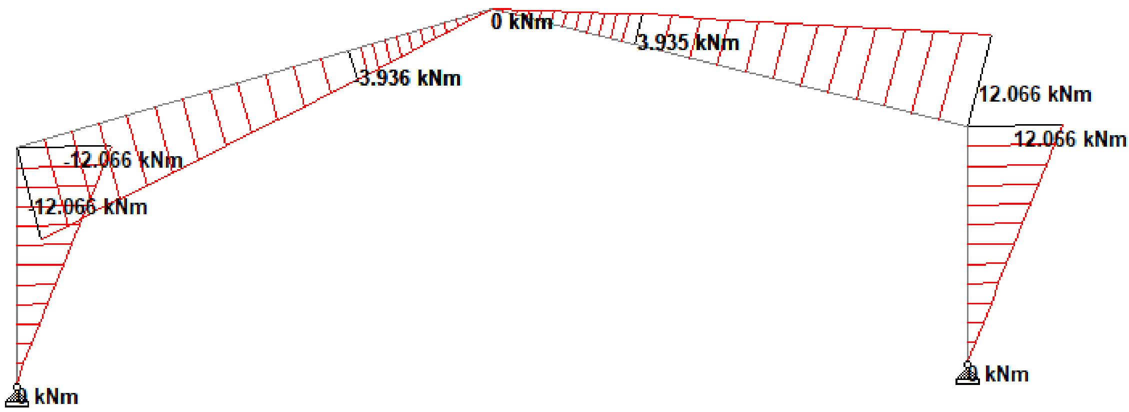


Figure 4.45: Moment output under Seismic Load

4.3.8 Most severe load case (1.2DL+1.6 RLL-0.8WL)

a) Axial Force

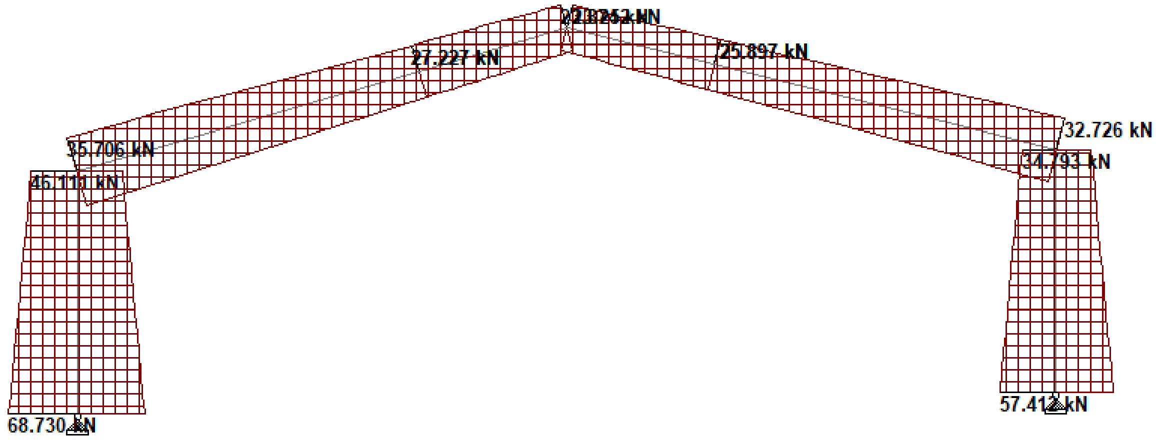


Figure 4.46: Most severe load case-Axial Force

b) Shear Force

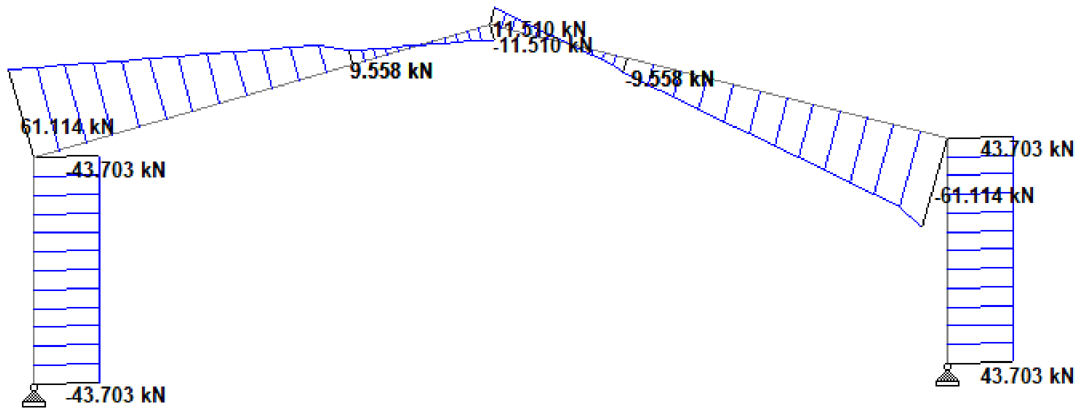


Figure 4.47: Most severe load case-Shear Force

c) Moment

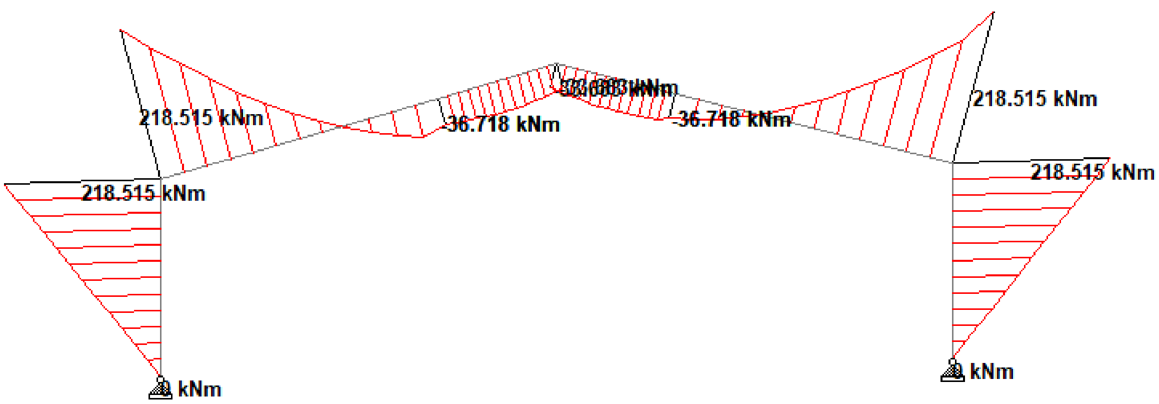


Figure 4.48: Most severe load case-Moment

4.4 Connections Design

4.4.1 Base Plate and Anchor Bolts Design

4.4.1.1 *Design forces*

The worst load combination from the analysis of the Staad Pro model had the reaction forces shown in Table 4.3.

Table 4.3: Staad Pro Reaction forces for worst load case- base plate and anchor bolts design

Reaction	Load Combination	Absolute Force (kN)
F_x (*Shear*)	*0.9DL -1.3WL*	*51.34*
F_y *(Compression)*	*1.2DL + 1.6 RLL*	*80.19*
Uplift	*WL*	*50.61*
$F_z = M_x = M_y = M_z$		*0*

4.4.1.2 *Arrangement*

The specifications of the steel column was: **H300 × 200 × 6 × 10**, where:

Height of section = 300 mm
Width of flange = 200 mm
Thickness of flange = 10 mm
Thickness of web = 6 mm

Try a base plate of preliminary size **350 mm x 250 mm x 12** mm thick.

4.4.2 Design	**Calculations**	**Ref**
	Compression $C = 80.19\ kN$ Uplift $U = 50.611\ kN$ Shear Force in X - direction $S_x = 51.34\ kN]$ Moment $= 0\ kNm$ No of bolts per pier $= 4$ **Forces per bolt** Compression $C = 20.04625\ kN$ Uplift U = 12.65275 kN	

	Shear Force in X - direction $S_x = 12.835$kN **Base Plate & Anchor Bolts Design** Using Grade 5.8: Yield stress of Base plate, $F_y = 355\ N/mm^2$ Yield stress of Anchor bolt, $F_y = 400\ N/mm^2$ Compressive Strength of Concrete, $f_{cu} = 30\ N/mm^2$ Bearing Stress of concrete = 0.6, $f_{cu} = 18\ N/mm^2$ Base Plate Area required = $C/0.6\, f_{cu} = 4454.722mm$ $= 66.74371\ mm\ \ x\ 66.74371mm$ Adopt 350 mm x 250 mm	
4.5 BASE PLATE THICKNESS	**Calculations**	**Ref**
	$t\ = \sqrt{}(2.5\, W\ (\, a^{\,2}\ -\ 0.3\, b^{\,2}\,)\ /\ F_y B$ $W\ \ = 0.9164\, N/mm^2$ $a\ = 25\ mm(longer\ edge\ distance)$ $b = 25\ mm(shorter\ edge\ distance)$ $F_y = 266.25\ N/mm^2\ (0.75 f_y)$ $t = 2.291 \times 437.5/266.25$ $t = 3.7646mm$ Adopt 12mm thick plate $M\ \ = 616080\ Nmm$ **Overall base plate equation** f_{max} = B x L + BL2 $f_{max} = 0.9164\ + 0.020117$ $f_{max} = 0.936517 < 12.$ OK **Anchor bolts diameter** Area of Bolt (A_s) Required (as per ASCE 10-97) $A_s = T/F_y + V/(u * 0.85 * F_y b)$ Where: $u = 0.55(coefficient\ of\ friction)$ $A_s\ \ \ = 31.63188\ +\ 68.63636$	

	$A_s \quad = 100.2682mm^2$ $A_s = \frac{\pi}{4} (D - 0.974 / n)^2$ Where: $n \quad = Number\ of\ threads\ per\ unit\ length$ $1.00282 = 0.785398\ (D - 0.974)^{25}$ $D = 13.73392mm$ Adopt Anchor bolt diameter of 24mm. **Length of Anchor bolts** $f_{bu} = \beta\sqrt{f_{cu}}$ Where: $f_{bu} = Design\ anchorage\ bond\ stress$ $\beta = Coefficient\ dependent\ on\ the\ bar\ type$ β = $\beta = 0.28$ for plain bars $f_{bu} = 1.533623\ N/mm^2$ $L = T / (\pi N D f_{bu})$ Where: $L = Anchorage\ Length\ Required\ for\ Each\ Bolt$ $L \quad = 109.4221mm$ Adopt Anchor bolt length of = 500mm	ASCE 10-97 Clause 3.12.8.4 of BS:8110-1:1997 Clause 3.12.8.3 of BS:8110-1:1997

4.6 Column – Beam Moment Connection

4.6.1 Design forces

The worst load combination from the analysis of the Staad Pro model had the reaction forces shown in Table 4.4: Staad Pro reaction forces for worst load case- column-beam moment connection.

Table 4.4: Staad Pro reaction forces for worst load case- column-beam moment connection

Reaction	Load Combination	Absolute Force kN/kNm
F_x $(Shear)$	$0.9DL - 1.3WL$	*51.34*
F_y *(Compression)*	$1.2DL + 1.6\,RLL$	*61.76*
M_z $(Moment)$	$1.2DL + 1.6\,RLL$	*225*

4.6.2 Arrangement

The steel column size is **H600 x 200 x 6 x 10**, where:

Height of section: 600 mm

Width of flange: 200 mm

Thickness of flange: 10 mm

Thickness of web: 6 mm

The steel column size is **H600 x 200 x 6 x 10**, where:

Height of section: 600 mm

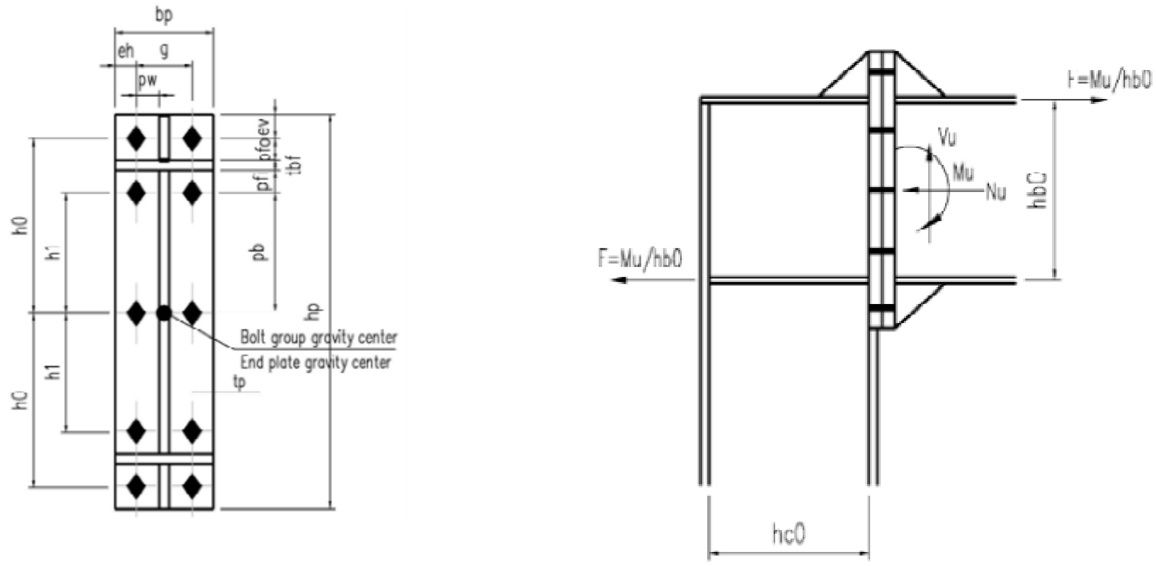
Width of flange: 200 mm

Thickness of flange: 10 mm

Thickness of web: 6 mm

Try end plate preliminary size of **800 mm × 200 mm × 22** mm thick.

Figure 4.49 shows Typical connection detail showing (a) Column to column and (b)Beam to Column



(a) (b)

Figure 4.49: Typical connection detail showing (a) Column to column and (b)Beam to Column

The following are the dimensions illustrated in Figure 4.49:

$bp\ =\ 200\,mm, hp\ = 800\,mm, tp\ =\ 200\,mm, eh\ = 50\,mm, ev\ = 50\,mm, pw =\ 45\,mm,$.

$pfo =\ 50\,mm, pfi\ = 50\,mm, pb = 240\,mm, ho =\ 350\,mm, h1\ = 240\,mm$

Try M20 bolt, Grade 10.8 with the slip resistance for the limit state of slip:

Coefficient of friction, $\mu\ = 0.3, D\ _u =\ 1.13, h_f =\ 1.0,\ T_b\ = 142\ kN, n_s\ =\ 1, n_i\ = 2$

$Single\ bolt\ shear\ strength\ = N^b v = \mu D\ _u h_f\ T_b n_s = 48.14\ kN$

Calculation of bolt tension owing to moment

$M_u\ =\ 2\,(N^b t, 1 * 2h0)\ + 2\,(N^b t, 2\ * 2h1), and\ N^b t, 1/\ N^b t, 2\ =\ h0/\ h1$

It follows that: $M_u\ \ =\ 2\,(N^b t, 2\ * 2h0 * h0/h1)\ + 2\,(N^b t, 2\ * 2h1),$

Thus, $225\ kNm\ =\ 2\,(N^b t, 2\ * 2 * 0.35 * 0.35/0.24)\ + 2\,(N^b t, 2\ * 2 * 0.24),$

$N^b t, 2\ =\ 74.95\ kN, while\ N^b, 1\ \ =\ 109.27\ kN$

$Required\ tension\ force, T_u\ =\ n_i\ N^b t, i\ =\ 368.44\ kN$

Combined tension and shear in slip- critical connections,

$N^b v, = \mu D\ _u h_f\ T_b n_s\ \left(1\ -\ \frac{Tu}{D\ _u\ T_b n_b}\right) = 20.51 kN$

$N^b v, i = \frac{Vu}{n} =\ \frac{51.34}{10} =\ 5.134\ \text{kN}\ <\ 20.51\ \text{kN}$ Therefore, Ok.

End Plate required thickness,

$t_p = \sqrt{\frac{6PwPfoNbt,1}{(pwbp+2pfo\ (pfo+pw))Fy}}\ =\ 14.23\ mm\ <\ 18\ mm$ Therefore, Ok.

4.7 Beam – Beam Moment Connection

4.7.1 Design forces

The worst load combination from the analysis of the Staad Pro model had the reaction forces shown in Table 4.5.

Table 4.5: Staad pro Reaction forces for worst Load case- Beam-Beam Moment connection

Reaction	Load Combination	Absolute Force kN/kNm
F_x $(Shear)$	$0.9DL - 1.3WL$	46.28
F_y (Compression)	$1.2DL + 1.6\,RLL$	10.62
M_z $(Moment)$	$1.2DL + 1.6\,RLL$	29.92

4.7.2 Arrangement

The steel column size is **H300 × 200 × 6 × 10**, where.

Height of section: 300 mm

Width of flange: 200 mm

Thickness of flange: 10 mm

Thickness of web: 6 mm

The steel column size was: **H300 × 180 × 6 × 8**, where:

Height of section: 300 mm

Width of flange: 180mm

Thickness of flange: 8 mm

Thickness of web: 6 mm

Try end plate preliminary size of **500 mm x 200 mm x 18** mm thick.

It follows that:

$bp = 200\,mm, hp = 500\,mm, \quad tp = 200\,mm, eh = 50\,mm, ev = 50\,mm, pw = 45\,mm,$

$pfo = 50\,mm, pfi = 50\,mm, ho = 200\,mm, h1 = 90\,mm.$

Try M20 bolt, Grade 10.8 with the slip resistance for the limit state of slip:

Coefficient of friction, $\mu = 0.3, D_u = 1.13, h_f = 1.0, T_b = 142\,kN, n_s = 1, n_i = 2$

$Single\ bolt\ shear\ strength = N^b v = \mu D_u h_f T_b n_s = 48.14\,kN$

Calculation of bolt tension owing to moment

$M_u = 2\,(N^b t, 2 * 2h0) + 2\,(N^b t, 2 * 2h1), and\ N^b t, 1/N^b t, 2 = h0/\,h1$

It follows that: $M_u = 2\,(N^b t,2\ *2h0 * h0/h1) + 2\,(N^b t,2\ *2h1)$

Thus, $225\ kNm\ =\ 2\,(N^b t,2\ *2*0.35*0.35/0.24)\ +2\,(N^b t,2\ *2*0.24),$

$$N^b t,2\ =\ 74.95\ kN, while\ N^b,1\ \ =\ 109.27\ kN$$

$Required\ tension\ force, T_u\ =\ n_i\, N^b t,i\ =\ 368.44\ kN$

Combined tension and shear in slip- critical connections,

$N^b v, = \mu D\ _u h_f\ T_b n_s\ \left(1\ -\ \frac{Tu}{D\ _u\ T_b n_b}\right) = 20.51 kN$

$N^b v,i = \frac{Vu}{n} = \frac{51.34}{10} =\ 5.134\ \text{kN}\ <\ 20.51\ \text{kN}$ Therefore, Ok.

End Plate required thickness,

$t_p = \sqrt{\frac{6PwPfoNbt,1}{(pwbp+2pfo\,(pfo+pw))Fy}}\ =\ 14.23\ mm\ <\ 18\ mm$ Therefore, Ok.

4.8 Purlin Design

4.8.1 Purlin size and Loads

Try purlin **Z200 x 75 x 20 x 2.2**

$The\ span\ L\ = 1.5\ m, yield\ strength\ F_y\ =\ 345\ N/mm^2, roof\ slope\ \alpha\ =\ 15°$

$Dead\ load\ =\ 0.15\ kN/m2\ x\ 1.5\ m\ =\ 0.225\ kN/m$

According to UBC Table 16- C,

$Tributary\ area\ A\ =\ 1.5\ m\ x\ 6\ m\ =\ 9\ m2\ \ <\ 18\ m2, Lr =\ 0.958\ kN/m2$

$Projected\ roof\ live\ load\ LR\ =\ 0.958\ x\ 1.5\ =\ 1.44\ kN/m$

According to the UBC Table 16–H, the roof element pressure coefficient is:

$Cq\ =\ (1.3 -\ 1)x\ 0.29/(9.29\ -0.93) + 1\ =\ 1.01\ (outward)$

$Wind\ load\ W\ =\ CeCqqsIwWe\ =\ 1.15\ x\ 1.01\ x\ 0.762\ x\ 1\ x\ 1.5\ =\ 1.33 kN/m$

Parallel to the roof slope

$DLy =\ DLcos2\ \alpha\ =\ 0.21\ kN/m, DLx =\ DLcos\ \alpha\ sin\ \alpha\ =\ 0.06\ kN/m, LRy =\ LR\ cos\ \alpha =\ 1.39\ kN/m$

$LRx =\ LR\ sin\ \alpha =\ 0.37\ kN/m, Wy\ =\ -1.33\ kN/m, Wx\ =\ 0\ kN/m,$

4.9 Foundation Design: Steel Warehouse

Concrete Stub Column and Foundation Design for the Steel Warehouse

Geometry

Steel column size is H300 x 200 x 6 x 10

Base plate dimensions = d x b = 250 mm x 350 mm

Try column size: B x D = 350 mm x 450 mm, height = 1.5 m

Figure 4.50 shows foundation plan and section drawing.

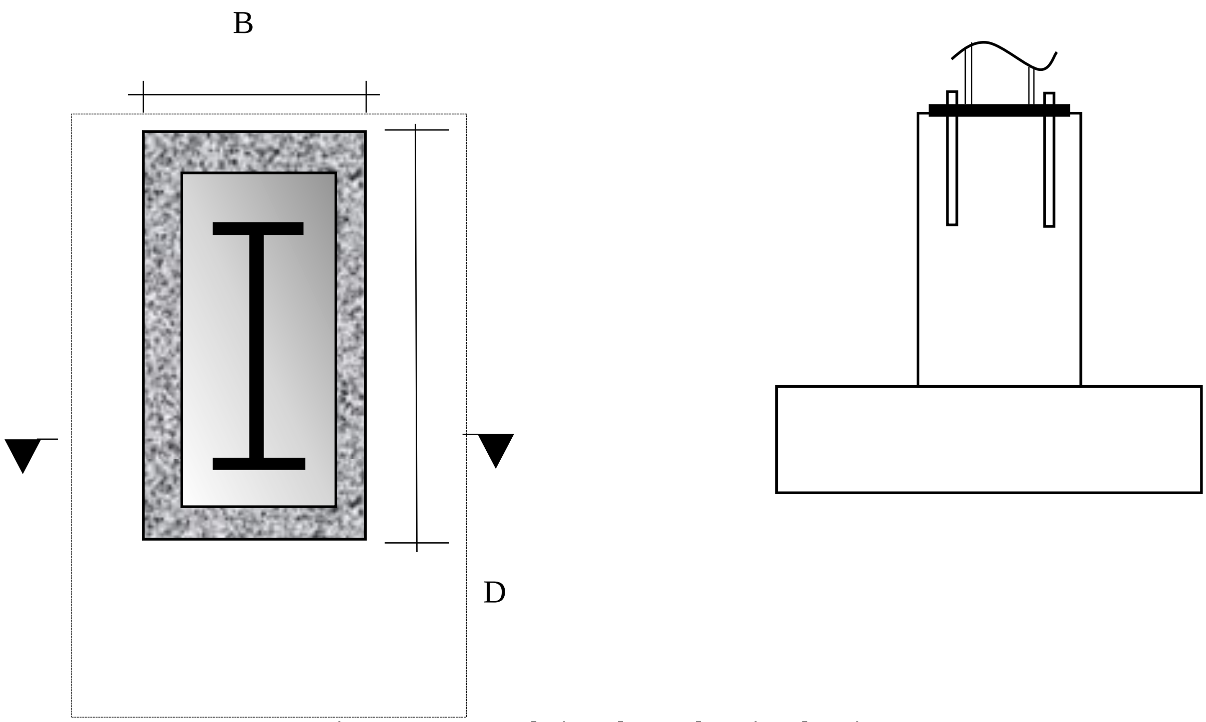


Figure 4.50: Foundation plan and section drawing

$Concrete\ strength\ fcu\ =\ 30\ N/mm^2, soil\ bearing\ capacit\ =\ 150\ kN/mm^2,$

$Factor\ of\ Safety\ (F.O.S)\ =\ 1.5\ \ x\ Loading.$

The worst load combination from the analysis of the Staad Pro model had the reaction forces shown in Table 4.6.

Table 4.6: Staad pro Reaction forces for worst Load case- Foundation Design,Steel warehouse

Reaction	Load Combination	Absolute Force (kN)
F_x (Shear)	$0.9DL\ -1.3WL$	51.34
F_y (Compression)	$1.2DL\ +\ 1.6\ RLL$	80.19
$Uplift$	WL	50.61
$F_z = M_y\ = M_y\ = M_z$	-	0

$The\ design\ load\ P_{ult} = 80.19\ kN + 0.45\ m\ x\ 0.35\ m\ x 1.5\ m\ x 24\ kN/m3 = 85.86\ kN$

$$P_{service} = 85.86 / 1.5 = 61.3\ kN$$

$$M_{xult} = 51.34\ kN\ x\ 1.5\ m = 77.01\ kNm$$

$$M_{xservice} = 51.34 / 1.5 = 51.34\ kNm$$

Design

The Excel sheets attached in Appendix A were used for the design.

The foundation design yielded **1800 × 1500 × 400 mm** thick isolated pads. The reinforcement for the foundation pads was: **T12 @ 200 BEW**.

4.10 Foundation Design - Concrete Warehouse

Geometry:

Concrete column of size B x D = 400 mm x 400 mm was used for the design.

The foundation supported 6 m long and 5m high masonry wall through the ground beam as shown in Figure 4.51 shows foundation plan and section.

