University of Southern Queensland

Faculty of Engineering and Surveying

Review of the Current Timber Industry in Malaysia

A dissertation submitted by

YAP Fui It

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Abstract

The timber industry is currently growing rapidly in Malaysia, who is the second largest tropical timber production exporter in the world. The timber industry contributes to various sectors such as furniture and components, panel products, mouldings and joinery, and the construction especially for the roof trusses. Most of the Malaysian buildings are adopted the timber roof truss system because of its availability, economics, simple design and fast installation due to the prefabricated method. However, there are some challenges such as the impact from steel trusses, raw material supply, and technology and techniques. This review will provide the information that will be extremely useful to the timber roofing industry.

62% of the total land area of Malaysia is covered by tropical forest. The natural resources are used for farming, agricultural, mining, timber and urbanisation and infrastructure. The forest use is controlled by the government to achieve a definite and stable forest resource. The timber must be certified by the Malaysian Timber Certification Council to show that the timber products are from the sustainable managed forests or else a penalty will be imposed. The forest industry and timber industry are closely related. The Malaysian timber industry can be classified into three main sectors, i.e. sawmilling, wood chipping and veneer manufacturing. The sawmilling produces the sawn timber that is adopted for the timber roof truss system.

The research aims to review the current timber industry in Malaysia, particularly in the construction technique of roof trusses. The objectives of this research are as follows:

- investigate the classifications, properties, uses and market of Malaysian timber;
- review the roofing industry in Malaysia;
- document the standard and quality of timber required for the timber trusses; and
- review the design method and the costing involved for the system.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

YAP Fui It
Student Number: 0050012464

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Signature

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Date

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ABBREVIATIONS

AAC	- Annual Allowable Cut
AUD	- Aussie Dollar Currency
FELDA	- Federal Land Development Authority
FRIM	- Forest Research Institute of Malaysia
HHW	- Heavy Hardwood
ITTO	- International Tropical Timber Organisation
LHW	- Light Hardwood
LVL	- Laminated Veneer Lumber
MHW	- Medium Hardwood
MGR	- Malaysian Grading Rules
MTC	- Malaysian Timber Council
MTCC	- Malaysian Timber Certification Council
MTIB	- Malaysian Timber Industry Board
NEP	- New Economic Policy
NFC	- National Forestry Council
NFP	- National Forestry Policy
PFE	- Permanent Forest Estate
R&D	- Research and development
RM	- Ringgit Malaysia Currency
SW	- Softwood
TVS	- Timber Verification Service

CHAPTER 1: INTRODUCTION

1.1 Rationale

The timber industry is currently growing rapidly in Malaysia. Malaysia is the second largest tropical timber production exporter in the world after Indonesia. The timber industry is crucial for the local construction sector, particularly for formwork and roof trusses. This review will investigate the development of the timber roofing sector in Malaysia in more depth.

Timber is particularly used for roof truss systems because of its natural characteristic properties. Most of the timber adopted for roofing are Grade A or B. Therefore, the timber mill plays a very important role to ensure the quality of the sawn timber which will be used for roof truss systems.

A case study will investigate the operations of a typical roof truss company in Malaysia. The costing of the timber roof truss fabrication for a project will be reviewed and analysed. Finally, the challenges that may be faced by the company or the timber roofing industry will be identified in this research project.

The review will provide information that will be extremely useful to the timber industry. The end result could be a marked improvement in the quality and quantity of timber products provided to local and international markets.

1.2 Research Goal

1.2.1 Aims

The research aims to review the current timber industry in Malaysia, particularly in the construction technique of roof trusses.

1.2.2 Objectives

The objectives of this research are as followed:

i) investigate the classifications, properties, uses and market of the Malaysian timber;

ii) review the timber roofing industry in Malaysia;

iii) document the standard and quality of timber required for the timber trusses; and

iv) review the design method and the costing involved for the truss system.

1.2.3 Hypothesis

Timber roofing industry will grow continuously in Malaysia due to the local demand and the industry is capable to face the challenges such as sustainability of forests and the competition of steel trusses.

1.3 RESEARCH METHODOLOGY

1.3.1 Literature Review

A literature review will be conducted to study the background and current development of the forestry and timber industry in Malaysia. Through the literature, the challenges that are faced by the industries, environmental issues for example, will be identified. Statistical data and the marketing information of the Malaysian timbers will be determined from government publications.

1.3.2 Interview

Interviews will be conducted with representatives from the local roof truss companies. Some valuable opinions regarding the challenges faced by the timber industry will be collected, as well as the factors involved in the design of timber roof systems.

1.3.3 Factory and Construction Site Visits

The process of manufacturing sawn timber will be inspected during the factory visit. The sawn timber mill produces timber based on the standard requirements which are set by the Malaysian Timber Industry Board (MTIB) who is the Grading Authority of Malaysia. A construction site visit will also be conducted during the fabrication of roof system of the building. This will provide some familiarity with the practices on the construction site.

1.3.4 Case Study

The organisational structure and the operations of a timber roof company will be investigated in order to identify the standard practices in the timber industry. The operations and development of the company will be investigated as parts of the case study. In addition, the costing of the timber roof system for a project will be reviewed and analysed.

1.4 Resource Analysis

1.4.1 Literature Sources

Most of the literature is taken from reference books and journals, whereas the statistical data is from the government publications. The resources are collected from the libraries of Malaysian Timber Council (MTC), Malaysian Timber Industry Board (MTIB) and Forest Research Institute of Malaysia (FRIM). The information from the internet is also listed in the literature review. On the other hand, some of the resources of the case study will be obtained from catalogues of roof truss companies.

1.4.2 Case Study Sources

Through the interview, more information about the quality control on the sawn timber may be collected during a visit to a sawn timber mill. The documents regarding the costing of the timber roof system for a project are obtained from a local construction contracting company.

CHAPTER 2: LITERATURE REVIEW

2.1 Background on Forestry Industry

2.1.1 Introduction of Forest in Malaysia

Malaysia is located in an equatorial region where the rainfall and humidity are high, there is little wind and it is sunny for the whole year round. Therefore, tropical rainforests are widely grown in Malaysia. 62% of the total land area of Malaysia is covered by the tropical forests. The Table 2.1 and 2.2 show the forest area and the permanent forest estate in Malaysia respectively. In 2002, the forested area was 19.29 million hectares. Out of the total forested land, 14.40 million hectares was designated as Permanent Forest Estate (PFE). The PFE includes 3.81 million hectares of protected forest and 10.59 million hectares is production forest. The total area of PFE is able to remain in 2003. However, the total forested area decreased to 19.89 million hectares in 2003 (Ministry of Primary Industries Malaysia, 2003). It is shown that the forest exploitation is increased whereas the amount of PFE has been maintained. There are more than 25, 000 plant species grown in the Malaysian forests (SLUSE, 2002).

The natural resources are used for the purposes of subsistence farming, commercial agricultural, mining, timber and urbanisation and infrastructure. These activities are critically essential to strengthen the economical growth in Malaysia.

Table 2.1: Forested Area in Malaysia (Million Hectares)

Region	2001	2002	2003
Peninsular Malaysia	5.94	5.90	5.90
Sabah	4.42	4.41	4.41
Sarawak	9.84	9.61	9.58
Total	20.20	19.92	19.89

(Source: Ministry of Primary Industries Malaysia, 2003)

Table 2.2: Permanent Forest Estate in Malaysia (Million Hectares)

Region	Protected		Productive		Total	
	2002	2003	2002	2003	2002	2003
Peninsular Malaysia	1.90	1.90	2.90	2.90	4.80	4.80
Sabah	0.91	0.91	2.69	2.69	3.60	3.60
Sarawak	1.00	1.00	5.00	5.00	6.00	6.00
Total	3.81	3.81	10.59	10.59	14.40	14.40

(Source: Ministry of Primary Industries Malaysia, 2003)

2.1.2 History of Forest Industry

Malaysia was once colonised by the British before seeking independence in 1957. The British were importing a lot of labour from China and India to develop the forestry, plantation and mining industries during the colonisation. As a result, there was division of races, such as Malay, Chinese and Indians which resulted in the differences in economic activities. The natural resources from the forests became cash crops for the British and were exported to European countries. The forest industry was mainly operated by the Chinese.

After the independence of Malaya in 1957, the ethnic differences became more visible such that the Chinese controlled the economy while the Malays remained economically left behind. As a result, clashes occurred between Chinese and Malays. Finally, New Economic Policy (NEP) was first introduced in 1971 in order to overcome this problem. According to the NEP, Malays have privileged right in certain economic areas, including the land rights. The land development projects of government such as the projects from Federal Land Development Authority (FELDA) were exclusive to the Malays and natives. However, the non-Malays such as Chinese and Indians are still relatively free hands in a capitalist economy. They are allowed to keep control of their businesses, including private estates and natural resource exploitation (SLUSE, 2002).

The implementation of NEP influenced the land uses and environment. The land adopted is mostly for the purposes of timber extraction, commercial agricultural (plantations) and shifting cultivation. Timber extraction from the forests is one of the main areas of economic growth in Malaysia (SLUSE, 2002). Therefore, large number of timber processing industries was developed and were able to grow continuously due to the availability of the raw materials.

2.1.3 Challenges Faced by the Forestry Industry

(i) Environmental Issues

The most critical impact faced by the forestry industry is environmental issues. The rainforest is destroyed when the timber extraction takes place. The uncontrolled clearing of tropical forests has risen a serious environmental problem. According to the International Tropical Timber Organisation (ITTO), less than 1 percent of tropical forest is managed and sustained after the harvesting (World Bank, 1994). However, many log producing countries such as Malaysia have realised that the significance sustaining of forests is beneficial in the long term (Forestry Department Malaysia, 1996).

(ii) Illegal Logging Activity

The effort of forest management will be rewarded if everyone obeys the rules and regulations that are set up by the authority. However, there may be some difficulties due to the illegal logging activity by irresponsible people. A high number of cases of illegal logging was occurred in 1991, i.e. 512 cases, before the amendment to National Forestry Act 1984 (Malaysian Timber Council, 2004).

(iii) Increased Labour Cost and Shortage of Workers

The issue of labour is also one of the problems that are experienced by the forest industry recently. The cost of labour is increased due to the shortage of workers in the forest industry (Hashim & Narchahaya Jr, 1998). The local people, especially the younger generation, are not willing to work in a hard, difficult and hot workplace. Therefore, the industry is facing difficulties in finding workers.

(iv) Fire in the Forest Due to the Shifting Cultivation and Dry Weather

Clearing and burning the native plants are part of the process of shifting cultivation activity. The fire may be spread from the plantation area to the nearby forest. Land clearing is the most probable cause of the forest fire in Malaysia. On the other hand, fire may also occur due to the dry weather. These can be resulted not only in the lost of natural resources, but also cause the air pollution (Wan Mohd Shukri, 2001).

2.1.4 The Solutions to the Problems

(i) Sustainable Forest Management

The National Forestry Policy (NFP) was implemented in 1978, to achieve a definite and stable forest resource. Under the policy, Permanent Forest Estate (PFE) was established to maintain the certain amount of forest area in Malaysia. Furthermore, the timber certification system is also one of the tools used to measure the sustainability of forest management. Malaysian Timber Certification Council (MTCC) is the authority to certify the timbers with the MTTC logo (WWF Malaysia, 2003). The timbers must be certified showing that these products are from the sustainable managed forests or else a penalty will be imposed on the transgressor (Hashim & Narchahaya Jr, 1998).

(ii) Enforcement of Laws Due to the Illegal Logging

The Malaysian forest amendments are according to the state forest laws. The states in Malaysia follow their own forest law respectively:

(a) Sabah – Sabah Forest Enactment 1992;
(b) Sarawak – Sarawak Forest Ordinance 1996; and
(c) Peninsular Malaysia – National Forest Act 1993.

All these laws contain the provisions for curbing and controlling the forest crimes, including illegal logging, and the ability of enforcement officers (Chen & Balu, 2002). The government has set up the sustainable timber harvesting as 25 – 30 year cycles. Therefore, only the big or mature trees can be logged. Furthermore, during the exploitation, the roads have to be carefully constructed to minimise the damage to the environment (SLUSE, 2002). Laws are amended with much higher fines and penalties, so that the forest crimes will be reduced.

(iii) Import of workers From Foreign Countries

Recently, Malaysia imports a lot of foreign workers from other countries such as Indonesia, Pakistan, Vietnam and China to fill the lack of workers in many industries. Foreign workers are hired in order to handle the labour shortage for both skilled and unskilled labours in the forest industry (Hashim & Narchahaya Jr, 1998).

2.2 Background on Timber Industry

2.2.1 Introduction of Timber Industry

The timber industry is one of the main economic activities in Malaysia. The availability of resources and the well development of wood processing infrastructure have supported the timber industry growth. The total amount of timber exports reached its highest level at US$4.7 billion in 2000. Malaysia became the world's largest exporter of hardwood logs and sawn timber (MalaysiaInformation.com, 2003). However, the production of timber decreased slightly in 2001. Thus, Malaysia becomes the world's second largest timber exporter after Indonesia. The largest amount of export for timber products are wooden furniture, followed by plywood and sawn timber (Ministry of Primary Industries Malaysia, 2003).

There are various sectors of timber industry in Malaysia. The structure of the industry is shown in Figure 2.1. They are classified into three main sectors, i.e. sawmilling, wood chipping and veneer manufacturing. Sawn timber is manufactured under the sawmilling sector. It produces treated sawn timber and mouldings and joinery products. On the other hand, the medium density fibreboard, pulp and paper, and particleboard are manufactured by wood chips and wood fibre. Then, veneer manufacturing produces plywood, laminated veneer lumber (LVL) and other veneer products. All these products are used for the purposes of furniture and housing materials (S. Rajan, 2003).

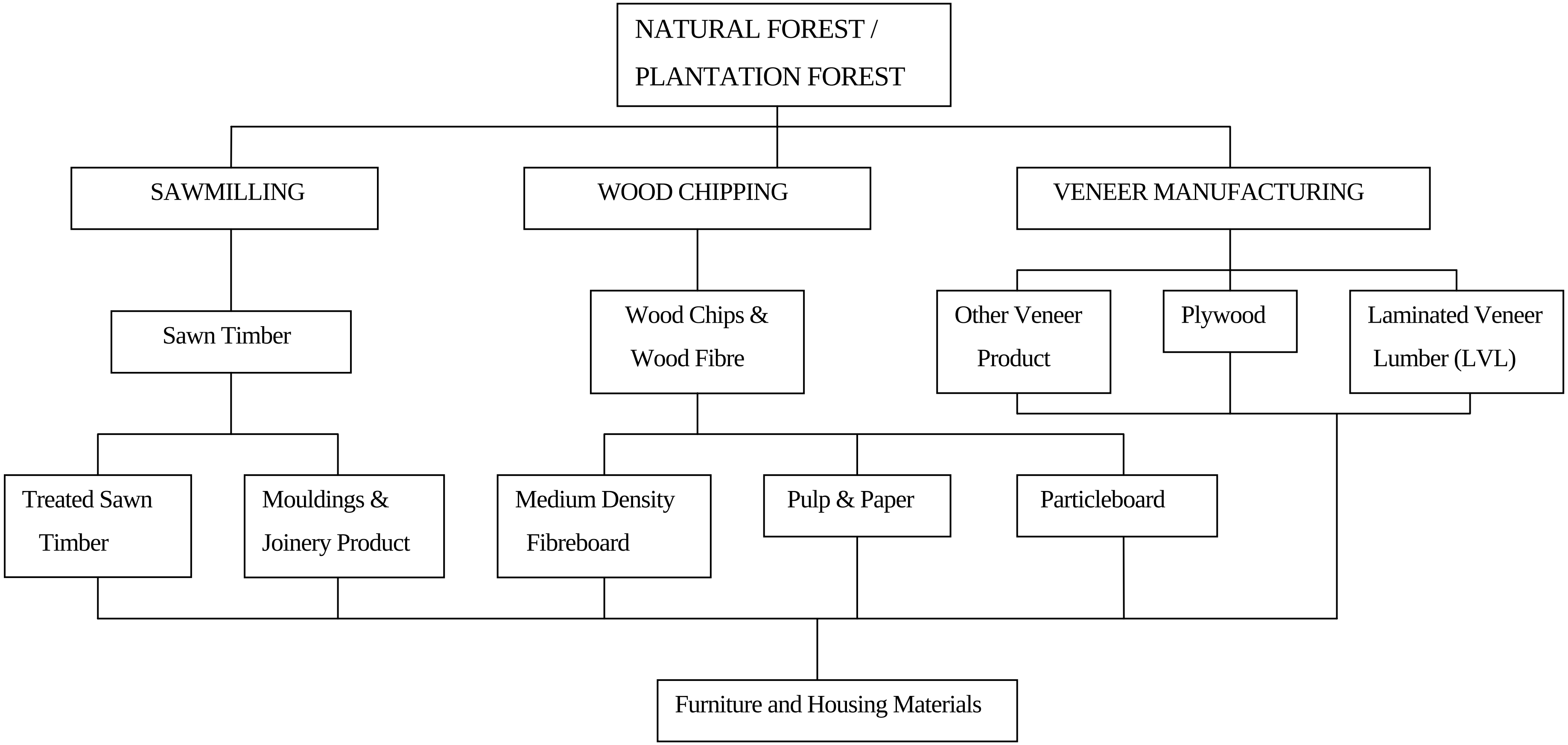


Figure 2.1: Structure of Various Sectors of Timber Industry in Malaysia

(Source: S. Rajan, 2003)

2.2.2 History of Timber Industry

Sawmilling was the earliest wood-based industry that established in Malaysia. Then, the plywood, moulding and chipboard industries emerged gradually and their contributions were significant to the Malaysian economy. These industries had expanded rapidly during 1980's due to the increasing demand in overseas markets. The number of processing mills increased significantly during that time (Hashim & Narchahaya Jr, 1998). The statistical data for the number of sawmills, and plywood and veneer mills in Malaysia show that there were 1, 438 mills in 2002 and 1, 265 in 2003 (Ministry of Primary Industries Malaysia, 2003).

Based on the statistic from the Ministry of Primary Industries of Malaysia 2003 (refer to Appendix, page B1), the export value of furniture is the highest among the wood-based products, followed by the plywood product. Therefore, the development of furniture and plywood manufacturing will be excellent in the near future.

2.2.3 Contribution of Timber Industry to Malaysian Economy

The export of timber products has contributed a lot to the Malaysian economy. It is one of the main foreign exchange-earners for the country. RM10.5 billion or 2.9% of the total export value was contributed by the manufacturing of wood products in 2002. The total sales of the wood-based products in both local and international was RM10.6 billion in which RM6.0 billion was contributed by the panel products such as plywood, medium density fibreboard and particle board. All the sales of wood-based products, i.e. furniture and components, panel products, and mouldings and joinery, were increased compared to the sales in 2001 (Ministry of International Trade and Industry Malaysia Report, 2003).

The employment in timber sectors is significant in Malaysia. According to statistics, there were 105, 366 employees in the wood-based products industry in 2002. Employment was increased by 4.1% compared to the previous year. The employment in the timber industry contributed 10.8% of the total manufacturing workforce in Malaysia (Ministry of International Trade and Industry Malaysia, 2003).

2.2.4 Challenges Faced by Timber Industry

(i) Raw Material Supply

The timber supply is limited by the National Forestry Policy (NFP) under the sustainable forest management. In 2001, the National Forestry Council (NFC) proposed that the annual allowable cut (AAC) was set to 1.36 million hectares. This was 23.7 % drop in the AAC compared to 2000 (Malaysian Timber Council, 2004). The statistic on the production of primary commodities in Malaysia shows that the production of the sawlogs is decreasing recently compared to the production in 1990's.

(ii) Sustainable Forest Management

The timber certification system was established under the sustainable forest management. As a result, an additional cost appeared for the purpose of accreditation. The increased price will probably be paid by the end-users, i.e. the consumers (Hashim & Narchahaya Jr, 1998).

(iii) Increased Labour Cost and Shortage of Skilled Workers

This situation is quite similar with the forestry industry faced as mentioned before. The shortage of local labours has increased the need for foreign labour. Furthermore, the need for the skilled and well-trained workers in the timber industry are increasing, particularly in the furniture and moulding sectors. Therefore, the workers' salary is increased in order to retain the workforce in the mill (Hashim & Narchahaya Jr, 1998).

(iv) Technology and Techniques

Automated equipment and machinery are widely used in the Malaysian timber industry. Malaysian Timber Industry Board (MTIB) states that the technology used in Malaysia is on par with the developed countries. However, due to the different nature of log from tropical hardwood versus softwood**,** not all of the technology used in developed countries is suitable for the Malaysian timber. Therefore, some modification of technology is needed to adapt the local timber characteristics (Hashim & Narchahaya Jr, 1998).

2.2.5 The Solutions to Against the Problems

(i) Alternative Raw Material

Alternative raw material, for example rubber wood, is used to substitute the natural resources. Rubber wood (*Hevea brasiliwnsis*) is timber from the rubber trees. It is initially grown only for its latex. It is recently used for manufacturing furniture and may also be used for the construction purposes. The Forest Research Institute of Malaysia (FRIM) has been doing a lot of research and development on rubber wood. The research has been taking place to develop new clones of the rubber species with a shorter maturity period which enables to produce higher wood and latex extraction to satisfy the rubber wood industry. Furthermore, the utilisation of wood waste is encouraged to produce panel product such as chipboard. According to the Eighth Malaysia Plan (2001-2005), the government will put some efforts in the research and development activities and develop new technologies in order to maximise the utilisation of wood waste (Economic Planning Unit, 2001).

(ii) Timber Certification System

The Malaysian Timber Certification Council (MTCC) has been working closely with other timber certification bodies. The objective of MTTC is to ensure that its certification scheme is committed to International Tropical Timber Organisation (ITTO) objectives. Malaysia will manage and develop its forests based on the guidelines, criteria and indicators formulated by ITTO (Nelson, 1996).