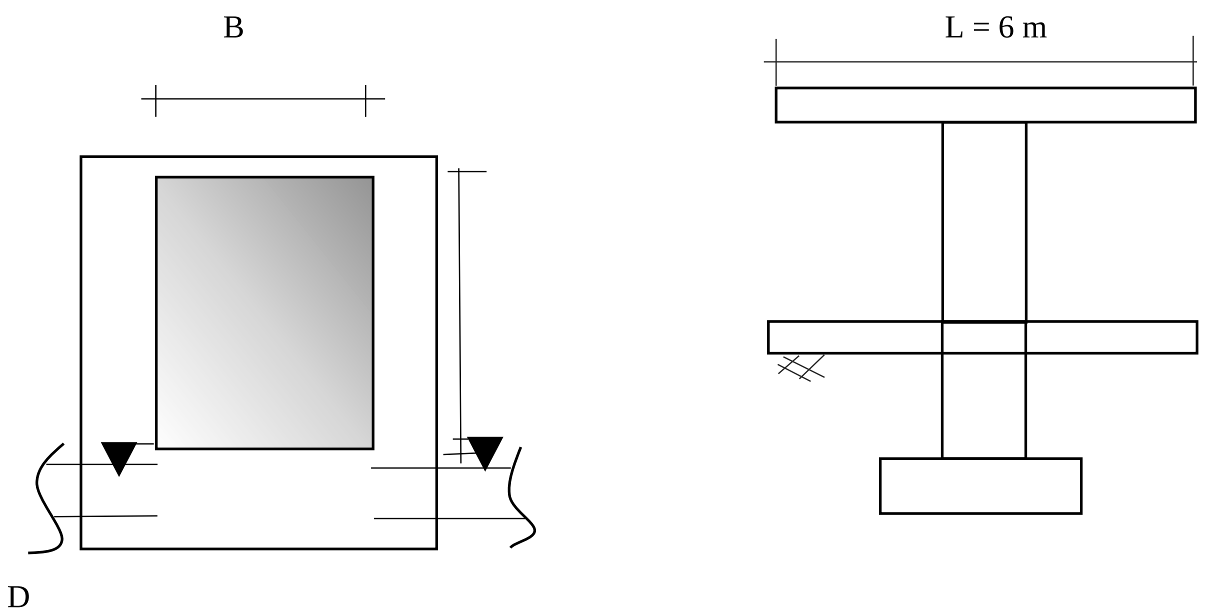


Figure 4.51: Concrete foundation plan and section

$Concrete\ strength\ fcu = 30\ N/mm^2,\ soil\ bearing\ strength = 150\ kN/mm^2, F.O.S = 1.5$

Loading

The worst load combination from the analysis of the Staad Pro model had the reaction forces shown in Table 4.7.

Table 4.7: Staad pro reaction forces for worst load case- foundation design, concrete warehouse

Reaction	Load Combination	Absolute Force (kN)
$Fx\ (Shear)$	$0.9DL\ - 1.3WL$	50.84
$Fy\ (Compression)$	$1.2DL\ +\ 1.6\ RLL$	98.98
$Uplift$	WL	50.61
$Fz\ =\ Mx\ =\ My\ =\ Mz$	-	0

$The\ design\ load\ P_{\ ult} = Compression\ +\ Concrete\ Stub\ +\ Masonry\ wall$

$$P_{\ ult} =\ 98.98\ +\ 0.4\ x\ 0.4\ x\ 1.5\ x\ 24\ x\ 1.4\ +\ 6\ x\ 5\ x\ 0.2\ x\ 20\ x\ 1.4$$

$$P_{\ ult} = 236.74\ kN$$

$$P_{\ service} = 236.74/1.5 = 157.83kN$$

$$M_{xult}\ =\ 50.84\ kN\ x\ 1.5\ m\ =\ 76.26\ kNm$$

$$M_{xservice}\ =\ 76.26/\ 1.5\ =\ 50.84\ kNm$$

Design

The Excel sheets in Appendix A were used for the design.

The foundation design yielded **1800 × 1800 × 300 mm** thick isolated pads. The reinforcement provided was: **T12 @ 200 BEW**.

4.11 Bills of Quantities Analysis

The Bills of Quantities (BQs) were taken off from the drawings, and the summarized results are shown in Table 4.8 and Table 4.9 for Structural Steel and Reinforced Concrete structures respectively. The complete BQs are provided in Appendix C attachment to this report.

Table 4.8: Steel structures summary for bills of quantities

Item	Steel Structure Cost (Ksh)
Substructures	5841970.00
Walling	7567270.00
Roof Construction and Finishes	2050000.00
Finishes	3707900.00
Windows	386660.00
Doors	544520.00
Builders work in connection with mechanical installations	500000.00
Builders work in connection with electrical installations	500000.00
	21098320.00
Preliminaries	1,500,000.00
Provisional Sums	4,305,000.00
Total Sum	26903320.00

Table 4.9: Concrete structure summary for bills of quantities

Item	Concrete Structure Cost (Ksh)
Substructures	5551990.00
RC Superstructures	943600.00
Walling	1330400.00
Roof Construction and Finishes	2050000.00
Finishes	3930700.00
Windows	386660.00
Doors	544520.00
Builders work in connection with mechanical installations	500000.00
Builders work in connection with electrical installations	500000.00
	15737870.00
Preliminaries	1,500,000.00
Provisional Sums	4,305,000.00
Total Sum	21542870.00

4.12 Calculation of Embedded Carbon (EC)

As described in the methodology, the quantities from the Bills of Quantities were converted to mass in kg. The conversion rates and references were inferred from the Inventory of Carbon and Energy (ICE) summary that is in Appendix D attached to this thesis.

Any item not covered by the ICE database was converted using available past research and/or material referenced in the thesis report. Table 4.10 and Table 4.11 give the summary of embedded carbon for the structural Steel and Reinforced Concrete structures respectively.

Table 4.10: Summary of embedded carbon for the structural steel structure

Item	**Steel Structure EC ($KgCo_2e/kg$)**
Substructures	69,330.67
Walling	52,894.19
Roof Construction and Finishes	3,522.43
Finishes	36,585.48
Windows	3,410.12
Doors	1,450.68
Total EC	**167,193.57**

Table 4.11: Summary of embedded carbon for the reinforced concrete structure

Item	**Concrete Structure EC ($KgCo_2e/kg$)**
Substructures	63,854.71
RC Superstructures	5,296.88
Walling	19,617.28
Roof Construction and Finishes	2,124.50
Finishes	56,075.13
Windows	760.67
Doors	1,450.68
Total EC	**149,179.85**

5 DISCUSSION

The London Energy Transformation Initiative (LETI) has conducted case studies for the selection of projects to showcase good practices in consideration of embodied carbon and whole-life carbon principles for construction (Mungai, 2014). The aim of their study was to develop a clear and understandable format and scope to provide a useful means of sharing lessons in reducing embodied carbon in construction while striking a balance of robust designs in projects.

This initiative has been taken by developed countries and Emerging Markets Developing Economies countries to tackle global warming.

Therefore, this study has demonstrated the direction that African countries can take to contribute to this agenda. The results clearly showed the impact of steel manufacturing on increased carbon emissions and the universality of concrete use.

In carrying out this study however, there are notable limitations:

1. Limit state design has the limitation that a structure can become unsatisfactory in a variety of ways, each of which must be considered independently against defined limits of satisfactory behaviour. Limit state design recognises that loads, materials, and design and construction methods are subject to inherent variability, making complete safety against any potential flaws impossible.
2. Less affluent populations are disproportionately affected by environmental degradation, and some natural capital, like ozone, cannot be replaced once it's depleted. Additionally, the loss of biodiversity due to extinct plant or animal species is irreversible. Moreover, there are uncertainties regarding the reliability of technological advancements.
3. Owing to the limitations of secondary data resources, changes to boundaries conditions were not possible in some cases, such as bush clearing, excavation etc.

6 CONCLUSIONS

This study employed the structural design principles of a typical industrial project to determine the most suitable building materials. A model structure of a 60m by 20m, by 7.73m high, double-volume portal frame industrial shed was designed using both structural steel and reinforced concrete. The two model structures were subjected to the same loads and their costs, carbon footprints, and time taken in construction were compared.

The overall objective of the study was to determine the most economically environmentally friendly and most time efficient building material. Results from the study have shown that concrete is the most economical by being 20% cheaper compared to steel construction. It is also more environmentally friendly by having 10% less embodied carbon than steel.

Specific Objectives have been addressed as below:

1. The objective to carry out a Cost-Benefit analysis of structural steel and reinforced concrete construction has been successfully achieved and concrete construction has been determined as a cheaper method of construction by up to 20%.
2. The objective to carry out the carbon footprint analysis of structural steel and reinforced concrete has been successfully accomplished by determining concrete construction has 10% less embodied carbon compared to steel construction.
3. The objective to analyse the overall time taken has been achieved by determining that this is a subjective item based on characteristic, need and urgency of the structure.

Equivalent Carbon (EC) analysis was performed, and the results are tentative because of the subjectivity of the database and the fact that the embodied carbon for some items was extremely difficult to quantify due to a lack of previous information/data on the subject. However, assuming that these conditions are the same for both structures, it is safe to say that the results are accurate representations of the expected results. Steel structures contain more carbon than concrete structures do. This is due to the manufacturing of the material.

7 RECOMMENDATIONS

Following the findings of this study, the following recommendations were made for further research including one recommendation for research application:

1. Further research can be conducted using software programmes tailored to have input more focussed input, such as: material properties and characteristics, size of structure and other design parameters and the output to be the determination of the carbon footprints of structural steel, reinforced concrete and other types of structures like timber, aluminium, and different composite materials.
2. In this study, there were limitations to site-specific scenarios affecting carbon analysis of activities and locations of construction sites in relation to the sources of construction materials. Therefore, it is recommended for further research that a database be created with all pe-construction activities and their approximate embodied carbon figures.
3. Recommendation for application of this research is the development of technical specifications to include the lowest embodied carbon designs for buildings, and lifecycle assessment and embodied carbon energy assessment for construction projects.

REFERENCES

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APPENDICES

Appendix A: Additional Information for Chapter 4

Appendix B: Drawings

Appendix C: Bills of Quantities

Appendix D: Carbon Footprint Analysis

Appendix A: Additional Information for Chapter 4

Appendix A: Additional Information for Chapter 4

1.1 Reaction Summary

	Node	L/C	Horizontal FX (kN)	Vertical FY (kN)	Horizontal FZ (kN)	MX (kNm)	Moment MY (kNm)	MZ (kNm)
Max FX	6	30:0.9DL-1.3WLX	**51.340**	-48.570	0.000	0.000	0.000	0.000
Min FX	1	29:0.9DL+1.3 WLX	**-51.343**	-48.570	0.000	0.000	0.000	0.000
Max FY	1	17:1.2DL+1.6RLL+0.8WLZ	45.199	**80.185**	0.000	0.000	0.000	0.000
Min FY	1	4:+WLX	-45.728	**-50.611**	0.000	0.000	0.000	0.000
Max FZ	1	5:+EQX	-0.963	-0.586	**0.000**	0.000	0.000	0.000
Min FZ	1	5:+EQX	-0.963	-0.586	**0.000**	0.000	0.000	0.000
Max MX	1	5:+EQX	-0.963	-0.586	0.000	**0.000**	0.000	0.000
Min MX	1	5:+EQX	-0.963	-0.586	0.000	**0.000**	0.000	0.000
Max MY	1	5:+EQX	-0.963	-0.586	0.000	0.000	**0.000**	0.000
Min MY	1	5:+EQX	-0.963	-0.586	0.000	0.000	**0.000**	0.000
Max MZ	1	5:+EQX	-0.963	-0.586	0.000	0.000	0.000	**0.000**
Min MZ	1	5:+EQX	-0.963	-0.586	0.000	0.000	0.000	**0.000**

Steel Design (Track 2) Beam 1 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER TABLE RESULT/ CRITICAL COND/ RATIO/ LOADING/

FX MY MZ LOCATION

===

1 TAP ERED PASS BS-4.3.6 0.858 17

76.36 C 0.00 225.99 5.00

===

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 500.00

Gross Area = 98.00 Net Area = 98.00 Eff. Area = 83.00

	z-z axis	y-y axis
Moment of inertia :	51072.668	1338.167
Plastic modulus :	2021.000	214.500
Elastic modulus :	1702.422	133.817
Effective modulus :	1879.306	200.678
Shear Area :	36.000	30.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : SEMI-COMPACT

Squash Load : 2695.00

Axial force/Squash load : 0.028

	z-z axis	y-y axis
Compression Capacity :	2423.2	973.5
Tension Capacity :	2695.0	2695.0
Moment Capacity :	540.8	44.2
Reduced Moment Capacity :	540.8	44.2

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	26.016	124.582
Radius of gyration (cm)	:	19.219	4.013
Effective Length	:	5.000	5.000

LTB Moment Capacity (kNm) and LTB Length (m): 98.22, 5.000

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 225.99 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 462 kN : qw = 164 N/mm2

d = 280 mm : t = 9 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.104	29	-	51.3	-	-	-
BS-4.3.6	0.858	17	-	45.2	-	226.0	-
BS-4.6 (T)	0.027	4	50.6	-	-	-	-
BS-4.7 (C)	0.498	17	76.4	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 4 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER TABLE RESULT/ CRITICAL COND/ RATIO/ LOADING/

FX MY MZ LOCATION

===

4 TAP ERED PASS BS-4.3.6 0.831 17

76.36 C 0.00 225.99 0.00

===

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 500.00

Gross Area = 68.00 Net Area = 68.00 Eff. Area = 83.00

		z-z axis	y-y axis
Moment of inertia	:	10242.667	1335.667
Plastic modulus	:	776.000	207.000
Elastic modulus	:	682.844	133.567
Effective modulus	:	847.266	194.460
Shear Area	:	36.000	60.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : SEMI-COMPACT

Squash Load : 2695.00

Axial force/Squash load : 0.028

		z-z axis	y-y axis
Compression Capacity	:	2423.2	906.5
Tension Capacity	:	2695.0	2695.0
Moment Capacity	:	540.8	44.2
Reduced Moment Capacity	:	540.8	44.2

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	26.016	124.582
Radius of gyration (cm)	:	19.219	4.013
Effective Length	:	5.000	5.000

LTB Moment Capacity (kNm) and LTB Length (m): 253.07, 5.000

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 225.99 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 957 kN : qw = 164 N/mm2

d = 580 mm : t = 9 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.052	30	-	51.3	-	-	-
BS-4.3.6	0.831	17	-	45.2	-	226.0	-
BS-4.6 (T)	0.027	9	50.6	-	-	-	-
BS-4.7 (C)	0.502	17	76.4	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 5 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER	TABLE	RESULT/	CRITICAL COND/	RATIO/	LOADING/
	FX	MY	MZ	LOCATION	
5	TAP ERED	PASS	BS-4.3.6	0.987	17
	63.71 C	0.00	225.99	0.00	

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 725.62

Gross Area = 81.12 Net Area = 81.12 Eff. Area = 99.12

		z-z axis	y-y axis
Moment of inertia	:	12061.498	1603.974
Plastic modulus	:	919.728	249.936
Elastic modulus	:	804.100	160.397
Effective modulus	:	919.728	249.936
Shear Area	:	43.200	72.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : PLASTIC

Squash Load : 3220.80

Axial force/Squash load : 0.020

		z-z axis	y-y axis
Compression Capacity	:	2754.2	805.8
Tension Capacity	:	3220.8	3220.8
Moment Capacity	:	555.5	53.1
Reduced Moment Capacity	:	555.5	53.1

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	37.900	180.259
Radius of gyration (cm)	:	19.146	4.025
Effective Length	:	7.256	7.256

LTB Moment Capacity (kNm) and LTB Length (m): 151.45, 7.256

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 225.99 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 1140 kN : qw = 164 N/mm2

d = 576 mm : t = 12 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.052	17	-	61.8	-	-	-
BS-4.3.6	0.987	17	-	61.8	-	226.0	-
BS-4.6 (T)	0.013	4	28.1	-	-	-	-
BS-4.7 (C)	0.496	17	63.7	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 6 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER	TABLE	RESULT/	CRITICAL COND/	RATIO/	LOADING/
	FX	MY	MZ	LOCATION	

===

6	TAP ERED	PASS	BS-4.3.6	0.349	30
	24.17 T	0.00	27.24	1.55	

===

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 310.98

Gross Area = 45.84 Net Area = 45.84 Eff. Area = 45.84

		z-z axis	y-y axis
Moment of inertia	:	7285.861	778.111
Plastic modulus	:	541.464	132.156
Elastic modulus	:	485.724	86.457
Effective modulus	:	510.230	106.549
Shear Area	:	25.920	18.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : SEMI-COMPACT

Squash Load : 1260.60

Axial force/Squash load : 0.019

		z-z axis	y-y axis
Compression Capacity	:	1139.4	742.8
Tension Capacity	:	1260.6	1260.6
Moment Capacity	:	140.3	28.5
Reduced Moment Capacity	:	140.3	28.5

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

	x-x axis	y-y axis
Slenderness :	24.667	75.480
Radius of gyration (cm) :	12.607	4.120
Effective Length :	3.110	3.110

LTB Moment Capacity (kNm) and LTB Length (m): 106.50, 3.110

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 27.24 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 281 kN : qw = 164 N/mm2

d = 284 mm : t = 6 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.040	17	-	11.9	-	-	-
BS-4.3.6	0.349	30	-	3.2	-	27.2	-
BS-4.6 (T)	0.022	4	28.1	-	-	-	-
BS-4.7 (C)	0.314	17	47.0	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 7 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER TABLE RESULT/ CRITICAL COND/ RATIO/ LOADING/

FX MY MZ LOCATION

===

7 TAP ERED PASS BS-4.3.6 0.352 29

24.42 T 0.00 26.53 1.81

===

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 310.98

Gross Area = 45.84 Net Area = 45.84 Eff. Area = 45.84

		z-z axis	y-y axis
Moment of inertia	:	7285.861	778.111
Plastic modulus	:	541.464	132.156
Elastic modulus	:	485.724	86.457
Effective modulus	:	510.230	106.549
Shear Area	:	25.920	18.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : SEMI-COMPACT

Squash Load : 1260.60

Axial force/Squash load : 0.019

		z-z axis	y-y axis
Compression Capacity	:	1139.4	743.0
Tension Capacity	:	1260.6	1260.6
Moment Capacity	:	140.3	28.5
Reduced Moment Capacity	:	140.3	28.5

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

	x-x axis	y-y axis
Slenderness :	24.667	75.480
Radius of gyration (cm) :	12.607	4.120
Effective Length :	3.110	3.110

LTB Moment Capacity (kNm) and LTB Length (m): 105.54, 3.110

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 26.53 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 281 kN : qw = 164 N/mm2

d = 284 mm : t = 6 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.040	17	-	11.9	-	-	-
BS-4.3.6	0.352	29	-	1.3	-	26.5	-
BS-4.6 (T)	0.022	9	28.1	-	-	-	-
BS-4.7 (C)	0.316	17	47.0	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 8 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER	TABLE	RESULT/	CRITICAL COND/	RATIO/	LOADING/
	FX	MY	MZ	LOCATION	

===

8	TAP ERED	PASS	BS-4.3.6	0.994	17
	63.71 C	0.00	225.99	7.26	

===

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 725.62

Gross Area = 117.12 Net Area = 117.12 Eff. Area = 99.12

		z-z axis	y-y axis
Moment of inertia	:	60605.344	1608.294
Plastic modulus	:	2406.528	260.736
Elastic modulus	:	2020.178	160.829
Effective modulus	:	1412.139	260.736
Shear Area	:	43.200	36.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : PLASTIC

Squash Load : 3220.80

Axial force/Squash load : 0.020

		z-z axis	y-y axis
Compression Capacity	:	2754.2	810.2
Tension Capacity	:	3220.8	3220.8
Moment Capacity	:	555.5	53.1
Reduced Moment Capacity	:	555.5	53.1

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	37.900	180.259
Radius of gyration (cm)	:	19.146	4.025
Effective Length	:	7.256	7.256

LTB Moment Capacity (kNm) and LTB Length (m): 70.51, 7.256

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 225.99 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 546 kN : qw = 164 N/mm2

d = 276 mm : t = 12 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.104	17	-	61.8	-	-	-
BS-4.3.6	0.994	17	-	61.8	-	226.0	-
BS-4.6 (T)	0.013	9	28.1	-	-	-	-
BS-4.7 (C)	0.495	17	63.7	-	-	-	-

Torsion and deflections have not been considered in the design.

Utilization Ratio

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
1	Taper	Taper	0.858	1.000	0.858	BS-4.3.6	17		30.7E	1.34E	27.667
4	Taper	Taper	0.831	1.000	0.831	BS-4.3.6	17		30.7E	1.34E	27.667
5	Taper	Taper	0.987	1.000	0.987	BS-4.3.6	17		36.3E	1.61E	47.578
6	Taper	Taper	0.349	1.000	0.349	BS-4.3.6	30		7.29E		8.189
7	Taper	Taper	0.352	1.000	0.352	BS-4.3.6	29		7.29E		8.189
8	Taper	Taper	0.994	1.000	0.994	BS-4.3.6	17		36.3E	1.61E	47.578

Base Pressure

Node	L/C	FX (N/mm^2)	FY (N/mm^2)	FZ (N/mm^2)
1	5:+EQX	0.000	0.000	0.000
	1:DL	0.000	0.000	0.000
	3:RLL	0.000	0.000	0.000
	4:+WLX	0.000	0.000	0.000
	9:-WLX	0.000	0.000	0.000
	2:1.2DL+1.6RLL+0.8	0.000	0.000	0.000
	14:1.4DL	0.000	0.000	0.000
	15:1.2DL+0.5RLL	0.000	0.000	0.000
	16:1.2DL + 1.6RLL -	0.000	0.000	0.000
	17:1.2DL+1.6RLL+0.	0.000	0.000	0.000
	18:1.2DL+1.6RLL-	0.000	0.000	0.000
	19:1.2DL + 1.3WLX +	0.000	0.000	0.000
	20:1.2DL+1.3WLZ+0	0.000	0.000	0.000
	21:1.2DL-1.3WLX	0.000	0.000	0.000
	22:1.2DL-1.3WLZ+	0.000	0.000	0.000
	23:1.2DL+1.0EQX	0.000	0.000	0.000
	24:1.2DL+1.0 EQZ	0.000	0.000	0.000
	25:0.9DL+1.0 EQX	0.000	0.000	0.000
	26:0.9DL-1.0 EQX	0.000	0.000	0.000
	27:0.9DL+1.0EQZ	0.000	0.000	0.000
	28:0.9DL-1.0EQZ	0.000	0.000	0.000
	29:0.9DL+1.3 WLX	0.000	0.000	0.000
	30:0.9DL-1.3WLX	0.000	0.000	0.000
	31:0.9DL+1.3WLZ	0.000	0.000	0.000
	32:0.9DL-1.3WLZ	0.000	0.000	0.000
	33:1.0 DL +1.0 RLL	0.000	0.000	0.000
	34:1,0 DL +1.0 WLX	0.000	0.000	0.000
	35:1,0 DL - 1.0 WLX	0.000	0.000	0.000
	36:1.0 DL + 1.0 WLZ	0.000	0.000	0.000
	37:1.0DL - 1.0 WLZ	0.000	0.000	0.000
	38:1.0DL+ 0.714EQX	0.000	0.000	0.000
	39:1.0DL - 0.714EQX	0.000	0.000	0.000
	40:0.9DL+0.714EQX	0.000	0.000	0.000
	41:0.9DL-0.714EQX	0.000	0.000	0.000
	42:0.9DL+0.714EQZ	0.000	0.000	0.000
	43:0.9DL-0.714EQZ	0.000	0.000	0.000
	44:1.0 DL + 0.75 RLL	0.000	0.000	0.000
	45:1.0 DL+0.75 RLL -	0.000	0.000	0.000
	46:1.0DL+0.75 RLL +	0.000	0.000	0.000
	47:1.0 DL +0.75RLL -	0.000	0.000	0.000
	48:1.0 DL+O.75RLL	0.000	0.000	0.000

	49:1.0DL+0.75RLL+0	0.000	0.000	0.000
6	5:+EQX	0.000	0.000	0.000
	1:DL	0.000	0.000	0.000
	3:RLL	0.000	0.000	0.000
	4:+WLX	0.000	0.000	0.000
	9:-WLX	0.000	0.000	0.000
	2:1.2DL+1.6RLL+0.8	0.000	0.000	0.000
	14:1.4DL	0.000	0.000	0.000
	15:1.2DL+0.5RLL	0.000	0.000	0.000
	16:1.2DL + 1.6RLL -	0.000	0.000	0.000
	17:1.2DL+1.6RLL+0.	0.000	0.000	0.000
	18:1.2DL+1.6RLL-	0.000	0.000	0.000
	19:1.2DL + 1.3WLX +	0.000	0.000	0.000
	20:1.2DL+1.3WLZ+0	0.000	0.000	0.000
	21:1.2DL-1.3WLX	0.000	0.000	0.000
	22:1.2DL-1.3WLZ+	0.000	0.000	0.000
	23:1.2DL+1.0EQX	0.000	0.000	0.000
	24:1.2DL+1.0 EQZ	0.000	0.000	0.000
	25:0.9DL+1.0 EQX	0.000	0.000	0.000
	26:0.9DL-1.0 EQX	0.000	0.000	0.000
	27:0.9DL+1.0EQZ	0.000	0.000	0.000
	28:0.9DL-1.0EQZ	0.000	0.000	0.000
	29:0.9DL+1.3 WLX	0.000	0.000	0.000
	30:0.9DL-1.3WLX	0.000	0.000	0.000
	31:0.9DL+1.3WLZ	0.000	0.000	0.000
	32:0.9DL-1.3WLZ	0.000	0.000	0.000
	33:1.0 DL +1.0 RLL	0.000	0.000	0.000
	34:1,0 DL +1.0 WLX	0.000	0.000	0.000
	35:1,0 DL - 1.0 WLX	0.000	0.000	0.000
	36:1.0 DL + 1.0 WLZ	0.000	0.000	0.000
	37:1.0DL - 1.0 WLZ	0.000	0.000	0.000
	38:1.0DL+ 0.714EQX	0.000	0.000	0.000
	39:1.0DL - 0.714EQX	0.000	0.000	0.000
	40:0.9DL+0.714EQX	0.000	0.000	0.000
	41:0.9DL-0.714EQX	0.000	0.000	0.000
	42:0.9DL+0.714EQZ	0.000	0.000	0.000
	43:0.9DL-0.714EQZ	0.000	0.000	0.000
	44:1.0 DL + 0.75 RLL	0.000	0.000	0.000
	45:1.0 DL+0.75 RLL -	0.000	0.000	0.000
	46:1.0DL+0.75 RLL +	0.000	0.000	0.000
	47:1.0 DL +0.75RLL -	0.000	0.000	0.000
	48:1.0 DL+O.75RLL	0.000	0.000	0.000
	49:1.0DL+0.75RLL+0	0.000	0.000	0.000

Base Pressure Summary

	Node	L/C	FX (N/mm^2)	FY (N/mm^2)	FZ (N/mm^2)
Max FX	1	5:+EQX	**0.000**	0.000	0.000
Min FX	1	5:+EQX	**0.000**	0.000	0.000
Max FY	1	5:+EQX	0.000	**0.000**	0.000
Min FY	1	5:+EQX	0.000	**0.000**	0.000
Max FZ	1	5:+EQX	0.000	0.000	**0.000**
Min FZ	1	5:+EQX	0.000	0.000	**0.000**