(iii) Technology and Techniques

The new automated wood working machines are adopted in many Malaysian timber companies. Most of the woodworking and furniture machines are imported from Germany, Japan, Italy and Taiwan (MTIB, 1998b). It helps to achieved higher productivity and fulfils the strict quality requirements. As a result, the labour cost is reduced because a lesser number of workers is needed to operate the timber mill (Hashim & Narchahaya Jr, 1998). In addition, the waste of raw material may be reduced by these technologies and techniques.

(iv) Sustainable Forest Management

According to the Seventh Malaysia Plan (1995-2000), Malaysia will emphasise on long term management of its natural resources in order to maintain the ecosystem and protect the environment. Furthermore, the enforcement against illegal logging will be intensified to ensure the annual allowable cut (AAC) of the Malaysian logs is under control (Wong Nelson, 1996).

CHAPTER 3: BACKGROUND OF MALAYSIAN TIMBER

3.1 Malaysian Grading Rules

3.1.1 Introduction

Malaysia has a complete set of timber grading system. The Grading Authority is the Malaysian Timber Industry Board (MTIB) and the standards procedures are based on the Malaysian Grading Rules (MGR). The MTIB is established to oversee the overall development of the timber industry in Malaysia. The MTIB provides Timber Verification Service (TVS) to ensure the standard and quality of the timber products.

The quality of the timber is identified in terms of durability, strength and appearance. However, for the structural members which are designed by the engineering calculations emphasis on the aspects of durability and strength, rather than appearance. The correct timber species that to be chosen is very essential for the high strength requirement. In addition, the desired moisture content and the proper treatment of the timbers are the main factors in order to obtain the certain standards. Therefore, the inspection is necessary to ensure the proper methods are adopted by the timber manufacturers in order to meet the specifications.

Basically, the MGR for the sawn hardwood timber is divided into two major parts, general market specifications and special market specifications. The MTIB employs Quality Control Inspectors to supervise the grading, and issue the Grading and Inspection Certificates for the timber products. Furthermore, the Quality Control Inspectors supervise the kiln drying as directed by the Grading Authority. Then, the Timber Grader and Dry Kiln Operator who possess the certificates of competency which are issued by the Grading Authority conduct their duties according to the MGR. Sometimes, the authority will check the work of the Timber Grader under the request of the buyer.

In order to ensure the Rules will be accurately applied, every Timber Grader are allowed and recommended to bring along some equipment such as a sharp knife, a lens, a brush, a two foot ruler, a properly graduated length measuring stick, a piece of string or fine wire, a Tally book, and a copy of the MGR. Before the grading starts, the grader has to read the contract carefully, as well as the relevant note for that particular timber. The Grader also needs to check the light condition during the inspection. Sufficient light is crucial to avoid any mistakes in grading. Night grading is totally prohibited (MTC, 2002).

Malaysian timbers are classified into four categories, which are Heavy Hardwoods, Medium Hardwoods, Light Hardwoods, and Softwoods. These are the standard timber names that will be used in the contracts, Schedule of Timber Shipped and Grading or Inspection Certificates. The classification is based on their densities. Generally, the denser timber will obtain higher strength. The timber characteristics influence their applications for structural or non-structural purposes.

3.1.2 General Market Specification

General market specification for timber product is stated in the MGR. These rules provide the standard for grading boards and planks which are usually re-sawn before to be the end products. The timbers may be graded as Prime, Select, Standard, Sound, Serviceable, and Utility. The identification of these grades depends on the timber’s width, length, sapwood, knots, spring, warp, wane and brittle heart. All these factors are important to identify the quality of the sawn timber in order to serve a specific purpose. Furthermore, there are various types of cutting requirements for the individual grades of timber and the minimum cutting requirement is stated for every grade (Refer to Appendix B2).

The grades are usually be listed together with the "and better" basis under one tally, one grade mark and one price. However, the basis is not applicable in the Utility grade. The "Utility and better" is marked as "Merchantable". The grade mark is the symbol that is used to identify the given grade for the timber. This grade mark indicates that the "lowest grade" of the timber. In other words, the quality of the timber is better than what is the timber grader have been graded. Therefore, the grades are normally listed as:

- SELECT AND BETTER – should normally include the full product of the log in Select and Prime grades;
- STANDARD AND BETTER – should normally include the full product of the log in Standard, Select and Prime grades;
- SOUND AND BETTER – should normally include the full product of the log in Sound, Standard, Select and Prime grades;
- SERVICEABLE AND BETTER – should normally include the full product of the log in Serviceable, Sound, Standard, Select and Prime grades; and
- MERCHANTABLE – should normally include the full product of the log in Utility, Serviceable, Sound, Standard, Select and Prime grades. Hence, the timber that is graded as "Merchantable" possesses higher quality than the ordinary "run-of-mill" because the under standard timber is rejected during the grading (MTC, 2002).

The rules also classify the grading of timber containing scattered pin holes, included phloem, or latex or leaf traces, but few or not other defects.

- PHND (Pin Holes No Defect) – some of the Malaysian timbers such as Chengal and Kapur have pin or needle holes which commonly occur scattered over the face of a piece. Therefore, the minimum number of clear face cuttings cannot be obtained free of such holes;

- IPND (Included Phloem No Defect) – Kempas, Tualang and Jongkong are the examples of timbers that included phloem which commonly occurs on the face of a piece. Therefore, it may be difficult to obtain the minimum number of clear face cuttings for free of such included phloem; and
- LTND (Latex Traces or Leaf Traces No Defect) – some timbers, for examples Jelutong and Pulai, are latex traces or leaf traces. It is impossible to obtain the minimum number of clear face cuttings for free of such traces.

The timber that is purchased under these specification must be met the cutting requirement of each grade as defined in the rules of General Market Specifications.

The timber is kiln dried is one of the main factors for increasing the strength property of the timber. Based on the Rules, the timber should be graded, check-graded and measured before the kiln drying process is conducted for shipping dry timber**.** The recommended sawn sizes (shown in Appendix B7) have to be strictly followed. This is because to prevent the possible scantness for the high shrinkage properties of certain timber species after kiln drying (MTC, 2002).

Checks, warps, splits, separation of knots and resin pockets, and cracked knots, caused by kilning shall not be considered as defects. However, the serious splitting, deep checking, excessive separation of knots and resin pockets, badly cracked knots, collapse, honeycombing, and undue scorching other than that of a superficial nature shall be considered as defects and must be rejected by the Dry Kiln Operator (MTC, 2002).

3.1.3 Special Market Specifications

The special market specifications provide the grading rules for:

- Prime wide and panels;
- Strips (including strip flooring);
- Shorts (including block flooring);
- Cross arms;
- Wagon planks;

- Railways sleepers and crossings;
- Scantlings;
- Large scantlings and squares;
- Decks; and
- Stress grading.

The scantlings and stress grading sections will only be discussed in this research. Scantling is defined as a piece of sawn timber with rectangular section and the thickness usually equals or exceeds half its width (MTC, 2002). The scant sawn timber is undersize which means the sawn timber that is measured, at the time of inspection, less than the dimensions specified. Under the scope of the Scantlings Section, the scantlings for structural members should be graded under Stress Grading Section.

The structural members that have been designed by engineering calculations do not be graded from the timber appearance. This is because good appearance is not a main factor for the structural members but the strength capacity of the timber. There are three types of grades under the Stress Grading as shown in Table 3.1.

Table 3.1: Grades and Grade Marks under the Stress Grading.

Grades	Select Structural	Standard Structural	Common Building
Grade Marks	F | D I	F | D II	F | D III

(Source: Malaysian Timber Council, 2002)

According to the Stress Grading Rules, a piece of timber of a given size in a grade must have a certain minimum strength to support the applied load. The grades are multi-purpose grades which mean they are applicable to all of the structural timbers. They can be used for beams or columns and the recommended working stresses will be applied respectively. The rules allow the members to be re-sawing to shorter lengths, but will not cause defects beyond the extent permitted in the grade concerned (MTC, 2002).

The Standard Structural grade timber is adopted for normal purposes. The rules allow certain defects exist at the end of the piece of timber. The end-trimming is allowed for the bolts and other timber connectors be used in pieces when lengths are specified. In addition, the rules also agree that the occurring of end splits after grading.

On the other hand, the Select Structural grade is adopted for special purposes, particularly where the maximum value of strength to weight ratio of the timber is emphasised. Then, the Common Building grade timber is for wooden member which is used in the parts of a building. However, they are not usually designed by the engineering calculations. This rule provides a guideline to the quality of the timber that is used in the high quality construction (MTC, 2002).

The rules provide the methods of measuring defects as well as the maximum permissible limits of the various kinds of defects for each grade. The defects that might be existed in the timber are sloping grade, curvature, holes, borer, knots, decay, sound sapwood, wane, end splits, twist, brittle heart, open shakes, surface checks and end checks (Refer to Appendix B8).

The defects of the timber will influence its strength capacity. Therefore, serious defects are not permitted in the structural members. The limitations of these defects that stated in the Stress Grading Section are essential in grading to obtain the high quality of timber in term of strength capacity.

3.1.4 Definition of Strength Group

The strength grouping method is based on the compressive strength parallel to grain. There are four categories of strength groups for the Malaysian timbers, i.e. strength groups A, B, C and D. Strength Group A is identified for the extremely strong timber, whereas the weakest timbers are classified as Strength Group D. The range of the compressive strength for the corresponding strength groups are shown in Table 3.2.

Table 3.2: Strength Grouping Table.

Strength Group	Compressive strength parallel to grain (N/mm^2)
A	Greater than 55.2; extremely strong
B	41.4 – 55.2; very strong
C	27.6 – 41.4; moderately strong
D	Less than 27.6; weakest

(Source: Malaysian Timber Council, 2002)

3.2 Classification and Density Range of the Timbers

There are four categories of the classification of Malaysian Timbers. They are Heavy Hardwoods (HHW), Medium Hardwoods (MHW), Light Hardwoods (LHW) and Softwoods (SW). The Hardwood and Softwood are classified for the normal botanical convention. Table 3.3 shows that there are three categories of Hardwoods are classified based on the range of the density. The particular timber is classified by taking its average density at 15% moisture content (MTC, 2002). This is the standard to getting the density that will lie on the range in order to classify the timber.

Table 3.3: Timber Classification Table.

Classification	Density Range (15% m.c.)
Heavy Hardwood	800 – 1120 kg/m^3
Medium Hardwood	720 – 880 kg/m^3
Light Hardwood	400 – 720 kg/m^3
Softwood (Botanical distinction)	385 – 735 kg/ m^3

(Source: Malaysian Timber Council, 2002)

However, there are some exceptions for the HHW category when considering the priority on the natural durability over the density of the timber. For example, Merbau which having an air-dry density of 800 kg/m^3, is classified as HHW because of its heartwood being naturally durable (MTC, 2002). Malaysian Grading Rules has introduced 100 species groups of timbers into the Hardwood categories (Refer to Appendix B11).

3.2.1 Heavy Hardwoods (HHWs)

The HHWs are heavy timber and having the density range from 800 to 1120 kg/m^3 at 15% moisture content. Furthermore, the timbers are naturally durable due to toxic substances that contained within their tissues. Therefore, they are mostly adopted for construction materials especially in the exposed conditions without undergoing any preservative treatment. Since the sapwood is not naturally durable, it requires preservative treatment to prevent the destroying from the termites (P. K. B. Menon, 1993).

3.2.2 Medium Hardwoods (MHWs)

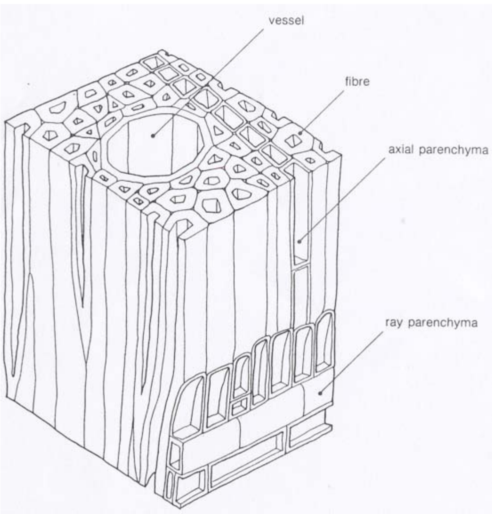
The MHWs are moderately heavy to heavy timbers and having the density range from 720 to 880 kg/m^3 at 15% moisture content. They are moderately durable and are mostly used for moderately heavy to heavy construction purposes. The MHWs require proper preservative treatment in order to gain the durability if they are used in exposed conditions and in ground contact. However, the MHWs are naturally durable enough under temperature conditions where the activity of the wood destroying agents is less (P. K. B. Menon, 1993).

3.2.3 Light Hardwoods (LHWs)

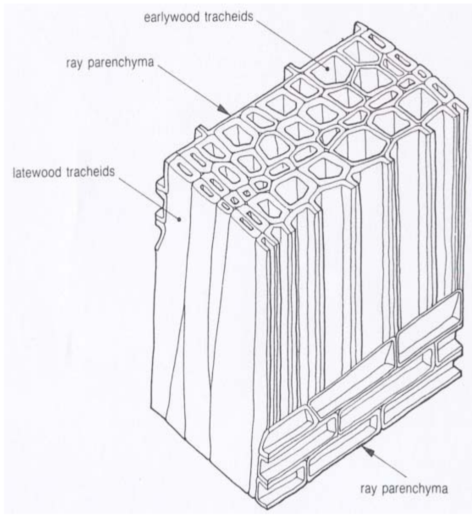
The LHWs are relatively light timbers and having the density range from 400 to 720 kg/m^3 at 15% moisture content. They are not naturally durable in tropical climate but are quite durable when used in temperature conditions. The LHWs are mostly adopted for general utility timbers, high class joinery work, cabinet making, furniture and decorative panelling. Since the LHWs are weak in durability, they need to be treated with chemical preservatives to avoid the fungi, insects and termites to destroy the timbers (P. K. B. Menon, 1993).

3.2.4 Softwoods (SWs)

There not many softwood species of commercial significant in Malaysia. Softwood is the timber that contains tracheids instead of vessels (pores) as the hardwood contained. The density range from 385 to 735 kg/m^3 and the SWs are mainly adopted as decorative plywood and panelling. There are only three species of softwoods introduced by the MGR. Damar Minyak (*Agathis spp.*) is the only one that is commercial significant at the moment (P. K. B. Menon, 1993).



(a)



(b)

Figure 3.1: Diagrams of a cube of (a) hardwood, and (b) softwood. Magnification $\times$ 250. (Source: Keith R., 1993)

3.3 The Uses of the Popular Malaysian Timbers

Most of the Malaysian timbers are hardwoods. Hardwoods have more strength capacity compared with softwoods. Therefore, hardwoods are suitable for both structural and non-structural construction purposes. A certain species of timber possesses the characteristics that will affect its uses. Table 3.4 shows that the uses of the some popular Malaysian timbers.

Table 3.4: The Uses of the Popular Malaysian Timbers.

Standard Name	Classification	Strength Group	Uses
Balau (*Shorea spp.*)	HHW	A	All heavy constructions, bridges, railway sleepers, piling, beams and posts.
Belian (*Eusideroxylon zwageri*)	HHW	A	All heavy constructions, marine piling, boat construction, posts and heavy-duty flooring.
Bitis (*Madhuca utilis*)	HHW	A	Heavy construction, bridges, piers, railway sleepers, beams and posts.
Chengal (*Neobalanocarpus heimii*)	HHW	A	Marine construction, bridges, boat construction, and heavy-duty flooring.
Kempas (*Koompassia malaccensis*)	MHW	A	All heavy constructions, railway sleepers, beams, posts, joists and rafters.
Keriung (*Dipterocarpus spp.*)	MHW	B	Heavy and general construction, posts, beams, joists, flooring and bridges.
Mengkulang (*Heritiera spp.*)	MHW	B	Furniture panelling, decorative work, sliced

			veneers and plywood.
Punah (*Tetramerista glabra*)	MHW	A	Heavy construction, posts, beams, joists, rafters, and heavy-duty flooring.
Dark Red Meranti (*Shorea spp.*)	LHW	C	Joinery, furniture, beams, posts, joists, rafters, panelling, and plywood.
Jelutong (*Dyera spp.*)	LHW	D	Manufacture of pencils, toys, battery separators, cabinets, and dowels.
Meranti Bakau (*Shorea uliginosa*)	LHW	C	All general light constructions, joinery, plywood and furniture.
Nyatoh (*Saptaceae spp.*)	LHW	C	Furniture, decorative interior finishing, veneer and plywood.

(Source: Malaysian Timber Council, 2002)

Note: ( ) is the botanical name of the timber species.

3.4 The Markets of the Malaysian Timbers

Malaysia is one of the largest exporters of the tropical hardwood logs, sawn timber, tropical plywood, veneer and mouldings in the world. The productivity of timber products is increasing and significant for the local and international demands. Sawn timber and manufactured timber such as plywood, chipboard, moulding, oriented strand board and laminated veneer lumber are the main products in the Malaysian timber industry supplied for the markets.

3.4.1 Local Market

The local construction sector is the largest market for the sawn timber and plywood (MTIB, 1998c). These timber products are mainly used for formwork, roof trusses and other structural members. In addition, the contributions of other timber products such as furniture and mouldings are essential to satisfy the local demand. There are also other minor uses of timber in the boat building and mining sector in Malaysia.

3.4.2 International Market

The earning from the international market is very important for the Malaysian economy. The major international market of the timber products are Japan, China, India, Taiwan, Singapore, Australia, United Kingdom, U.S.A, and South Korea. According to the statistics from the Ministry of Primary Industries of Malaysia, the export values of the wood based products are shown in Table 3.5.

Table 3.5: Export Value of the Wood Based Products.

(RM Million)

Wood Based Products	1990	2001	2002	2003e (Jan – July)
Sawn logs	4, 041.20	1, 529.02	1, 789.90	1, 139.23
Sawn timber	3, 064.70	2, 271.41	2, 227.49	1, 474.48
Dressed timber	-	158.86	184.80	-
Moulding & Dowels	487.80	965.80	1, 005.60	589.87
Veneer sheet	202.60	478.38	431.29	-
Plywood	818.30	3, 345.21	3, 652.46	2, 209.28
Particle boards	-	1, 208.27	1, 187.08	-
Furniture & parts	-	5, 200.11	5, 658.74	3, 388.12

(Source: Ministry of Primary Industries of Malaysia, 2003)

From the data above, it shows that the highest export earning of the wood based product is from furniture and parts. Sawn logs and timber are decreased compared with last century because of the sustainable forest management by Malaysia to endeavour to protect the environment. However, the export values of manufactured timber such as moulding and plywood are increased due to the government support.

CHAPTER 4: TIMBER ROOFING SECTOR IN MALAYSIA

4.1 Introduction of the Timber Used for Roofing

Most of the roof systems for the Malaysian buildings are made from timber. The other types of roof system such as steel truss and concrete slab are not so frequently used as timber roofing. The main factor that Malaysians refuse to adopt the steel truss is the cost involved but the steel truss systems are becoming popular recently. On the other hand, concrete slab roofs have some disadvantages such as leakage from the rain water due to the poor workmanship. The timber roof trusses are popular in Malaysia because they are cheap and easy to construct. However, this material faces some problems such as durability and strength capacity due to the Malaysian weather and the termite. Therefore, this is essential to control the quality of the sawn timber in order to guard against the problems.

First of all, the suitable species of timber should be properly chosen, for example strong timber is normally used for the structural purposes such as roof truss system. During the selection of the species, there are seven criteria that need to be considered. They include physical properties, mechanical properties, durability, wood-working qualities, availability and cost of the timber (Chu Y. P, 1992).

Dimensional stability, ease of wood-working and resistance to warping are the desired physical properties for the roof truss timber. The appearances of timber such as colour, texture and grain pattern are not important as the trusses are concealed. However, these appearances may be important when the roofing members are required to show their aesthetic value (Chu Y. P, 1992).

The strength of timber is related to the size of the member. The larger the size of the member the higher the strength obtained. Therefore, the high strength species of the timber is suitable to use for the high strength member in order to design a reasonable size for it.

The major problem of the durability for the timber roof truss is attack from fungi, termites and other insects. The timber must be treated by preservatives before being fabricated. Good workmanship, good ventilation and sound engineering practice are also important to ensure the durability of the timber roofing (Chu Y. P, 1992).

Good resistance to splitting is critically important for the wood working properties of the timber trusses, particularly for the joints of roof trusses using nails as fasteners. In addition, the good wood working timber can be nailed fairly easily (Chu Y. P, 1992).

Finally, the availability and cost also affect the selection of the timber species for the roofing system. The supply of the different species of timber varies in different parts of Malaysia. To save the transportation costs, the availability of the particular timber near the construction site will be considered. The cost of timber is based on the species required, for example *Bitis* is more expensive than *Meranti*.

There are three types of strength group in the classification of timbers for roof truss construction; they are strength group A, B and C. They are further divided into several subdivisions relating to particular characteristics. The classification is shown in Table 4.1.

Table 4.1: Classification of Timbers for Roof Truss Construction.

Strength Group	Naturally durable, no treatment required except sapwood		Non durable, can be treated		Non durable, difficult to treat	
	Prone to splitting	Not prone to splitting	Prone to splitting	Not prone to splitting	Prone to splitting	Not prone to splitting
A	*Balau* *Red Balau* *Bitis* *Chengal* *Giam* *Kekatong*	*Keranji*	*Kempas* *Mertas* *Tualang*		*Mata Ulat* *Penaga*	
B	*Kapur* *Merbau* *Resak*	*Tembusu*	*Keledang* *Keruing* *Kulim* *Merawan* *Merpauh* *Perupok*	*Mengkulang*		*Nyalin* *Punah* *Rengas*
C			*Bintangor* *Kungkur* *Mempisang* *Meranti, white* *Ramin* *Simpoh*	*Durian* *Machang* *Meranti, Bakau* *Penarahan*	*Meranti, light red* *Meranti, yellow*	*Gerutu* *Kedondong* *Melantai* *Melunak* *Meranti, dark red* *Mersawa* *Nyatoh* *Sepetir* *Terap*

(Source: Chu Y. P, 1992)

After the selection of the species of timber, the roof truss should be designed based on the accepted engineering practice and proved by testing or prototype testing. Currently most of the companies have developed their own software for roof truss design. The strength capacity of the member will be checked by analysis using computer software.