Statics Check Results

L/C		FX (kN)	FY (kN)	FZ (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
5:+EQX	Loads	1.927	0.000	0.000	0.000	0.000	-11.718
5:+EQX	Reactions	-1.927	0.000	0.000	0.000	0.000	11.718
	Difference	-0.000	0.000	0.000	0.000	0.000	0.000
1:DL	Loads	-0.000	-38.275	0.000	0.000	0.000	-382.751
1:DL	Reactions	0.000	38.275	0.000	0.000	0.000	382.751
	Difference	-0.000	-0.000	0.000	0.000	0.000	0.000
3:RLL	Loads	-0.000	-71.525	0.000	0.000	0.000	-715.251
3:RLL	Reactions	0.000	71.525	0.000	0.000	0.000	715.251
	Difference	-0.000	-0.000	0.000	0.000	0.000	0.000
4:+WLX	Loads	34.200	87.074	0.000	0.000	0.000	729.264
4:+WLX	Reactions	-34.200	-87.074	0.000	0.000	0.000	-729.264
	Difference	0.000	0.000	0.000	0.000	0.000	-0.000
9:-WLX	Loads	-34.200	87.074	0.000	0.000	0.000	1.01E 3
9:-WLX	Reactions	34.200	-87.074	0.000	0.000	0.000	-1.01E 3
	Difference	0.000	-0.000	0.000	0.000	0.000	-0.000

1.2 8.2 DESIGN RESULTS

Job Information

	Engineer	Checked	Approved
Name:	DKG	DKG	
Date:	21-Oct-20		

Structure Type SPACE FRAME

Number of Nodes	7	Highest Node	9
Number of Elements	6	Highest Beam	8

Number of Basic Load Cases	5
Number of Combination Load Cases	37

Included in this printout are data for:

All The Whole Structure

Included in this printout are results for load cases:

Type	L/C	Name
Primary	5	+EQX
Primary	1	DL
Primary	3	RLL
Primary	4	+WLX
Primary	9	-WLX
Combination	2	1.2DL+1.6RLL+0.8WLX
Combination	14	1.4DL
Combination	15	1.2DL+0.5RLL
Combination	16	1.2DL + 1.6RLL - 0.8WLX
Combination	17	1.2DL+1.6RLL+0.8WLZ
Combination	18	1.2DL+1.6RLL- 0.8WLZ
Combination	19	1.2DL + 1.3WLX + 0.5RLL
Combination	20	1.2DL+1.3WLZ+0.5RLL
Combination	21	1.2DL-1.3WLX +0.5RLL
Combination	22	1.2DL-1.3WLZ+ 0.5RLL
Combination	23	1.2DL+1.0EQX
Combination	24	1.2DL+1.0 EQZ
Combination	25	0.9DL+1.0 EQX
Combination	26	0.9DL-1.0 EQX
Combination	27	0.9DL+1.0EQZ
Combination	28	0.9DL-1.0EQZ
Combination	29	0.9DL+1.3 WLX
Combination	30	0.9DL-1.3WLX
Combination	31	0.9DL+1.3WLZ
Combination	32	0.9DL-1.3WLZ
Combination	33	1.0 DL +1.0 RLL
Combination	34	1,0 DL +1.0 WLX
Combination	35	1,0 DL - 1.0 WLX
Combination	36	1.0 DL + 1.0 WLZ
Combination	37	1.0DL - 1.0 WLZ
Combination	38	1.0DL+ 0.714EQX
Combination	39	1.0DL - 0.714EQX
Combination	40	0.9DL+0.714EQX

Combination	41	0.9DL-0.714EQX
Combination	42	0.9DL+0.714EQZ
Combination	43	0.9DL-0.714EQZ
Combination	44	1.0 DL + 0.75 RLL + 0.75 WLX
Combination	45	1.0 DL+0.75 RLL -0.75WLX
Combination	46	1.0DL+0.75 RLL + 0.75 WLZ
Combination	47	1.0 DL +0.75RLL -0.75WLZ
Combination	48	1.0 DL+O.75RLL +0.75EQX
Combination	49	1.0DL+0.75RLL+0.75EQZ

Nodes

Node	X (m)	Y (m)	Z (m)
1	0.000	0.000	0.000
2	0.000	5.000	0.000
5	20.000	5.000	0.000
6	20.000	0.000	0.000
7	10.000	7.730	0.000
8	7.000	6.911	0.000
9	13.000	6.911	0.000

Beams

Beam	Node A	Node B	Length (m)	Property	□ (degrees)
1	1	2	5.000	4	0
4	5	6	5.000	4	0
5	2	8	7.256	2	0
6	8	7	3.110	3	0
7	7	9	3.110	3	0
8	9	5	7.256	1	0

Section Properties

Prop	Section	Area (cm^2)	I_{yy} (cm^4)	I_{zz} (cm^4)	J (cm^4)	Material
1	Taper	99.120	1.61E 3	36.3E 3	47.578	STEEL
2	Taper	99.120	1.61E 3	36.3E 3	47.578	STEEL
3	Taper	45.840	778.111	7.29E 3	8.189	STEEL

4	Rect 0.40x0.40	1.6E 3	213E 3	213E 3	360E 3	CONCRETE

Materials

Mat	Name	E (kN/mm^2)	□	Density (kg/m^3)	□ (/°C)
3	STEEL	205.000	0.300	7.83E 3	12E -6
4	STAINLESSSTEEL	197.930	0.300	7.83E 3	18E -6
5	ALUMINUM	68.948	0.330	2.71E 3	23E -6
6	CONCRETE	21.718	0.170	2.4E 3	10E -6

Supports

Node	X (kN/mm)	Y (kN/mm)	Z (kN/mm)	rX (kN-m/deg)	rY (kN-m/deg)	rZ (kN-m/deg)
1	Fixed	Fixed	Fixed	-	-	-
6	Fixed	Fixed	Fixed	-	-	-

Basic Load Cases

Number	Name
5	+EQX
1	DL
3	RLL
4	+WLX
9	-WLX

Combination Load Cases

Comb.	Combination L/C Name	Primary	Primary L/C Name	Factor
2	1.2DL+1.6RLL+0.8WLX	1	DL	1.20
		3	RLL	1.60
		4	+WLX	0.80
14	1.4DL	1	DL	1.40
15	1.2DL+0.5RLL	1	DL	1.20
		3	RLL	0.50

16	1.2DL + 1.6RLL - 0.8WLX	1	DL	1.20
		3	RLL	1.60
		9	-WLX	0.80
17	1.2DL+1.6RLL+0.8WLZ	1	DL	1.20
		3	RLL	1.60
18	1.2DL+1.6RLL- 0.8WLZ	1	DL	1.20
		3	RLL	1.60
19	1.2DL + 1.3WLX + 0.5RLL	1	DL	1.20
		4	+WLX	1.30
		3	RLL	0.50
20	1.2DL+1.3WLZ+0.5RLL	1	DL	1.20
		3	RLL	0.50
21	1.2DL-1.3WLX +0.5RLL	1	DL	1.20
		4	+WLX	1.30
		3	RLL	0.50
22	1.2DL-1.3WLZ+ 0.5RLL	1	DL	1.20
		3	RLL	0.50
23	1.2DL+1.0EQX	1	DL	1.20
		5	+EQX	1.00
24	1.2DL+1.0 EQZ	1	DL	1.20
25	0.9DL+1.0 EQX	1	DL	0.00
		5	+EQX	1.00
26	0.9DL-1.0 EQX	1	DL	0.90
27	0.9DL+1.0EQZ	1	DL	0.90
28	0.9DL-1.0EQZ	1	DL	1.00
29	0.9DL+1.3 WLX	1	DL	0.90
		4	+WLX	1.30
30	0.9DL-1.3WLX	1	DL	0.90
		9	-WLX	1.30
31	0.9DL+1.3WLZ	1	DL	0.90
32	0.9DL-1.3WLZ	1	DL	0.90
33	1.0 DL +1.0 RLL	1	DL	1.00
		3	RLL	1.00
34	1,0 DL +1.0 WLX	1	DL	1.00
		4	+WLX	1.00
35	1,0 DL - 1.0 WLX	1	DL	1.00
36	1.0 DL + 1.0 WLZ	1	DL	1.00
37	1.0DL - 1.0 WLZ	1	DL	1.00
38	1.0DL+ 0.714EQX	1	DL	1.00
		5	+EQX	0.71
39	1.0DL - 0.714EQX	1	DL	1.00
40	0.9DL+0.714EQX	1	DL	0.90
		5	+EQX	0.71
41	0.9DL-0.714EQX	1	DL	0.90
42	0.9DL+0.714EQZ	1	DL	0.90
43	0.9DL-0.714EQZ	1	DL	0.90
44	1.0 DL + 0.75 RLL + 0.75 WLX	1	DL	1.00
		3	RLL	0.75
		4	+WLX	0.75
45	1.0 DL+0.75 RLL -0.75WLX	1	DL	1.00
		3	RLL	0.75
		9	-WLX	0.75
46	1.0DL+0.75 RLL + 0.75 WLZ	1	DL	1.00
		3	RLL	0.75
47	1.0 DL +0.75RLL -0.75WLZ	1	DL	1.00
		3	RLL	0.75
48	1.0 DL+O.75RLL +0.75EQX	1	DL	1.00
		3	RLL	0.75
		5	+EQX	0.75
49	1.0DL+0.75RLL+0.75EQZ	1	DL	1.00
		3	RLL	0.75

UBC Loading Definition

Zone Z	Importance Factor	Rw X	Rw Z	Site Soil	Ct	Period X (sec)	Period Z (sec)	Accidental Torsion
0.150	1.000	5.600	5.600	4.000	0.049	-	-	No

Selfweight included

Beam Loads : 1 DL

Beam	Type	Direction	Fa	Da (m)	Fb	Db	Ecc. (m)
5	UNI kN/m	GY	-0.900	-	-	-	-
6	UNI kN/m	GY	-0.900	-	-	-	-
7	UNI kN/m	GY	-0.900	-	-	-	-
8	UNI kN/m	GY	-0.900	-	-	-	-

Selfweight : 1 DL

Direction	Factor
Y	-1.000

Beam Loads : 3 RLL

Beam	Type	Direction	Fa	Da (m)	Fb	Db	Ecc. (m)
5	UNI kN/m	GY	-3.450	-	-	-	-
6	UNI kN/m	GY	-3.450	-	-	-	-
7	UNI kN/m	GY	-3.450	-	-	-	-
8	UNI kN/m	GY	-3.450	-	-	-	-

Beam Loads : 4 +WLX

Beam	Type	Direction	Fa	Da (m)	Fb	Db	Ecc. (m)
1	UNI kN/m	GX	4.200	-	-	-	-
4	UNI kN/m	GX	2.640	-	-	-	-
5	UNI kN/m	GY	4.740	-	-	-	-
6	UNI kN/m	GY	4.740	-	-	-	-
7	UNI kN/m	GY	3.660	-	-	-	-
8	UNI kN/m	GY	3.660	-	-	-	-

Seismic Loading : 5 +EQX

Code	Direction	Factor
UBC	X	1.000

Beam Loads : 9 -WLX

Beam	Type	Direction	Fa	Da (m)	Fb	Db	Ecc. (m)
1	UNI kN/m	GX	-2.640	-	-	-	-
4	UNI kN/m	GX	-4.200	-	-	-	-
5	UNI kN/m	GY	3.660	-	-	-	-
6	UNI kN/m	GY	3.660	-	-	-	-
7	UNI kN/m	GY	4.740	-	-	-	-
8	UNI kN/m	GY	4.740	-	-	-	-

Node Displacement Summary

	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)	rX (rad)	rY (rad)	rZ (rad)
Max X	2	29:0.9DL+1.3 WLX	**35.202**	0.062	0.000	35.202	0.000	0.000	0.000
Min X	5	30:0.9DL-1.3WLX	**-35.125**	0.062	0.000	35.125	0.000	0.000	-0.000
Max Y	7	29:0.9DL+1.3 WLX	23.823	**42.494**	0.000	48.716	0.000	0.000	0.002
Min Y	7	17:1.2DL+1.6RLL+0.8WLZ	-0.058	**-69.671**	0.000	69.671	0.000	0.000	0.000
Max Z	1	5:+EQX	0.000	0.000	**0.000**	0.000	0.000	0.000	-0.001
Min Z	1	5:+EQX	0.000	0.000	**0.000**	0.000	0.000	0.000	-0.001
Max rX	1	5:+EQX	0.000	0.000	0.000	0.000	**0.000**	0.000	-0.001
Min rX	1	5:+EQX	0.000	0.000	0.000	0.000	**0.000**	0.000	-0.001
Max rY	1	5:+EQX	0.000	0.000	0.000	0.000	0.000	**0.000**	-0.001
Min rY	1	5:+EQX	0.000	0.000	0.000	0.000	0.000	**0.000**	-0.001
Max rZ	6	30:0.9DL-1.3WLX	0.000	0.000	0.000	0.000	0.000	0.000	**0.011**
Min rZ	1	29:0.9DL+1.3 WLX	0.000	0.000	0.000	0.000	0.000	0.000	**-0.011**
Max Rst	7	17:1.2DL+1.6RLL+0.8WLZ	-0.058	-69.671	0.000	**69.671**	0.000	0.000	0.000

Beam Displacement Detail Summary

Displacements shown in italic indicate the presence of an offset

	Beam	L/C	d (m)	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	1	29:0.9DL+1.3 WLX	5.000	**35.202**	0.062	0.000	35.202
Min X	4	30:0.9DL-1.3WLX	0.000	**-35.125**	0.062	0.000	35.125
Max Y	7	29:0.9DL+1.3 WLX	0.933	24.074	**43.323**	0.000	49.562
Min Y	6	17:1.2DL+1.6RLL+0.8WLZ	3.110	-0.057	**-69.671**	0.000	69.671
Max Z	1	5:+EQX	0.000	0.000	0.000	**0.000**	0.000
Min Z	1	5:+EQX	0.000	0.000	0.000	**0.000**	0.000
Max Rst	6	17:1.2DL+1.6RLL+0.8WLZ	3.110	-0.057	-69.671	0.000	**69.671**

Beam End Displacement Summary

Displacements shown in italic indicate the presence of an offset

	Beam	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	1	2	29:0.9DL+1.3 WLX	**35.202**	0.062	0.000	35.202
Min X	4	5	30:0.9DL-1.3WLX	**-35.125**	0.062	0.000	35.125
Max Y	6	7	29:0.9DL+1.3 WLX	23.823	**42.494**	0.000	48.716
Min Y	6	7	17:1.2DL+1.6RLL+0.8WLZ	-0.057	**-69.671**	0.000	69.671
Max Z	1	1	5:+EQX	0.000	0.000	**0.000**	0.000
Min Z	1	1	5:+EQX	0.000	0.000	**0.000**	0.000
Max Rst	6	7	17:1.2DL+1.6RLL+0.8WLZ	-0.057	-69.671	0.000	**69.671**

Beam End Force Summary

The signs of the forces at end B of each beam have been reversed. For example: this means that the Min Fx entry gives the largest tension value for an beam.

	Beam	Node	L/C	Axial	Shear		Torsion	Bending	
				Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	1	1	17:1.2DL+1.6RLL+0.8WLZ	**98.979**	-44.359	0.000	0.000	0.000	0.000
Min Fx	1	2	29:0.9DL+1.3 WLX	**-51.439**	23.542	-0.000	-0.000	-0.000	-185.960
Max Fy	5	2	17:1.2DL+1.6RLL+0.8WLZ	62.904	**61.981**	0.000	0.000	0.000	221.797
Min Fy	8	5	17:1.2DL+1.6RLL+0.8WLZ	62.904	**-61.981**	-0.000	-0.000	-0.000	221.797
Max Fz	1	1	5:+EQX	-1.402	2.502	**0.000**	0.000	0.000	0.000
Min Fz	1	1	5:+EQX	-1.402	2.502	**0.000**	0.000	0.000	0.000
Max Mx	1	1	5:+EQX	-1.402	2.502	0.000	**0.000**	0.000	0.000
Min Mx	1	1	5:+EQX	-1.402	2.502	0.000	**0.000**	0.000	0.000
Max My	1	1	5:+EQX	-1.402	2.502	0.000	0.000	**0.000**	0.000
Min My	1	1	5:+EQX	-1.402	2.502	0.000	0.000	**0.000**	0.000
Max Mz	1	2	17:1.2DL+1.6RLL+0.8WLZ	76.359	-44.359	-0.000	-0.000	-0.000	**221.797**
Min Mz	1	2	29:0.9DL+1.3 WLX	-51.439	23.542	-0.000	-0.000	-0.000	**-185.960**

Beam Force Detail Summary

Sign convention as diagrams:- positive above line, negative below line except Fx where positive is compression. Distance d is given from beam end A.

	Beam	L/C	d (m)	Axial	Shear		Torsion	Bending	
				Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	1	17:1.2DL+1.6RLL+0.8WLZ	0.000	**98.979**	-44.359	0.000	0.000	0.000	0.000
Min Fx	1	29:0.9DL+1.3 WLX	5.000	**-51.439**	23.542	-0.000	-0.000	-0.000	-185.960
Max Fy	5	17:1.2DL+1.6RLL+0.8WLZ	0.000	62.904	**61.981**	0.000	0.000	0.000	221.797
Min Fy	8	17:1.2DL+1.6RLL+0.8WLZ	7.256	62.904	**-61.981**	-0.000	-0.000	-0.000	221.797

Max Fz	1	5:+EQX	0.000	-1.402	2.502	**0.000**	0.000	0.000	0.000
Min Fz	1	5:+EQX	0.000	-1.402	2.502	**0.000**	0.000	0.000	0.000
Max Mx	1	5:+EQX	0.000	-1.402	2.502	0.000	**0.000**	0.000	0.000
Min Mx	1	5:+EQX	0.000	-1.402	2.502	0.000	**0.000**	0.000	0.000
Max My	1	5:+EQX	0.000	-1.402	2.502	0.000	0.000	**0.000**	0.000
Min My	1	5:+EQX	0.000	-1.402	2.502	0.000	0.000	**0.000**	0.000
Max Mz	1	17:1.2DL+1.6RLL+0.8WLZ	5.000	76.359	-44.359	-0.000	-0.000	-0.000	**221.797**
Min Mz	1	29:0.9DL+1.3 WLX	5.000	-51.439	23.542	-0.000	-0.000	-0.000	**-185.960**

Reaction Summary

	Node	L/C	Horizontal FX (kN)	Vertical FY (kN)	Horizontal FZ (kN)	MX (kNm)	Moment MY (kNm)	MZ (kNm)
Max FX	6	30:0.9DL-1.3WLX	**50.841**	-34.475	0.000	0.000	0.000	0.000
Min FX	1	29:0.9DL+1.3 WLX	**-50.842**	-34.475	0.000	0.000	0.000	0.000
Max FY	1	17:1.2DL+1.6RLL+0.8WLZ	44.359	**98.979**	0.000	0.000	0.000	0.000
Min FY	1	4:+WLX	-45.227	**-50.611**	0.000	0.000	0.000	0.000
Max FZ	1	5:+EQX	-2.502	-1.402	**0.000**	0.000	0.000	0.000
Min FZ	1	5:+EQX	-2.502	-1.402	**0.000**	0.000	0.000	0.000
Max MX	1	5:+EQX	-2.502	-1.402	0.000	**0.000**	0.000	0.000
Min MX	1	5:+EQX	-2.502	-1.402	0.000	**0.000**	0.000	0.000
Max MY	1	5:+EQX	-2.502	-1.402	0.000	0.000	**0.000**	0.000
Min MY	1	5:+EQX	-2.502	-1.402	0.000	0.000	**0.000**	0.000
Max MZ	1	5:+EQX	-2.502	-1.402	0.000	0.000	0.000	**0.000**
Min MZ	1	5:+EQX	-2.502	-1.402	0.000	0.000	0.000	**0.000**

Steel Design (Track 2) Beam 5 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

MEMBER TABLE RESULT/ CRITICAL COND/ RATIO/ LOADING/

FX MY MZ LOCATION

===

5 TAP ERED PASS BS-4.3.6 0.968 17

62.90 C 0.00 221.80 0.00

===

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 725.62

Gross Area = 81.12 Net Area = 81.12 Eff. Area = 99.12

	z-z axis	y-y axis
Moment of inertia :	12061.498	1603.974
Plastic modulus :	919.728	249.936
Elastic modulus :	804.100	160.397
Effective modulus :	1412.139	249.936
Shear Area :	43.200	72.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : PLASTIC

Squash Load : 3220.80

Axial force/Squash load : 0.020

	z-z axis	y-y axis
Compression Capacity :	2754.2	801.5
Tension Capacity :	3220.8	3220.8
Moment Capacity :	555.5	53.1
Reduced Moment Capacity :	555.5	53.1

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

	x-x axis	y-y axis
Slenderness :	37.900	180.259
Radius of gyration (cm) :	19.146	4.025
Effective Length :	7.256	7.256

LTB Moment Capacity (kNm) and LTB Length (m): 151.58, 7.256

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 221.80 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 1140 kN : qw = 164 N/mm2

d = 576 mm : t = 12 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.052	17	-	62.0	-	-	-
BS-4.3.6	0.968	17	-	62.0	-	221.8	-
BS-4.6 (T)	0.012	4	27.6	-	-	-	-
BS-4.7 (C)	0.487	17	62.9	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 6 Check 1

ALL UNITS ARE - KN   METE (UNLESS OTHERWISE Noted)

MEMBER   TABLE   RESULT/   CRITICAL COND/   RATIO/   LOADING/

FX   MY   MZ   LOCATION

===

6   TAP ERED   PASS   BS-4.3.6   0.408   30

23.69 T   0.00   30.79   1.55

===

MATERIAL DATA

Grade of steel   = S 275

Modulus of elasticity   = 205 kN/mm2

Design Strength (py)   = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length =   310.98

Gross Area =   45.84 Net Area =   45.84 Eff. Area =   45.84

		z-z axis	y-y axis
Moment of inertia	:	7285.861	778.111
Plastic modulus	:	541.464	132.156
Elastic modulus	:	485.724	86.457
Effective modulus	:	510.230	106.549
Shear Area	:	25.920	18.000

DESIGN DATA (units - kN,m)   BS5950-1/2000

Section Class   : SEMI-COMPACT

Squash Load   : 1260.60

Axial force/Squash load :   0.019

		z-z axis	y-y axis
Compression Capacity	:	1139.4	742.8
Tension Capacity	:	1260.6	1260.6
Moment Capacity	:	140.3	28.5
Reduced Moment Capacity	:	140.3	28.5

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	24.667	75.480
Radius of gyration (cm)	:	12.607	4.120
Effective Length	:	3.110	3.110

LTB Moment Capacity (kNm) and LTB Length (m): 106.50, 3.110

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 30.79 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 281 kN : qw = 164 N/mm2

d = 284 mm : t = 6 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.039	17	-	11.7	-	-	-
BS-4.3.6	0.408	30	-	3.1	-	30.8	-
BS-4.6 (T)	0.022	4	27.6	-	-	-	-
BS-4.7 (C)	0.356	17	45.7	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 7 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

```
MEMBER     TABLE      RESULT/   CRITICAL COND/     RATIO/     LOADING/
              FX          MY          MZ      LOCATION
=======================================================================
    7    TAP ERED    PASS    BS-4.3.6         0.411       29
            23.94 T        0.00         30.13       1.81
=======================================================================
```

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 310.98

Gross Area = 45.84 Net Area = 45.84 Eff. Area = 45.84

		z-z axis	y-y axis
Moment of inertia	:	7285.861	778.111
Plastic modulus	:	541.464	132.156
Elastic modulus	:	485.724	86.457
Effective modulus	:	510.230	106.549
Shear Area	:	25.920	18.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : SEMI-COMPACT

Squash Load : 1260.60

Axial force/Squash load : 0.019

		z-z axis	y-y axis
Compression Capacity	:	1139.4	743.0
Tension Capacity	:	1260.6	1260.6
Moment Capacity	:	140.3	28.5
Reduced Moment Capacity	:	140.3	28.5

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	24.667	75.480
Radius of gyration (cm)	:	12.607	4.120
Effective Length	:	3.110	3.110

LTB Moment Capacity (kNm) and LTB Length (m): 105.54, 3.110

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 30.13 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 281 kN : qw = 164 N/mm2

d = 284 mm : t = 6 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.039	17	-	11.7	-	-	-
BS-4.3.6	0.411	29	-	1.1	-	30.1	-
BS-4.6 (T)	0.022	9	27.6	-	-	-	-
BS-4.7 (C)	0.358	17	46.1	-	-	-	-

Torsion and deflections have not been considered in the design.

Steel Design (Track 2) Beam 8 Check 1

ALL UNITS ARE - KN METE (UNLESS OTHERWISE Noted)

```
MEMBER     TABLE      RESULT/   CRITICAL COND/     RATIO/     LOADING/
               FX         MY          MZ       LOCATION
=======================================================================
     8     TAP ERED     PASS     BS-4.3.6          0.971        17
                62.90 C         0.00        221.80        7.26
=======================================================================
```

MATERIAL DATA

Grade of steel = S 275

Modulus of elasticity = 205 kN/mm2

Design Strength (py) = 274 N/mm2

SECTION PROPERTIES (units - cm)

Member Length = 725.62

Gross Area = 117.12 Net Area = 117.12 Eff. Area = 99.12

		z-z axis	y-y axis
Moment of inertia	:	60605.344	1608.294
Plastic modulus	:	2406.528	260.736
Elastic modulus	:	2020.178	160.829
Effective modulus	:	1412.139	260.736
Shear Area	:	43.200	36.000

DESIGN DATA (units - kN,m) BS5950-1/2000

Section Class : PLASTIC

Squash Load : 3220.80

Axial force/Squash load : 0.020

		z-z axis	y-y axis
Compression Capacity	:	2754.2	810.2
Tension Capacity	:	3220.8	3220.8
Moment Capacity	:	555.5	53.1
Reduced Moment Capacity	:	555.5	53.1

BUCKLING CALCULATIONS (units - kN,m)

(axis nomenclature as per design code)

		x-x axis	y-y axis
Slenderness	:	37.900	180.259
Radius of gyration (cm)	:	19.146	4.025
Effective Length	:	7.256	7.256

LTB Moment Capacity (kNm) and LTB Length (m): 70.51, 7.256

LTB Coefficients & Associated Moments (kNm):

mLT = 1.00 : mx = 0.00 : my = 0.00 : myx = 0.00

Mlt = 221.80 : Mx = 0.00 : My = 0.00 : My = 0.00

Shear Buckling check is required: Vb = 546 kN : qw = 164 N/mm2

d = 276 mm : t = 12 mm : a = 0 mm : pyf = 274 N/mm2

BS-4.4.3.2 status = PASS : BS-4.4.3.3 status = PASS

CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

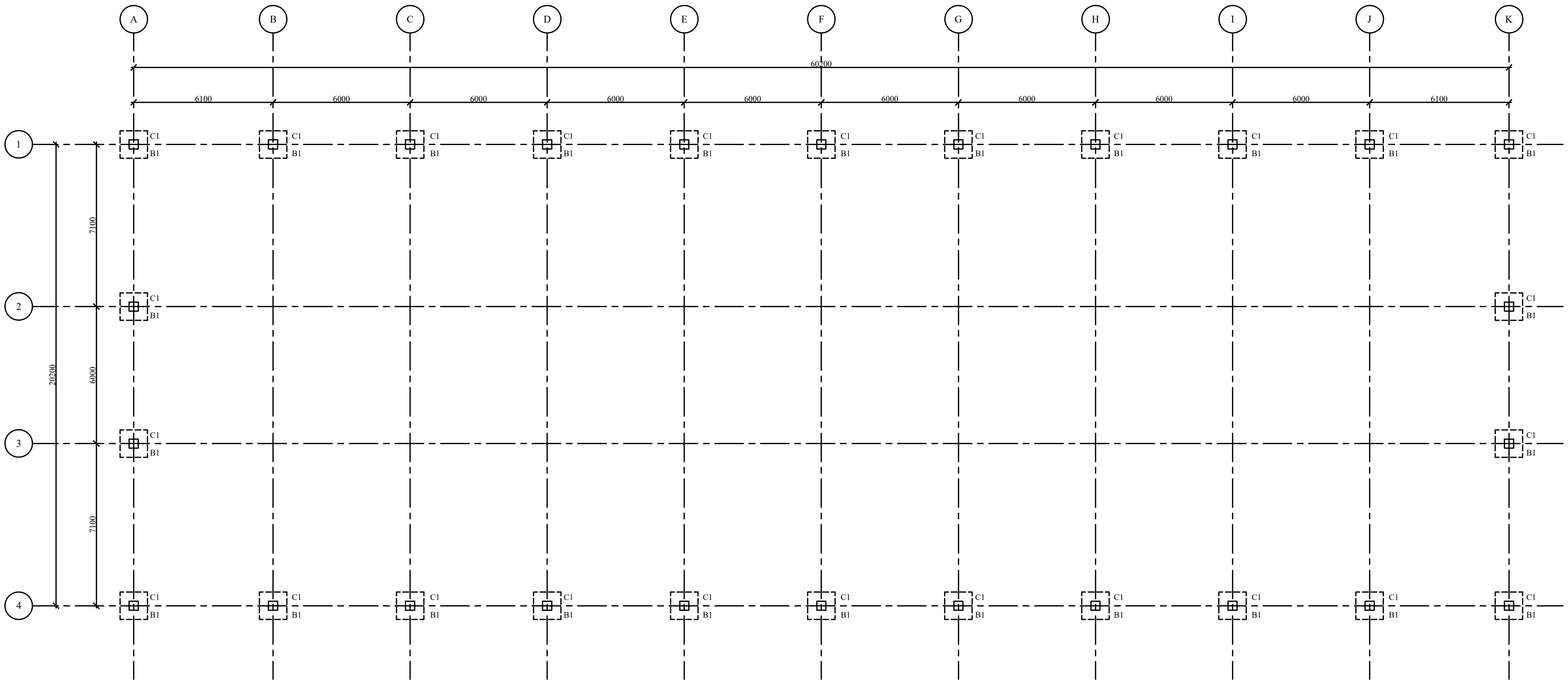
CLAUSE	RATIO	LOAD	FX	VY	VZ	MZ	MY
BS-4.2.3-(Y)	0.104	17	-	62.0	-	-	-
BS-4.3.6	0.971	17	-	62.0	-	221.8	-
BS-4.6 (T)	0.012	9	27.6	-	-	-	-
BS-4.7 (C)	0.487	17	62.9	-	-	-	-

Torsion and deflections have not been considered in the design.

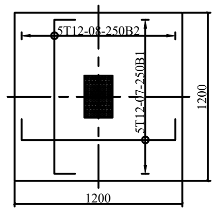
Base Pressure Summary

	Node	L/C	FX (N/mm^2)	FY (N/mm^2)	FZ (N/mm^2)
Max FX	1	5:+EQX	**0.000**	0.000	0.000
Min FX	1	5:+EQX	**0.000**	0.000	0.000
Max FY	1	5:+EQX	0.000	**0.000**	0.000
Min FY	1	5:+EQX	0.000	**0.000**	0.000
Max FZ	1	5:+EQX	0.000	0.000	**0.000**
Min FZ	1	5:+EQX	0.000	0.000	**0.000**

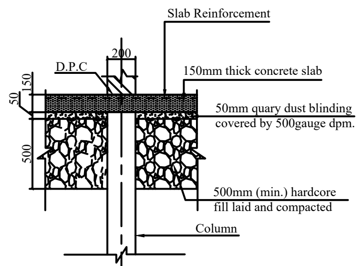
Appendix B: Drawings



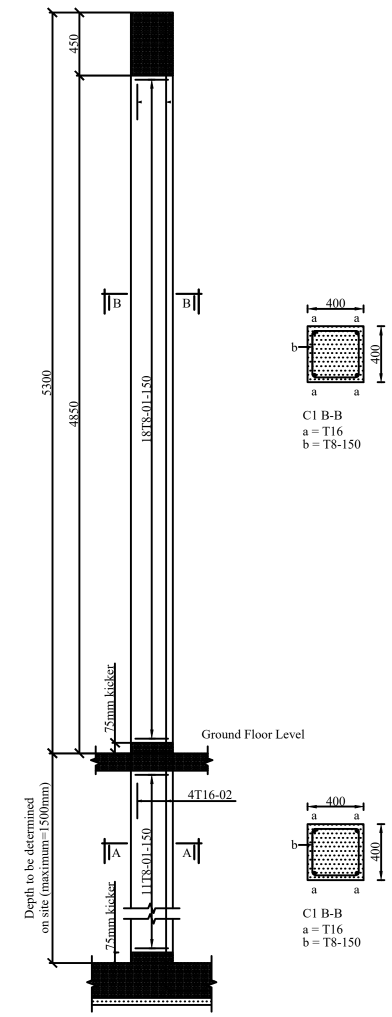
FOUNDATION LAYOUT
SCALE 1:100



COLUMN BASE B1 (26 No. Thus)
1200x1200x400
SCALE 1:25



FOUNDATION DETAILS
SCALE 1:25



COLUMN C1 (26 No. Thus)
SCALE 1:25

MARK	DATE	MADE BY	REVISIONS	ISSUES

GENERAL NOTES

1. Only figured dimensions to be taken from this drawing.
2. This drawing is to be read in conjunction with other structural/architectural drawings.
3. All dimensions, unless otherwise specified, are in millimeters.
4. Concrete cover for reinforcement to be as follows:-
   Slabs - 20mm
   Beams - 25mm
   Columns - 30mm
   Bases - 50mm
5. All black cotton soil to be removed before construction at foundation base locations.
6. Concrete strength to be 25/20 for all structural elements.
7. Concrete strength for blinding to be class 15/40.
8. High yield steel reinforcement bars to BS4449 are denoted by 'T'.
9. Mild steel reinforcement bars to BS4449 are denoted by 'R'.
10. All steel reinforcement to be approved by the Structural Engineer.
11. Surface bed hardcore to be laid in separately compacted 150mm layers on firm approved ground.
12. Design ground bearing pressure = 250kN/m²
13. All foundation levels must be approved by the structural engineer.
14. All masonry walls to be not less than 200mm thick.
15. All masonry walls to be reinforced with hoop iron at every alternate courses
16. All masonry units must have a minimum strength of 7N/mm²

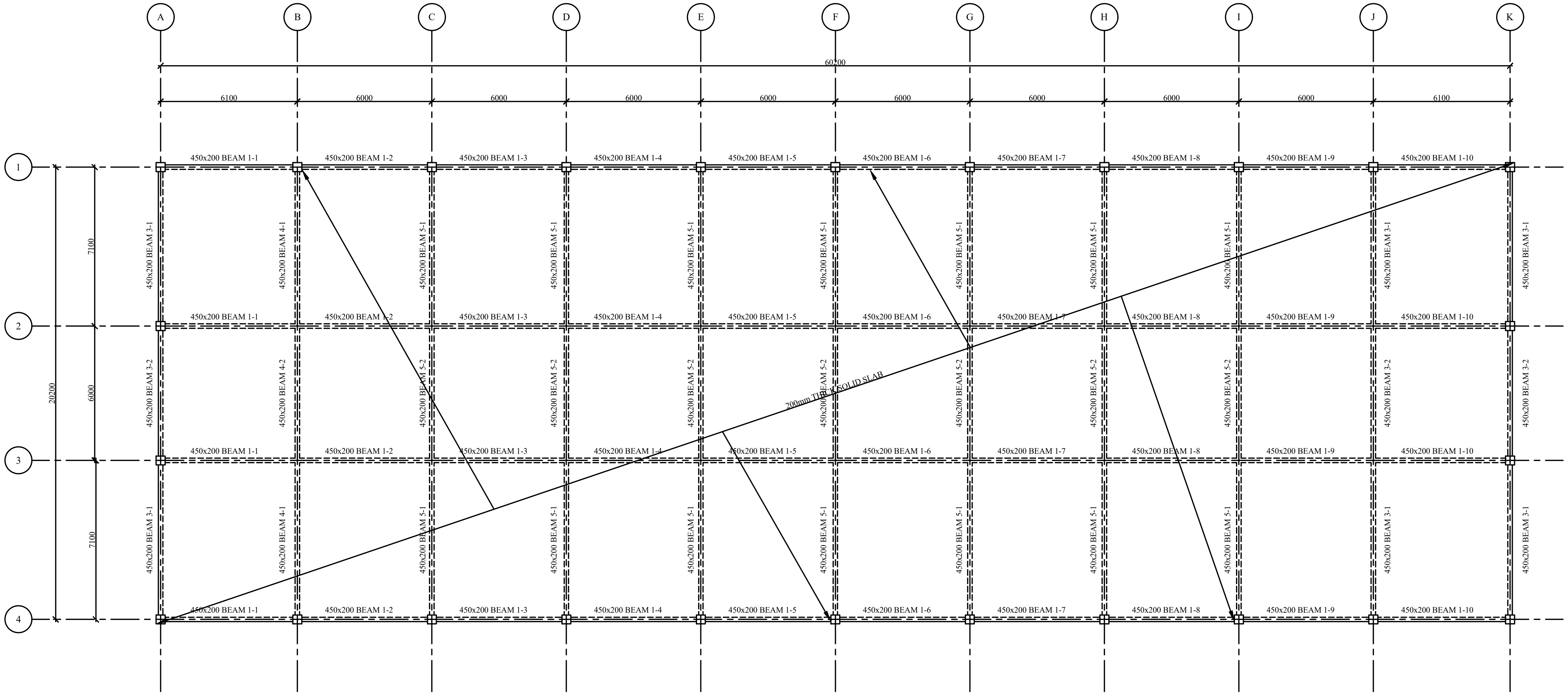
CLIENT:

TITLE:

DATE :

SCALE : As shown

Drg. No. 01



GROUND FLOOR LAYOUT
SCALE 1:100

MARK	DATE	MADE BY	REVISIONS	ISSUES

GENERAL NOTES

1. Only figured dimensions to be taken from this drawing.
2. This drawing is to be read in conjunction with other structural/architectural drawings.
3. All dimensions, unless otherwise specified, are in millimeters.
4. Concrete cover for reinforcement to be as follows:-
   Slabs - 20mm
   Beams - 25mm
   Columns - 30mm
   Bases - 50mm
5. All black cotton soil to be removed before construction at foundation base locations.
6. Concrete strength to be 25/20 for all structural elements.
7. Concrete strength for blinding to be class 15/40.
8. High yield steel reinforcement bars to BS4449 are denoted by 'T'.
9. Mild steel reinforcement bars to BS4449 are denoted by 'R'.
10. All steel reinforcement to be approved by the Structural Engineer.
11. Surface bed hardcore to be laid in separately compacted 150mm layers on firm approved ground.
12. Design ground bearing pressure = 250kN/m²
13. All foundation levels must be approved by the structural engineer.
14. All masonry walls to be not less than 200mm thick.
15. All masonry walls to be reinforced with hoop iron at every alternate courses
16. All masonry units must have a minimum strength of 7N/mm²

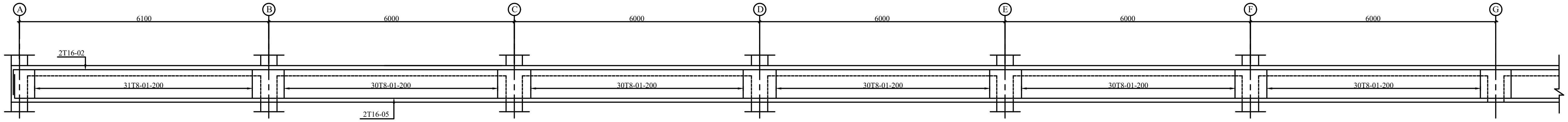
CLIENT:

TITLE:

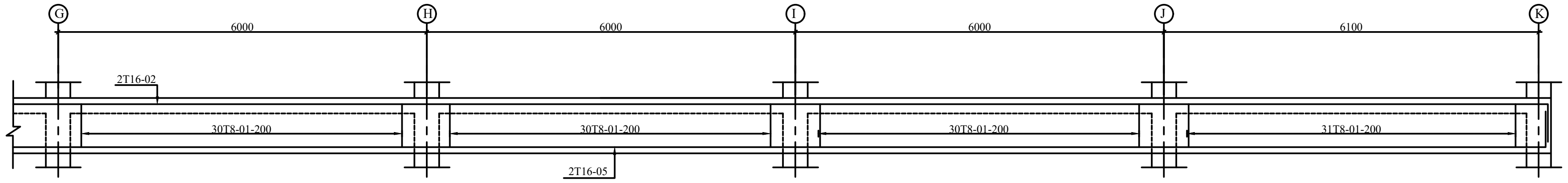
DATE :

SCALE : As shown

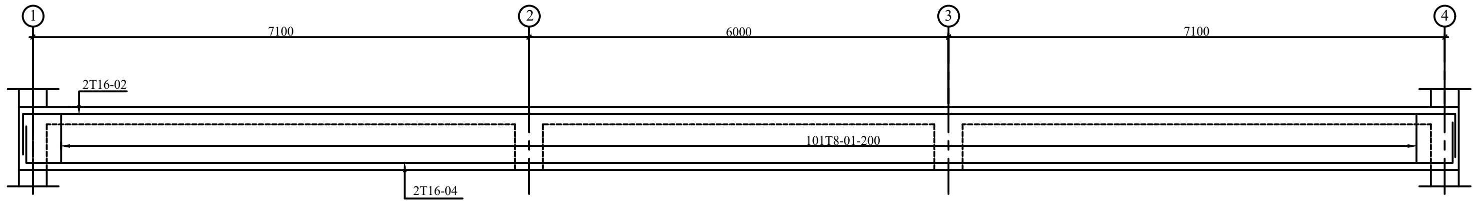
Drg. No. 01



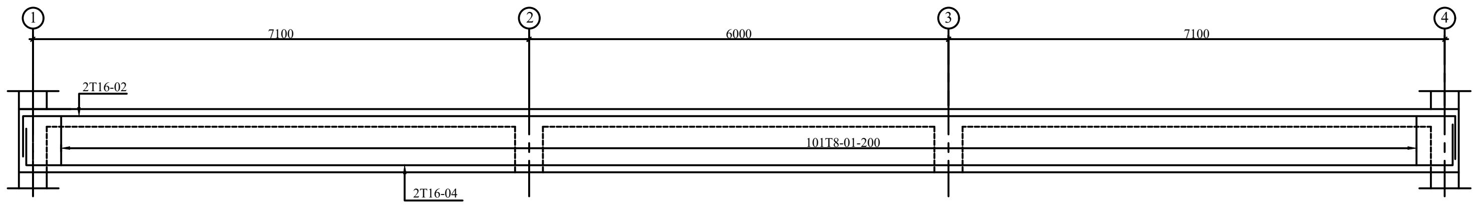
450x200 BEAM 1
SCALE 1:50



450x200 BEAM 1 (Cont)
SCALE 1:50



450x200 BEAM 3
SCALE 1:50



450x200 BEAM 4&5
SCALE 1:50

MARK	DATE	MADE BY	REVISIONS	ISSUES

GENERAL NOTES

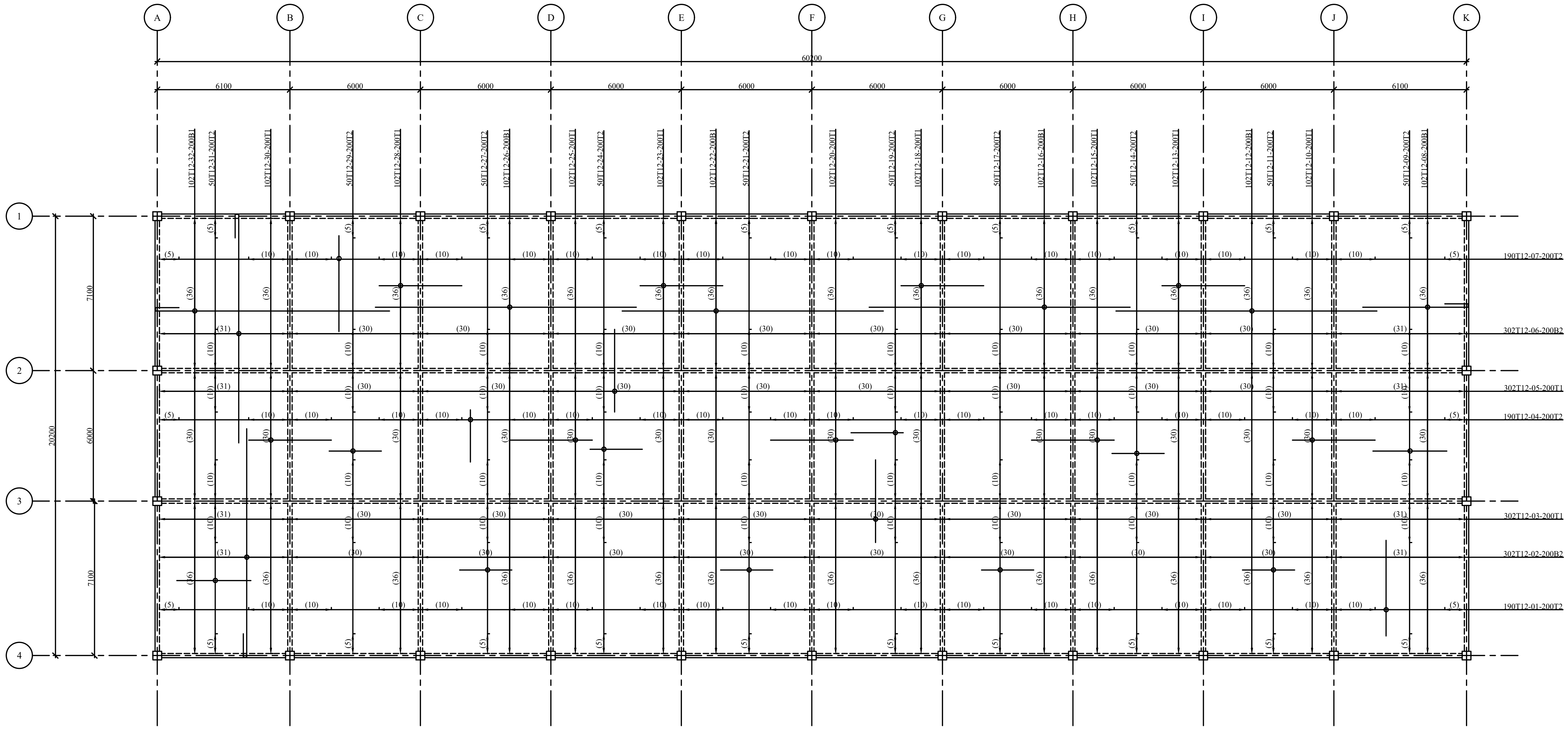
1. Only figured dimensions to be taken from this drawing.
2. This drawing is to be read in conjunction with other structural/architectural drawings.
3. All dimensions, unless otherwise specified, are in millimeters.
4. Concrete cover for reinforcement to be as follows:-
   Slabs - 20mm
   Beams - 25mm
   Columns - 30mm
   Bases - 50mm
5. All black cotton soil to be removed before construction at foundation base locations.
6. Concrete strength to be 25/20 for all structural elements.
7. Concrete strength for blinding to be class 15/40.
8. High yield steel reinforcement bars to BS4449 are denoted by 'T'.
9. Mild steel reinforcement bars to BS4449 are denoted by 'R'.
10. All steel reinforcement to be approved by the Structural Engineer.
11. Surface bed hardcore to be laid in separately compacted 150mm layers on firm approved ground.
12. Design ground bearing pressure = $250kN/m^2$
13. All foundation levels must be approved by the structural engineer.
14. All masonry walls to be not less than 200mm thick.
15. All masonry walls to be reinforced with hoop iron at every alternate courses
16. All masonry units must have a minimum strength of $7N/mm^2$

CLIENT:

TITLE:

DATE : December, 2020
SCALE : As shown

Drg. No. 01



GROUND FLOOR SLAB R.C. DETAILS

SCALE 1:100

MARK	DATE	MADE BY	REVISIONS	ISSUES

GENERAL NOTES

1. Only figured dimensions to be taken from this drawing.
2. This drawing is to be read in conjunction with other structural/architectural drawings.
3. All dimensions, unless otherwise specified, are in millimeters.
4. Concrete cover for reinforcement to be as follows:-
   Slabs - 20mm
   Beams - 25mm
   Columns - 30mm
   Bases - 50mm
5. All black cotton soil to be removed before construction at foundation base locations.
6. Concrete strength to be 25/20 for all structural elements.
7. Concrete strength for blinding to be class 15/40.
8. High yield steel reinforcement bars to BS4449 are denoted by 'T'.
9. Mild steel reinforcement bars to BS4449 are denoted by 'R'.
10. All steel reinforcement to be approved by the Structural Engineer.
11. Surface bed hardcore to be laid in separately compacted 150mm layers on firm approved ground.
12. Design ground bearing pressure = 250kN/m²
13. All foundation levels must be approved by the structural engineer.
14. All masonry walls to be not less than 200mm thick.
15. All masonry walls to be reinforced with hoop iron at every alternate courses
16. All masonry units must have a minimum strength of 7N/mm²

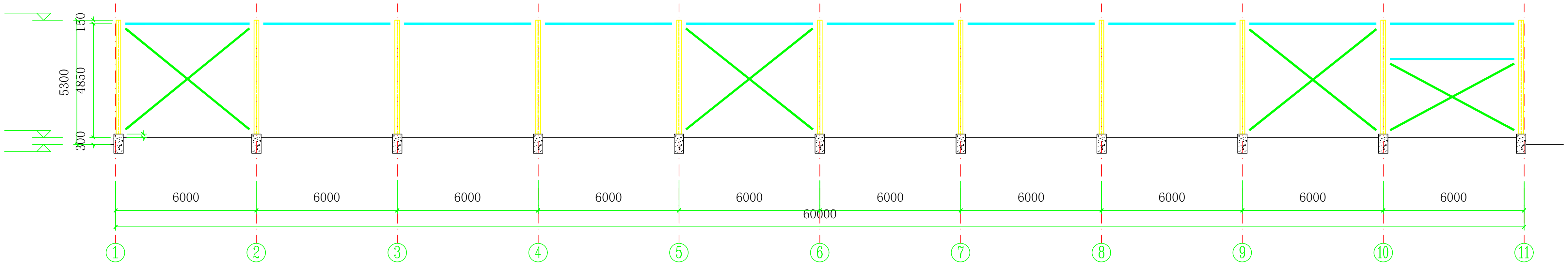
CLIENT:

TITLE:

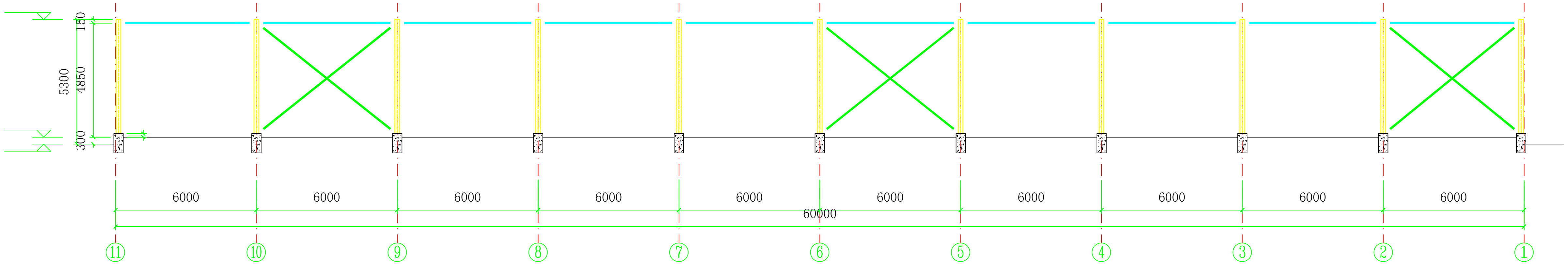
DATE :