However, it is still necessary to check the validity of the results in order to ensure the accuracy of the design.

4.2 Types of Common Roof Shape

The shape of the roof is designed based on the imagination and engineering point of view. The variety of the roof shapes presents the aesthetic value of the architectural feature of the building. However, the designer has to consider the span, roof and wind loading as well for the particular project. The simpler the roof shapes the greater the economy for the project (MiTek, 1997).

There are four common types of roof shapes in the domestic construction which are Gable Roof, Hip Roof, Dutch Hip Roof, and 'L' and 'T' Shape Roof. There are shown in Figure 4.1 to Figure 4.4.

(i) GABLE ROOF

- simplest and most economic.

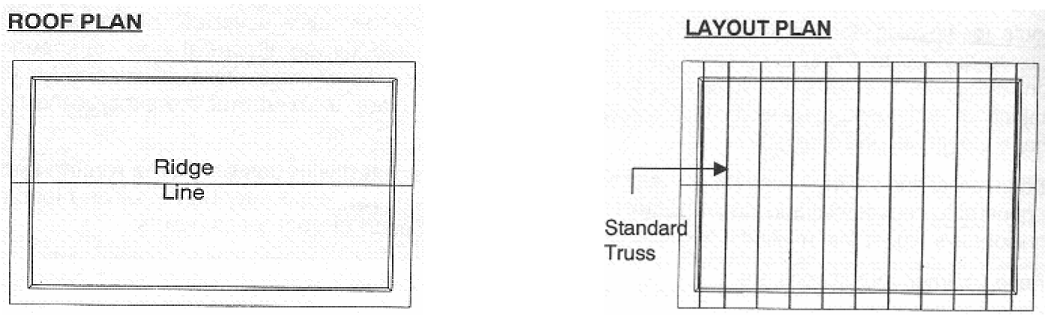


Figure 4.1: Gable Roof.

(Source: MiTek Asia Sdn. Bhd, 1997)

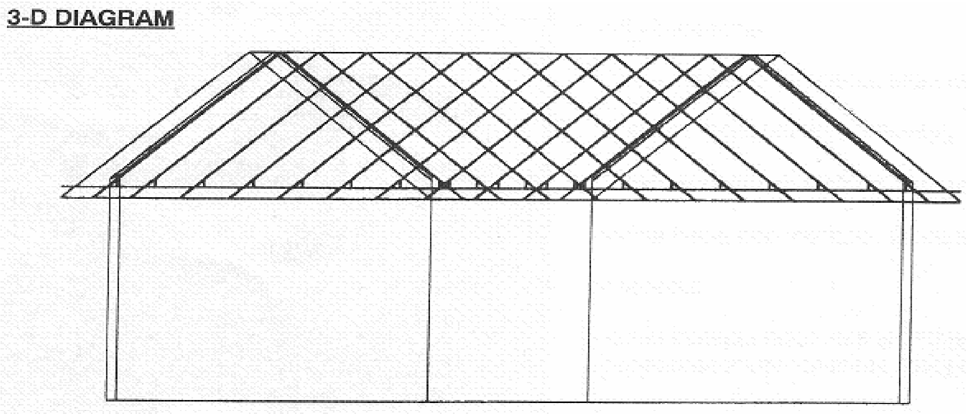
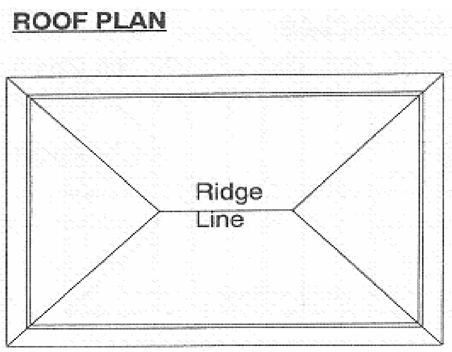


Figure 4.1: Gable Roof (cont.).

(Source: MiTek Asia Sdn. Bhd, 1997)

(ii) HIP ROOF

- mostly used in local buildings.



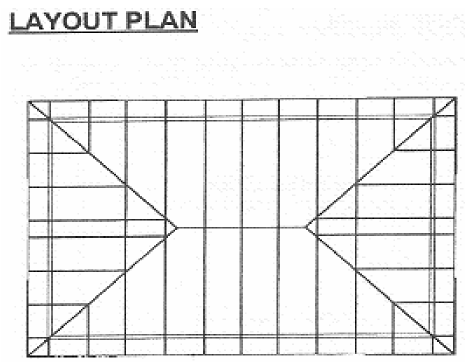


Figure 4.2: Hip Roof.

(Source: MiTek Asia Sdn. Bhd, 1997)

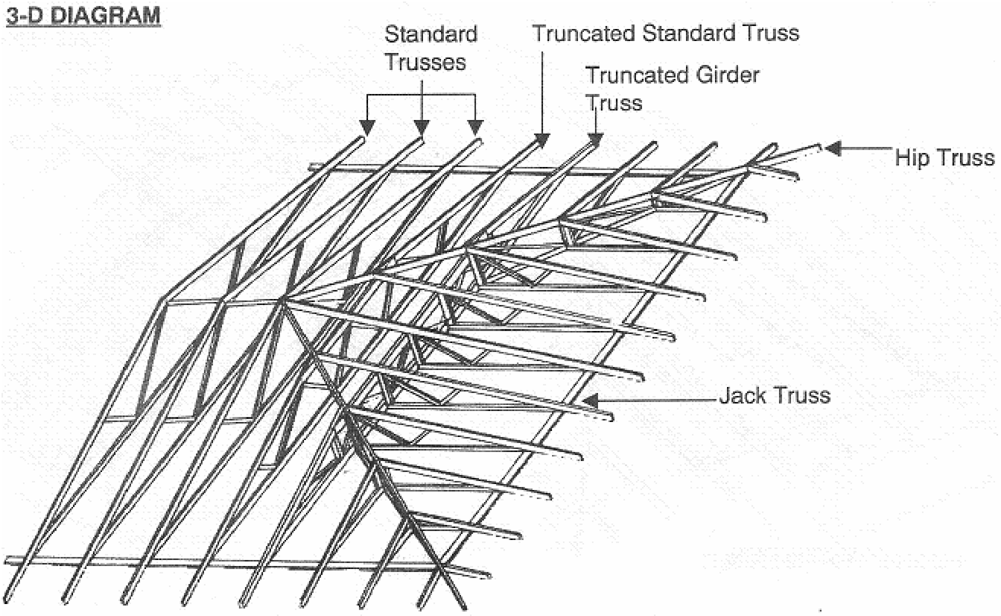
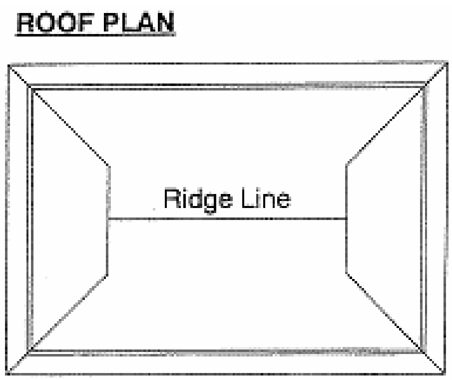


Figure 4.2: Hip Roof (cont.).

(Source: MiTek Asia Sdn. Bhd, 1997)

(iii) DUTCH HIP ROOF



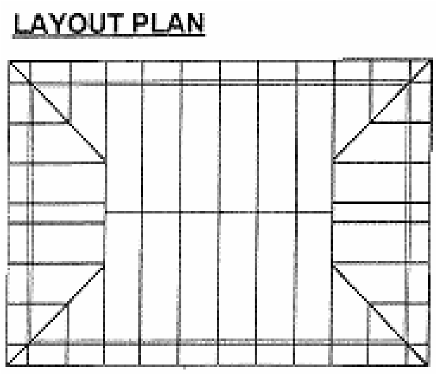


Figure 4.3: Dutch Dip Roof.

(Source: MiTek Asia Sdn. Bhd, 1997)

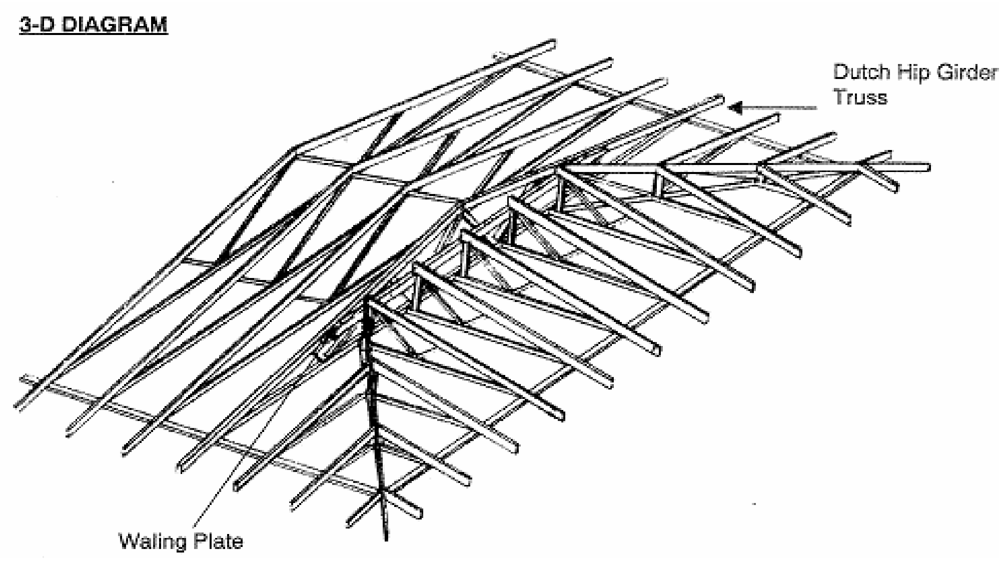


Figure 4.3: Dutch Dip Roof (cont.).

(Source: MiTek Asia Sdn. Bhd, 1997)

(iv) ‘L’ and ‘T’ Shaped Roof

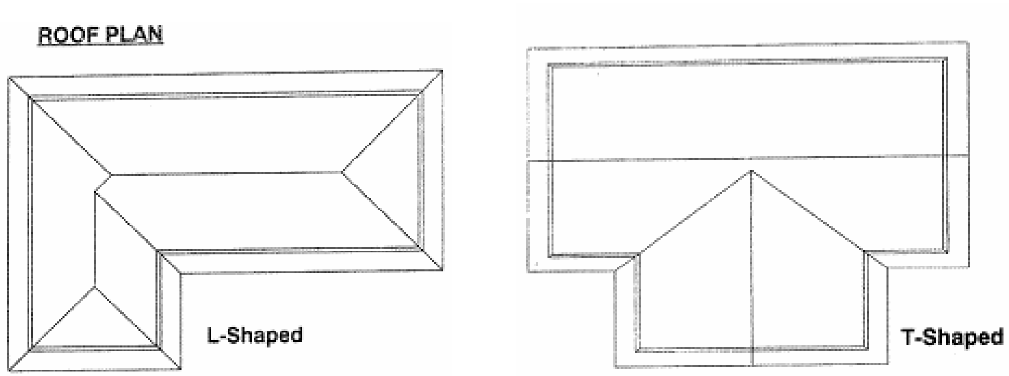


Figure 4.4: ‘L’ and ‘T’ Shaped Roof.

(Source: MiTek Asia Sdn. Bhd, 1997)

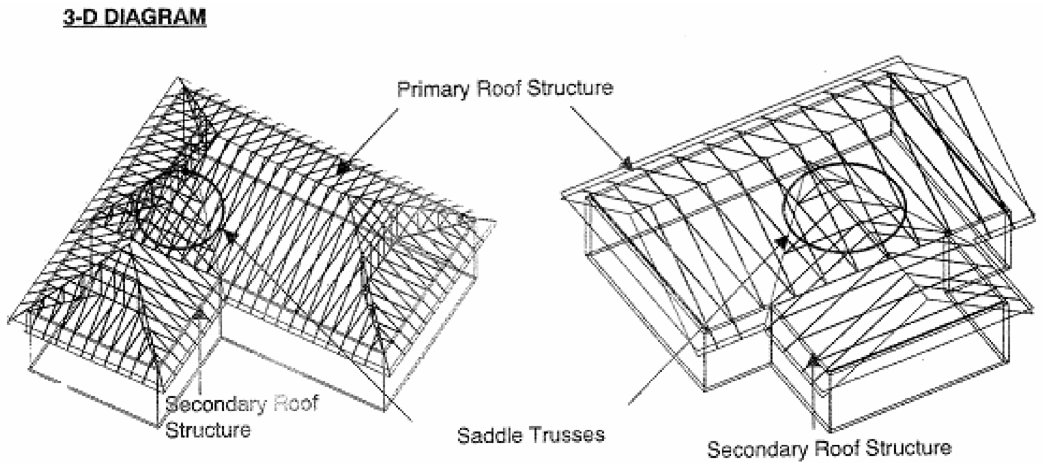


Figure 4.4: 'L' and 'T' Shaped Roof (cont.).
(Source: MiTek Asia Sdn. Bhd, 1997)

4.3 Truss Shapes and Spans

The truss shapes are designed due to the consideration with loading and span. The shapes of the trusses also affect the system performance. The most common timber truss shapes and the recommended spans by the MiTek Asia Company are listed in Appendix B12.

4.4 The Applications of the Timber Truss System

The application of the timber truss system achieves the advantages of carrying wind load, aesthetic and economic viewpoints. It is widely used in most of the buildings in Malaysia such as schools, hospitals, hostels, hotels, detached houses, terrace houses, condominiums, mosques and government buildings.

(a) Application of Timber Trusses in Terrace House.

(b) Application of Timber Trusses in Condominium.

Figure 4.5: Examples of Timber Truss System Applications.

(Source: MiTek Asia Sdn. Bhd, 1997)

CASE STUDY

CHAPTER 5: TIMBER ROOF TRUSS SYSTEM DESIGN

5.1 Company Profile

MiTek Asia Private Limited Company is a Malaysian company who works through a national network of License Fabricators. The company provides the fabrication and manufacturing of timber trusses licenses to a local company based on their timber industry experience, high standard of management, professional approach to the building industry and motivation and commitment to becoming a Licensed Fabricator.

MiTek Asia provides timber roof trusses design services to consulting engineers, architects and other regulatory bodies. The company also manufactures the Gang-Nail's products such as machinery and fasteners for the prefabricated timber building products manufacturing, and other timber connectors.

MiTek Asia supplies two third of the prefabricated roof trusses used in the Malaysian market and ensures the quality of their products.

5.2 Design Procedures

Before any competitive tendering of a project, all documentations have to be completed including the roof trusses plans and specifications. The documentation is prepared by the design company, MiTek Asia to produces the cover page, roof layout, bracing layout, truss hold down details, truss to truss connection details, bracing details, truss details and other details that related to the roof truss system. The design services are provided to all architects, consulting engineers and the builders at the early stage of the project.

(a) Cover Page

The cover page of the roof trusses document includes the design basis code of the design company, the table of contents, the design criteria and the notation of the document. Most of the design criteria such as the specifications of the trusses and the loading on the roof trusses are stated by architect.

During the design, the designer must take particular consideration on the additional loads by the M&E services and the water tank position. The stress grade of the timber can be either F14 or F11, the moisture of the timber can be chosen either dry or green, and J2 or J3 of the joint group is chosen during the timber selection. Since Malaysia is free from the cyclone disaster, the maximum of the design wind velocity is 33 m/s. Finally, the notations of rafters (R), hip rafter (HR), batten/purlin size, wall plate size and underpurlin (U/P) are defined in the cover page.

(b) Roof Layout

Roof layout shows the roof shape of the building which is designed by the architect. The roof shapes that are commonly adopted in Malaysian buildings are Gable Roof, Hip

Roof, Dutch Hip Roof, 'L' shaped roof, 'T' shaped roof and the combination among these roof shapes. The dimension of the roof is clearly shown and every truss is labelled.

(c) Bracing Layout

The position of the bracing system of the roofing can be determined in the bracing layout. According to the MiTek Asia design, the bracing system is fabricated by their product which is Gang-Nail 'Speedbrace'. Speedbrace is patented as a tension bracing system for the roof trusses. This is very important to prevent the trusses from buckling especially for long span trusses.

(d) Truss Hold Down Details

The truss hold down details show the connection at the heel of the roof trusses. The heel joint is typically a meeting point of three members of the roof truss. The timber connectors such as Gang-Nail Universal Trip-L-Grip can be used for that particular connection as shown in Figure 5.1. The minimum of the nails number for the connectors in each position are stated clearly in the truss hold down details.

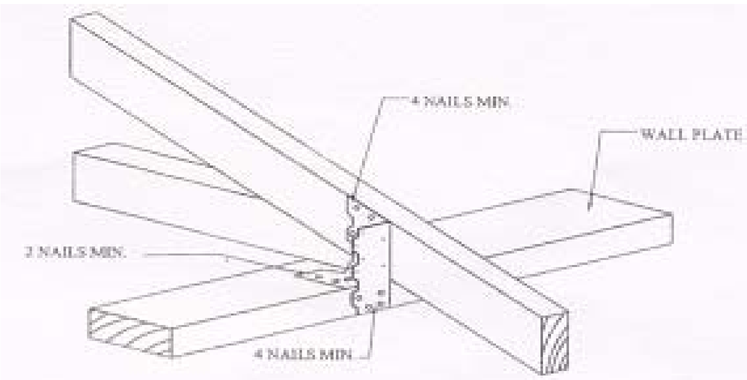


Figure 5.1: Roof Truss to Wall Plate Details Using one number Gang-Nail "Trip-L-Grip.

(e) Truss to Truss Connection Details

Truss to truss connection details are essential for the fabricator. There are many kinds of the truss to truss connection, connection of rafter/jack to hip truss for example. The details should be unambiguous to avoid mistakes during the fabrication of the roof trusses. Figure 5.2 below shows an example of truss to truss connection details.

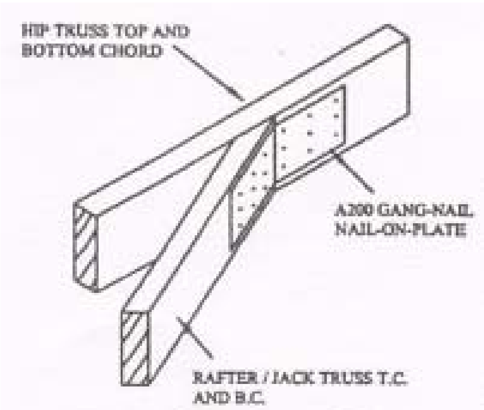


Figure 5.2: Example of Truss to Truss Connection Details.

(f) Bracing Details

Bracing Details show the details of the bracing members, Figure 5.3 for example. The size of the member and the number of the member used for bracing system are defined in the detail. Furthermore, the number and sizes of the nails that are adopted for fixing each of the braced members are also stated here. The bracing system is typically fabricated as a vertical diagonal bracing to the web members and top chord diagonal bracing.

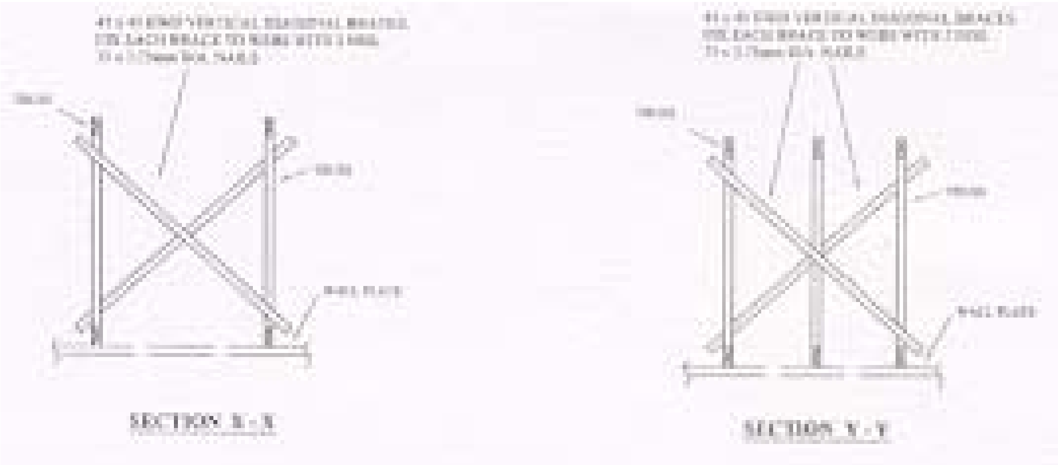


Figure 5.3: Example of Bracing Details.

(g) Truss Details

The structure of a particular roof truss is drawn clearly in the truss details. Figure 5.4 shows an example of truss details of a project. The degree of the pitch, the sizes of the members and the dimension of the roof truss are also available in the drawing. Each member is labelled with the symbols of ‘T’ indicates top chord, ‘B’ indicate bottom chord and ‘W’ indicate web.

There are timber list and plate list on the right side of the drawing. The depth of members, stress group and the specification of the timber are also defined for each of the member under the timber list. In addition, the moisture content and the thickness of the timber are stated as well. On the other hand, all of the joints in the truss are numbered and the connectors such as plates are defined under the plate list information.