SCALE : As shown

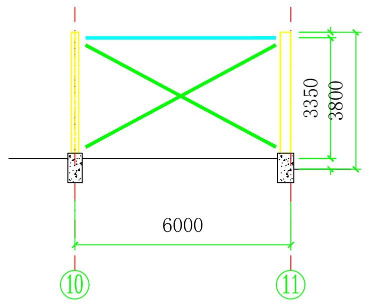
Drg. No. 01



A Axis Structure Layout



D Axis Structure Layout



B Axis Structure Layout

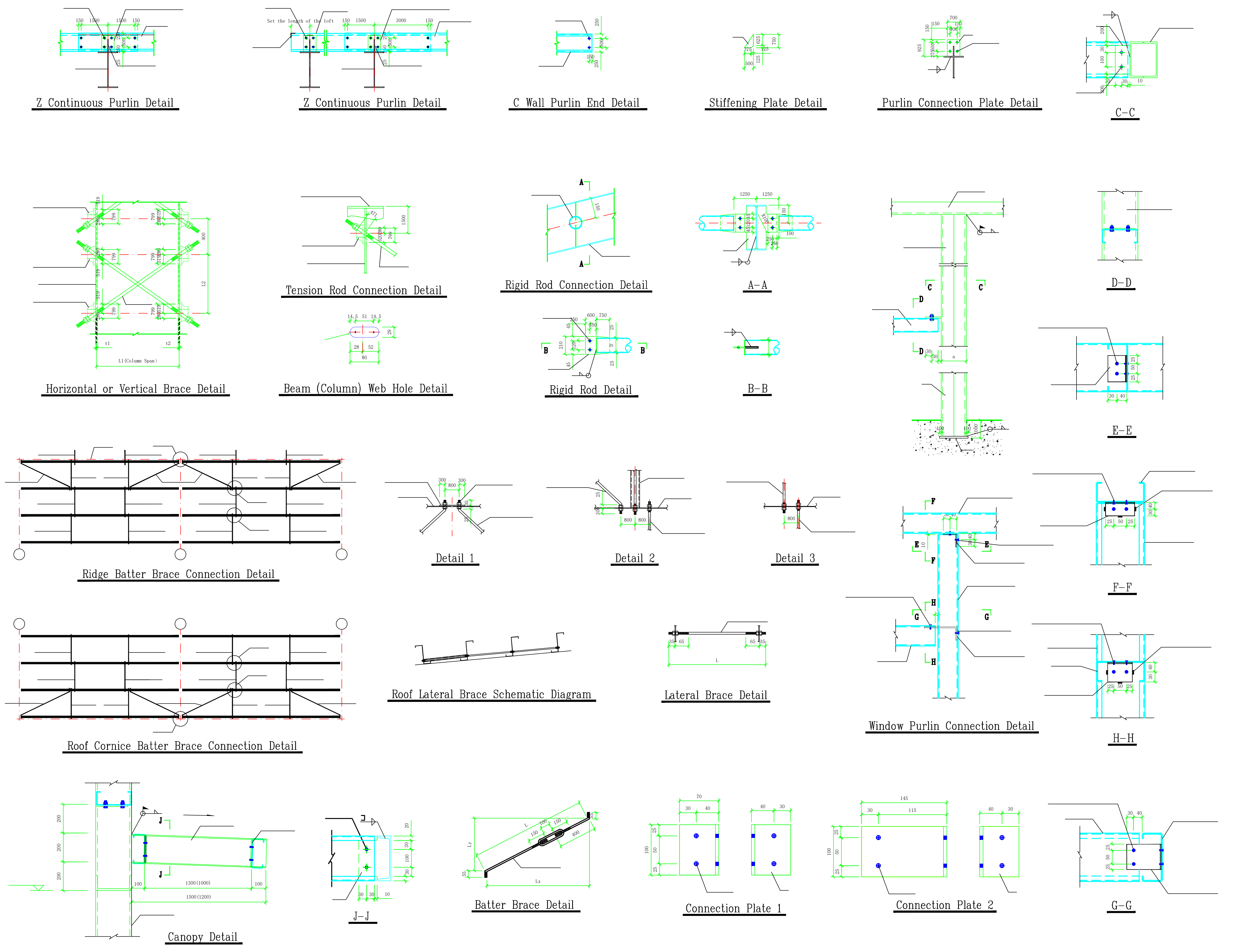
NOTES:

KIBOS WAREHOUSE

ADB AXIS STRUCTURE LAYOUT

THESIS RESEARCH PROJECT

DYNA GAKII KAARIA | F56/87946/2016



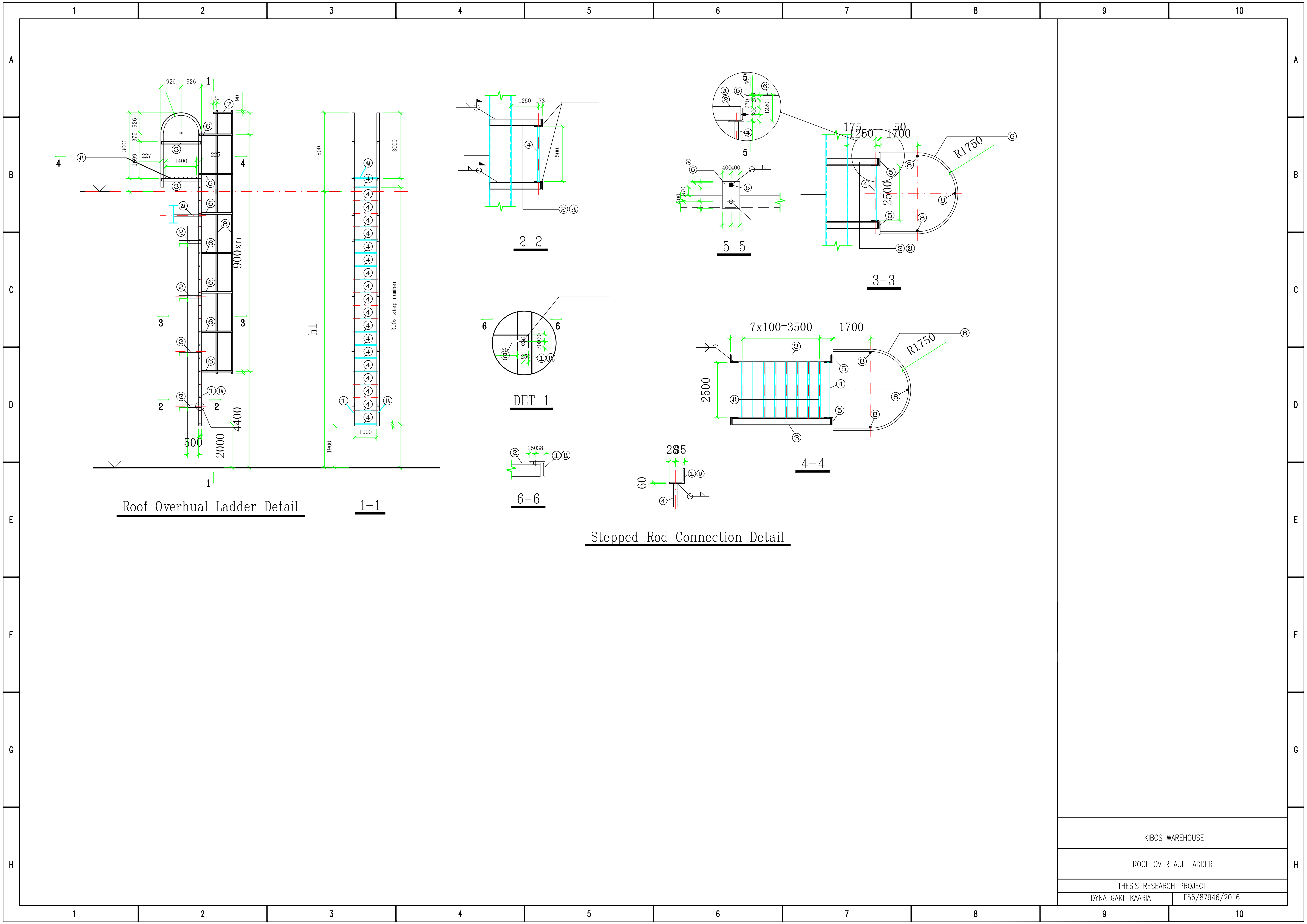
NOTES:

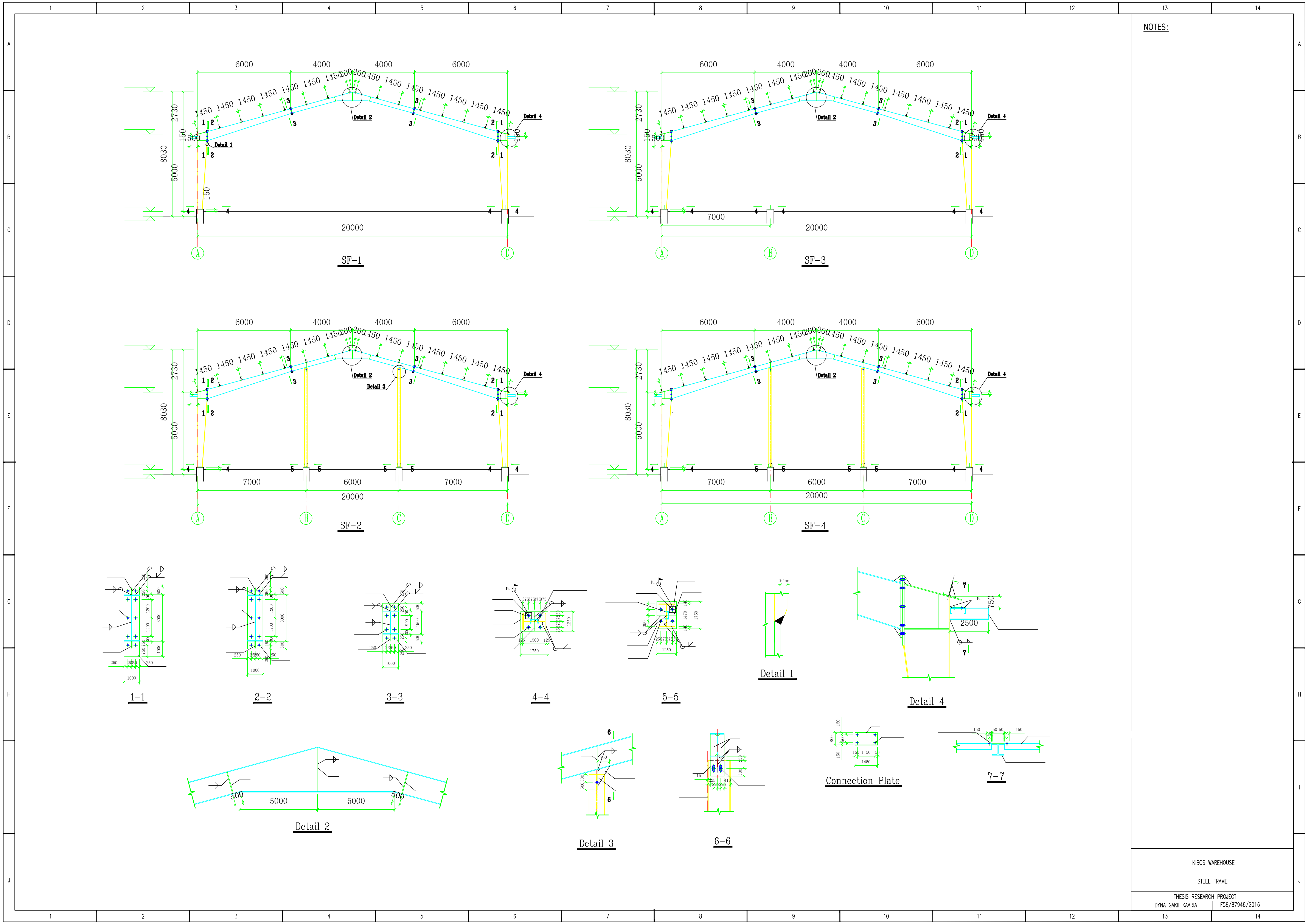
KIBOS WAREHOUSE

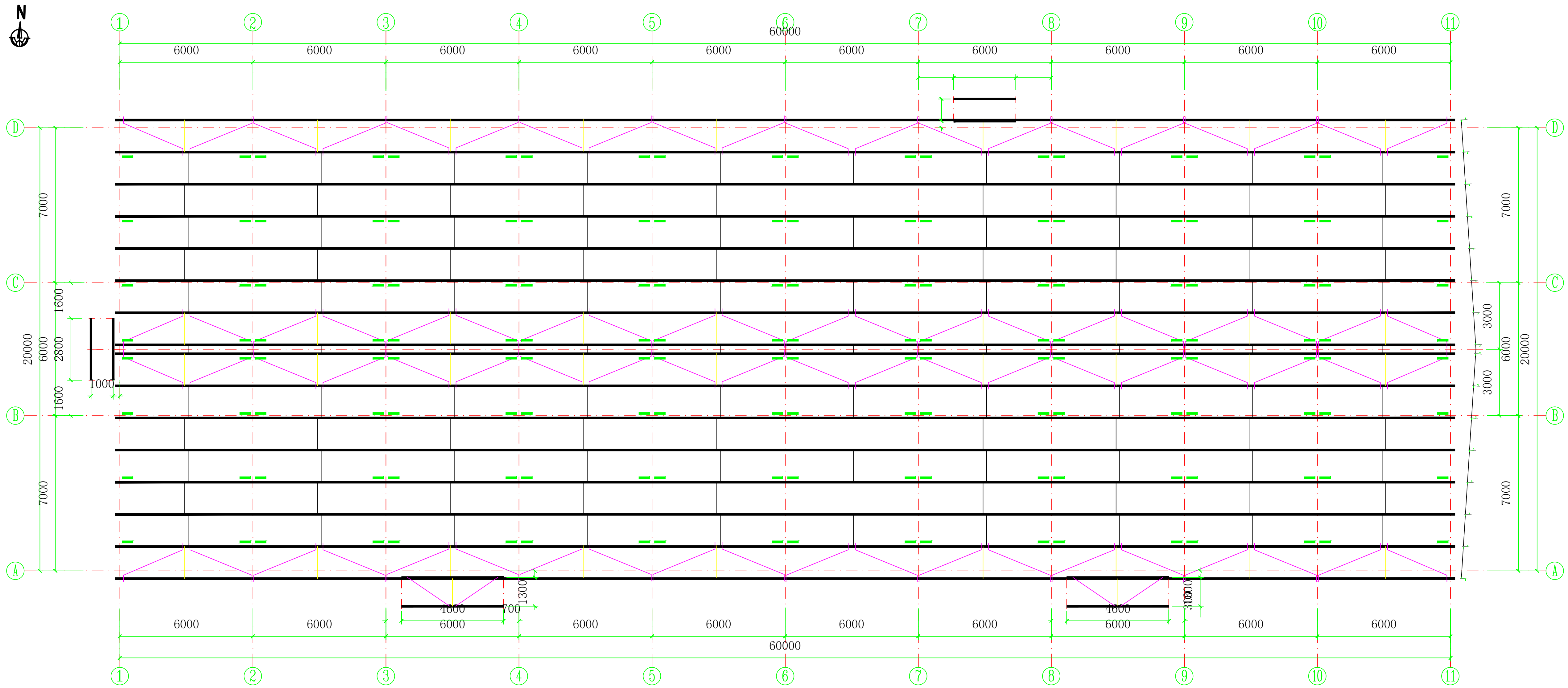
JOINT DETAILS

THESIS RESEARCH PROJECT

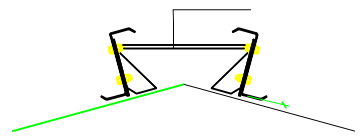
DYNA GAKII KAARIA | F56/87946/2016


Roof Overhual Ladder Detail
1-1
2-2
5-5
3-3
DET-1
4-4
6-6
Stepped Rod Connection Detail
KIBOS WAREHOUSE
ROOF OVERHAUL LADDER
THESIS RESEARCH PROJECT
DYNA GAKII KAARIA
F56/87946/2016

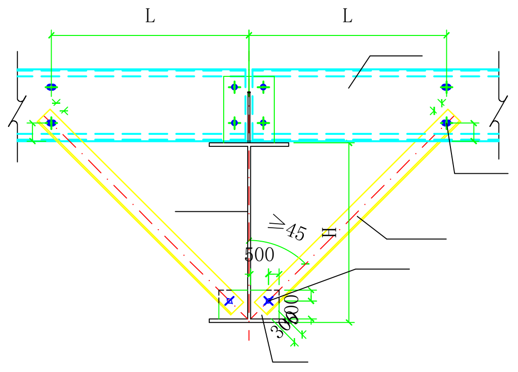

NOTES:
SF-1
SF-2
SF-3
SF-4
6000
4000
1450
200
2730
5000
8030
7000
20000
Detail 1
Detail 2
Detail 3
Detail 4
1-1
2-2
3-3
4-4
5-5
6-6
7-7
Connection Plate
KIBOS WAREHOUSE
STEEL FRAME
THESIS RESEARCH PROJECT
DYNA GAKII KAARIA
F56/87946/2016



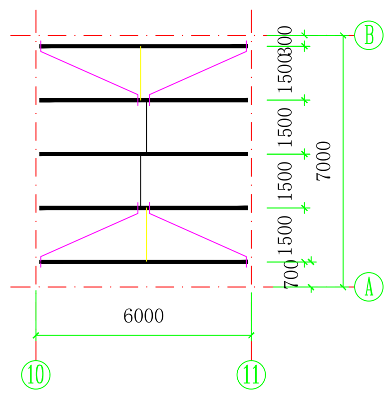
Store House Roof Purlin Layout Plan



Roof Purlin Connection Detail on Ridge



Angle Brace Connection Detail



Office Roof Purline Layout Plan

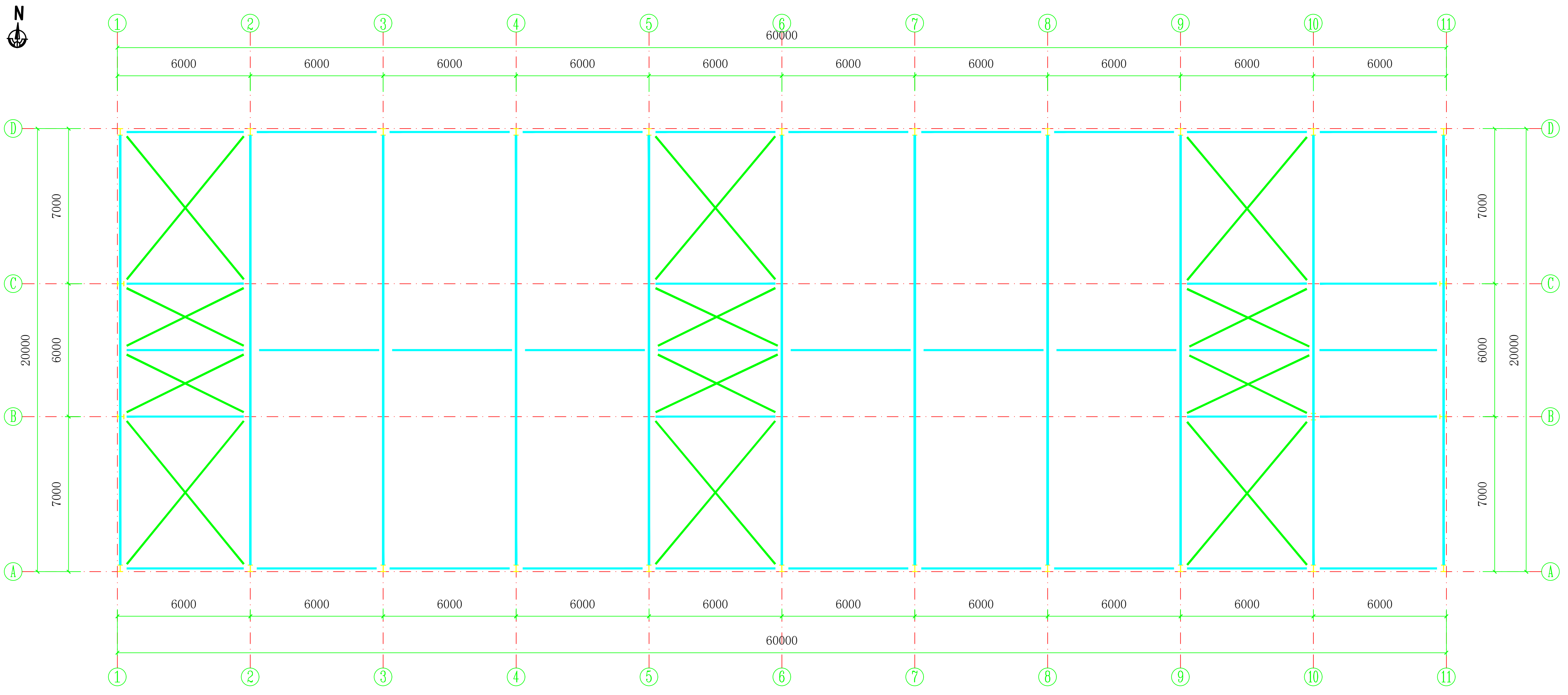
NOTES:

KIBOS WAREHOUSE

STORE HOUSE ROOF PURLIN LAYOUT

THESIS RESEARCH PROJECT

DYNA GAKII KAARIA	F56/87946/2016



Store House Roof Structure Layout Plan

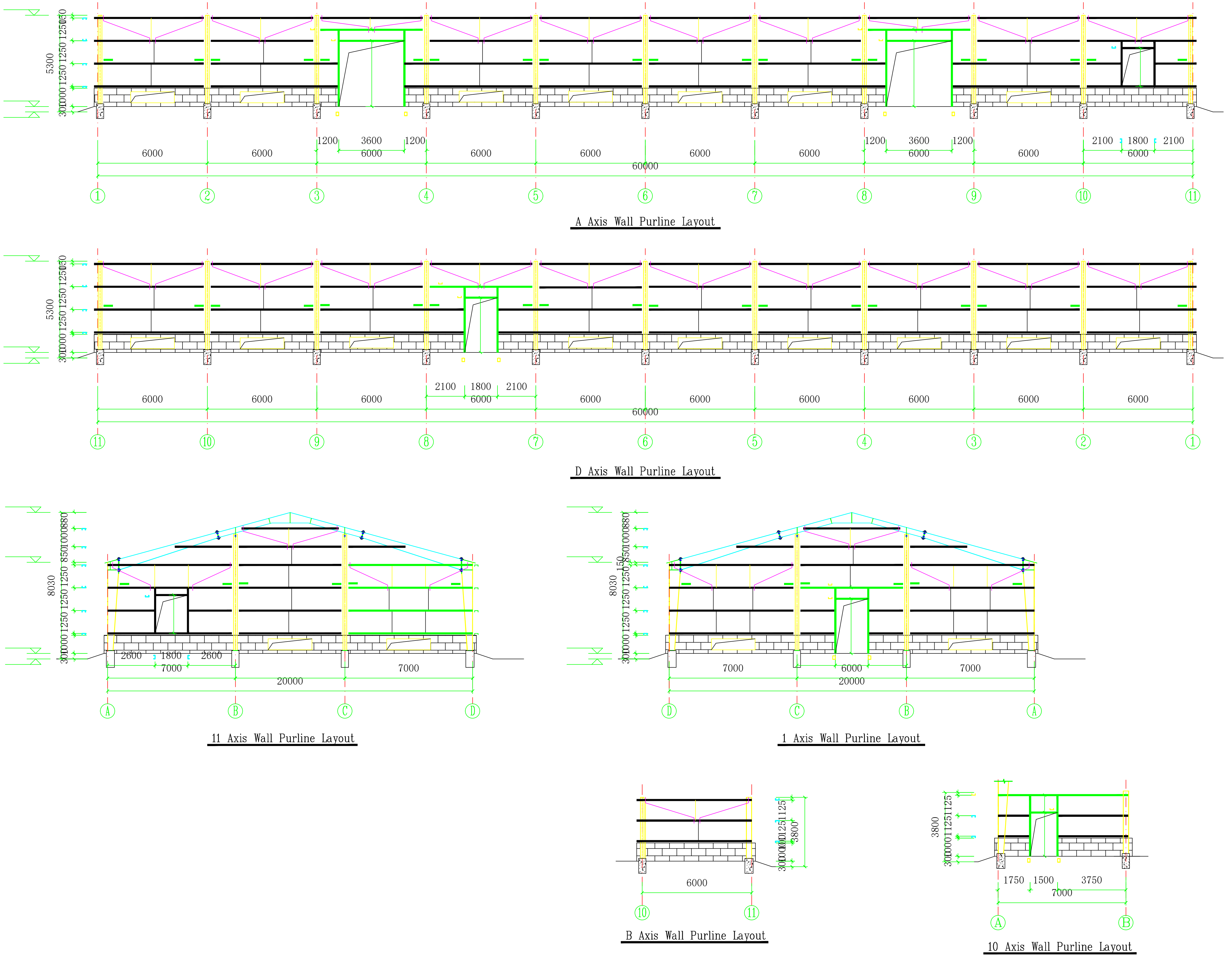
NOTES:

KIBOS WAREHOUSE

STORE HOUSE ROOF STRUCTURE LAYOUT PLAN

THESIS RESEARCH PROJECT

DYNA GAKII KAARIA	F56/87946/2016



NOTES:

KIBOS WAREHOUSE

STORE HOUSE WALL PURLIN LAYOUT

THESIS RESEARCH PROJECT

DYNA GAKII KAARIA | F56/87946/2016

Appendix C: Bills of Quantities

BILLS OF QUANTITIES (CONCRETE STRUCTURE)					
Item	**Description**	**Unit**	**Qty**	**Rate**	**Amount (Kshs.)**
	ELEMENT NO. 1				
	SUBSTRUCTURES (ALL PROVISIONAL)				
	Excavations and Earthworks				
	Excavations to include; trimming sides and bottoms of excavations to approval;				
A	Excavate pits for column bases not exceeding 1.5meters deep starting from ground level	Cm	20	300	6,000.00
					-
B	Excavate trenches for strip footing not exceeding 1.5meters deep starting from ground levels	Cm	81	300	- 24,300.00
					-
C	Extraover all excavations for excavating in soft rock including for 'tuff' (provisional)	Cm	1	900	900.00
					-
D	Extraover all excavations for excavating in hard rock of all types	Cm	1	1500	1,500.00
	Disposal				
E	Backfill with selected excavated material around foundations; grade and compact to falls, crossfalls and slopes, top of back fill (m.s); standard compaction to 95% M.D.D AASHTO T180; in layers not exceeding 150mm thick; including double or multi handling of excavated materials if required	Cm	3	400	1,200.00
					-
F	Load, remove and deposit surplus excavated material away from site; including double and multi - handling where required	Cm	100	400	- 40,000.00
					-
	Filling				
	Hardcore or other approved filling, as described				
G	300mm hardcore fill or equal and approved; levelled and graded to falls, crossfalls and slopes; blind with 50mm quarry dust layer; heavy compaction by rolling to 98% MDD AASHTO	Sm	1126	360	405,360.00
					-
H	Imported selected and approved hardcore or other equal and approved material to make up levels: scarify, spread, grade and compact to falls, cross falls and slopes: in layers not exceeding 225mm: standard compaction to 98% S.P.M.D.D	Cm	1	1000	- - 1,000.00
	Sundries				
I	Allow for planking , strutting and shoring to sides of all excavations; and keeping all excavations free from all fallen materials (provisional)	Item	1		50,000.00
J	Allow for keeping excavations free from mud and all waters including for spring or running water (provisional)	Item	1		50,000.00
	Sub - Total Carried to Collection				**580,260.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	Surface treatment				
	Anti - termite treatment				
A	Approved chemical anti-termite treatment as Premise 200 SC supplied by Bayer Environmental Science executed by an approved specialist under a ten-year guarantee,to surfaces of hardcore and tops of foundation walls; applied strictly in accordance with the manufacturer's instructions	Sm	1126	80	90,080.00
	Thermal and Moisture Protection				
	Damp-proof membrane				
B	1000 gauge polythene or other equal and approved damp-proof membrane, laid over blinded hardcore (m.s) with 400mm side and end laps; fully taped edges (measured nett, allow for laps)	Sm	1126	150	168,900.00
	Damp-proof courses, as described, to walls; 3-ply bituminous felt bedded in cement sand (1:4) mortar with 300mm end laps;				
C	250mm wide	Lm	112	150	16,800.00
	Liquid waterproof Admixture: as 'Sika - 1' or equal and approved: application strictly in accordance with the manufacturer's printed instructions executed by a specialist under a ten-year guarantee; rate to allow for preparing all concrete surfaces				
D	Vertical sides of walls internally (m.s)	Sm	160	1400	224,000.00
E	Floors internally (m.s)	Sm	160	1400	224,000.00
	Concretework				
	Insitu Concrete; Cement grade 42.5				
	Plain; class 15; in				
F	Blinding; 50mm thick under bases	Sm	38	500	19,000.00
G	Blinding; 50mm thick under strip footings	Sm	269	500	134,500.00
	V.R.C; class 25; in				
H	Column bases	Cm	13	14000	182,000.00
I	Substructure Columns	Cm	5	14000	70,000.00
J	Strip footing	Cm	67	14000	938,000.00
K	150mm thick ground loor slab	Sm	1200	2100	2,520,000.00
	Sub - Total Carried to Collection				**4,587,280.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	Substructure Walling				
	Natural hard machine cut stone; selected and approved; in walling with a crushing strength of 7.5 N/mm²; walling bedded and jointed in cement and sand (1:3) mortar in 200mm course height; reinforcement with and including 25mm wide x 20 gauge hoop iron and column wall ties at every alternate course as described; including cutting as required; in;				
A	200mm thick founadtion walling	Sm	145	1650	239,250.00
					-
	Shuttering				-
					-
	Sawn formwork; to				-
					-
B	Vertical edges of surface slab over 150mm but not exceeding 225mm girth	Lm	162	600	97,200.00
					-
	Plinth Finishes				-
					-
	15 mm cement and sand (1:3) render,finished with woodfloat to;				-
					-
C	Concrete/masonry surfaces to receive stone cladding (m.s.)	Sm	96	500	48,000.00
	Sub - Total Carried to Collection				**384,450.00**
	COLLECTION				
	From Page 1				580,260.00
	From Page 2				4,587,280.00
	From Above				384,450.00
	Total for Substructures Carried to Grand Summary				**5,551,990.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 2				
	RC SUPERSTRUCTURES				
	Lintels				
	In insitu concrete class 25/20, including formwork;				
A	200 x 200mm lintol, reinforced with and including four 12mm diameter mild steel T - rods and 8mm diameter stirrups at 200mm centres	Lm	63	1,200	75,600.00
					-
	In insitu concrete class 25/20 in:				
B	Superstructure Columns	Cm	20	14,000	280,000.00
C	Beams	Cm	42	14,000	588,000.00
	Total for RC Superstructures Carried to Grand Summary				**943,600.00**

	ELEMENT NO. 2				
	WALLING				
	External Walling				
	Natural hard machine cut stone; selected and approved; in walling with a crushing strength of 7.5 N/mm²; walling bedded and jointed in cement and sand (1:3) mortar in 200mm, course height; reinforcement with and including 25mm wide x 20 gauge hoop iron and column wall ties at every alternate course as described; including cutting as required; in;				
A	200mm thick walling	Sm	776	1650	1,280,400.00 -
	Steel ladder				
B	5000 mm long x 400 mm wide overall size ladder; comprising of 2No x 3500 mm long 40 mm diameter x 4 mm thick vertical tubing fixed to slabs at top and bottom at 45degrees from horizontal with 20 x 20 x 4 mm base plates grouted in concrete; 14 No 20 mm diameter x 360 mm long G.S step tubes welded or bolted to vertical members as before described; factory primed and painted in waterproof gloss paint	No	1	50000	50,000.00
	Total for Walling Carried to Main Summary				**1,330,400.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 4				
	ROOF STRUCTURE				
A	Roof truss 3-6m span comprising 100 x 50 x 4mm rectangular hollow section top and bottom chord, 50 x 50 x 4m square hollow section internal members including all plates, cleats, holes and welding and hoisting approximately 10.35m high above ground level	Kgs	546	280	152,880.00
	Roof covering				
B	Gauge 28 boxed profile roofing sheets as IT 5 prepainted galvanized sheets manufactured by Mabati Rolling Mills (MRM) Ltd or other equal and approved manufacturer: fixed to steel purlins with and including capped weather J-bolts	Sm	330	1800	594,000.00
	Polycarbonate				
C	5mm Polycarbonate sheets roof cladding fixed to steel frames complete with connectors screwed to details and approval	Sm	29	8500	246,500.00
	Cyclones				
D	Supply and fix cyclones at manufacturers specifications	No	16	30000	480,000.00
	Rain water disposal				-
					-
	Heay gauge UPVC pies and fittings : solvent welded connections : allow for outlets : with metal brackets at 750 mm centres				-
					-
					-
E	150mm gutter	Lm	120	1800	216,000.00
F	150mm diameter downpipes	Lm	20	1500	30,000.00
					-
G	Extra over for swan neck	No	4	500	2,000.00
					-
H	Extra over for shoe	No	4	500	2,000.00
					-
I	150mm diameter wrot iron fulbora outlet; cast in concrete	No	400	4500	1,800,000.00
	Total for Roof Structure Carried to Grand Summary				**2,050,000.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 5				
	FINISHES				
	External Wall finishes				-
	Mortar; Cement and sand (1:4) backings;				
A	12mm backing finished to receive wall tiles (m.s)	Sm	160	500	80,000.00
	Internal Wall finishes				
	15 mm cement and sand (1:3) render,finished with woodfloat to;				-
					-
B	Concrete/masonry surfaces and reveals to receive wall finish (m.s.)	Sm	776	500	388,000.00
					-
	Prepare and apply one undercoat; one skimming coat; two finishing coats first quality matt emulsion paint from an approved supplier (approval by the project Architect); application strictly to supplier's written instructions; to:-				- - - -
C	Plastered walls	Sm	776	400	310,400.00
					- -
	Internal Floor Finishes				- -
	Cement and sand (1:4) screeds, backings, beds etc				- -
D	32mm bed finished to receive floor tiles (m.s)	Sm	1200	500	600,000.00
					-
	Ceramic floor tiles				- -
	Provide a prime cost rate of [Kshs 1,000.00/sm] for supply of Ceramic floor tiles (tenderer to add the cost of collection, cutting, grouting, adhesive, spaces and all other materials and laying to completion) as selected by the Architect: take and fix only ceramic tiles to floors on prepared bed (m.s) with proprietary adhesive; jointed and pointed in coloured proprietary grouting: including spacers as required, edge trims and expansion joint as necessary: all to Architect's approval: to;				- - - - - - -
E	Floor generally	Sm	1200	2000	2,400,000.00
					-
F	100mm skirting to ditto	Lm	160	200	32,000.00
					-
	Sub - Total Carried to Collection				**3,810,400.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	Internal Ceiling Finishes				
	Plaster; 9mm thick first coat of cement and sand (1:3); 3mm second coat of cement and lime putty (1:10); steel trowelled smooth				-
A	12mm thick to concrete soffits and sides of beams	Sm	3	500	1,500.00
					-
	Prepare and apply one undercoat; one skimming coat; two finishing coats first quality matt emulsion paint from an approved supplier (approval by the project Architect); application strictly to supplier's written instructions; to:-				- - - -
B	Plastered concrete soffits and sides of beams (m.s)	Sm	3	400	1,200.00
					-
	12mm thick gypsum plasterboard suspended ceiling on and including approved heavy duty steel studwork support at approved centres to the entire satisfaction of the				
C	To the office	Sm	42	2800	117,600.00
	Sub - Total Carried to Collection				**120,300.00**
	COLLECTION				
	From Page 6				3,810,400.00
	From Above				120,300.00
	Total for Finishes Carried to Main Summary				**3,930,700.00**
	ELEMENT NO. 6				
	WINDOWS				
A	Supply, assemble and fix RAL 7022 powder coated aluminium louvres size 38 x 72 x 2mm at 65mm centers fixed at 45 degrees to the approval of the architect.	Sm	29	10000	290,000.00
					-
	Powder coated aluminium section windows including accessories to Architects approval : 50 x 50 mm frames : aluminium glazing beads, powder coated alumnium window cills and wash leather, neoprene gaskets strip: complete with and including 6 mm clear laminated glass as specified by architect including butt jointed glazing with silicone sealant where shown and as directed by the Architect: installed by an approved domestic sub-contractor: to Architects window schedule: all opening windows to have "Bonn Series" or equal and approved friction stay hinges with restrictor stay, satin anodised				
B	Window overall size 1800 x 2100mm high	No	2	41580	83,160.00
	Finishing to reveals				- -
	15 mm cement and sand (1:3) render,finished with woodfloat to;				- -
C	Concrete/masonry surfaces to receive external wall finish (m.s.)	Sm	27	500	13,500.00
					-
	Total for Windows Carried to Main Summary				**386,660.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 7				
	DOORS				
	Purposed made mild steel doors and screens; welded smooth; pin type hinges; one coat red oxide painted				-
	Mild steel double leaf door overall size 1800 x 3000 mm high; comprising 50 x 50 x 3 mm thick RHS external frame fishtail grouted into concrete/block/masonry walling; 50 x 50 x 3mm RHS horizontal intermediate frames welded onto and including 50 x 50 x 3mm RHS surround frame at 600mm centres both ways; 25 x 3 mm thick flat door stopper with and including for 25 mm x 25 mm x 2 mm SHS beading; door leaf infilled with 2mm thick pressed metal panels profiled to form 300mm panels welded; all welding, grounding to a smooth finish including for priming door with one coat red oxide primer; pointed internally and externally with approved mastic sealant	No	3	54000	162,000.00
	Manually operated steel slatted roller shutter door : 100 x 100 x 6 mm angle frame fixed to block walls or concrete frame; complete with rolling gear and housing ; pull handles, 2 No. padlock hasps ; aluminium painted finish				-
A	Shutter overall size 3600 x 3600mm high	No	2	142560	285,120.00
	Supply and fix the following ironmongery; as UNION				-
B	BP-DW-402525 brass ball bearing hinges; 100 mm	Prs	38.0	400	15,200.00
C	7724 SIL door closer; non hold open	No	4	15000	60,000.00
D	DS-2058 PL floor mounted door stops	No	6	200	1,200.00
E	100-05-77 B 3-Lever mortice lock with scroll design brass handles	No	6	3500	21,000.00
	Total for Doors Carried to Main Summary				**544,520.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 9				
	BWIC WITH PLUMBING, DRAINAGE AND MECHANICAL INSTALLATIONS				
	Inspect all drawings and Mechanical Bills of Quantities as provided or at the Engineer's office: allow for all builders work associated with the following				
A	Cut away for sanitary fittings and pipework : form all holes, chases, etc and make good after the plumber	Item	1		500,000.00
	Total for BWIC With Mechanical Installations Carried to Main Summary				**500,000.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 10				
	BWIC WITH ELECTRICAL INSTALLATIONS				
	Inspect all drawings and Electrical Bills of Quantities as provided or at the Engineer's office: allow for all builders work associated with the following				
A	Cut away for electrical points, fittings and equipment : form all holes, chases, etc and make good after the electrician	Item	1		500,000.00
	Total for BWIC With Electrical Installations Carried to Main Summary				**500,000.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	MAIN SUMMARY				
				Page	
1	Substructures				5,551,990.00
2	RC Superstructures				943,600.00
3	Walling				1,330,400.00
4	Roof Construction and Finishes				2,050,000.00
5	Finishes				3,930,700.00
6	Windows				386,660.00
7	Doors				544,520.00
8	Builders work in connection with mechanical installations				500,000.00
9	Builders work in connection with electrical installations				500,000.00
	Total for Main Building Carried to Grand Summary			**Kshs.**	**15,737,870.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	SECTION NO. 5 - PRIME COST SUMS				
A	Provide a prime cost sum for Electrical Installations	Item	1	1500000	1,500,000.00
B	Allow for Profit	Item		2.5%	37,500.00
C	Allow for General and Special attendance	Item			37,500.00
D	Provide a prime cost sum for Mechanical Installations	Item	1	2500000	2,500,000.00
E	Allow for Profit	Item		2.5%	62,500.00
F	Allow for General and Special attendance	Item			62,500.00
G	Provide a prime cost sum for Signage	Item	1	100000	100,000.00
H	Allow for Profit	Item		2.5%	2,500.00
I	Allow for General and Special attendance	Item			2,500.00
	Total for PC Sums Carried to Grand Summary			Kshs.	4,305,000.00

	GRAND SUMMARY		
		Page	Amount
1	PRELIMINARIES		1,500,000.00
2	MAIN BUILDING		15,737,870.00
4	PRIME COST AND PROVISIONAL SUMS		4,305,000.00
	TOTAL COSTRUCTION COST (VAT INCLUSIVE)	KSHS.	21,542,870.00

BILLS OF QUANTITIES (STEEL STRUCTURES)

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 1				
	SUBSTRUCTURES (ALL PROVISIONAL)				
	Excavations and Earthworks				
	Excavations to include; trimming sides and bottoms of excavations to approval;				
A	Excavate pits for bases in hardcore fill not exceeding 1.5meters deep starting from ground lev	Cm	1200	300	360,000.00
					-
B	Excavate trenches for strip footing in hardcore fill not exceeding 1.5meters deep starting from ground levels	Cm	29	300	- 8,700.00
					-
C	Extraover all excavations for excavating in soft rock including for 'tuff' (provisional)	Cm	1	900	900.00
					-
D	Extraover all excavations for excavating in hard rock of all types	Cm	1	1500	1,500.00
					-
					-
	Disposal				-
					-
E	Backfill with selected excavated material around foundations; grade and compact to falls, crossfalls and slopes, top of back fill (m.s); standard compaction to 95% M.D.D AASHTO T180; in layers not exceeding 150mm thick; including double or multi handling of excavated materials if required	Cm	1080	400	- - - 432,000.00
					-
F	Load, remove and deposit surplus excavated material away from site; including double and multi - handling where required	Cm	1	400	- 400.00
					-
					-
	Filling				-
					-
	Hardcore or other approved filling, as described				-
					-
G	300mm hardcore fill or equal and approved; levelled and graded to falls, crossfalls and slopes; blind with 50mm quarry dust layer; heavy compaction by rolling to 98% MDD AASHTO	Sm	1168	360	- 420,480.00
					-
H	Imported selected and approved hardcore or other equal and approved material to make up levels: scarify, spread, grade and compact to falls, cross falls and slopes: in layers not exceeding 225mm: standard compaction to 98% S.P.M.D.D	Cm	1	1000	- - 1,000.00
	Sundries				
I	Allow for planking , strutting and shoring to sides of all excavations; and keeping all excavations free from all fallen materials (provisional)	Item	1		50,000.00
J	Allow for keeping excavations free from mud and all waters including for spring or running water (provisional)	Item	1		50,000.00
	Sub - Total Carried to Collection				**1,324,980.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	Surface treatment				
	Anti - termite treatment				
A	Approved chemical anti-termite treatment as Premise 200 SC supplied by Bayer Environmental Science executed by an approved specialist under a ten-year guarantee,to surfaces of hardcore and tops of foundation walls; applied strictly in accordance with the manufacturer's instructions	Sm	1168	80	- 93,440.00
	Thermal and Moisture Protection				
	Damp-proof membrane				
B	1000 gauge polythene or other equal and approved damp-proof membrane, laid over blinded hardcore (m.s) with 400mm side and end laps; fully taped edges (measured nett, allow for laps)	Sm	1168	150	175,200.00
					-
	Damp-proof courses, as described, to walls; 3-ply bituminous felt bedded in cement sand (1:4) mortar with 300mm end laps;				- -
					-
C	250mm wide	Lm	160	150	24,000.00
					-
	Liquid waterproof Admixture: as 'Sika - 1' or equal and approved: application strictly in accordance with the manufacturer's printed instructions executed by a specialist under a ten-year guarantee; rate to allow for preparing all concrete surfaces				- - -
					-
D	Vertical sides of walls internally (m.s)	Sm	160	1400	224,000.00
					-
E	Floors internally (m.s)	Sm	160	1400	224,000.00
					-
	Concretework				-
					-
	Insitu Concrete; Cement grade 42.5				-
					-
	Plain; class 15; in				-
					-
F	Blinding; 50mm thick under bases	Sm	485	500	242,500.00
					-
G	Blinding; 50mm thick under strip footings	Sm	91	500	45,500.00
					-
	V.R.C; class 25; in				
H	150mm thick ground loor slab	Sm	1200	2100	2,520,000.00
	Sub - Total Carried to Collection				**3,548,640.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	Substructure steel columns				
A	200 x 200 x 4mm Thick square hollow section column.	Kgs	280	280	78,400.00
B	200 x 200 x 10mm thick mild steel base plate four times drilled for 12mm diameter bolt (measured seperately)	No	14	800	11,200.00
C	12mm diameter holding down bolts 300mm long with head, nut and washer cast into and including mortice in concrete and run with gauged mortar.	No	20	400	8,000.00
D	Extra over for welded connections.	No	18	350	6,300.00
					-
	Mesh fabric reinforcement ref A142 to B.S 4483; weighing 2.22 kg per square metre and setting in concrete with 200mm side and end laps (measured nett, allow for laps); from approved supplier; in				-
E	Horizontal surface slabs	Sm	1200	400	480,000.00
	Shuttering				-
	Sawn formwork; to				-
F	Vertical edges of surface slab over 150mm but not exceeding 225mm girth	Lm	162	600	97,200.00
	Walling				-
	Natural hard machine cut stone; selected and approved; in walling with a crushing strength of 7.5 N/mm²; walling bedded and jointed in cement and sand (1:3) mortar in 200mm course height; reinforcement with and including 25mm wide x 20 gauge hoop iron and column wall ties at every alternate course as described; including cutting as required; in;				-
G	200mm thick founadtion walling	Sm	145	1650	239,250.00
	Plinth Finishes				-
	15 mm cement and sand (1:3) render,finished with woodfloat to;				-
H	Concrete/masonry surfaces to receive stone cladding (m.s.)	Sm	96	500	48,000.00
	Sub - Total Carried to Collection				**968,350.00**
	COLLECTION				
	From Page 1				1,324,980.00
	From Page 2				3,548,640.00
	From Above				968,350.00
	Total for Substructures Carried to Grand Summary				**5,841,970.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 3				
	WALLING				
	Lintels				
	In insitu concrete class 25/20, including formwork;				-
					-
A	200 x 200mm lintol, reinforced with and including four 12mm diameter mild steel T - rods				-
	and 8mm diameter stirrups at 200mm centres	Lm	63	1,200	75,600.00
		Concrete			-
	Superstructure steel columns	Steel	298.935		-
B	200 x 200 x 4mm Thick square hollow section column.	Kgs	8280	280	2,318,400.00
					-
C	75 x 75 x 4mm Thick square hollow section column bracing	Kgs	504	280	141,120.00
					-
D	200 x 200 x 10mm thick mild steel base plate four times drilled for 12mm diameter bolt (measured seperately)	No	84	800	67,200.00
					-
E	12mm diameter holding down bolts 300mm long with head, nut and washer cast into and including mortice in concrete and run with gauged mortar.	No	120	400	48,000.00
					-
F	Extra over for welded connections.	No	104	350	36,400.00
	Steel beams				
G	200 x 200 x 4mm Thick square hollow section beam.	Kgs	7360	280	2,060,800.00
H	12mm diameter holding down bolts 300mm long with head, nut and washer cast into and including mortice in concrete and run with gauged mortar	No	109	400	43,600.00
J	Extra over for welded connections.	No	93	350	32,550.00
	External Walling				-
					-
	Natural hard machine cut stone; selected and approved; in walling with a crushing strength of 7.5 N/mm²; walling bedded and jointed in cement and sand (1:3) mortar in 200mm, course height; reinforcement with and including 25mm wide x 20 gauge hoop iron and column wall ties at every alternate course as described; including cutting as required; in;				- - - -
K	200mm thick walling	Sm	160	1650	264,000.00
					-
	Boxed Profile Sheets				-
					-
	Gauge 28 boxed profile sheets as IT 5 prepainted galvanized sheets manufactured by Mabati Rolling Mills (MRM) Ltd or other equal and approved manufacturer: fixed to steel purlins with and including capped weather J-bolts				-
					-
L	To walls	Sm	962	1800	1,731,600.00
					-
	Steel ladder				
M	5000 mm long x 400 mm wide overall size ladder; comprising of 2No x 3500 mm long 40 mm diameter x 4 mm thick vertical tubing fixed to slabs at top and bottom at 45degrees from horizontal with 20 x 20 x 4 mm base plates grouted in concrete; 14 No 20 mm diameter x 360 mm long G.S step tubes welded or bolted to vertical members as before described; factory primed and painted in waterproof gloss paint	No	1	50000	50,000.00
	Polyvarbonate Panel				
N	5mm Polycarbonate sheets wall cladding fixed to steel frames complete with connectors screwed to details and approval	Sm	48	8500	408,000.00
	Louvres				
O	Supply, assemble and fix RAL 7022 powder coated aluminium louvres size 38 x 72 x 2mm at 65mm centers fixed at 45 degrees to the approval of the architect.	Sm	29	10000	290,000.00
	Total for Walling Carried to Main Summary				**7,567,270.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 4				
	ROOF STRUCTURE				
A	Roof truss 3-6m span comprising 100 x 50 x 4mm rectangular hollow section top and bottom chord, 50 x 50 x 4m square hollow section internal members including all plates, cleats, holes and welding and hoisting approximately 10.35m high above ground level (T1) (In 2 No.	Kgs	546	280	152,880.00
	Roof covering				
B	Gauge 28 boxed profile roofing sheets as IT 5 prepainted galvanized sheets manufactured by Mabati Rolling Mills (MRM) Ltd or other equal and approved manufacturer: fixed to steel purlins with and including capped weather J-bolts	Sm	330	1800	594,000.00
	Polycarbonate				
C	5mm Polycarbonate sheets roof cladding fixed to steel frames complete with connectors screwed to details and approval	Sm	29	8500	246,500.00
	Cyclones				
D	Supply and fix cyclones at manufacturers specifications	No	16	30000	480,000.00
	Rain water disposal				-
					-
	Heay gauge UPVC pies and fittings : solvent welded connections : allow for outlets : with metal brackets at 750 mm centres				-
					-
					-
E	150mm gutter	Lm	120	1800	216,000.00
F	150mm diameter downpipes	Lm	20	1500	30,000.00
					-
G	Extra over for swan neck	No	4	500	2,000.00
					-
H	Extra over for shoe	No	4	500	2,000.00
					-
I	150mm diameter wrot iron fulbora outlet; cast in concrete	No	400	4500	1,800,000.00
	Total for Roof Structure Carried to Grand Summary				**2,050,000.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 5				
	FINISHES				
	External Wall finishes				-
	Mortar; Cement and sand (1:4) backings;				
A	12mm backing finished to receive wall tiles (m.s)	Sm	160	500	80,000.00
	Provide a prime cost rate of [Kshs 1,000.00/sm] for supply of Ceramic wall tiles (tenderer to add the cost of collection, cutting, grouting, adhesive, spaces and all other materials and laying to completion) as selected by the Architect: take and fix only ceramic tiles to walls on prepared bed (m.s) with proprietary adhesive; jointed and pointed in coloured proprietary grouting: including spacers as required, edge trims and expansion joint as necessary: all to Architect's approval: to;				
B	To brick walls externally	Sm	160	2000	320,000.00
	Internal Wall finishes				
	15 mm cement and sand (1:3) render,finished with woodfloat to;				-
					-
C	Concrete/masonry surfaces and reveals to receive wall finish (m.s.)	Sm	160	500	80,000.00
					-
	Prepare and apply one undercoat; one skimming coat; two finishing coats first quality matt emulsion paint from an approved supplier (approval by the project Architect); application strictly to supplier's written instructions; to:-				-
					-
					-
					-
D	Plastered walls	Sm	160	400	64,000.00
					-
E	Ditto to louvres	Sm	29	400	11,600.00
					-
	Internal Floor Finishes				-
					-
	Cement and sand (1:4) screeds, backings, beds etc				-
					-
F	32mm bed finished to receive floor tiles (m.s)	Sm	1200	500	600,000.00
					-
	Ceramic floor tiles				-
					-
	Provide a prime cost rate of [Kshs 1,000.00/sm] for supply of Ceramic floor tiles (tenderer to add the cost of collection, cutting, grouting, adhesive, spaces and all other materials and laying to completion) as selected by the Architect: take and fix only ceramic tiles to floors on prepared bed (m.s) with proprietary adhesive; jointed and pointed in coloured proprietary grouting: including spacers as required, edge trims and expansion joint as necessary: all to Architect's approval: to;				-
					-
					-
					-
					-
					-
G	Floor generally	Sm	1200	2000	2,400,000.00
					-
H	100mm skirting to ditto	Lm	160	200	32,000.00
					-
	Sub - Total Carried to Collection				**3,587,600.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	Internal Ceiling Finishes				
	Plaster; 9mm thick first coat of cement and sand (1:3); 3mm second coat of cement and lime putty (1:10); steel trowelled smooth				-
A	12mm thick to concrete soffits and sides of beams	Sm	3	500	1,500.00
					-
	Prepare and apply one undercoat; one skimming coat; two finishing coats first quality matt emulsion paint from an approved supplier (approval by the project Architect); application strictly to supplier's written instructions; to:-				-
					-
					-
					-
B	Plastered concrete soffits and sides of beams (m.s)	Sm	3	400	1,200.00
					-
	12mm thick gypsum plasterboard suspended ceiling on and including approved heavy duty steel studwork support at approved centres to the entire satisfaction of the Architect.				
C	To the office	Sm	42	2800	117,600.00
	Sub - Total Carried to Collection				**120,300.00**
	COLLECTION				
	From Page 6				3,587,600.00
	From Above				120,300.00
	Total for Finishes Carried to Main Summary				**3,707,900.00**
	ELEMENT NO. 6				
	WINDOWS				
A	Supply, assemble and fix RAL 7022 powder coated aluminium louvres size 38 x 72 x 2mm at 65mm centers fixed at 45 degrees to the approval of the architect.	Sm	29	10000	290,000.00
					-
	Powder coated aluminium section windows including accessories to Architects approval : 50 x 50 mm frames : aluminium glazing beads, powder coated alumnium window cills and wash leather, neoprene gaskets strip: complete with and including 6 mm clear laminated glass as specified by architect including butt jointed glazing with silicone sealant where shown and as directed by the Architect: installed by an approved domestic sub-contractor: to Architects window schedule: all opening windows to have "Bonn Series" or equal and approved friction stay hinges with restrictor stay, satin anodised aluminium window handles and locking device				
B	Window overall size 1800 x 2100mm high	No	2	41580	83,160.00
	Finishing to reveals				-
					-
	15 mm cement and sand (1:3) render,finished with woodfloat to;				-
					-
C	Concrete/masonry surfaces to receive external wall finish (m.s.)	Sm	27	500	13,500.00
					-
	Total for Windows Carried to Main Summary				**386,660.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 7				
	DOORS				
	Purposed made mild steel doors and screens; welded smooth; pin type hinges; one coat red oxide painted				-
	Mild steel double leaf door overall size 1800 x 3000 mm high; comprising 50 x 50 x 3 mm thick RHS external frame fishtail grouted into concrete/block/masonry walling; 50 x 50 x 3mm RHS horizontal intermediate frames welded onto and including 50 x 50 x 3mm RHS surround frame at 600mm centres both ways; 25 x 3 mm thick flat door stopper with and including for 25 mm x 25 mm x 2 mm SHS beading; door leaf infilled with 2mm thick pressed metal panels profiled to form 300mm panels welded; all welding, grounding to a smooth finish including for priming door with one coat red oxide primer; pointed internally and externally with approved mastic sealant	No	3	54000	162,000.00
	Manually operated steel slatted roller shutter door : 100 x 100 x 6 mm angle frame fixed to block walls or concrete frame; complete with rolling gear and housing ; pull handles, 2 No. padlock hasps ; aluminium painted finish				-
A	Shutter overall size 3600 x 3600mm high	No	2	142560	285,120.00
	Supply and fix the following ironmongery; as UNION				-
B	BP-DW-402525 brass ball bearing hinges; 100 mm	Prs	38.0	400	15,200.00
C	7724 SIL door closer; non hold open	No	4	15000	60,000.00
D	DS-2058 PL floor mounted door stops	No	6	200	1,200.00
E	100-05-77 B 3-Lever mortice lock with scroll design brass handles	No	6	3500	21,000.00
	Total for Doors Carried to Main Summary				**544,520.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 9				
	BWIC WITH PLUMBING, DRAINAGE AND MECHANICAL INSTALLATIONS				
	Inspect all drawings and Mechanical Bills of Quantities as provided or at the Engineer's office: allow for all builders work associated with the following				
A	Cut away for sanitary fittings and pipework : form all holes, chases, etc and make good after the plumber	Item	1		500,000.00
	Total for BWIC With Mechanical Installations Carried to Main Summary				**500,000.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	ELEMENT NO. 10				
	BWIC WITH ELECTRICAL INSTALLATIONS				
	Inspect all drawings and Electrical Bills of Quantities as provided or at the Engineer's office: allow for all builders work associated with the following				
A	Cut away for electrical points, fittings and equipment : form all holes, chases, etc and make good after the electrician	Item	1		500,000.00
	Total for BWIC With Electrical Installations Carried to Main Summary				**500,000.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	MAIN SUMMARY				
				Page	
1	Substructures				5,841,970.00
3	Walling				7,567,270.00
4	Roof Construction and Finishes				2,050,000.00
5	Finishes				3,707,900.00
6	Windows				386,660.00
7	Doors				544,520.00
9	Builders work in connection with mechanical installations				500,000.00
10	Builders work in connection with electrical installations				500,000.00
	Total for Main Building Carried to Grand Summary			**Kshs.**	**21,098,320.00**

Item	Description	Unit	Qty	Rate	Amount (Kshs.)
	SECTION NO. 5 - PRIME COST SUMS				
A	Provide a prime cost sum for Electrical Installations	Item	1	1500000	1,500,000.00
B	Allow for Profit	Item		2.5%	37,500.00
C	Allow for General and Special attendance	Item			37,500.00
D	Provide a prime cost sum for Mechanical Installations	Item	1	2500000	2,500,000.00
E	Allow for Profit	Item		2.5%	62,500.00
F	Allow for General and Special attendance	Item			62,500.00
G	Provide a prime cost sum for Signage	Item	1	100000	100,000.00
H	Allow for Profit	Item		2.5%	2,500.00
I	Allow for General and Special attendance	Item			2,500.00
	Total for PC Sums Carried to Grand Summary			**Kshs.**	**4,305,000.00**

GRAND SUMMARY

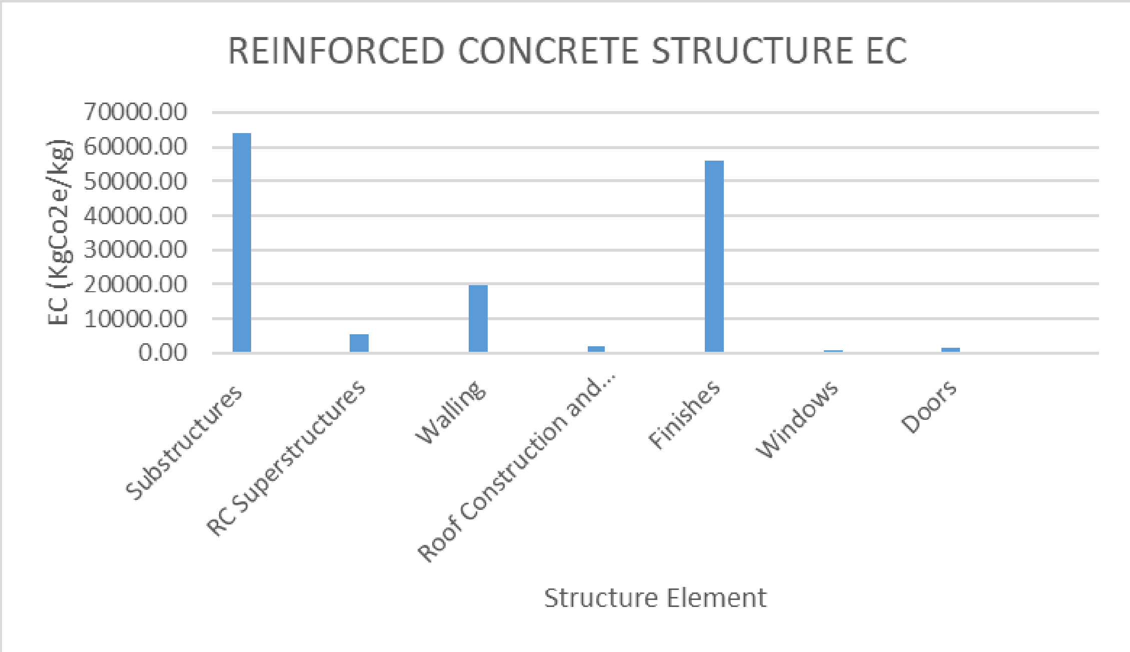
		Page	Amount
1	PRELIMINARIES		1,500,000.00
2	MAIN BUILDING		21,098,320.00
4	PRIME COST AND PROVISIONAL SUMS		4,305,000.00
	TOTAL COSTRUCTION COST (VAT INCLUSIVE)	KSHS.	26,903,320.00

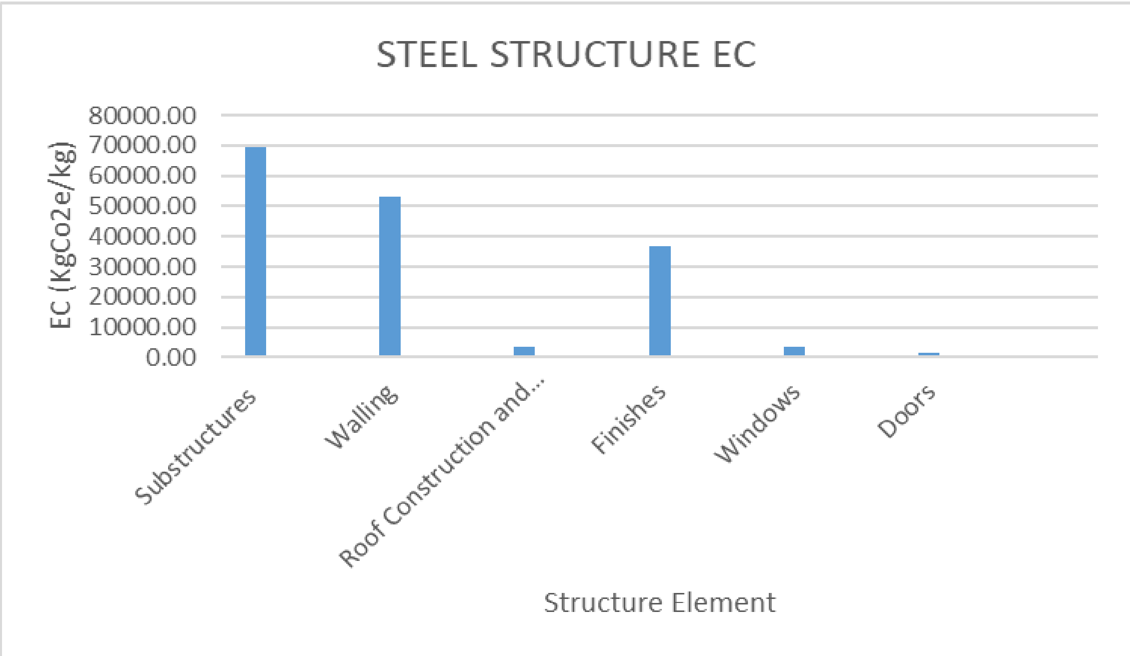
Appendix D: Carbon Footprint Analysis

Appendix D: Carbon Footprint Analysis

Item	Concrete Structure EC (KgCo2e/kg)
Substructures	63854.71
RC Superstructures	5296.88
Walling	19617.28
Roof Construction and Finishes	2124.50
Finishes	56075.13
Windows	760.67
Doors	1450.68
Total EC	**149179.85**

Item	Steel Structure EC (KgCo2e/kg)
Substructures	69330.67
Walling	52894.19
Roof Construction and Finishes	3522.43
Finishes	36585.48
Windows	3410.12
Doors	1450.68
Total EC	**167193.57**


REINFORCED CONCRETE STRUCTURE EC
EC (KgCo2e/kg)
70000.00
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
Substructures
RC Superstructures
Walling
Roof Construction and...
Finishes
Windows
Doors
Structure Element


STEEL STRUCTURE EC
EC (KgCo2e/kg)
80000.00
70000.00
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
Substructures
Walling
Roof Construction and...
Finishes
Windows
Doors
Structure Element

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Aggregate				
General (Gravel or Crushed Rock)	0.083	0.0048	0.0052	Estimated from measured UK industrial fuel consumption data
Aluminium	Main data source: International Aluminium Institute (IAI) LCA studies (www.world-aluminium.org)			
General	155	8.24	9.16	Assumed (UK) ratio of 25.6% extrusions, 55.7% Rolled & 18.7% castings. Worldwide average recycled content of 33%.
Virgin	218	11.46	12.79	
Recycled	29.0	1.69	1.81	
Cast Products	159	8.28	9.22	Worldwide average recycled content of 33%.
Virgin	226	11.70	13.10	
Recycled	25.0	1.35	1.45	
Extruded	154	8.16	9.08	Worldwide average recycled content of 33%.
Virgin	214	11.20	12.50	
Recycled	34.0	1.98	2.12	
Rolled	155	8.26	9.18	Worldwide average recycled content of 33%.
Virgin	217	11.50	12.80	
Recycled	28	1.67	1.79	
Asphalt				
Asphalt, 4% (bitumen) binder content (by mass)	2.86	0.059	0.066	1.68 MJ/kg Feedstock Energy (Included). Modelled from the bitumen binder content. The fuel consumption of asphalt mixing operations was taken from the Mineral Products Association (MPA). It represents typical UK industrial data. Feedstock energy is from the bitumen content.
Asphalt, 5% binder content	3.39	0.064	0.071	2.10 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Asphalt, 6% binder content	3.93	0.068	0.076	2.52 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Asphalt, 7% binder content	4.46	0.072	0.081	2.94 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Asphalt, 8% binder content	5.00	0.076	0.086	3.36 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Bitumen				
General	51	0.38 - 0.43 (?)	0.43 - 0.55 (?)	42 MJ/kg Feedstock Energy (Included). Feedstock assumed to be typical energy content of Bitumen. Carbon dioxide emissions are particularly difficult to estimate, range given.
Brass				
General	44.00	2.46 (?)	2.64 (?)	Poor data availability. It is believed that the data may be largely dependent upon ore grade. Poor carbon data, making estimate of embodied carbon difficult.
Virgin	80.00	4.47 (?)	4.80 (?)	
Recycled	20.00	1.12 (?)	1.20 (?)	
Bricks				
General (Common Brick)	3.00	0.23	0.24	
EXAMPLE: Single Brick	6.9 MJ per brick	0.53 kgCO2 per brick	0.55	Assuming 2.3 kg per brick.
Limestone	0.85	?	-	
Bronze				
General	69.0 (?)	3.73 (?)	4.0 (?)	Average of the only two references
Carpet				
General Carpet	74 (187 per sqm)	3.9 (9.8 per sqm)	-	For per square meter estimates see material profile. Difficult to estimate, taken from Ref. 94.
Felt (Hair and Jute) Underlay	19.00	0.97	-	Ref. 94.
Nylon (Polyamide), pile weight 300 g/m2	130 MJ per sqm	6.7 (GWP) per sqm	6.7 (GWP) per sqm	Total weight of this carpet 1,477 g/m2. See Refs. 277 & 279. These carpets (inc. below) are a tufted surface pile made of 100% nylon (polyamide) with a woven textile backing and flame proofed on the basis of aluminium hydroxide.
Nylon (Polyamide), pile weight 500 g/m2	180 MJ per sqm	9.7 (GWP) per sqm	9.7 (GWP) per sqm	Total weight of this carpet 1,837 g/m2. See Refs. 277 & 279.
Nylon (Polyamide), pile weight 700 g/m2	230 MJ per sqm	12.7 (GWP) per sqm	12.7 (GWP) per sqm	Total weight of this carpet 2,147 g/m2. See Refs. 277 & 279.
Nylon (Polyamide), pile weight 900 g/m2	277 MJ per sqm	15.6 (GWP) per sqm	15.6 (GWP) per sqm	Total weight of this carpet 2,427 g/m2. See Refs. 277 & 279.
Nylon (Polyamide), pile weight 1100 g/m2	327 MJ per sqm	18.4 (GWP) per sqm	18.4 (GWP) per sqm	Total weight of this carpet 2,677 g/m2. See Refs. 277 & 279.
Carpet tiles, nylon (Polyamide), pile weight 300 g/m2	178 MJ per sqm	7.75 (GWP) per sqm	7.75 (GWP) per sqm	Total weight of this carpet 4,123 g/m2. See Refs. 277 & 279. These carpet tiles (inc. below) are a tufted surface pile made of 100% nylon (polyamide) fleece-covered bitumen backing and flame-proofed on the basis of aluminium hydroxide
Carpet tiles, nylon (Polyamide), pile weight 500 g/m2	229 MJ per sqm	10.7 (GWP) per sqm	10.7 (GWP) per sqm	Total weight of this carpet 4,373 g/m2. See Refs. 277 & 279.
Carpet tiles, nylon (Polyamide), pile weight 700 g/m2	279 MJ per sqm	13.7 (GWP) per sqm	13.7 (GWP) per sqm	Total weight of this carpet 4,623 g/m2. See Refs. 277 & 279.
Carpet tiles, nylon (Polyamide), pile weight 900 g/m2	328 MJ per sqm	16.7 (GWP) per sqm	16.7 (GWP) per sqm	Total weight of this carpet 4,873 g/m2. See Refs. 277 & 279.
Carpet tiles, nylon (Polyamide), pile weight 1100 g/m2	378 MJ per sqm	19.7 (GWP) per sqm	19.7 (GWP) per sqm	Total weight of this carpet 5,123 g/m2. See Refs. 277 & 279.
Polyethylterepthalate (PET)	106.50	5.56	-	Includes feedstock energy
Polypropylene	95.40	4.98	-	Includes feedstock energy, for per square meter see material profile
Polyurethane	72.10	3.76	-	Includes feedstock energy
Rubber	67.5 to 140	3.61 to 7.48	-	
Saturated Felt Underlay (impregnated with Asphalt or tar)	31.70	1.65	-	Ref. 94.
Wool	106.00	5.53	-	For per square meter see material profile. See Refs. 63, 201, 202 & 281 (Same author).
Cement				
General (UK weighted average)	4.5	0.73	0.74	Weighted average of all cement consumed within the UK. This includes all factory made cements (CEM I, CEM II, CEM III, CEM IV) and further blending of fly ash and ground granulated blast furnace slag. This data has been estimated from the British Cement Association's factsheets (see Ref. 59). 23% cementitious additions on average.
Average CEM I Portland Cement, 94% Clinker	5.50	0.93	0.95	This is a standard cement with no cementitious additions (i.e. fly ash or blast furnace slag). Composition 94% clinker, 5% gypsum, 1% minor additional constituents (mac's). This data has been estimated from the British Cement Association's factsheets (see Ref. 59.).
6-20% Fly Ash (CEM II/A-V)	5.28 to 4.51	0.88 (@ 6%) to 0.75 (@ 20%)	0.89 to 0.76	See material profile for further details.
21-35% Fly Ash (CEM II/B-V)	4.45 to 3.68	0.74 to 0.61	0.75 to 0.62	
21-35% GGBS (CEM II/B-S)	4.77 to 4.21	0.76 to 0.64	0.77 to 0.65	
36-65% GGBS (CEM III/A)	4.17 to 3.0	0.63 to 0.38	0.64 to 0.39	
66-80% GGBS (CEM II/B)	2.96 to 2.4	0.37 to 0.25	0.38 to 0.26	
Fibre Cement Panels - Uncoated	10.40	1.09	-	Few data points. Selected data modified from Ref. 107.
Fibre Cement Panels - (Colour) Coated	15.30	1.28	-	
Mortar (1:3 cement:sand mix)	1.33	0.208	0.221	Values estimated from the ICE Cement, Mortar & Concrete Model
Mortar (1:4)	1.11	0.171	0.182	
Mortar (1:5)	0.97	0.146	0.156	
Mortar (1:6)	0.85	0.127	0.136	
Mortar (1:½:4½ Cement:Lime:Sand mix)	1.34	0.200	0.213	
Mortar (1:1:6 Cement:Lime:Sand mix)	1.11	0.163	0.174	

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Mortar (1:2:9 Cement:Lime:Sand mix)	1.03	0.145	0.155	
Cement stabilised soil @ 5%	0.68	0.060	0.061	Assumed 5% cement content.
Cement stabilised soil @ 8%	0.83	0.082	0.084	Assumed 8% stabiliser contents (6% cement and 2% quicklime)

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Ceramics				
General	10.00	0.66	0.70	Very large data range, difficult to select values for general ceramics.
Fittings	20.00	1.07	1.14	Ref. 1.
Sanitary Products	29.00	1.51	1.61	Limited data.
Tiles and Cladding Panels	12.00	0.74	0.78	Difficult to select, large range, limited data. See Ref. 292.
Clay				
General (Simple Baked Products)	3.00	0.23	0.24	General simple baked clay products (inc. terracotta and bricks)
Tile	6.50	0.45	0.48	
Vitrified clay pipe DN 100 & DN 150	6.20	0.44	0.46	
Vitrified clay pipe DN 200 & DN 300	7.00	0.48	0.50	
Vitrified clay pipe DN 500	7.90	0.52	0.55	
Concrete				
General	0.75	0.100	0.107	**It is strongly recommended to avoid selecting a 'general' value for concrete.** Selecting data for a specific concrete type (often a ready mix concrete) will give greater accuracy, please see material profile. Assumed cement content 12% by mass.
16/20 Mpa	0.70	0.093	0.100	Using UK weighted average cement (more representative of 'typical' concrete mixtures).
20/25 MPa	0.74	0.100	0.107	
25/30 MPa	0.78	0.106	0.113	
28/35 MPa	0.82	0.112	0.120	
32/40 MPa	0.88	0.123	0.132	
40/50 MPa	1.00	0.141	0.151	

% Cement Replacement - Fly Ash	0%	15%	30%	0%	15%	30%	0%	15%	30%	Note 0% is a concrete using a CEM I cement (not typical)
GEN 0 (6/8 MPa)	**0.55**	0.52	0.47	**0.071**	0.065	0.057	**0.076**	0.069	0.061	**Compressive strength designation C6/8 Mpa. 28 day compressive strength under British cube method of 8 MPa, under European cylinder method 6 MPa.** Possible uses: Kerb bedding and backing. Data is only cradle to factory gate but beyond this the average delivery distance of ready mix concrete is 8.3 km by road (see Ref. 244).
GEN 1 (8/10 MPa)	**0.70**	0.65	0.59	**0.097**	0.088	0.077	**0.104**	0.094	0.082	Possible uses: mass concrete, mass fill, mass foundations, trench foundations, blinding, strip footing.
GEN 2 (12/15 MPa)	**0.76**	0.71	0.64	**0.106**	0.098	0.087	**0.114**	0.105	0.093	-
GEN 3 (16/20 MPa)	**0.81**	0.75	0.68	**0.115**	0.105	0.093	**0.123**	0.112	0.100	Possible uses: garage floors.
RC 20/25 (20/25 MPa)	**0.86**	0.81	0.73	**0.124**	0.114	0.101	**0.132**	0.122	0.108	-
RC 25/30 (25/30 MPa)	**0.91**	0.85	0.77	**0.131**	0.121	0.107	**0.140**	0.130	0.115	Possible uses: reinforced foundations.
RC 28/35 (28/35 MPa)	**0.95**	0.90	0.82	**0.139**	0.129	0.116	**0.148**	0.138	0.124	Possible uses: reinforced foundations, ground floors.
RC 32/40 (32/40 MPa)	**1.03**	0.97	0.89	**0.153**	0.143	0.128	**0.163**	0.152	0.136	Possible uses: structural purposes, in situ floors, walls, superstructure.
RC 40/50 (40/50 MPa)	**1.17**	1.10	0.99	**0.176**	0.164	0.146	**0.188**	0.174	0.155	Possible uses: high strength applications, precasting.
PAV1	**0.95**	0.89	0.81	**0.139**	0.129	0.115	**0.148**	0.138	0.123	Possible uses: domestic parking and outdoor paving.
PAV2	**1.03**	0.97	0.89	**0.153**	0.143	0.128	**0.163**	0.152	0.137	Possible uses: heavy duty outdoor paving.

% Cement Replacement - Blast Furnace Slag	0%	25%	50%	0%	25%	50%	0%	15%	30%	Note 0% is a concrete using a CEM I cement
GEN 0 (6/8 MPa)	**0.55**	0.48	0.41	**0.071**	0.056	0.042	**0.076**	0.060	0.045	See fly ash mixtures
GEN 1 (8/10 MPa)	**0.70**	0.60	0.50	**0.097**	0.075	0.054	**0.104**	0.080	0.058	
GEN 2 (12/15 MPa)	**0.76**	0.62	0.55	**0.106**	0.082	0.061	**0.114**	0.088	0.065	
GEN 3 (16/20 MPa)	**0.81**	0.69	0.57	**0.115**	0.090	0.065	**0.123**	0.096	0.070	
RC 20/25 (20/25 MPa)	**0.86**	0.74	0.62	**0.124**	0.097	0.072	**0.132**	0.104	0.077	
RC 25/30 (25/30 MPa)	**0.91**	0.78	0.65	**0.131**	0.104	0.076	**0.140**	0.111	0.081	
RC 28/35 (28/35 MPa)	**0.95**	0.83	0.69	**0.139**	0.111	0.082	**0.148**	0.119	0.088	
RC 32/40 (32/40 MPa)	**1.03**	0.91	0.78	**0.153**	0.125	0.094	**0.163**	0.133	0.100	
RC 40/50 (40/50 MPa)	**1.17**	1.03	0.87	**0.176**	0.144	0.108	**0.188**	0.153	0.115	
PAV1	**0.95**	0.82	0.70	**0.139**	0.111	0.083	**0.148**	0.118	0.088	
PAV2	**1.03**	0.91	0.77	**0.153**	0.125	0.094	**0.163**	0.133	0.100	

COMMENTS

The first column represents standard concrete, created with a CEM I Portland cement. The other columns are estimates based on a direct substitution of fly ash or blast furnace slag in place of the cement content. The ICE Cement, Mortar & Concrete Model was applied. **Please see important notes in the concrete material profile.**

REINFORCED CONCRETE - Modification Factors

For reinforcement add this value to the appropriate concrete coefficient for each 100 kg of rebar per m3 of concrete	1.04	0.072	0.077	Add for each 100 kg steel rebar per m3 concrete. Use multiple of this value, i.e. for 150 kg steel use a factor of 1.5 times these values.
EXAMPLE: Reinforced RC 25/30 MPa (with 110 kg per m3 concrete)	1.92 MJ/kg (0.78 + 1.04 * 1.1)	0.185 kgCO2/kg (0.106 + 0.072 * 1.1)	0.198 kgCO2/kg (0.113 + 0.077 * 1.1)	with 110 kg rebar per m3 concrete. UK weighted average cement. This assumes the UK typical steel scenario (59% recycled content). Please consider if this is in line with the rest of your study (goal and scope) or the requirements of a predefined method.

PRECAST (PREFABRICATED) CONCRETE - Modification Factors

For precast add this value to the selected coefficient of the appropriate concrete mix	0.45	0.027	0.029	For each 1 kg precast concrete. This example is using a RC 40/50 strength class and is not necessarily indicative of an average precast product. Includes UK recorded plant operations and estimated transportation of the constituents to the factory gate (38km aggregates, estimated 100km cement). Data is only cradle to factory gate but beyond this the average delivery distance of precast is 155km by road (see Ref. 244). UK weighted average cement. See also the new report on precast concrete pipes (Ref 300).
EXAMPLE: Precast RC 40/50 MPa	1.50 MJ/kg (1.00 + 0.50)	0.168 kgCO2/kg (0.141 + 0.027)	0.180 kgCO2/kg (0.151 + 0.029)	
EXAMPLE: Precast RC 40/50 with reinforcement (with 80kg per m^3)	2.33 MJ/kg (1.50 + 1.04 * 0.8)	0.229 kgCO2/kg (0.171 + 0.072 * 0.8)	0.242 kgCO2/kg (0.180 + 0.077 * 0.8)	

CONCRETE BLOCKS (ICE CMC Model Values)

Block - 8 MPa Compressive Strength	0.59	0.059	0.063	Estimated from the concrete block mix proportions, plus an allowance for concrete block curing, plant operations and transport of materials to factory gate.
Block - 10 MPa	0.67	0.073	0.078	
Block -12 MPa	0.72	0.082	0.088	
Block -13 MPa	0.83	0.100	0.107	
Autoclaved Aerated Blocks (AAC's)	3.50	0.24 to 0.375	-	Not ICE CMC model results.