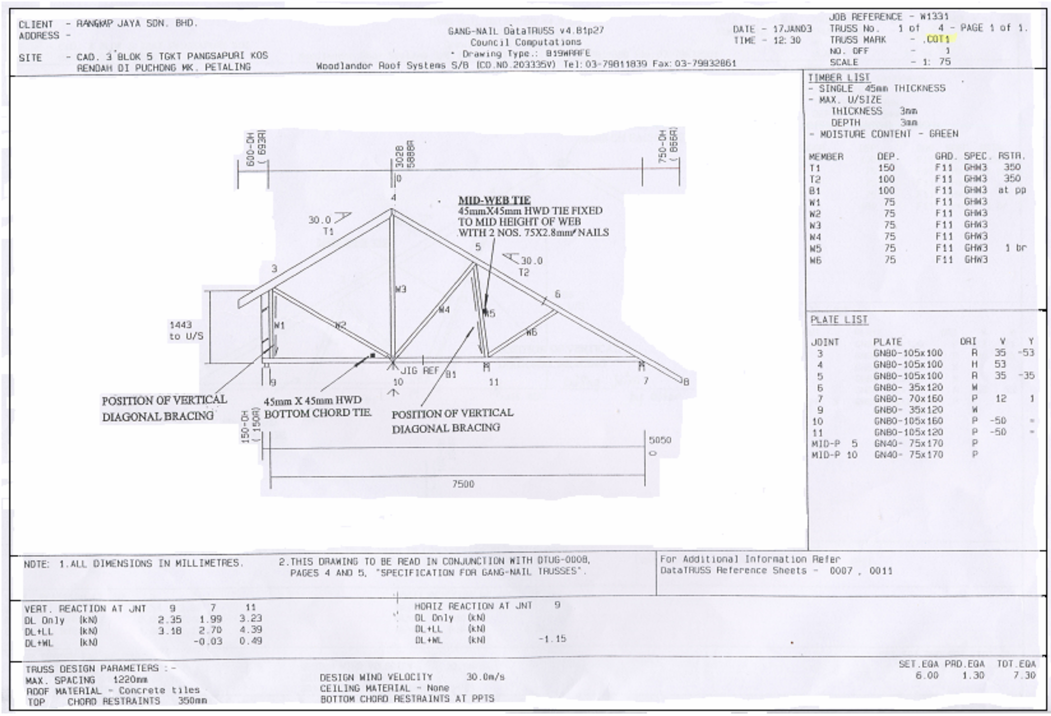


Figure 5.4: Example of Truss Details.

(h) Other Details

Other fixing of the roof truss systems such as saddle truss may be also included in some of the designs. Therefore, the saddle truss fixing detail which is shown in Figure 5.5 for example, must be included in the document. The drawing can be presented in plan, sections and three dimension illustrations. Every component is clearly labelled and the sizes of the members are stated. Then, the specifications of the timber connectors such as the sizes of the nails and the type of the plate used for the particular truss are defined as well.

Any ambiguous information in the design document will raise problems during the fabrication of the roof trusses. Therefore, it can be concluded that every single detail of the documentation is very important to ensure the actual design trusses are applied on the buildings.

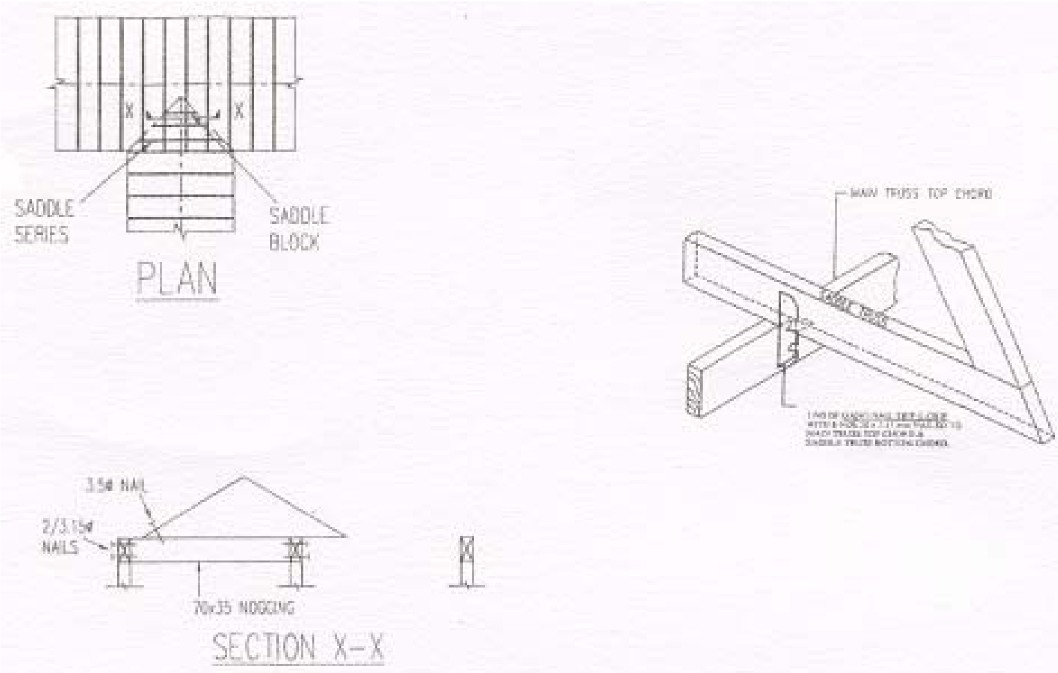


Figure 5.5: Example of Saddle Truss Fixing Details.

5.3 Design Method

The Gang-Nail Trusses are designed based on the Australian Code of AS1720 Timber Structures Code Design Methods. The design also follows the criteria in the Building Code of AS1684-National Timber Framing Code. The design loadings comply with the Malaysian Uniform By-Law where appropriate. MiTek and other fabricators' designs are based on the local available species of timber. Therefore, the Gang-Nail Trusses design is necessary to be corrected the stress grade and the joint group that been outlined in AS1720. Domestic, commercial and industrial buildings are the general types of building in Malaysia. Gang-Nail Trusses are designed in accordance with the characteristics of the Malaysian timber and the local weather condition in order to produce a quality roof truss system.

5.3.1 AS1684-National Timber Framing Code

The standard AS1684 specifies requirements for the selection, placement and fixing of structural timber members of conventional framed buildings. This is a very important standard as a basis for the layout and the installation of prefabricated roof trusses.

However, there are some limitations when using the AS1684 standard. First, the maximum design wind velocity is limited to 33 m/s. This value is more than enough for the roofing design of the Malaysian buildings. It is also limited to domestic type construction with standard roof and ceiling loads.

5.3.2 Uniform Building By-Laws

The Malaysian Uniform Building By-Laws states that on the flat roofs and sloping roofs up to and including 10° where no access is provided to the rood except for maintenance such as cleaning and repairing, an imposed load of 0.25 kN/m^2 is allowed, or a vertical load of 0.9 kN concentrated on a square with 125 millimetres side. Both of the loadings are measured in the plane of the roof. The greater stresses produced among these two is then taken under consideration in the roof design.

On the other hand, for the roof with a slope greater than 10° where no access is provided except for maintenance, the allowable imposed loads should be taken for:

(a) a roof slope of 30°, less than 0.25 kN/m^2 measured on the plane or a vertical load of 0.9 kN concentrated on a square with a 300 millimetres side, whichever produces the greater stress;

(b) a roof slope of 75° or more, no allowance of imposed load is needed; and

(c) a roof slope between 30° and 75°, the allowable imposed load may be obtained by the linear interpolation between 0.25 kN/m^2 for a 30° roof slope and for a 75° roof slope.

5.3.3 The Classification of Stress Grade and Joint Group for Malaysian Timber

Under the Malaysian Grading Rules, the Malaysian timbers are classified into four types of strength group, i.e. A, B, C and D grades. However, it is necessary to assign the correct stress grade (F) for the Malaysian timber species to be used for the design under the AS1720 methods (MiTek Asia Sdn. Bhd, 1997). Therefore, the stress grade that is adopted by the Malaysian Gang-Nail roofing design has been modified and is normally divided into two subgroups of standard and selected which are stated under the Malaysian stress grading system.

On the other hand, for the purpose of joints design, the joint classification is necessary to distinguish the joint strength properties of the species. There is a close relationship between the density and the joint strength of the species. The denser of timber the stronger the joint it has. The Malaysian timbers are classified into five groups, namely J1, J2, J3, J4 and J5 (Chu Y. P, 1987). Table 5.1 is a list of stress grades and joint classifications for the Malaysian timber species that are commonly used in the construction purposes.

Table 5.1: The Classifications of the Stress Grade and Joint Group for the Malaysian Timber Species.

Species	Stress Grade		Joint Group
	Standard	Selected	
Balam	F11	F14	J4
Balau (red)	F14	F17	J2
Chengal	F17		J1
Kapur	F14	F17	J2
Kempas	F14		J2
Keruing	F14	F17	J3
Mengkulang	F11	F14	J3
Meranti (dark red)	F8	F11	J4
Meranti (light red)	F7	F8	J4

Meranti (white)	F11	F14	J4
Tualang	F14		J2
Kulim	F14		J2

(Source: MiTek Asia Sdn. Bhd, 2004)

5.3.4 Building Types in Malaysia

The buildings in Malaysia are classified into three types which are domestic, commercial and industrial buildings. They have their roof and truss characters respectively that have to take into consideration during the roof truss deign.

Houses, flats, shops and offices are the examples of the domestic building in Malaysia. They are reinforced concrete column and beam construction. The walls are normally bricks and partition. The spaces of trusses are close together with 1200 mm centre to centre, whereas the small truss spans up to 10 metres are applied. The roof trusses are applied with the standard handling, erection and bracing details and the timber brace is normally used. Generally the point loads are only be induced by the solar units, hot water services and occasionally air-conditional units.

The commercial buildings include restaurants, schools, sport facilities and hall. They are reinforced concrete construction or the steel structures construction. The special bracing is needed to stabilised walls and trusses. Speedbrace or Strap bracing is normally used in the Gang-Nail design for the bracing system. The spaces of trusses are larger than the domestic building which is 1830 – 2000 mm centre to centre and large span of trusses are required. The special loads due to the air-conditional units and folding doors may also be considered for the roof trusses design of the commercial building.

Finally, the examples of industrial building are factories and farm buildings. They are normally portal type or cantilevered column construction. They are constructed with very large truss spans and spacings which are commonly more than 2000 mm. There are no ceilings and internal walls in this type of building. Therefore, industrial building has different design criteria and the deflection is not as critical consideration (MiTek Asia Sdn. Bhd, 2004).

5.3.5 Gang-Nail Trusses Design

There are eleven main steps in the trusses design method as below:

Step 1: Job Details

The design wind velocity is determined but not more than 33 m/s.

Step 2: Truss Details

The truss details that are specified include roof material such as concrete tiles, the spacings of top and bottom chords restraints, ceiling material if available, attic ceiling material, attic ceiling restraint, attic wall lining, attic flooring if necessary, the spacing of truss centres, the degrees of pitch, the external and internal pressure coefficients, the space of top chord to match at heel, preferred timber for top chords, bottom chords and webs, and the consequent of the failure class. These specifications are essential at the beginning stage of the roof trusses design.

Step 3: Materials specifications

The description and the code of the roof, ceiling and attic ceiling materials are stated respectively. In addition, the dead loads and their self-weight are specified individually. The particular care is taken on the top chord overhang due to the eave lining during the design.

On the other hand, the code and description of the species timber are defined together with their stress grade, joint group and sizes.

Then, the assumptions in the plate design will also be listed.

Step 4: Criticality Codes for Timber Design

The name of the software used for the design and the country code are specified here.

Step 5: Design Data for a Particular Truss

The dead load on top and bottom chords, parallel support factor (k8), grid factor (k9), live load, loading type, the truss mark, actual thickness the lengths of the overhang, cutoff and cantilever if available, are needed to be specified clearly before the analysis of the structure.

Step 6: Joint Coordinates Used for Analysis

Every joint in the trusses are numbered in terms of the X-coordinate and the Y-coordinate. The locations of the vertical support and horizontal support are specified at the Joint Number. Then, the truss geometry used in the analysis and loading diagram is produced together with the labelling of the joint number and the dimensions of each member of the truss.

Step 7: Designed Timber Sizes and Grades

Every member is labelled and the timber species, sizes, stress grades, restraints and pitch are specified.

Step 8: Applied Elementary Loads

The uniformly distributed loads of dead load, live load and wind load are applied on the members respectively. Furthermore, the load duration factor (k1) is considered on each of the applications of the elementary loads for the timber, plate-teeth and plate steel.

Step 9: Resulting Axial Forces and Bending Moments

The roof truss system is then analysed by the computer software. The values of axial force, bending moment and the shear force of every member are displayed due to the different load cases. The load duration factor (k1) is again taken into account when applying these combined load cases.

Step 10: Deflections, Support Joints and Reactions

The long term deflection due to the dead load for the non-support joint is shown. The long term horizontal displacement and the vertical and horizontal reactions due to the different of load cases at the support joint are also analysed by the computer software.

Step 11: Truss Notes, Warnings and Error Messages

The truss notes, warnings and error messages that are given by the software must be considered seriously when the design is proceeding. The design has to be re-designed if necessary.

After finishing that particular truss, the steps from Step 5 to Step 11 are repeated for another kind of truss.

The computer software brings a lot of advantages for the design process specially the ease of design, the speed of design and the accuracy of calculations. However, the validity of these values has to be checked to avoid the mistake of programming of the software.

CHAPTER 6: PROJECTS ANALYSIS

6.1 Project 1

6.1.1 Project Description

Project 1 was a proposed 30 unit Double Storey Terrace House in Jalan Kinrara, Puchong which is located at the Selangor State in Malaysia. Terrace houses are commonly built for residential purposes in Malaysia. It is of reinforced concrete columns and beams construction while the roof system is timber trusses and concrete tiles.

The area for one unit is about 6 metres by 9 metres which varies slightly with three slightly different designs. The height is about 6 metres for all types. There are three common types of the house designs in this project, namely corner lot, internal lot and end lot for a terrace of building. Figure 6.1 shows the corner lot and internal lot of the double storey houses. Hip Roof shapes were adopted in the construction of the 30 unit double storey terrace house. There were twenty truss shapes which were different in lengths, degree of pitch and the loading. This number of timber truss shapes was needed to suit the architectural features and other requirements.

The roof truss system had been designed as simply as possible to avoid any confusion during the fabrication and the installation. There was only one type of timber species, one size of the timber thickness and two standard depths in the timber trusses for the whole design. The roof truss layout is shown in Appendix C, page C1.

Figure 6.1: Corner Lot and Internal Lot Units of Double Storey Terrace Houses.

6.1.2 Design Requirements

Malaysia is not affected by cyclones and the building which is situated at Puchong is about 30 km from the coast. Therefore, 30 m/s design wind velocity was decided for the roof truss system. Concrete tiles were used for the roof material, while ceiling material was 4.5 mm flat fibre cement board. Both of these materials contributed to the permenant load on the roof trusses. On the other hand, an additional load was designed for the end lot unit of houses to take into account the water tank. According to the design criteria, the trusses were not designed to support a water tank unless indicated for the particular truss, HTS2-TANK for example. Next, the live load of 0.25 kPa which was subjected on the roof plane was stated by the architect of the building.

There were two kinds of truss details that were specified by the architect, namely as Group Number 1 and Group Number 2. Both materials have the same details except for the pitch. 30 degree of pitch is adopted for the Group Number 1, whereas 25 degree for the Group Number 2. The top chord was restrained at 350 mm centres, and the bottom chord at 600 mm centres. Truss centres of 1 220 mm were specified and 97 mm was designed for the top chord to match at heel. Then, the external pressure coefficient of -0.90 was used and the internal pressure coefficient was 0.20. Finally, the timber species for the top chords, bottom chords and webs are Green Hard Wood.

The dead load of the concrete tiles was 0.508 kPa and 0.046 kPa in self weight. Then, the ceiling materials were subjected by the dead load of 0.128 kPa and the self weight of 0.046 kPa. Furthermore, 0.080 kPa was taken into consideration for the additional dead load on the top chord overhang due to the eave lining of the roof. The pressure coefficient on underside of top chord overhang was 0.80. The normal mode was expected for the consequence of failure class of the timber truss system.

6.1.3 Design Specifications

First of all, the green hard wood with the strength group of S4 and the joint group of J3 was chosen for all of the roofing design. This group of timber species was having the equivalent stress grade of F11. The Malaysian Grading Rules state that the ‘green timber’ is the timber which has been freshly sawn or is only partially seasoned. In other words, the free water still remains within the cells of the timber (MTC, 2002). Therefore, large long term creep factor for the unseasoned timber was taken for the design consideration. It had taken the factor of 3.0 for this project.

The timber thickness of 45 mm with the undersize of 3 mm was used for the both Truss Group 1 and 2. Therefore, the actual thickness of the timber truss was 42 mm. Besides that, the undersize on the depth of the timber was 3 mm as well. There were twenty types of truss shapes available for the double storey terrace houses that were labelled as different names of the truss marks by the designer.

The truss layout and the summary of the result of the roof truss design for a particular truss in the double storey terrace house project are shown in the Appendix C1 to C12. This information was provided by the main contractor company of this project, Rangkap Jaya Sdn. Bhd, which had been analysed and applied by the client of the project.

6.1.4 Design Analysis and Costing

One timber species was adopted as standard for the trusses throughout the project. The most important factor that must be considered during the selection of timber is its strength. Furthermore, the timber roof will not be exposed and subjected to an adverse environment. The green hard wood can be used due to its high strength group of S4 and joint group J3.

By using the same stress grade of the timber, in most of the trusses, the top and bottom chords sizes were 100 mm in depth while 75 mm for the size of the webs. However, 150 mm may also be used for the bottom chord in where large bending moment has existed due to the uniformly distributed loads and the point loads that were applied to the truss. For the truss mark T2B-Tank and HTS2-Tank, the 150 mm bottom chords have been used to withstand the applied loadings. The trusses were designed to carry the water tank. It was noticed that there were high compressive forces applied to the top chords and high bending moment values have occurred at the bottom chords which were the critical members in the roofing design. Due to the high force from the water tank, the sizes of the critical webs for both members were larger which are 100 mm rather than 75 mm and bracing was provided to stabilise the structure from buckling. The position of the water tank is essential during the design work and installation of the roof truss system.

The following table shows the cost involved for the timber roof trusses of the 30 Unit Double Storey Terrace Houses project.

Table 6.1: The Costing for the Timber Roof Trusses of Project 1.

Description	Rate (AUD)	Quantity (m^2)			Amount (AUD)		
		Corner	Inter	End	Corner	Inter	End
30° pitch roof	11.40	134	1586	134	1, 527.60	18, 080.40	1, 527.60
25° pitch roof	11.40	26	312	28	296.40	3, 556.80	319.20
Subtotal					1, 824.00	21, 637.20	1, 846.80
Total					25, 308.00		

Note: The unit rate of the timber roof truss was provided by the roof truss fabricator who was one of the sub-contractors of the project.

There were two different types of timber roof trusses, namely 30° pitch roof and 25° pitch roof. The roof construction cost of these roofs was having the same unit rate of RM 32.00 (AUD 11.40, with the exchange rate of 2.80) per metre squared which was offered by the sub-contractor of the project. The cost was only for the timber roof trusses and not other costs such as roof covering. The quantity of the roof construction was counted separately for corner, internal and end units. Finally, the total cost of the timber roof trusses was RM 71, 040.00 (AUD25, 308.00) for the 30 Unit Double Storey Terrace Houses project.

Figure 6.2: Roof Construction of Project 1 in Progress.

6.2 Project 2

6.2.1 Project Description

Project 2 was the Sri Panglima 3 Blocks of 5 Storeys Low Cost Apartment which is located in Puchong. It is located in the Selangor State, Malaysia. 5 storeys low cost apartment is frequently constructed to satisfy the demand of the low income people. As the Project 1 above, this type of building is constructed by the reinforced columns and beams, and the timber roof trusses are adopted for all of the three blocks of apartments.

The area of the Block 1 is about 22 m x 11 m, whereas the Block 2 and 3 are about 36 m x 10 m. The 5 storey apartment was 15 m in height. Since these are low cost project which is less than RM42, 000 (AUD 15, 000.00) of sales price per unit of house, all of the designs including the roof truss system are very simple and less architectural features including the roof shape of the buildings. Gable Roof shapes were used in the construction of the three blocks of 5 storey apartments. There were only four kinds of roof truss shapes which were different in length and loadings. Their roles were mainly to carry the required loadings rather than for architectural feature of the building. Therefore, the roofing cost was controlled by the simple design and fabrication of the roof truss system.

There was only one type of timber species used for the whole roof trusses. The system was simplified by adopting a standard thickness of the timber and standard depths of size.

Figure 6.3: Sri Panglima Three Blocks of 5 Storeys Low Cost Apartment.

6.2.2 Design Requirements

The construction site of the Project 2 is situated in the same geographical location with the Project 1. The wind load that is subjected on the five storey height of building is not so critical. Therefore, 30 m/s of the wind design wind velocity was considered for the roofing system. The roof trusses were not designed to carry any mechanical and electrical loads such as water tank and air-conditioning units. Therefore, there was only one kind of applied elementary load which was full strip uniformly distributed loads existed on the timber trusses. The live loads of 0.25 kPa were expected by the architect of the Project 2.

There was only one kind of truss detail that was named as Group Number 1, was specified by the architect. The top chord was restrained at 350 mm centres, and 600 mm for the bottom chord restraint. Truss centres of 1220 mm were specified and 97 mm was designed for the top chord to match at heel. The 30° of pitch was applied for all of the trusses. On the other hand, the external pressure coefficient of -0.90 was specified while

0.20 for the internal pressure coefficient. Green hard wood species of timber was used for the top chords, bottom chords and the webs of the trusses for whole project.