NOMINAL PROPORTIONS METHOD (Volume), Proportions from BS 8500:2006 (ICE Cement, Mortar & Concrete Model Calculations)

1:1:2 Cement:Sand:Aggregate	1.28	0.194	0.206	High strength concrete. All of these values were estimated assuming the **UK average content of cementitious additions** (i.e. fly ash, GGBS) for **factory supplied cements** in the UK, see Ref. 59, plus the proportions of other constituents.
1:1.5:3	0.99	0.145	0.155	Often used in floor slab, columns & load bearing structure.
1:2:4	0.82	0.116	0.124	Often used in construction of buildings under 3 storeys.
1:2.5:5	0.71	0.097	0.104	
1:3:6	0.63	0.084	0.090	Non-structural mass concrete.
1:4:8	0.54	0.069	0.074	

BY CEM I CEMENT CONTENT - kg CEM I cement content per cubic meter concrete (ICE CMC Model Results)

120 kg / m^3 concrete	0.49	0.060	0.064	Assumed density of 2,350 kg/m3. Interpolation of the CEM I cement content is possible. These numbers assume the **CEM I cement content (not the total cementitious content**, i.e. they do not include cementitious additions). They may also be used for fly ash mixtures without modification, but they are likely to slightly underestimate mixtures that have additional GGBS due to the higher embodied energy and carbon of GGBS (in comparison to aggregates and fly ash).
200 kg / m^3 concrete	0.67	0.091	0.097	
300 kg / m^3 concrete	0.91	0.131	0.140	
400kg / m^3 concrete	1.14	0.170	0.181	
500 kg / m^3 concrete	1.37	0.211	0.224	

MISCELLANEOUS VALUES

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Fibre-Reinforced	**7.75 (?)**	**0.45 (?)**	**-**	Literature estimate, likely to vary widely. High uncertainty.
Very High GGBS Mix	**0.66**	**0.049**	**0.050**	Data based on Lafarge 'Envirocrete', which is a C28/35 MPa, very high GGBS replacement value concrete

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Copper				
EU Tube & Sheet	42.00	2.60	2.71	EU production data, estimated from Kupfer Institut LCI data. 37% recycled content (the 3 year world average). World average data is expected to be higher than these values.
Virgin	57.00	3.65	3.81	
Recycled	16.50	0.80	0.84	
Recycled from high grade scrap	18 (?)	1.1 (?)		Uncertain, difficult to estimate with the data available.
Recycled from low grade scrap	50 (?)	3.1 (?)		
Glass				
Primary Glass	15.00	0.86	0.91	Includes process CO2 emissions from primary glass manufacture.
Secondary Glass	11.50	0.55	0.59	EE estimated from Ref 115.
Fibreglass (Glasswool)	28.00	1.54	-	Large data range, but the selected value is inside a small band of frequently quoted values.
Toughened	23.50	1.27	1.35	Only three data sources
Insulation				
General Insulation	45.00	1.86	-	Estimated from typical market shares. Feedstock Energy 16.5 MJ/kg (Included)
Cellular Glass	27.00	-	-	Ref. 54.
Cellulose	0.94 to 3.3	-	-	
Cork	4.00	0.19	-	Ref. 55.
Fibreglass (Glasswool)	28.00	1.35	-	Poor data difficult to select appropriate value
Flax (Insulation)	39.50	1.70	-	Ref. 2. 5.97 MJ/kg Feedstock Energy (Included)
Mineral wool	16.60	1.20	1.28	
Paper wool	20.17	0.63	-	Ref. 2
Polystyrene	See Plastics	See Plastics	-	see plastics
Polyurethane	See Plastics	See Plastics	-	see plastics
Rockwool	16.80	1.05	1.12	Cradle to Grave
Woodwool (loose)	10.80	-	-	Ref. 205.
Woodwool (Board)	20.00	0.98	-	Ref. 55.
Wool (Recycled)	20.90	-	-	Refs. 63, 201, 202 & 281.
Iron				
General	25.00	1.91 (?)	2.03	It was difficult to estimate the embodied energy and carbon of iron with the data available.
Lead				
General	25.21	1.57	1.67	Allocated (divided) on a mass basis, assumes recycling rate of 61%
Virgin	49.00	3.18	3.37	
Recycled	10.00	0.54	0.58	Scrap batteries are a main feedstock for recycled lead
Lime				
General	5.30	0.76	0.78	Embodied carbon was difficult to estimate
Linoleum				
General	25.00	1.21	-	Data difficult to select, large data range.
Miscellaneous				
Asbestos	7.40	-	-	Ref. 4.
Calcium Silicate Sheet	2.00	0.13	-	Ref. 55.
Chromium	83	5.39	-	Ref. 22.
Cotton, Padding	27.10	1.28	-	Ref. 38.
Cotton, Fabric	143	6.78	-	Ref. 38.
Damp Proof Course/Membrane	134 (?)	4.2 (?)	-	Uncertain estimate.
Felt General	36	-	-	
Flax	33.50	1.70	-	Ref. 2.
Fly Ash	0.10	0.008	-	No allocation from fly ash producing system.
Grit	0.12	0.01	-	Ref. 114.
Ground Limestone	0.62	0.032	-	
Carpet Grout	30.80	-	-	Ref. 169.
Glass Reinforced Plastic - GRP - Fibreglass	100	8.10	-	Ref. 1.
Lithium	853	5.30	-	Ref. 22.
Mandolite	63	1.40	-	Ref. 1.
Mineral Fibre Tile (Roofing)	37	2.70	-	Ref. 1.
Manganese	52	3.50	-	Ref. 22.
Mercury	87	4.94	-	Ref. 22.
Molybedenum	378	30.30	-	Ref. 22.
Nickel	164	12.40	-	Ref. 114.
Perlite - Expanded	10.00	0.52	-	Ref. 114.
Perlite - Natural	0.66	0.03	-	Ref. 114.
Quartz powder	0.85	0.02	-	Ref. 114.
Shingle	11.30	0.30	-	Ref. 70.
Silicon	2355	-	-	Ref. 167.
Slag (GGBS)	1.60	0.083	-	Ground Granulated Blast Furnace Slag (GGBS), economic allocation.
Silver	128.20	6.31	-	Ref. 148.
Straw	0.24	0.01	-	Refs. 63, 201, 202 & 281.
Terrazzo Tiles	1.40	0.12	-	Ref. 1.
Vanadium	3710	228	-	Ref. 22.
Vermiculite - Expanded	7.20	0.52	-	Ref. 114.
Vermiculite - Natural	0.72	0.03	-	Ref. 114.
Vicuclad	70.00	-	-	Ref. 1.
Water	0.01	0.001	-	
Wax	52.00	-	-	Ref. 169.
Wood stain/Varnish	50.00	5.35	-	Ref. 1.
Yttrium	1470	84.00	-	Ref. 22.
Zirconium	1610	97.20	-	Ref. 22.
Paint				
General	70.00	2.42	2.91	Large variations in data, especially for embodied carbon. Includes feedstock energy. Water based paints have a 70% market share. Water based paint has a lower embodied energy than solvent based paint.
EXAMPLE: Single Coat	10.5 MJ/Sqm	0.36 kgCO2/Sqm	0.44	Assuming 6.66 Sqm Coverage per kg
EXAMPLE: Double Coat	21.0 MJ/Sqm	0.73 kgCO2/Sqm	0.87	Assuming 3.33 Sqm Coverage per kg
EXAMPLE: Triple Coat	31.5 MJ/Sqm	1.09 kgCO2/Sqm	1.31	Assuming 2.22 Sqm Coverage per kg
Waterborne Paint	59.00	2.12	2.54	Waterborne paint has a 70% of market share. Includes feedstock energy.
Solventborne Paint	97.00	3.13	3.76	Solventborne paint has a 30% share of the market. Includes feedstock energy. It was difficult to estimate carbon emissions for Solventborne paint.
Paper				
Paperboard (General for construction use)	24.80	1.29	-	Excluding calorific value (CV) of wood, excludes carbon sequestration/biogenic carbon storage.
Fine Paper	28.20	1.49	-	Excluding CV of wood, excludes carbon sequestration
EXAMPLE: 1 packet A4 paper	70.50	3.73	-	Standard 80g/sqm printing paper, 500 sheets a pack. Doesn't include printing.
Wallpaper	36.40	1.93	-	
Plaster				

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
General (Gypsum)	1.80	0.12	0.13	Problems selecting good value, inconsistent figures, West et al believe this is because of past aggregation of EE with cement
Plasterboard	6.75	0.38	0.39	See Ref [WRAP] for further info on GWP data, including disposal impacts which are significant for Plasterboard.
Plastics	Main data source: Plastics Europe (www.plasticseurope.org) ecoprofiles			
General	80.50	2.73	3.31	35.6 MJ/kg Feedstock Energy (Included). Determined by the average use of each type of plastic used in the European construction industry.
ABS	95.30	3.05	3.76	48.6 MJ/kg Feedstock Energy (Included)
General Polyethylene	83.10	2.04	2.54	54.4 MJ/kg Feedstock Energy (Included). Based on average consumption of types of polyethylene in European construction
High Density Polyethylene (HDPE) Resin	76.70	1.57	1.93	54.3 MJ/kg Feedstock Energy (Included). Doesn't include the final fabrication.
HDPE Pipe	84.40	2.02	2.52	55.1 MJ/kg Feedstock Energy (Included)
Low Density Polyethylene (LDPE) Resin	78.10	1.69	2.08	51.6 MJ/kg Feedstock Energy (Included). Doesn't include the final fabrication
LDPE Film	89.30	2.13	2.60	55.2 MJ/kg Feedstock Energy (Included)
Nylon (Polyamide) 6 Polymer	120.50	5.47	9.14	38.6 MJ/kg Feedstock Energy (Included). Doesn't include final fabrication. Plastics Europe state that two thirds of nylon is used as fibres (textiles, carpets…etc) in Europe and that most of the remainder as injection mouldings. Dinitrogen monoxide and methane emissions are very significant contributors to GWP.
Nylon (polyamide) 6,6 Polymer	138.60	6.54	7.92	50.7 MJ/kg Feedstock Energy (Included). Doesn't include final fabrication (i.e. injection moulding). See comments for Nylon 6 polymer.
Polycarbonate	112.90	6.03	7.62	36.7 MJ/kg Feedstock Energy (Included). Doesn't include final fabrication.
Polypropylene, Orientated Film	99.20	2.97	3.43	55.7 MJ/kg Feedstock Energy (Included).
Polypropylene, Injection Moulding	115.10	3.93	4.49	54 MJ/kg Feedstock Energy (Included). If biomass benefits are included the CO2 may reduce to 3.85 kgCO2/kg, and GWP down to 4.41 kg CO2e/kg.
Expanded Polystyrene	88.60	2.55	3.29	46.2 MJ/kg Feedstock Energy (Included)
General Purpose Polystyrene	86.40	2.71	3.43	46.3 MJ/kg Feedstock Energy (Included)
High Impact Polystyrene	87.40	2.76	3.42	46.4 MJ/kg Feedstock Energy (Included)
Thermoformed Expanded Polystyrene	109.20	3.45	4.39	49.7 MJ/kg Feedstock Energy (Included)
Polyurethane Flexible Foam	102.10	4.06	4.84	33.47 MJ/kg Feedstock Energy (Included). Poor data availability for feedstock energy
Polyurethane Rigid Foam	101.50	3.48	4.26	37.07 MJ/kg Feedstock Energy (Included). Poor data availability for feedstock energy
PVC General	77.20	2.61	3.10	28.1 MJ/kg Feedstock Energy (Included). Based on market average consumption of types of PVC in the European construction industry
PVC Pipe	67.50	2.56	3.23	24.4 MJ/kg Feedstock Energy (Included). If biomass benefits are included the CO2 may reduce to 2.51 kgCO2/kg, and GWP down to 3.23 kg CO2e/kg.
Calendered Sheet PVC	68.60	2.61	3.19	24.4 MJ/kg Feedstock Energy (Included). If biomass benefits are included the CO2 may reduce to 2.56 kgCO2/kg, and GWP down to 3.15 kg CO2e/kg.
PVC Injection Moulding	95.10	2.69	3.30	35.1 MJ/kg Feedstock Energy (Included). If biomass benefits are included the CO2 may reduce to 2.23 kgCO2/kg, and GWP down to 2.84 kg CO2e/kg.
UPVC Film	69.40	2.57	3.16	25.3 MJ/kg Feedstock Energy (Included)
Rubber				
General	91.00	2.66	2.85	40 MJ/kg Feedstock Energy (Included)
Sand				
General	0.081	0.0048	0.0051	Estimated from real UK industrial fuel consumption data
Sealants and adhesives				
Epoxide Resin	137.00	5.70	-	42.6 MJ/kg Feedstock Energy (Included). Source: www.plasticseurope.org
Mastic Sealant	62 to 200	-	-	
Melamine Resin	97.00	4.19	-	Feedstock energy 18 MJ/kg - estimated from Ref 34.
Phenol Formaldehyde	88.00	2.98	-	Feedstock energy 32 MJ/kg - estimated from Ref 34.
Urea Formaldehyde	70.00	2.76	-	Feedstock energy 18 MJ/kg - estimated from Ref 34.
Soil				
General (Rammed Soil)	0.45	0.023	0.024	
Cement stabilised soil @ 5%	0.68	0.060	0.061	Assumed 5% cement content.
Cement stabilised soil @ 8%	0.83	0.082	0.084	Assumed 8% stabiliser content (6% cement and 2% lime).
GGBS stabilised soil	0.65	0.045	0.047	Assumed 8% stabiliser content (8% GGBS and 2% lime).
Fly ash stabilised soil	0.56	0.039	0.041	Assumed 10% stabiliser content (8% fly ash and 2% lime).

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Steel	Main data source: International Iron & Steel Institute (IISI) LCA studies (www.worldsteel.org)			
UK (EU) STEEL DATA - EU average recycled content - See material profile (and Annex on recycling methods) for usage guide				
General - UK (EU) Average Recycled Content	**20.10**	**1.37**	**1.46**	EU 3-average recycled content of 59%. Estimated from UK's consumption mixture of types of steel (excluding stainless). **All data doesn't include the final cutting of the steel products to the specified dimensions or further fabrication activities.** Estimated from World Steel Association (Worldsteel) LCA data.
Virgin	35.40	2.71	2.89	
Recycled	9.40	0.44	0.47	Could not collect strong statistics on consumption mix of recycled steel.
Bar & rod - UK (EU) Average Recycled Content	**17.40**	**1.31**	**1.40**	EU 3-average recycled content of 59%
Virgin	29.20	2.59	2.77	
Recycled	8.80	0.42	0.45	
Coil (Sheet) - UK (EU) Average Recycled Content	**18.80**	**1.30**	**1.38**	Effective recycled content because recycling route is not typical. EU 3-average recycled content of 59%
Virgin	32.80	2.58	2.74	
Recycled	Not Typical Production Route			
Coil (Sheet), Galvanised - UK (EU) Average Recycled Content	**22.60**	**1.45**	**1.54**	Effective recycled content because recycling route is not typical. EU 3-average recycled content of 59%
Virgin	40.00	2.84	3.01	
Engineering steel - Recycled	**13.10**	**0.68**	**0.72**	
Pipe- UK (EU) Average Recycled Content	**19.80**	**1.37**	**1.45**	Effective recycled content because recycling route is not typical. EU 3-average recycled content of 59%
Virgin	34.70	2.71	2.87	
Recycled	Not Typical Production Route			
Plate- UK (EU) Average Recycled Content	**25.10**	**1.55**	**1.66**	Effective recycled content because recycling route is not typical. EU 3-average recycled content of 59%
Virgin	45.40	3.05	3.27	
Recycled	Not Typical Production Route			
Section- UK (EU) Average Recycled Content	**21.50**	**1.42**	**1.53**	
Virgin	38.00	2.82	3.03	
Recycled	10.00	0.44	0.47	
Wire - Virgin	**36.00 (?)**	**2.83 (?)**	**3.02**	
Stainless	**56.70**	**6.15**		World average data from the Institute of Stainless Steel Forum (ISSF) life cycle inventory data. Selected data is for the most popular grade (304). Stainless steel does not have separate primary and recycled material production routes.
OTHER STEEL DATA - 'R.O.W' and 'World' average recycled contents - See material profile (and Annex on recycling methods) for usage guide				
General - R.O.W. Avg. Recy. Cont.	26.20	1.90	2.03	Rest of World (non-E.U.) consumption of steel. 3 year average recycled content of 35.5%.
General - World Avg. Recy. Cont.	25.30	1.82	1.95	Whole world 3 year average recycled content of 39%.
Bar & rod- R.O.W. Avg. Recy. Cont.	22.30	1.82	1.95	Comments above apply. See material profile for further information.
Bar & rod - World Avg. Recy. Cont.	21.60	1.74	1.86	
Coil - R.O.W. Avg. Recy. Cont.	24.40	1.81	1.92	
Coil - World Avg. Recy. Cont.	23.50	1.74	1.85	
Coil, Galvanised - R.O.W. Avg. Recy. Cont.	29.50	2.00	2.12	
Coil, Galvanised - World Avg. Recy. Cont.	28.50	1.92	2.03	
Pipe - R.O.W. Avg. Recy. Cont.	25.80	1.90	2.01	
Pipe - World Avg. Recy. Cont.	24.90	1.83	1.94	
Plate - R.O.W. Avg. Recy. Cont.	33.20	2.15	2.31	
Plate - World Avg. Recy. Cont.	32.00	2.06	2.21	
Section - R.O.W. Avg. Recy. Cont.	28.10	1.97	2.12	
Section - World Avg. Recy. Cont.	27.10	1.89	2.03	
Stone	Data on stone was difficult to select, with high standard deviations and data ranges.			
General	**1.26 (?)**	**0.073 (?)**	**0.079**	ICE database average (statistic), uncertain. See material profile.
Granite	**11.00**	**0.64**	**0.70**	Estimated from Ref 116.
Limestone	**1.50**	**0.087**	**0.09**	Estimated from Ref 188.
Marble	**2.00**	**0.116**	**0.13**	
Marble tile	**3.33**	**0.192**	**0.21**	Ref. 40.
Sandstone	**1.00 (?)**	**0.058 (?)**	**0.06**	Uncertain estimate based on Ref. 262.
Shale	**0.03**	**0.002**	**0.002**	
Slate	**0.1 to 1.0**	**0.006 to 0.058**	**0.007 to 0.063**	Large data range
Timber	Note: These values were difficult to estimate because timber has a high data variability. These values exclude the energy content of the wooden product (the Calorific Value (CV) from burning). See the material profile for guidance on the new data structure for embodied carbon (i.e. split into foss and bio)			
General	**10.00**	**0.30_{fos}+0.41_{bio}**	**0.31_{fos}+0.41_{bio}**	Estimated from UK consumption mixture of timber products in 2007 (Timber Trade Federation statistics). Includes 4.3 MJ bio-energy. All values do not include the CV of timber product and exclude carbon storage.
Glue Laminated timber	**12.00**	**0.39_{fos}+0.45_{bio}**	**0.42_{fos}+0.45_{bio}**	Includes 4.9 MJ bio-energy.
Hardboard	**16.00**	**0.54_{fos}+0.51_{bio}**	**0.58_{fos}+0.51_{bio}**	Hardboard is a type of fibreboard with a density above 800 kg/m3. Includes 5.6 MJ bio-energy.
Laminated Veneer Lumber	**9.50**	**0.31_{fos}+0.32_{bio}**	**0.33_{fos}+0.32_{bio}**	Ref 150. Includes 3.5 MJ bio-energy.
MDF	**11 (?)**	**0.37_{fos}+0.35_{bio}**	**0.39_{fos}+0.35_{bio}**	Wide density range (350-800 kg/m3). Includes 3.8 MJ bio-energy.
Oriented Strand Board (OSB)	**15.00**	**0.42_{fos}+0.54_{bio}**	**0.45_{fos}+0.54_{bio}**	Estimated from Refs. 103 and 150. Includes 5.9 MJ bio-energy.
Particle Board	**14.50**	**0.52_{fos}+0.32_{bio}**	**0.54_{fos}+0.32_{bio}**	Very large data range, difficult to select appropriate values. Modified from CORRIM reports. Includes 3.2 MJ bio-energy (uncertain estimate).
Plywood	**15.00**	**0.42_{fos}+0.65_{bio}**	**0.45_{fos}+0.65_{bio}**	Includes 7.1 MJ bio-energy.
Sawn Hardwood	**10.40**	**0.23_{fos}+ 0.63_{bio}**	**0.24_{fos}+ 0.63_{bio}**	It was difficult to select values for hardwood, the data was estimated from the CORRIM studies (Ref. 88). Includes 6.3 MJ bio-energy.
Sawn Softwood	**7.40**	**0.19_{fos}+0.39_{bio}**	**0.20_{fos}+0.39_{bio}**	Includes 4.2 MJ bio-energy.
Veneer Particleboard (Furniture)	**$23_{(fos+bio)}$**	**(?)**	**(?)**	Unknown split of fossil based and biogenic fuels.
Tin				
Tin Coated Plate (Steel)	**19.2 to 54.7**	**1.04 to 2.95**	**-**	
Tin	**250.00**	**13.50**	**14.47**	lack of modern data, large data range
Titanium				
Virgin	**361 to 745**	**19.2 to 39.6 (??)**	**20.6 to 42.5 (??)**	lack of modern data, large data range, small sample size
Recycled	**258.00**	**13.7 (??)**	**14.7 (??)**	lack of modern data, large data range, small sample size
Vinyl Flooring				
General	**68.60**	**2.61**	**3.19**	23.58 MJ/kg Feedstock Energy (Included), Same value as PVC calendered sheet. *Note: the book version of ICE contains the wrong values. These values are up to date*
Vinyl Composite Tiles (VCT)	**13.70**	**-**	**-**	Ref. 94.
Zinc				
General	**53.10**	**2.88**	**3.09**	Uncertain carbon estimates, currently estimated from typical UK industrial fuel mix. Recycled content of general Zinc 30%.
Virgin	72.00	3.90	4.18	
Recycled	9.00	0.49	0.52	

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon

Miscellaneous (No material profiles):

	Embodied Energy - MJ	Embodied Carbon - Kg CO2		
PV Modules	**MJ/sqm**	**Kg CO2/sqm**		
Monocrystalline	**4750 (2590 to 8640)**	**242 (132 to 440)**	-	Embodied carbon estimated from typical UK industrial fuel mix. This is not an ideal method.
Polycrystalline	**4070 (1945 to 5660)**	**208 (99 to 289)**	-	
Thin Film	**1305 (775 to 1805)**	**67 (40 to 92)**	-	
Roads	Main data source: ICE reference number 147			
Asphalt road - Hot construction method - 40 yrs	**2,509 MJ/Sqm**	**93 KgCO2/Sqm**	**99 KgCO2/Sqm**	730 MJ/Sqm Feedstock Energy (Included). For more detailed data see reference 147. (Swedish study). The data in this report was modified to fit within the ICE framework. Includes all sub-base layers to construct a road. Sum of construction, maintenance, operation.
Construction	1,069 MJ/Sqm	30.9 KgCO2/Sqm	32.8 KgCO2/Sqm	480 MJ/Sqm Feedstock Energy (Included)
Maintenance - 40 yrs	471 MJ/Sqm	11.6 KgCO2/Sqm	12.3 KgCO2/Sqm	250 MJ/Sqm Feedstock Energy (Included)
Operation - 40 yrs	969 MJ/Sqm	50.8 KgCO2/Sqm	54.0 KgCO2/Sqm	Swedish scenario of typical road operation, includes street and traffic lights (95% of total energy), road clearing, sweeping, gritting and snow clearing.
Asphalt road - Cold construction method - 40 yrs	**3,030 MJ/Sqm**	**91 KgCO2/Sqm**	**97 KgCO2/Sqm**	1,290 MJ/kg Feedstock Energy (Included). Sum of construction, maintenance, operation.
Construction	825 MJ/Sqm	26.5 KgCO2/Sqm	28.2 KgCO2/Sqm	320 MJ/Sqm Feedstock Energy (Included)
Maintenance - 40 yrs	1,556 MJ/Sqm	13.9 KgCO2/Sqm	14.8 KgCO2/Sqm	970 MJ/Sqm Feedstock Energy (Included)
Operation - 40 yrs	969 MJ/Sqm	50.8 KgCO2/Sqm	54.0 KgCO2/Sqm	See hot rolled asphalt.
Concrete road - 40 yrs	**2,084 MJ/Sqm**	**142 KgCO2/Sqm**	**-**	Sum of construction, maintenance, operation.
Construction	885 MJ/Sqm	77 KgCO2/Sqm	-	
Maintenance - 40 yrs	230 MJ/Sqm	14.7 KgCO2/Sqm	-	
Operation - 40 yrs	969 MJ/Sqm	50.8 KgCO2/Sqm	-	Swedish scenario of typical road operation, includes street and traffic lights (95% of total energy), and also road clearing, sweeping, gritting and snow clearing.

Note: *The above data for roads were based on a single reference (ref 145). There were other references available but it was not possible to process the reports into useful units (per sqm). One of the other references indicates a larger difference between concrete and asphalt roads than the data above. If there is a particular interest in roads the reader is recommended to review the literature in further detail.*

Windows	MJ per Window			
1.2mx1.2m Single Glazed Timber Framed Unit	**286 (?)**	**14.6 (?)**	**-**	Embodied carbon estimated from typical UK industrial fuel mix
1.2mx1.2m Double Glazed (Air or Argon Filled):	**--**	**--**	**-**	--
Aluminium Framed	**5470**	**279**	**-**	
PVC Framed	**2150 to 2470**	**110 to 126**	**-**	
Aluminium -Clad Timber Framed	**950 to 1460**	**48 to 75**	**-**	
Timber Framed	**230 to 490**	**12 to 25**	**-**	
			-	
Krypton Filled Add:	**510**	**26**	**-**	
Xenon Filled Add:	**4500**	**229**	**-**	

NOTE: Not all of the data could be converted to full GHG's. It was estimated from the fuel use only (i.e. Not including any process related emissions) the full CO2e is approximately 6 percent higher than the CO2 only value of embodied carbon. This is for the average mixture of fuels used in the UK industry.