The dead load of the concrete tiles was 0.508 kPa and 0.046 kPa for its self weight were considered in the roofing design. Then, 0.156 kPa of dead load were subjected on the attic ceiling material. As the Project 1, 0.800 kPa of additional dead load were considered for the top chord overhang and 0.80 of pressure coefficient on the underside of top chord overhang. The normal mode was expected for the consequence of failure class during the design.

6.2.3 Design Specifications

The design company, MiTek Asia Company has made their design of the timber roof trusses to be effective and efficient. Therefore, they always use the same species of timber which obtained the same specifications and same sizes of the timber for many projects in Malaysia. F11 green hard wood was also adopted and 3.0 of the long term creep factor was considered for the Project 2. The actual thickness of the timber was 42 mm in size was used for the whole truss system.

There were only four types of truss shapes consisted for these apartments. The dead loads that were specified for the top chord and the bottom chord were 0.546 kPa and 0.069 kPa respectively.

The truss layout and the summary of the result of the roof truss design for a certain truss in the three blocks of 5 storey apartment was shown in the Appendix C13 to C16. This information was provided by the main contractor company of the Project 2, Rangkap Jaya Sdn Bhd, which had been analysed and applied by the client of the project.

6.2.4 Design Analysis and Costing

Similarly, the Sri Panglime 5 Storeys Low Cost Apartment was used only one types of timber species for all of the trusses in the project. F11 timber is adequate for the design with the small wind velocity subjected on the building.

Referring to the analysis data from Appendix C14 and C16, 100 mm sizes of the timber were adopted for the top and bottom chords, while 75 mm for the webs. There was only one exemption where the high bending moment was induced at the top chord of COT1.

The design wind velocity for the Project 2 was having the same value with the Project 1. Therefore, both design methods were very similar and easy to design with the aids of the computer software. Furthermore, there was no other additional load such as water tank considered for this project. Since this was a low cost building, the design was to be as simple as possible and the material requirements were as economic as possible.

Table 6.2 shows the cost involved for the timber roof truss system of the Three Blocks of 5 Storeys Low Cost Apartment project.

Table 6.2: The Costing for the Timber Roof Trusses of Project2.

Description	Rate (AUD)	Quantity (m^2)	Amount (AUD)
Block 1: Roof trusses set at 30 degree pitch (area measured on slope)	15.00	964	14, 460.00
Block 2: Roof trusses set at 30 degree pitch (area measured on slope)	15.00	1, 289	19, 335.00
Block 3: Roof trusses set at 30 degree pitch (area measured on slope)	15.00	1, 289	19, 335.00
		Total	53, 130.00

Note: The unit rate of the timber roof truss was provided by the roof truss fabricator who was one of the sub-contractors of the project.

The roof construction cost for the Three Blocks of 5 Storeys Low Cost Apartment project was RM42.00 (AUD 15.00) per metre square unit. The total area of the roof system for the Block 1 was 964 m^2, 1, 289 m^2 for each of Block 2 and Block 3. The total cost for the roof construction for the Project 2 was RM148, 764.00 (AUD 53, 130.00). The cost was only covered the roof construction and not included the roof finishes and rainwater goods costs.

According to the Bills of Quantities, this cost was counted for the design, fabricate, deliver, hoist and fix approved proprietary prefabricated timber roof trusses of sawn pressure treated timber including all timber framing, wall and top plates, battens, bracing, fixing bolts and nuts, ties, connector, packers, blocking pieces and everything necessary to complete the installation structurally, functionally and aesthetically including provision of all necessary shop drawings. The Priced Bills of Quantities stated that there are 10 years guarantee for the Contractor's Design Portion of Work.

Figure 6.4: Roof Construction of Project 2 in Progress.

6.3 Project 3

6.3.1 Project Description

The third project that to be investigated was the One Block of 11 Storeys Medium Low Cost Apartment. The building is located at Jalan TK4/12, Taman Kinrara, Puchong, Selangor, Malaysia. This is a high rise building and for residential purpose. As usual, the building was constructed by the reinforced concrete columns and beams. The timber trusses were used for the roof structure of the building and covered by the concrete tiles.

The area of the building is 49 m x 21 m and height is about 33 m. Combination between Hip Roof, ‘L’ and ‘T’ shaped of the roof shapes were adopted for the Project 3. There were twenty-two types of truss shapes with different in length, degree of pitch and loading conditions. Since the project was medium low cost, the roofing system contained more architectural features and the design was more complicated than the Project 2 which is also an apartment but lower cost.

To avoid mistakes during fabrication and installation, the design criteria was standardised by using one type of timber species, one size of timber thickness and three sizes of timber depths for the trusses design.

Figure 6.5: One Block of 11 Storeys Medium Low Cost Apartment.

6.3.2 Design Requirements and Specifications

Unlike the previous cases, the design wind velocity for the Project 3 was 35.0 m/s. The higher value was taken because this is a high rise building with 33 metres in height. There were two types of truss details which were Group Number 1 and Group Number 2. The major requirements for both trusses including the top and bottom chords restraints, truss centres, external and internal pressure coefficients, top chord to match at heel, timber species and the consequence of failure class were taken the same values with the Project 1 and Project 2. The only difference characteristic between the Group Number 1 and 2 were the pitches of 30° and 35° respectively.

The dead loads that were applied on the roof structure, timber stress group and timber thickness used, were also taken the same considerations with the previous case studies for this project.

The truss layout and the summary of the result of the roof truss design for a particular truss in the 11 storeys apartment project are shown in the Appendix C17 to C29. This information was provided by the main contractor company of this project, Rangkap Jaya Sdn. Bhd, which had been analysed and applied by the client of the project.

6.3.3 Design Analysis and Costing

All of the design requirements and specifications of Project 3 were same as the Project 1 and Project 2 except the design wind velocity. Since the building was eleven floors and about 33 metres in height, the higher impact from the wind was considered during the design.

All of the trusses were not designed to carry any mechanical and electrical loads such as water tank and air-conditioning units for the Project 3. Most of the top and bottom chords were 100 mm in sizes while 75 mm for the webs sizes. However, there was one top chord, Top Chord 2 (T2) from TG3 was 125 mm in depth. From the truss analysis from the Appendix C27, it is shown that the T2 is the critical member which is having the highest bending moment of 0.717 kN/m, shear force of 0.46 kN/m and deflection of 4 mm in this particular timber truss. These critical effects came from the additional point loads and uniformly distributed loads subjected on the T2 member. Webs of W3, W4 and W5 were having the sizes of 100 mm in TG3 truss. According to the analysis from the computer software, the critical values of the axial force of -5.639 kN occurred at W3 and W5. Therefore, the larger sizes of timber were needed to overcome the high forces. There was a brace assembled at W3 and W5 to avoid the buckling happened. There were seven number of webs were assembled in TG3 to stabilise the truss against to the high loadings.

Then, S1 and S3 were the least critical of trusses in the truss system. All of the members including top chords, bottom chords and webs were only 75 mm in depths. There were only basic full strip uniformly distributed loads impacted on these trusses. In addition, the spans of S1 and S3 were not so long. The spans were only 4897 mm and 3431 mm respectively.

The table shown below is the cost involved for timber trusses of the 11 Storey Medium Low Cost Apartment project.

Table 6.3: The Costing for the Timber Roof Trusses of Project 3.

Description	Rate (AUD)	Quantity (m^2)	Amount (AUD)
Roof trusses set at 30 degree pitch (area measured on slope)	18.00	2, 646	47, 628.00
		Total	47, 628.00

Note: The unit rate of the timber roof truss was provided by the roof truss fabricator who was one of the sub-contractors of the project.

The roof construction cost for the One Block of 11 Storeys Medium Low Cost Apartment project was RM50.40 (AUD 18.00) per metre square unit. The total area of the roof system was 2646 m^2 and the roof construction cost was RM133, 358.40 (AUD 47, 628.00). The cost was not covered the roof finishes such as sundries and concrete roofing tiles, and the rainwater goods such as roof drainage.

According to the Bills of Quantities, this cost was covered the design, fabricate, deliver, hoist and fix approved proprietary prefabricated timber roof trusses of sawn pressure treated timber including all timber framing, wall and top plates, battens, bracing, fixing bolts and nuts, ties, connector, packers, blocking pieces and everything necessary to complete the installation structurally, functionally and aesthetically including provision of all necessary shop drawings. The Priced Bills of Quantities stated that there are 10 years guarantee for the Contractor’s Design Portion of Work.

Figure 6.6: Roof Construction of Project 3 in Progress.

6.4 Comparison between the Project Studies

All of these three projects were designed by the MiTek Asia Sdn Bdn while the Woodlandor Roof System Sdn Bhd was responsible for the fabrication and installation of the roof trusses. The Woodlandor Roof System Company was the sub-contractor who responsible for the roof construction for the projects. As mentioned before, the designers applied same type of timber species and standard sizes of the timber used for most of the projects unless specific requirement from the client. The design methods for all of these three projects were similar for the corresponding roof truss shapes. Critical members which may came from the additional loadings such as water tank, were only needed to take certain caution during the design process.

These three cases that have investigated are the buildings for the residential purposes and located in same region in Malaysia. However, these projects are difference in height and costing which might affect the timber trusses design. Project 1 was double storey houses while Project 2 was 5 storeys apartment. Both of the projects were taken the same design wind velocity of 30m/s because 6 m and 15 m of the buildings height are not impacted by the strong wind very much. This can be interpreted by the low height of the buildings and also surrounded by the other obstacles from the higher buildings. On the other hand, Project 3 was 11 storeys apartment which is 33 m height of building. Thus, higher design wind velocity of 35 m/s is necessary for the high rise building.

There were three trusses which were T2B-Tank, HTG1A and HTS2-Tank in the Project 2 subjected by high loads on the top and bottom chords. The critical member of HTG1A was Top Chord 2, T2. Hence, 150 mm of timber size rather than the standard size of 100 mm was applied for T2 to reduce the high bending moment induced due to the full strip uniformly distributed loads, point loads and additional uniformly distributed loads. Then, 150 mm of timber size was adopted as well for Bottom Chord 1, B1, for T2B-Tank and HTS2-Tank trusses. Both trusses were designed to carry the water tank load and therefore high bending moments were induced at the bottom chords for these trusses. On the other hand, for Project 2, 150 mm depth of timber was only applied in T1 of COT1. The roof truss system of the Project 2 was much simpler compared to the Project 1 and Project 3. The critical member of the roof truss system in the Project 3 existed at T2 in TG3 truss. However, the 125 mm of timber was adequate to overcome the critical bending moment in the truss. There were three webs of TG3 were subjected high axial forces due to the full strip uniformly distributed loads, point loads and additional uniformly distributed loads that impacted on the top and bottom chords. W3, W4 and W5 were assembled by 100 mm depth of timbers. Other than the critical cases above, all of the timber sizes of the top and bottom chords for the three projects were 100 mm while 75 mm for the webs sizes.

Comparing among the Bills of Quantities of these projects, the 30 unit of Double Storey Terrace Houses was having the lowest unit rate which was RM32.00 (AUD 11.40) for every metre square unit. Unlike the high rise building, the cost of roof construction of double storey house was lower because the installation cost is less. The unit rate of 1 Block of 11 Storeys Medium Low Cost Apartment was the highest among these projects. The rate of RM50.40 (AUD 18.00) was tendered by the roofing contractor. The higher cost of roof construction was charged because of the more complex timber roof trusses design due to the architectural features of the building and the higher installation cost for the high rise building roof construction. The rate of roof construction for Sri Panglima 5 Storeys Low Cost Apartment project was RM42.00 (AUD 15.00) which was a reasonable rate because the installation cost was higher than the double houses but lower than the 11 storeys building. The timber trusses designs for Project 2 were the simplest due to the low project cost which was specified by the client.

The timber truss system was designed to be as simple as possible for the corresponding architectural roof shapes design. The requirements of the client affect the roofing design and the cost involved for the roof construction. However, the process of the roofing design and the installation are efficient and effective by using the computer software and the prefabricated timber roof trusses method respectively.

CHAPTER 7: DISCUSSION

7.1 Timber Roofing Construction

The three projects of timber roof trusses were designed by the MiTek Aia Sdn Bhd by using their own developed design software and the Gang-Nail technology. According to the MiTek Asia Company, all of the timber roofing designs by them are based on the Australian Standard, AS1720 but some modifications have been made to suit the local conditions. For example, Malaysian weather is not as severe as Australian weather, so a standard value of the design wind velocity will be considered for a particular region.

The standard requirements for the timber roofing design are essential to improve the productivity effectively and efficiently. Malaysia has potential to develop the timber roof truss system. Malaysia has complete manufacturing plants for the timber connectors and sawn timber, truss plant equipment for assembly, design engineering office, and computer design software are all available here. Basically, the Malaysian roofing industry system is made up of four groups; the specifier who is the architect, manufacturers who produce the connectors, roof structure system design and the sawn timber, the fabricator for the pre-fabricated trusses, and the contractor to install the roof trusses on the building.

7.1.1 The Specifier

Architect is the building designer as well as the roof designer. They have the ability to choose a right system including roof system to suit an entire building. They are responsible to complete the wishes and desires of their clients. For example, a client requires a low cost apartment project, the architect will design the building which is fulfilled the specifications in term of simple architectural features. Their designs are also based on the coordinating suppliers who are the MiTek Asia Sdn Bhd and the fabricators for the case studies in this research. Their presentation work for all aspects of a roof system is extremely important to their customers, fabricators and the contractors.

7.1.2 The Manufacturers

MiTek Asia Sdn. Bhd. is the manufacturer of the Gang-Nail Connector Plates and supplies the connectors to the timber roof truss fabricators in Malaysia. In addition, MiTek Asia also provides the truss fabricating equipment and engineering services to their national network of licensed fabricators.

Sawn timbers that are used for the roof trusses are produced in sawmill. Malaysia has a number of timbers sawmill which normally carry out the typical process for the sawn timber manufacturing. There are five steps of timber manufacturing from an ordinary timber to a quality timber truss. First of all, the process begins with the selection of timber. The timbers are supplied by the logging industry and then are sawn to the desired dimensions for the timber roof trusses. Next, the timber sawn is dried through the kiln-drying for example, to the moisture content of 15%. This is the ideal moisture content that is specified in the Malaysian Grading Rules to ensure the quality of the timber so that there are no further internal movements such as warp, crack, twist or split after the installation of the roof trusses. Through the seasoning process, the timber will be gained higher structural strength and lighter in weight. The preservative treatment is the next step for the sawn timber production. They use high technology plant for the treatment process such as pressurization and double-vacuum impregnation of timber with the chemicals. The preservatives are essential for the timber roof trusses in order to avoid attack from termites, insects and other wood-borers. The fourth step is the cross-cut process due to the required length of timber. The end-grains are then treated with colour preservative paste to protect the cut-surfaces of the timber. Finally, the treated sawn timbers are ready to be assembled and fabricated into roof trusses.

Every process that is carried out by the individual manufacturer is very important and not independent. The productions of sawn timber, connectors and the trusses design are interrelated in order to produce the high quality of the timber roof truss system. These factors are playing the main roles in the current development of the Malaysian timber roofing industry.

7.1.3 The Fabricator and the Contractor

The licensed fabricator is the independently owned company. Besides the fabrication, they can work directly with the contractors and the specifier to assure the structural components that meet the design and the budget guidelines. The fabricator is responsible to provide the shop drawings for inspection and modification. Normally, the location of fabrication factory is nearby so that the specifier is allowed to conduct a quality inspection during the timber roof truss fabrication. This is a very good working relationship in order to produce an effective truss system structurally.

According to the MiTek Asia Company, the fabricators should supply the trusses with the aspects of economy of timber, labour and financing costs in mind. However, the quality of the timber trusses still be considered. The fabricators have to ensure there is no variation in the truss profile for a particular batch. Furthermore, the timber grade and quality are needed to be complied with the specifications that are stated in the contract. The fabricators are also advised to hire a right personnel to handle the design programs which are provided by the Gang-Nail design computer programs. This is important for sales and marketing personnel of the fabricators to assist and advise to their customers in order to help them to optimise the costs.

The contractor is the party who bids for job from project owner, whereas the fabricator is generally will serve as a subcontractor for the roofing job. The subcontractor will provide a quotation for the roof construction to the main contractor of the project. The subcontractor is responsible to produce good services and quality trusses as mentioned in the contract. They will supply and delivery the trusses to the project site, and install the trusses. They must adopt the correct erection method and fix the bracing system based on the details during the installation to prevent sagging and leaking for the roof truss.

The procedure of the timber roofing construction in Malaysia is systematic and controlled. The operation of the timber roofing industry has summarised as below:

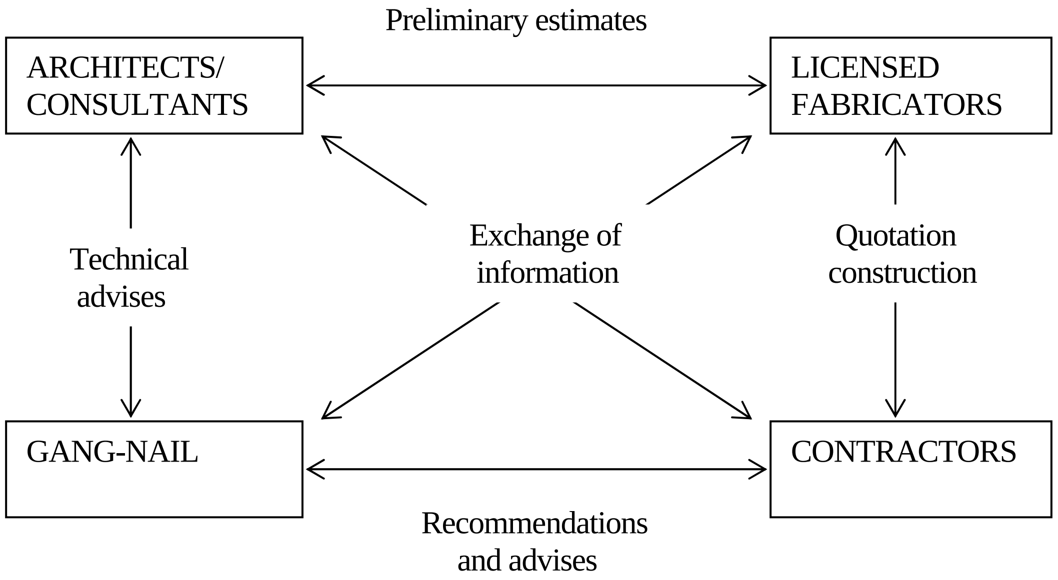


Figure 7.1: The Relationship among the Specifier, Gang-Nail, Fabricators and Contractor.

(Source: MiTek Asia Sdn Bhd, 2004)

7.2 Quality Control of the Timber Roof Trusses

MiTek Asia Sdn. Bhd. has adopted the self-developed software, DataTruss to design the roof truss system for the three projects. The software is programmed according to the Australian Standard Design Code. The DataTruss is developed especially for the Gang-Nail Timber Truss System. In addition, the Malaysian Standard Design Code will still be used to double checking for the roof truss structural analysis. In other words, the structural behaviour of the timber roof truss will be analysed again and checked whether fulfil the Malaysian Standard. Therefore, the Gang-Nail design is very conservative and safe.

The fabricators are also one of the main parties to control the quality of the timber roof trusses of a building. As the Gang-Nail Truss System Licence authority, MiTek Asia Company has controlled their licensed fabricators by establishment of the Fabricator Support Department. The task of the department is to monitor the fabricators to complete their responsibility to produce a good quality of trusses. MiTek Asia Company also provides trainings which are related to the truss design, truss fabrication at plant and truss installation at site to the licensed fabricators' staff. These kinds of trainings are crucial for the fabricators in order to produce the best quality of the trusses if they fully understand the operation system of the timber roof construction and other considerations such as the design criteria and the functions of various types of timber connector.

The timbers sawn which are manufactured by the fabricators have the same dimension and straightness for each truss. The manufacturer has to ensure the product to be consistency, reliability and productivity. The Gang-Nail Trusses are then tested by the local authorities such as the Forest Research Institute Malaysia and the Public Works Department Malaysia to prove the quality of the timber roof trusses. The quality of the Gang-Nail Trusses are fulfilled the Australian Standard as well as the Malaysian Standard. Since the quality of the products are so trusted and assured, the MiTek Asia Sdn. Bhd. provides a design warranty for each design.

The improvement of the timber roof trusses quality can be conducted due to the developments of the timber connectors and the chemical used for the timber treatment by the timber mills. Research and development efforts are essential to obtain the higher quality and quantity of the timber roof truss system and hence the timber roofing industry in Malaysia.

7.3 Advantages of Using Timber Roof Trusses

Most of the Malaysian buildings prefer to adopt the timber roof truss system because there are a lot of advantage and cost saving. Gang-Nail technology has contributed a lot for the Malaysian timber roofing industry. They apply the Gang-Nail plates and the qualified timber species for the prefabricated timber roof truss to achieve the cost saving aspect.

By using the computer facility, the MiTek design has been made it easy in such a way that using the standard timber species, standard timber sizes and thickness for most of the projects which are used for general purposes. These factors allow them to save time in estimating the material required for a job and simplify the difficulty during the erection and fabrication. The prefabrication approach also eliminates on-site labour for cutting and fitting roof rafters and therefore, a skilled carpenter is not required. As a result, the entire roof structure can be delivered at once and overcome the delay that might be due to the incomplete materials on-site and the bad weather.

Most of the trusses are designed with consistent spacing and symmetrical in the roof layout. The designer has designed as many identical trusses as possible for a project. Every designed truss is labelled carefully to avoid the complexity during the installation of the roof trusses. Therefore, cut down the roof construction time and the cost of installation.

Since the timber roof truss is prefabricated and manufactures at plant, there is less site cutting and less cleaning up, and no loose timber on site only trusses. The fabricated trusses stored on site ready for erection are less likely to be pilfered than the loose timber and also difficult to cart away. Hence, the reduction in site wastage and losses can be achieved.

By adopting the Gang-Nail technology and design, 16 metres of clear span can be readily obtained. The 16 metres clear span is long enough for most of the designs including for the architectural flexibility and large room. Since the long clear span can be obtained, there is no beam or internal load bearing wall needed for the building structure. Due to the long clear span advantage, the building is allowed to have future alteration by the modification of the floor plan without changing the roof structure.

All of the Gang-Nail trusses are designed using the advanced structural engineering software. The MiTek software can design for almost any roof shape whether it is simple, complex or even combination of roof shape. The trusses are flexible to design in such a way that trusses are custom-made to any design, pitch or span for a new building. Timber roof truss system is able to be designed to match an existing structure as well.

Compared with the steel trusses, the only light weight steel truss which is high material cost has competitive performance with the timber roof trusses. However, people still prefer to use the timber roof truss system for most of the buildings particularly for the residential houses in Malaysia. Besides the material cost involved, under the fire condition, the light weight steel trusses will just collapse due to high temperature, whereas the timber roof truss will still remain intact until the fire burns through the timber. Unlike the timber material, the workmanship and the site installation are very crucial issues as steel is a homogeneous material. The performance of the steel truss system is dependent on the accuracy of steel manufacturing and steel trusses erection.

The steel truss system is normally used for the commercial building. Therefore, to houses owners, the light weight steel trusses are very costly. In addition, the steel trusses are not as flexible as the timber roof trusses to make any renovation. It is extremely difficult to alter the steel roof structure. Furthermore, steel is prone to lighting strike compared with timber. As a result, a proper and good lighting arrestor is needed to be installed together with the steel roof structure which further cost a lot of money.

The timber has a better strength to weight ratio as compared to the steel. This is very important to the structural design and the construction consideration. Besides that, timber is a more environmental friendly material over steel. Timber is a potentially renewable natural resource whereas steel is non-renewable and it consumes much energy to produce a tonne of steel material.

A lot of termites, insects and other wood borers that might attack the timber roof trusses exist in Malaysia due to the tropical climate. However, this is no longer a problem as the Malaysian timber industry obtains the complete timber treatment facilities and good chemical to avoid these organisms to damage the timber trusses. Furthermore, most of the termites only attack the materials that intact on the ground surface. The termites do not fly into the roof and impossible to attack the treated timber! Therefore, the timber roof trusses are highly recommended for most of the buildings in Malaysia.

7.4 Challenges Faced by the Timber Roofing Industry

The competition of steel truss system is one of the challenges that is faced by the current timber roofing industry. People will choose steel trusses because they obtain some advantages which could not get from the timber trusses. Timber truss is normally adopted for residential purpose while steel truss is for commercial used. However, steel trusses are still used for some houses, for example detached houses which possess more architectural features including the roof shape.

Another problem that is faced by the industry is the behaviour of the project's client. For those clients who are traditional minded, resist changing and refusing to use the high technology materials for the projects. They still prefer to adopt the conventional roof system which they think that is the most economic method. However, it is not true for all cases. For a reasonably small building, it is no doubt that the conventional system is cheaper but it is very difficult to construct for the large project, say 100 units of houses and also for the complicated design of roof shape. The overall costs which include the material cost, labour cost, speed of installation and ease of transportation should be considered as a whole.

According to the MiTek Asia Sdn. Bhd., competition among the fabricators may be risen difficulty to the company. The company should carefully choose the fabricator for a project according to their competent, ability, capability and trustiness. This is essential to ensure the best quality of timber roof truss system is produced and then perform the best function and long lasting after installation on the building.

The MiTek Asia Sdn. Bhd. has no Research and Development Department because they just follow the technology and technique which are developed from the Australian Company. However, MiTek Aisa Company is suggested to have some R&D work to improve the current technology used in the Malaysian timber roofing industry and probably develop a new technology and introduce to overseas.

CHAPTER 8: CONCLUSION AND FUTURE DEVELOPMENT

8.1 Conclusion

The development of the current timber roofing industry in Malaysia is fairly good. It is expected that the development will be continued and growing in future due to the systematic operations for timber and roofing industries.

Malaysia has well timber classification rules to grade the quality of the sawn timber. Most of the Malaysian timbers are hardwoods which possess high strength property and durable. Therefore, timber material is widely used in Malaysian market especially the construction sector such as roofing system.

Timber roofing has been using from centuries ago till now. Today, advanced technology is applied to the timber and connector manufacturing, roofing design, and construction method. Based on the Malaysian Grading Rules, standard and quality of sawn timber is produced and hence the quality of the roof system is assured.

The design method and the cost involved of truss system are investigated through the case studies. The design cost is reduced by using the computer software while the prefabricated method has minimised the construction cost for the projects. The overall roof construction cost is dependent on the roof shape, area and height of the building.

The timber roofing industry will grow continuously in Malaysia due to the local demand and their capability to face the challenges such as the competition of steel trusses and sustainability of forests.

8.2 Future Development

Some recommendations are provided to improve the quality of the timber roof truss system, and hence increase the productivity effectively and efficiently.

(i) Better treatment technology and technique – to produce the timber be more durable, strong and smaller size. As a result, save natural resources and cost;

(ii) Alternative material – for example, appropriate treated of rubber wood to substitute the hardwoods that are decreasing in their population; and

(iii) Higher advanced technology and technique – improve the performance of the timber connector for example; develop more reliability of the computer software in order to increase the speed as well as the accuracy of the timber roof system design.

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APPENDIX A

PROJECT SPECIFICATION

Appendix A

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR:	**YAP Fui It**
Topic:	Review of the Current Timber Industry in Malaysia
SUPERVISOR:	DR. DAVID WOOD
ASSOCIATE SUPERVISOR:	MR. LIM JEE YAT
PROJECT AIM:	This project aims to review the current timber industry in Malaysia, particularly in roofing sector.
SPONSORSHIP:	None
PROGRAMME:	**Issue B, 13 August 2004**

1. Research the background information on forestry industry and timber industry.
2. Investigate the classification, properties, uses and market of the Malaysian timber and the challenges faced by the timber industry.
3. Review on the timber roofing industry in Malaysia and the standard quality required for the timber trusses.

Case Study:

4. Research the design methods for the trusses systems and the costing for a few construction projects.
5. Investigate the procedures involved in the roofing construction industry in Malaysia.
6. Identify the challenges that are faced by the Malaysian timber roofing company.

AGREED: ________________ (Student)   ___________________ (Supervisor)

_____________ (Dated)   _____________ (Dated)

APPENDIX B

SUPPORTING INFORMATION FOR REVIEW

TABLE 1-13

MALAYSIA : EXPORT VALUE OF PRIMARY COMMODITIES AND COMMODITY-BASED PRODUCT

(RM Million)

Commodities and Commodity-based Products	Unit	1990		2001		2002		2003(Jan-July)	
		Qt	RM million	Qty	RM million	Qty	RM million	Qty	RM million
Palm Oil	'000T	-	-	10,569.50	10,030.69	10,879.18	15,083.55	7,035.07	11,342.20
Palm Kernel Oil	'000T	-	-	847.19	645.39	686.29	1,089.86	399.33	132.12
Oleo Chemical	'000T	-	-	1,856.33	3,275.48	1,647.07	3,898.71	1,237.78	2,624.05
Palm-based Products	'000T	-	-	393.70	683.39	381.08	752.85	179.94	418.95
Palm Kernel Cake	'000T	-	-	1,850.89	234.80	1,580.45	268.87	1,005.65	178.42
Sub-Total	'000T	-	5,337.70	15,147.71	15,876.76	15,275.98	20,888.89	9,857.70	15,492.36
Crude Natural Rubber	'000T	-	-	879.85	1,806.41	686.07	2,491.81	541.42	1,806.65
Materials of Rubber	'000T	-	-	-	656.58	-	666.18	-	476.21
Tyres & Tubes	'000T	-	-	-	266.37	-	276.74	-	187.02
Articles of Rubber	'000T	-	-	-	366.81	-	297.59	-	249.22
Rubber Gloves	'000T	-	-	17,472.90	3,149.42	20,289.84	3,147.52	14,680.08	1,069.87
Sub-Total	'000T	-	4,697.48	18,290.75	6,343.59	21,176.91	7,003.94	15,288.36	4,376.98
Cocoa Beans	'000T	-	-	16.28	56.05	21.11	110.24	10.04	65.56
Cocoa Butter, Fats, Oil	'000T	-	-	43.03	319.48	35.66	356.08	23.94	291.75
Cocoa Powder	'000T	-	-	-	192.63	-	312.52	-	261.79
Chocolate	'000T	-	-	-	101.79	-	127.99	-	91.79
Sub-Total	'000T	-	725.08	59.31	666.88	56.76	906.85	33.98	710.81
Saw Logs	000m3	-	4,841.39	4,053.00	1,928.02	4,673.00	1,789.90	3,672.08	1,139.23
Sawn Timber	000m3	-	3,864.79	2,408.00	2,271.41	2,331.00	2,227.49	1,511.08	1,474.48
Dressed Timber	000m3	-	-	56.25	158.88	125.80	184.80	-	-
Moulding & Dowels	000m3	-	487.88	-	969.60	-	1,005.80	-	589.87
Veneer Sheet	000m3	-	202.60	669.00	478.38	630.00	431.29	-	-
Plywood	000m3	-	816.30	3,369.68	3,345.21	3,585.49	3,662.48	2,084.00	2,208.28
Particle Boards	'000T	-	-	-	1,208.27	-	1,192.88	-	-
Furniture & Parts		-	-	-	5,208.11	-	5,658.74	-	3,388.12
Wooden & Rattan		-	-	-	-	-	-	-	2,580.81
Others		-	-	-	-	-	-	-	865.17
Sub-Total	-	-	8,614.68	11,388.39	15,157.88	11,948.32	16,137.36	6,877.08	13,186.96

cont

Summary of Grades and Cutting Requirement, etc for General Market Specifications

Grade	**I. PRIME**	**II. SELECT**	**III. STANDARD**	**V. SERVICEABLE**
(a) Grade Mark	F | D *	F | D SEL	F | D A	F | D S
(b) Widths	6" and up, *see Note (ii)*	5" and up, *see Note (ii)*	4" and up, *see Note (ii)*	4" and up, *see Note (ii)*
(c) Lengths	6' and up, *see Note (ii)*	6' and up, *see Note (ii)*	6' and up, *see Note (ii)*	6' and up, *see Note (ii)*
(d) Sapwood	Must be excluded from clear face cutting.	Bright sapwood may be included in clear face cuttings unless it exceeds in the aggregate 1/3 the width of the piece or is present on both faces.	Bright sapwood may be included in clear face cuttings.	
(e) Knots	The average diameter of any sound knot shall not exceed 1/3 the width of the face on which it appears.	As in Prime grade.	The average diameter of any sound knot shall not exceed ½ the width of the face on which it appears.	
(f) Spring	Shall not exceed the proportion of 1" per 12' of length of the piece.	As in Prime grade.	Shall not exceed the proportion of 1" per 8' of length of the piece (as in Utility grade).	As in Standard grade.
(g) Warp (other than spring)	Not admitted if sufficient to prevent the whole piece from surfacing two sides to	As in Prime grade provided that slightly warped pieces 10" and wider are admitted if they can be ripped to produce 2 pieces each of which would grade Select and	Not admitted if sufficient to prevent the clear face cuttings from surfacing two sides to standard surfaced	As in Standard grade.

	standard surfaced thickness.	then not contain warp which would prevent those 2 pieces from surfacing two sides to standard surfaced thickness.	thickness should they be removed from the piece (as in Utility grade).	
(h) Wane				Allowed on the worse face and one edge only, as follows:- in widths 6" and up it should not exceed 1/6 the width of the piece; and in widths less than 6", it should not exceed 1/8 the width of the piece.
(i) Brittle Heart				Allowed on one face and edge only provided that the strength of the piece is not materially affected; may be included in the cuttings.
(j) Cutting Requirement	Admits pieces that will yield clear face cuttings as shown below. The portion outside the clear face cuttings will admit splits as in (iv) in Section A, but must otherwise be not worse than as defined	Admits pieces that will yield clear face cuttings as shown below. The portion outside the clear face cuttings will admit splits as in (iv) in Section A, but must otherwise be not	Admits pieces that will yield clear face cuttings as shown below. The portion outside the clear face cuttings will admit splits as in (iv) in Section A and any sound defect not materially	As for Standard grade except cuttings to be Sound Face Cuttings with brittle heart as in (i) above. The portion outside the cuttings will admit splits as in (iv) in Section A, wane as in (h)

	under sound face cuttings.			worse than as defined under sound face cuttings.			affecting the strength of the timber.			above, and any sound defect not materially affecting the strength of the timber.		
	S. A.*	**Percentage clear face**	**Cut**	**S.A.***	**Percentage clear face**	**Cut**	**S. A.***	**Percentage clear face**	**Cuts**	**S.A.***	**Percentage clear face**	**Cuts**
	3 - 4.9	12/12 (100%)	1	below 3	12/12 (100%)	1	2 - 4.9	8/12 (66 2/3%)	1	2 - 4.9	8/12 (66 2/3%)	1
	5 - 7.9	11/12 (91 2/3%)	1	3 - 4.9	9/12 (75%)	1	5 - 7.9	8/12 (66 2/3%)	2	5 - 7.9	8/12 (66 2/3%)	2
	8 - 10.9	11/12 (91 2/3%)	2	5 - 7.9	9/12 (75%)	2	8 - 10.9	8/12 (66 2/3%)	3	8 - 10.9	8/12 (66 2/3%)	3
		10/12 (83 1/3%)	1	8 - 10.9	9/12 (75%)	3	11 - 13.9	8/12 (66 2/3%)	4	11 - 13.9	8/12 (66 2/3%)	4
	11 - 13.9	11/12 (91 2/3%)	3	11 - 13.9	9/12 (75%)	4	14 & over	8/12 (66 2/3%)	5	14 & over	8/12 (66 2/3%)	5
		10/12 (83 1/3%)	2	14 & over	9/12 (75%)	5						
	14&over	11/12 (91 2/3%)	4									
		10/12 (83 1/3%)	3									
Minimum Cutting	4" x 5' = 20 units or 5" x 4' = 20 units			4" x 3' = 12 units or 3" x 4' = 12 units			4" x 2' = 8 units or 3" x 3' = 9 units			4" x 2' = 8 units or 3" x 3' = 9 units		
PHND	*See Section B I*			*See Section B I*			*See Section B I*					

IV. SOUND (or **BHND** (Borer Holes No Defect)).	:- As for Prime, Select and Standard grades except that pin and unstained shot holes are admitted in the cuttings as defined in Rule 34 (iii).
V. UTILITY	:- As for Serviceable grade except that wane is not to exceed ¼ the width of the piece and the piece is 100% sound face cutting admitting any sound defect not materially affecting the strength of the timber. **(S. A. * = Surface area in square feet)**

NOTE :-

i. **Groups of Grades** - The following are recognised under Section C of Part II :
   I. SELECT AND BETTER - should normally include the full product of the log in Select and Prime grades.
   II. STANDARD AND BETTER - should normally include the full product of the log in Standard, Select and Prime grades.
   III. SOUND AND BETTER - should normally include the full product of the log in Sound, Standard, Select and Prime grades.
   IV. SERVICEABLE AND BETTER - should normally include the full product of the log in Serviceable, Sound, Standard, Select and Prime grades.
   V. MERCHANTABLE - should normally include the full product of the log in Utility, Serviceable, Sound, Standard, Select and Prime grades.

ii. **Average widths and lengths**

As the size of logs reaching some mills is relatively small, cutting to high average widths such as 10" or more is not usually possible. If, therefore, it is desired to specify average widths in a contract those prescribed in the table below are the recommended maximum. A common log brought into the mills in Malaysia is 18 feet, so the attainment of good average length is possible. If, therefore, it is desired to specify average lengths in a contract, those prescribed in the table below are recommended.

PRIME to average 8" wide or better and 12' long or better
SELECT to average 7" wide or better and 11' long or better

STANDARD AND SOUND	to average 6" wide or better and 10' long or better
SERVICEABLE AND UTILITY	to average 5" wide or better and 9' long or better
SELECT AND BETTER	to average 8" wide or better and 12' long or better
STANDARD AND BETTER	to average 7" wide or better and 10' long or better
SOUND AND BETTER	to average 7" wide or better and 10' long or better
SERVICEABLE AND BETTER	to average 6" wide or better and 10' long or better
MERCHANTABLE	to average 6" wide or better and 10' long or better

APPENDIX XIV
(Rule 21 refers)

TABLE OF RECOMMENDED SAWING SIZES AND MAXIMUM OVERSIZE LIMITS

Unless specified to the contrary in these Rules, the recommended sawing sizes tabled below are applicable to all timber sawn full in accordance with Rule 21. Adequate precautions must however be taken when buying timber intended for Kiln Drying. Some timbers, notably Durian, Kapur, Keruing, Mengkulang, Dark Red Meranti, Light Red Meranti and Nyatoh have been found to have higher shrinkage properties, thereby resulting in possible scantness, especially in width, after Kiln Drying. In order to avoid this possible scantness, buyers are therefore advised to place orders for sizes sufficiently larger than the nominal sizes they would order for shipping dry timber.

(i) **Thickness**

Ordered Size (i.e. nominal size)	Recommended Sawing Size (off the saw)	Maximum Oversize (Fraction above nominal size at time of grading, Rule 25)
under 1"		1/8"
1"	1 1/8"	1/4"
1¼"	1 3/8"	1/4"
1½"	1 5/8"	1/4"
1¾"	1 7/8"	1/4"
2"	2 3/16"	1/4"
2½"	2 11/16"	1/4"
3"	3 3/16"	1/4"
3½"	3 ¾"	3/8"
4"	4 ½"	3/8"
5"	5 ¼"	3/8"
6" and over	6 3/8"	1/2"

(ii) **Widths.** *See* Rule 22 (b); recommended sawing sizes are :

Below 6"	¼" oversize (off the saw)
6" to below 8"	3/8" oversize
8" to below 10"	½" oversize
10" and over	5/8" oversize

(iii) **Lengths.** *See* Rule 27.

Example:- A board specified as 9" x 2" x 16' should come off the saw at about 9½" x 2 3/16" x 16'1".

Table of Grading Requirements for Multi-purpose Stress Grade			
Kind of Defect (Appendix XV)	**MAXIMUM PERMISSIBLE LIMITS FOR EACH GRADE**		
	I. Select Structural Grade See Note (b) below	**II. Standard Structural Grade See Note (b) below**	**III. Common Building Grade See Note (b) below**
(1) Sloping grain	1 in 16 (3/4 in. per ft.)	1 in 10.7 (1 1/8 in per ft.)	1 in 8 (1 1/2 in. per ft)
(2) Curvature	1/4 in. in 12 ft	1/2 in. in 12 ft.	3/4 in. in 12 ft.
(3) Holes, borer			
(a) Pin and Needle Holes (up to 1/6 in. dia.)	16 in 16 sq. in	32 in 16 sq. in	Unlimited if well scattered and not in groups
(b) Shot Holes(1/16 in. to 1/8 in. dia.) and Resin Pockets of similiar size	2 per sq. ft.	4 per sq. ft.	8 per sq. ft.
(c) Large Borer Holes, 1/8 in. to 1/4 in. dia	None	2 per sq. ft.	4 per sq. ft.
(d) Larger Borer Holes, over 1/4 in. dia.	Double their diameter and count as hollow knots		
(4) Knots			
(a) Sound	1/8 dimension of face, to max of 1 1/2" dia. 1 per 3' in length	1/4 dimension of face, to max. of 3" dia. 1 per 3' in length	1/3 dimension of face, to max. of 4" dia. 1 per 3' in length
(b) Unsound or hollow (Knot holes)	None	1/6 dimension of face, to max. of 2" dia. 1 per 8' in length	1/4 dimension of face, to max. of 3" dia. 1 per 8' in length
(5) Decay (Rot)	None	None, except in an unsound Knot	None, except in an unsound Knot
(6) Sound Sapwood,	1/6 sum of width and thickness	1/4 sum of width and thickness	1/3 sum of width and thickness

including Wane			
(7) End Splits and Included Phloem Intersecting ends	None	Longest split or strand of phloem, 3 in. at each end	Longest split or strand of phloem, 6 in. at each end
(8) Stain free from decay	Unlimited	Unlimited	Unlimited
(9) Twist	None apparent	1/4 in. in 12 ft.	1/2 in. in 12 ft.
(10) Compression failures	None	None	None
(11) Brittle heart	None	None	1/4 of cross-section at ends
(12) Boxed heart	Permissible only in large cross sections (exceeding about 9" x 9") of certain species : Grading Authority to be consulted		
(13) Blocked heart shakes	None	Strands 3 in. long, spaced 3 ft.	Strands 6 in. long, spaced 3 ft.
(14) Open shakes, Surface checks and End checks	1/6 thickness	1/3 thickness	1/2 thickness
(15) Included phloem not intersecting ends			
(a) Within 2 ft. of ends	None	Strands 6" long, unlimited in number	Strands 12" long, unlimited in number
(b) Elsewhere within middle half of depth	Strands 6" long, spaced 1 ft	Strands 12" long, spaced 1 ft	Strands 24" long, spaced 1 ft
(c) Elsewhere outside middle half of depth	Strands 12" long, spaced 1 ft	Strands 24" long, spaced 1 ft	Unlimited if tight
(16) Resin pockets above 1/8 in. dia. and	2" x 1/4", spaced 3 ft	5" x 3/8", spaced 3 ft	8" x 1/2", spaced 3 ft
Bark pockets	At the discretion of the Timber Grader, an equivalent area may be allowed		
(17) Wane	*refer to item (6)*		
(18) Undersize in dimensions	Not allowed in any grade; all timber must be sawn so that it measures not less than "bare" at the time of grading		

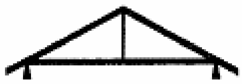
Notes :

a. The above grades are multi-purpose grades, as explained in para. (v) above
b. The limitation of defects in the Select, Standard and Common grades is generally such that the strength of graded members will not be less than 80%, 63% and 50% respectively of the strength of similar members in timber that is free of all defects
c. In pieces of square cross-section, curvature shall be measured in the direction in which it is the worse; in other rectangular pieces, only spring shall be limited as explained in para. (v). See also the table of permitted deviations in para. (vi)(b).
d. **Sapwood is allowed without limit in timber which is to be pressure impregnated with a suitable preservative; in such cases, item (6) refers to wane only.** Sapwood cannot be limited in the timbers marked with the letter (c) in Appendix I for the reasons stated there.

Table 1. Classification of Malaysian timbers (based on MGR 1984 Edition)

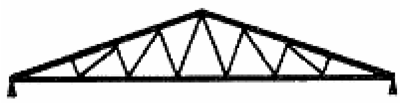
Heavy Hardwood	Medium hardwood	Light hardwood	Softwood
1.Balau	1. Alan batu	1. Alan bunga	1.Damar minyak
2. Red balau	2. Bekak	2. Ara	2. Podo
3. Belian	3. Derum	3. Babai	3. Sempilor
4. Bitis	4. Entapuloh	4. Bayur	
5. Chengal	5. Geriting/Teruntum	5. Berangan	
6. Giam	6. Kandis	6. Bintangor	
7. Kekatong	7. Kapur	7. Binuang	
8. Keranji	8. Kasai	8. Dedali	
9. Malagangai	9. Kayu malam	9. Durian	
10.Merbau	10.Kedang belum/ Tulang daing	10. Geronggang	
11.Penaga	11. Kelat	11. Gerutu	
12.Penyau	12. Keledang	12. Jelutong	
13.Resak	13. Kempas	13. Jongkong	
14.Tembusu	14. Keruing	14. Kedondong	
	15. Kerunum	15. Kelumpang	
	16. Kulim	16. Kembang semangkok	
	17. Mata ulat	17. Ketapang	
	18. Mempening	18. Kungkur	
	19. Mengkulang	19. Laran	
	20. Meransi	20. Machang	
	21. Merawan	21. Mahang	
	22. Merbatu	22. Medang	
	23. Merpauh	23. Melantai	
	24. Mertas	24. Melunak	
	25. Nyalin (Minyak berok)	25. Mempisang	
	26. Pauh kijang	26. Meranti bakau	
	27. Perah	27. Meranti, dark red	
	28. Petaling	28. Meranti, light red	
	29. Punah	29. Meranti, white	
	30. Ranggu	30. Meranti, yellow	
	31. Rengas	31. Merbulan	
	32. Semayur	32. Mersawa	
	33. Senumpul	33. Nyatoh	
	34. Simpoh	34. Pelajau	
	35. Tampoi	35. Penarahan	
	36. Tualang	36. Perupok	
		37. Petai	
		38. Pulai	
		39. Ramin	
		40. Rubberwood	
		41. Sengkuang	
		42. Sentang	
		43. Sepetir	
		44. Sesendok	
		45. Terap	
		46. Terentang	

TRUSS SHAPES AND SPANS



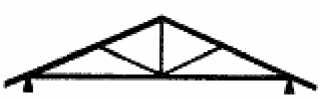
Kingpost Truss:

- spans up to 4.5 m; and
- mostly for house and garage construction.



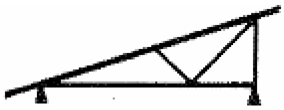
'C' Type Truss:

- spans up to 16 m; and
- mostly for commercial and industrial buildings.



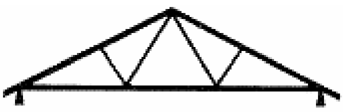
Queen Poet Truss:

- spans up to 6 m; and
- domestic type structures.



Half 'A' Truss:

- spans up to 6 m; and
- for residential construction with forming a decorative feature.

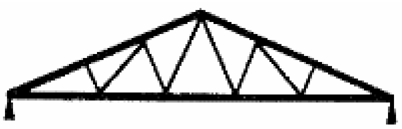


'A' Type Truss:

- spans up to 10 m; and
- most commonly used truss shape.

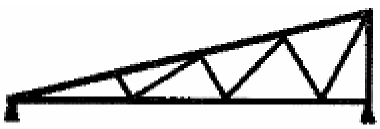
Half 'B' Truss:

- spans up to 8 m; and
- as for the Half 'A' Truss.



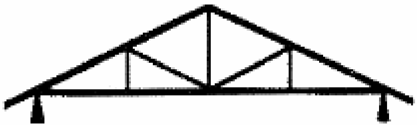
'B' Type Truss:

- spans up to 15 m; and
- mostly for residential and smaller commercial buildings.



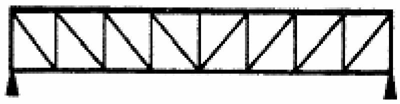
Half 'C' Truss:

- spans up to 11 m.
- as for the Half 'A' Truss.



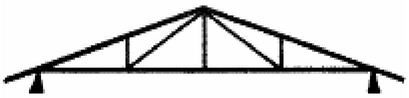
Howe Truss:

- spans up to 12 m; and
- for high bottom chord loading.



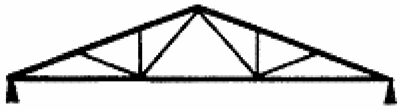
Parallel Chord Truss:

- spans up to 20 m.



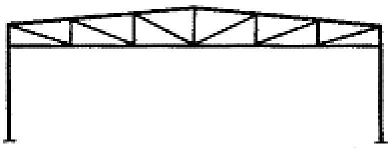
Pratt Truss:

- spans up to 12 m; and
- for reduction in lateral web braces.



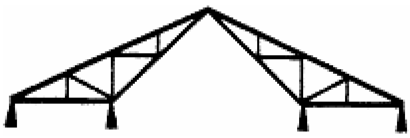
Fan Fink:

- spans up to 12 m; and
- for high top chord loading.



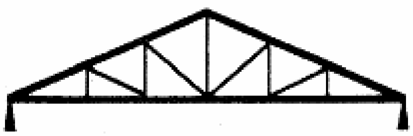
Portal Frame:

- spans up to 20 m; and
- for wide span in the standard commercial and industrial design.



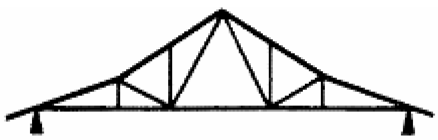
Inverted Cantilever:

- spans up to 20 m; and
- for special architectural effects in churches, restaurants, hotels, etc.



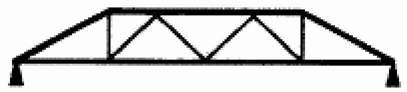
Double Howe Truss:

- spans up to 20 m; and
- for high bottom chord loading.



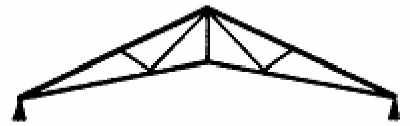
Bell Truss:

- spans up to 15 m; and
- for attractive 'Bell' shaped roof line.



Truncated Truss:

- spans up to 13 m; and
- facilitate Hip Roof construction.

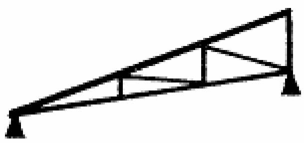


Scissors Truss:

- spans up to 15 m; and
- for vaulted ceiling effects.

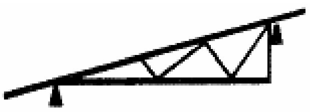
Jack Truss:

- spans to suit Truncated trusses.



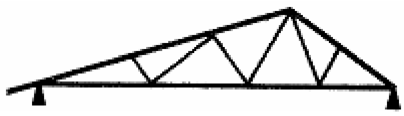
Half Scissors Truss:

- spans up to 10 m.



Hip Truss:

- spans to suit Truncated trusses.

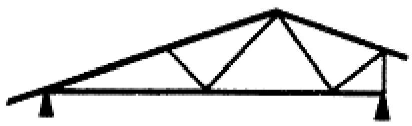


Dual Pitch:

- spans up to 13 m; and
- for special architectural effects.

Girder Truss:

- spans up to 15 m.



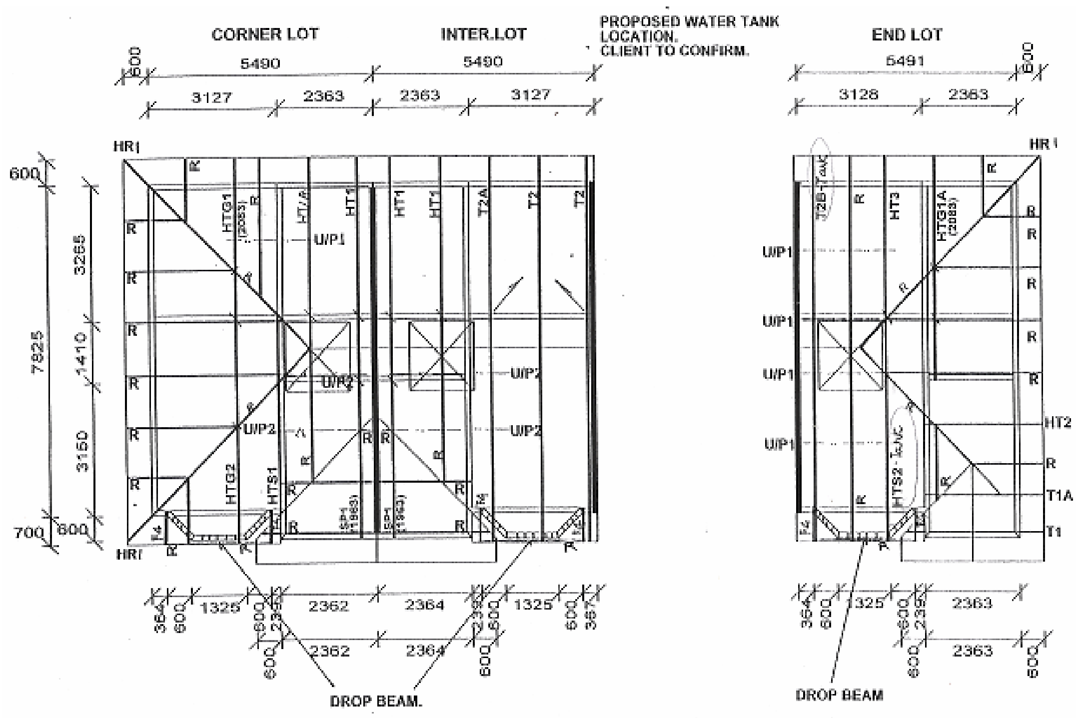
Cut-Off Truss:

- spans up to 12 m.

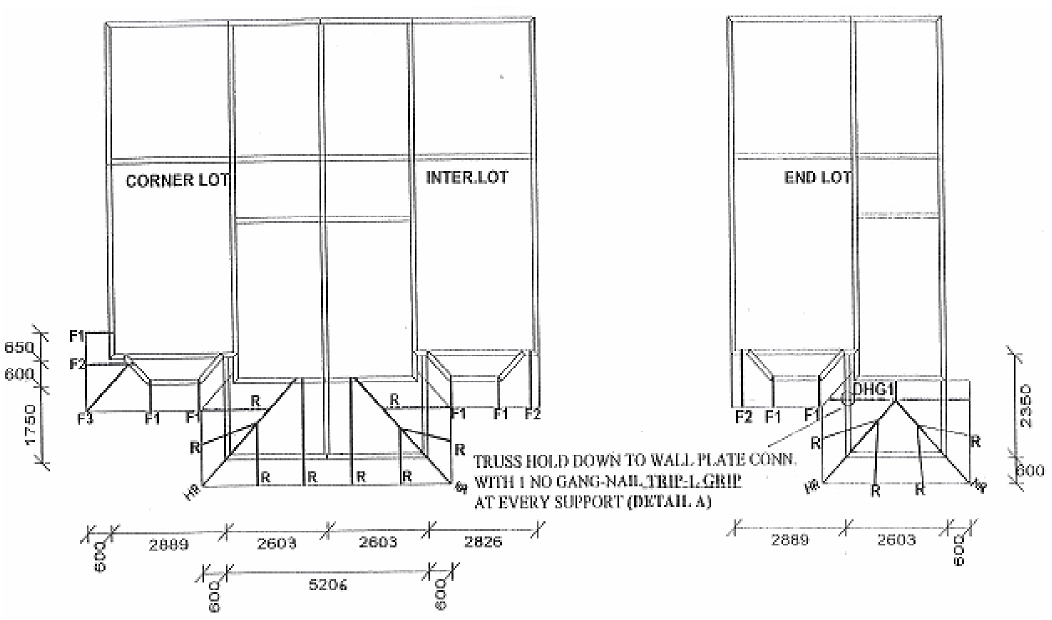
(Source: MiTek Asia Sdn. Bhd, 1997)

APPENDIX C

SUPPORTING INFORMATION FOR CASE STUDIES



(a)



(b)

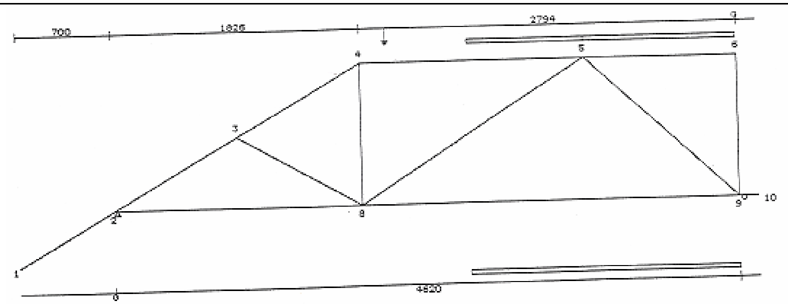
Figure C1: Roof Truss Layout for the Project 1.

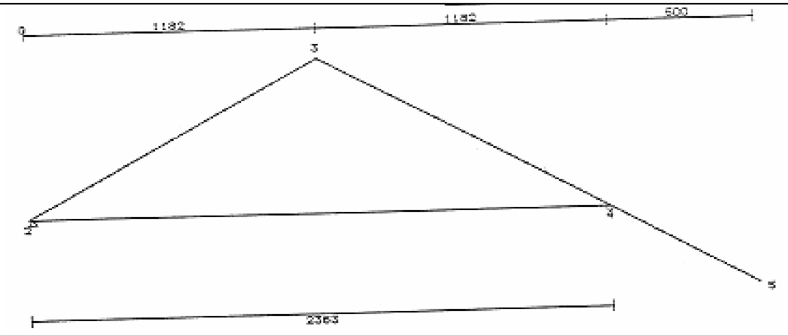
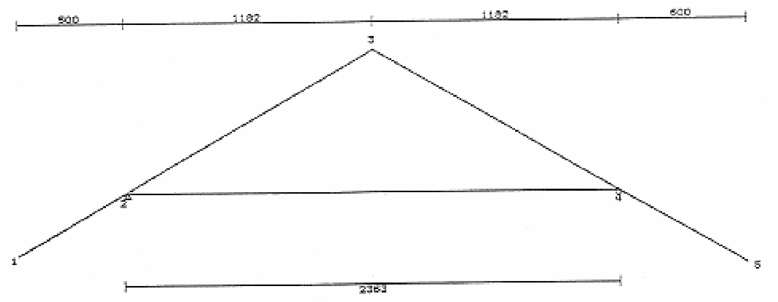
Table C1: Summary of the Result of the Roof Truss Design Analysis for the Project 1.

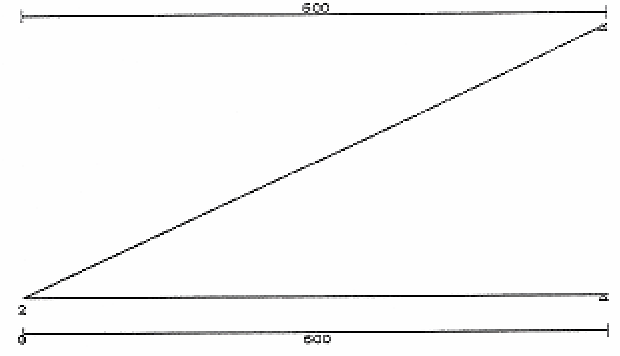
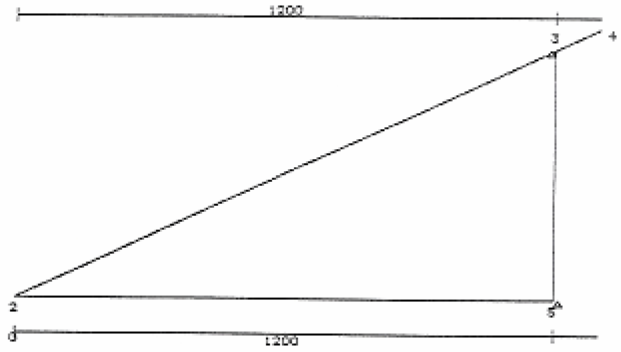
Note: (i) Top chords (T), bottom chords (B) and webs (W) are numbered consecutively from left to right.

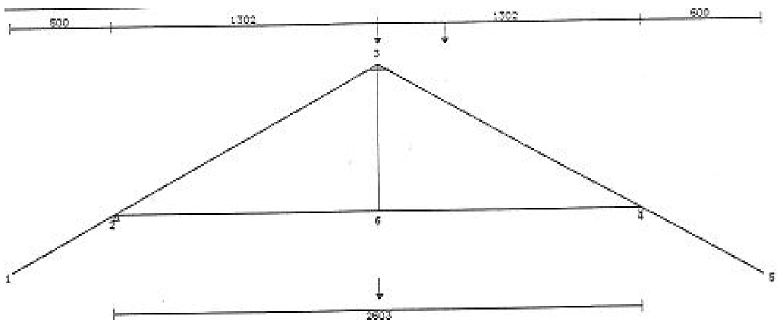
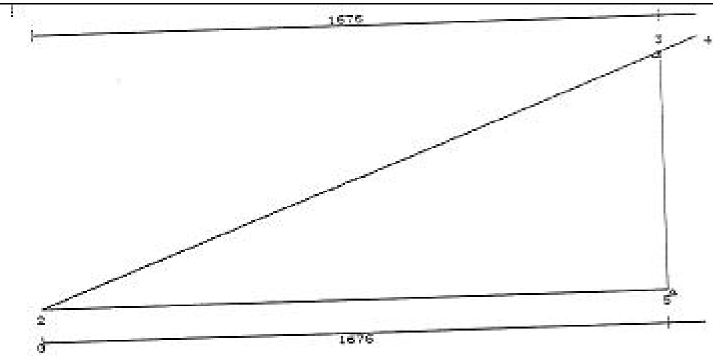
(ii) The positive value of the axial force indicates tension force.

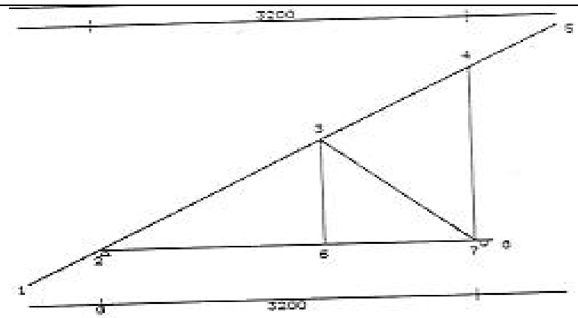
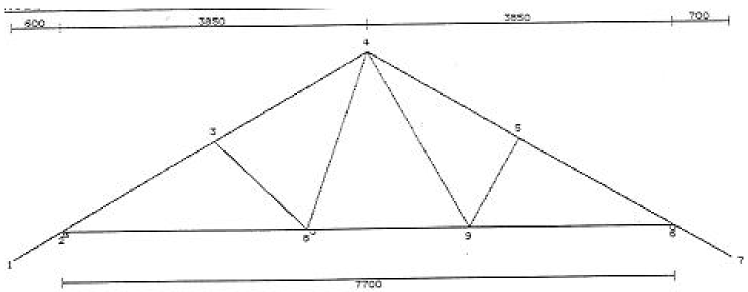
(iii) Load Case 1 (LC1): Dead load only; Load Case 2 (LC2): Dead Load + Live load; and Load Case 3 (LC3): Dead Load + Wind Load.

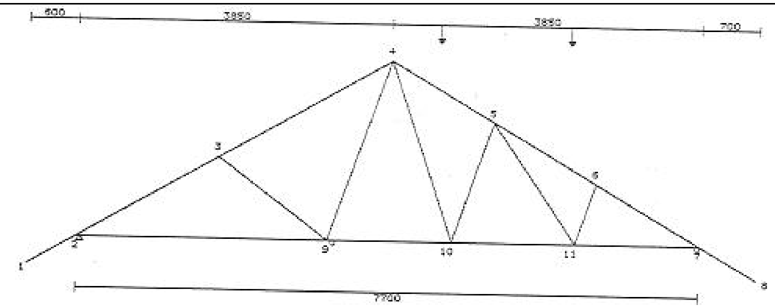
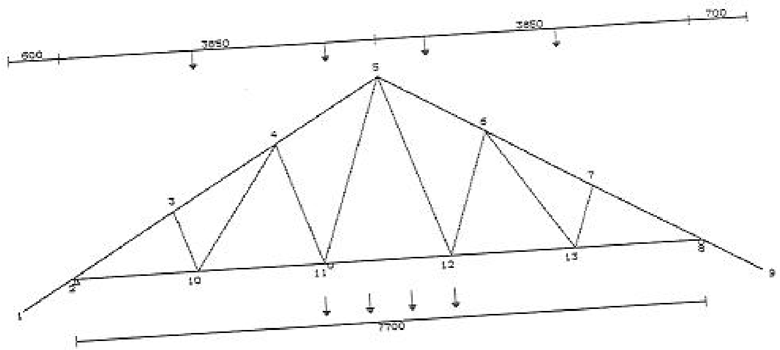
Truss Mark	Geometry and Loading Diagram	Member	Size (Depth)	Applied Elementary Loads	Critical Values
HTG2 (Pitch: 30°)	 Span: 4 620 mm Overhang: 700 mm (Left)	T1 T2 B1 W1 W2 W3 W4 W5	100 100 100 75 75 75 75 75	- Full Strip Uniformly Distributed Loads (UDL)on T1, T2 and B1; - Point Loads are subjected on T2; and - Additional UDL on the Panels 1 and 2 of T1, and the Panel 2 of B1.	Force (F): -5.847 kN at the Panel 1 of T1 and 5.064 kN at the Panel 1 of B1 from LC2. Moment (M): 0.460 kNm at the Panel 1 of T2 from LC2. Shear Force (S/F): 0.73 kN at W4 from LC1. Deflection (D): 9 mm at the Panel 2 of B1.

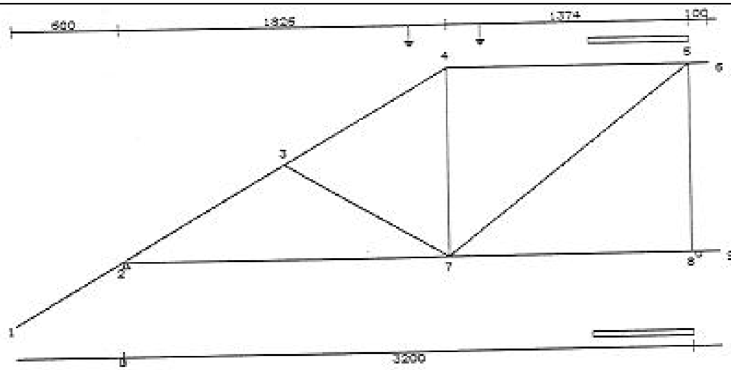
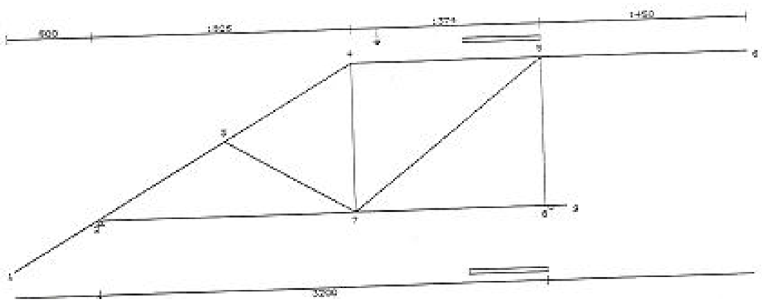
T1A (Pitch:30°)	 Span: 2 363 mm Overhang: 600 mm(Right)	T1 T2 B1	100 100 100	- Full Strip UDL on T1, T2 and B1.	F: -1.161 kN at T1 and T2 from LC2. M: 0.157 kNm at T1 and T2 from LC2. S/F: 0.16 kN at T1, T2 and B1 from LC1. D: 5 mm at B1.
T1 (Pitch: 30°)	 Span: 2 363 mm Overhang: 500 mm(Left); 600 mm (Right)	T1 T2 B1	100 100 100	- Full Strip UDL on T1, T2 and B1.	F: -1.161 kN at T1 and T2 from LC2. M: 0.157 kNm at T1 and T2 from LC2. S/F: 0.16 kN at T1, T2 and B1 from LC1. D: 5 mm at B1.

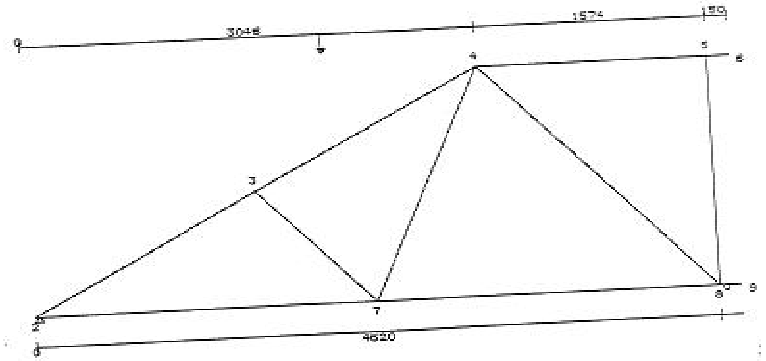
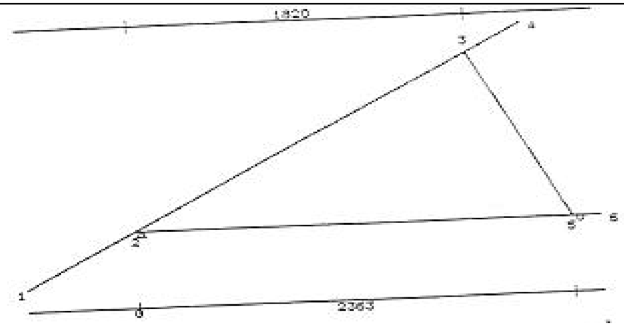
F1 (Pitch: 25°)	 Span: 600 mm	T1 B1	100 75	- Full Strip UDL on T1 and B1.	F: -0.795 kN at T1 and 0.877 kN at T2 from LC2. M: 0.1047 kNm at T1 from LC2. S/F: 0.06 kN at T1 from LC1. D: 0 mm.
F2 (Pitch:25°)	 Span:1 200 mm Overhang: 100 mm (Right)	T1 B1 W1	100 100 100	- Full Strip UDL on T1 and B1.	F: -1.590 kN at B1 and 1.754 kN at T1 from LC2. M: 0.152 kNm at T1 from LC2. S/F: 0.17 kN at T1 from LC1. D: 2 mm at T1.

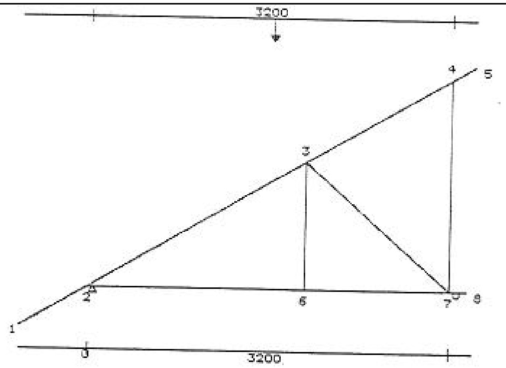
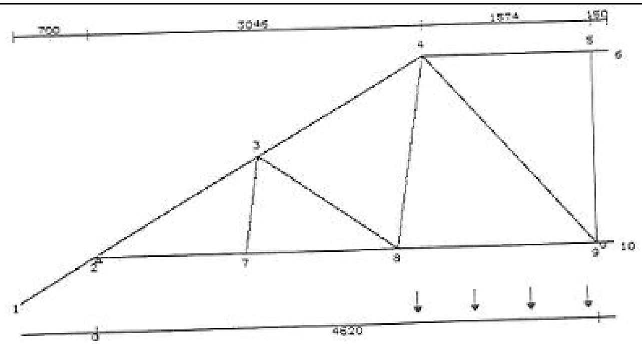
DHG1 (Pitch:25°)	 Span: 2 603 mm Overhang: 500 mm (Left); 600 mm (Right)	T1 T2 B1 W1	100 100 100 75	- Full Strip UDL on T1, T2 and B1.	F: -2.336 kN at T1 and T2, while 2.117 kN at B1 for both panels from LC2. M: 0.227 kNm at T1 and T2 from LC2. S/F: 0.26 kN at T1 and T2 from LC1. D: 2 mm at T1.
F3 (Pitch:25°)	 Span: 1 676 mm Overhang: 100 mm (Right)	T1 B1 W1	100 100 100	- Full Strip UDL on T1 and B1.	F: -2.506 kN at B1 and 2.706 kN at T1 from LC2. M: 0.291 kNm at T1 from LC2. S/F: 0.32 kN at T1 from LC1. D: 6 mm at T1.

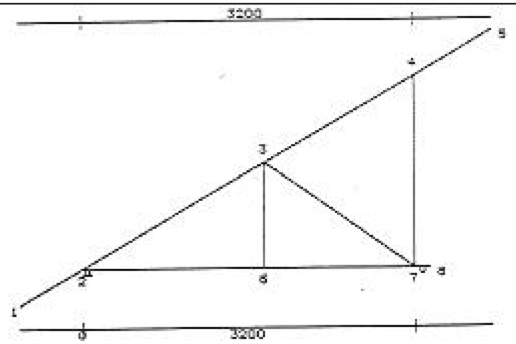
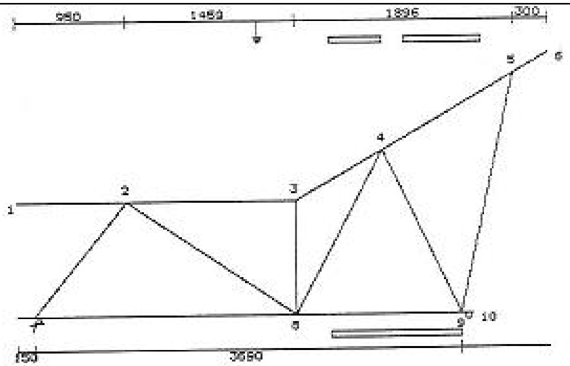
HT1 (Pitch: 30°)	 Span: 3 200 mm Overhang: 600 mm (Left); 750 mm (Right)	T1 B1 W1 W2 W3	100 75 75 75 75	- Full Strip UDL on T1 and B1.	F: -1.862 kN at W2 and 1.408 kN at B1 for both panels from LC2. M: 0.271 kNm at the Panel 1 of T1 from LC2. S/F: 0.43 kN at W2 from LC1. D: 5 mm at the Panel 1 of T1.
T2 (Pitch: 30°)	 Span: 7 700 mm Overhang: 600 mm (Left); 700 mm (Right)	T1 T2 B1 W1 W2 W3 W4	100 100 100 75 75 75 75	- Full Strip UDL on T1 and B1.	F: -3.911 kN at W2 and 2.438 kN at the Panel 3 of B1 from LC2. M: 0.272 kNm at the both panels of T1 and T2 from LC2. S/F: 0.51 kN at W2 from LC1. D: 9 mm at the Panel 1 of B1.

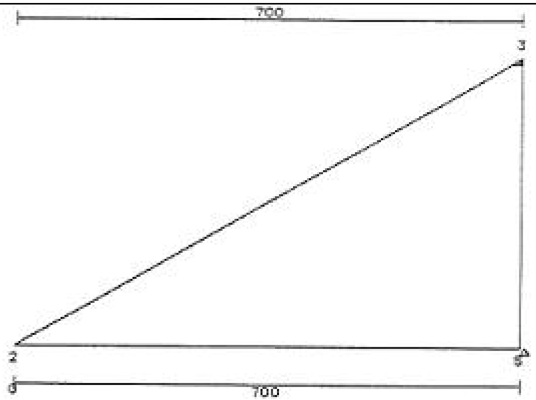
T2A (Pitch: 30°)	 Span: 7 700 mm Overhang: 600 mm (Left); 700 mm (Right)	T1 T2 B1 W1 W2 W3 W4 W5 W6	100 100 100 75 75 75 75 75 75	- Full Strip UDL on T1, T2 and B1; and - Point Loads are subjected on both panels on T2.	F: -5.344 kN at W2 and 4.292 kN at the Panel 4 of B1 from LC2. M: 0.332 kNm at the Panels 1 of T2 from LC2. S/F: 0.76 kN at W2 from LC1. D: 9 mm at the Panel 1 of B1.
T2B-Tank (Pitch: 30°)	 Span: 7 700 mm Overhang: 600 mm (Left); 700 mm (Right)	T1 T2 B1 W1 W2 W3 W4 W5 W6 W7 W8	100 100 100 75 75 75 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1; and - Point Loads are subjected on Panels 2 and 3 of T1, Panels 1 and 2 of T2, and Panels 2, 3 and 4 of B1.	F: -8.477 kN at W4 and 6.830 kN at W5 from LC2. M: 0.680 kNm at the Panels 3 of B1 from LC1 and LC2. S/F: 0.82 kN at W4 from LC1. D: 3 mm at the Panel 3 of T1 and Panel 1 of T2.

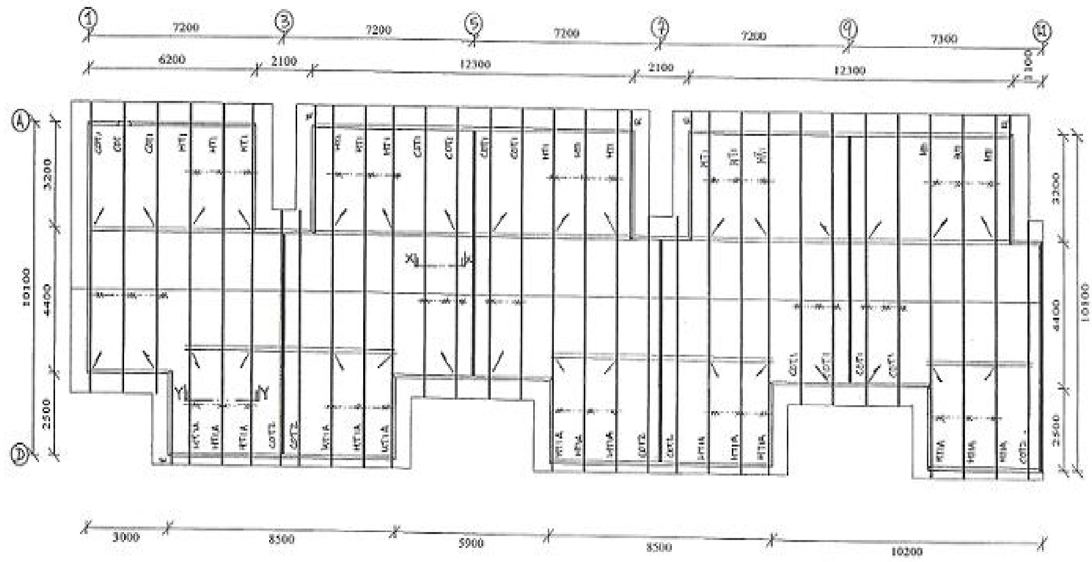
HTG1 (Pitch: 30°)	 Span: 3 200 mm Overhang: 600 mm (Left); 100 mm (Right)	T1 T2 B1 W1 W2 W3 W4	100 100 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1; - Point Loads are subjected on the Panel 2 of T1 and T2; and - Additional UDL onT2 and Panel 2 of B1.	F: -4.050 kN at Panel 1 of T1 and 3.507 kN at Panel 1 of B1 from LC2. M: 0.403 kNm at T2 from LC2. S/F: 0.46 kN at T2 from LC1. D: 5 mm at the T2.
HTG1A (Pitch: 30°)	 Span: 3 200 mm Overhang: 600 mm (Left); 1450 mm (Right)	T1 T2 B1 W1 W2 W3 W4	100 150 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1; - Point Loads are subjected on T2; and - Additional UDL on the T2 and Panel 2 of B1.	F: -4.150 kN at W4 and 2.994 kN at Panel 1 of B1 from LC2. M: 0.403 kNm at T2 from LC2. S/F: 0.36 kN at W4 from LC1. D: 1 mm at the T2 and the Panel 1 of B1.

HTS1 (Pitch: 30°)	 Span: 4 620 mm Overhang: 150 mm (Right)	T1 T2 B1 W1 W2 W3 W4	100 100 75 75 75 100 75	- Full Strip UDL on T1, T2 and B1; and - Point Loads are subjected on the Panel 2 of T1.	F: -4.624 kN at the Panel 1 of T1 and 4.004 kN at Panel 1 of B1 from LC2. M: 0.441 kNm at Panel 2 of T1 from LC2. S/F: 0.91 kN at W3 from LC1. D: 7 mm at both panels of B1.
HT2 (Pitch: 30°)	 Span: 2 363 mm Overhang: 600 mm (Left); 300 mm (Right)	T1 B1 W1	100 100 75	- Full Strip UDL on T1 and B1.	F: -1.152 kN at W1 from LC2. M: 0.360 kNm at T1 from LC2. S/F: 0.34 kN at T1 from LC1. D: 8 mm at T1.

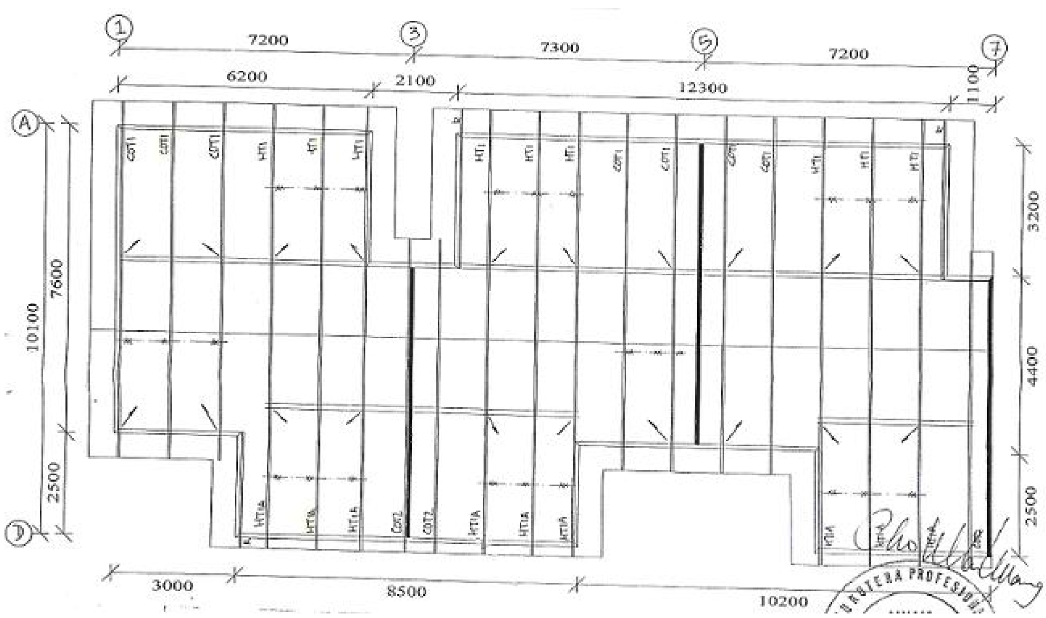
HT3 (Pitch: 30°)	 Span: 3 200 mm Overhang: 600 mm (Left); 200 mm (Right)	T1 B1 W1 W2 W3	100 75 75 75 75	- Full Strip UDL on T1 and B1; and - Point Loads are subjected on the Panel 1 of T1.	F: -2.326 kN at W2 and 1.758 kN at both panels of B1 from LC2. M: 0.364 kNm at Panel 1 of T1 from LC2. S/F: 0.57 kN at W2 from LC1. D: 7 mm at the Panel 1 of T1.
HTS2-Tank (Pitch: 30°)	 Span: 4 620 mm Overhang: 700 mm (Left); 150 mm (Right)	T1 T2 B1 W1 W2 W3 W4 W5	100 100 150 75 75 75 100 75	- Full Strip UDL on T1, T2 and B1; and - Point Loads are subjected on the Panel 3 of B1.	F: -6.786 kN at Panel 1 of T1 and 5.877 kN at the Panel 1 of B1 from LC2. M: 1.239 kNm at Panel 3 of B1 from LC1 and LC2. S/F: 0.66 kN at the Panel 3 of B1 from LC1. D: 6 mm at the Panel 3 of B1.

HT1A (Pitch: 30°)	 Span: 3 200 mm Overhang: 600 mm (Left); 750 mm (Right)	T1 B1 W1 W2 W3	100 75 75 75 75	- Full Strip UDL on T1 and B1.	F: -1.938 kN at W2 and 1.584 kN at both panels of B1 from LC2. M: 0.228 kNm at Panel 1 of T1 from LC2. S/F: 0.49 kN at W2 from LC1. D: 3 mm at the Panel 1 of T1.
SP1 (Pitch: 30°)	 Span: 3 690 mm Overhang: 950 mm (Left); 300 mm (Right)	T1 T2 B1 W1 W2 W3 W4 W5 W6	100 100 100 100 75 75 75 75 100	- Full Strip UDL on T1, T2 and B1; - Point Loads are subjected on the Panel 1 of T1; and - Additional UDL on the both panels of T2 and Panel 2 of B1.	F: -3.607 kN at W3 and 3.955 kN at W4 from LC2. M: 0.478 kNm at the Panel 1 of T1 from LC2. S/F: 0.64 kN at W5 from LC1. D: 3 mm at the T1 and the Panel 1 of B1

F4 (Pitch: 30°)	 Span: 700 mm	T1 B1 W1	100 100 100	- Full Strip UDL on T1 and B1.	F: -0.770 kN at B1 and 0.889 kN at T1 from LC2. M: 0.053 kNm at T1 from LC2. S/F: 0.07 kN at T1 from LC1. D: 0 mm.



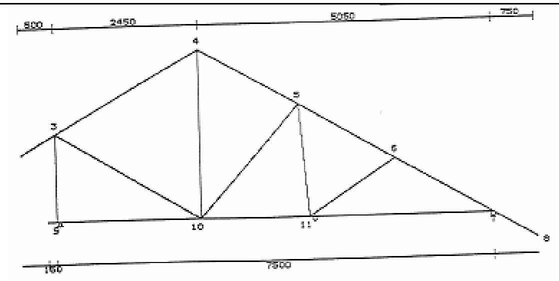
(a) Roof Plan for Block 2 and 3.

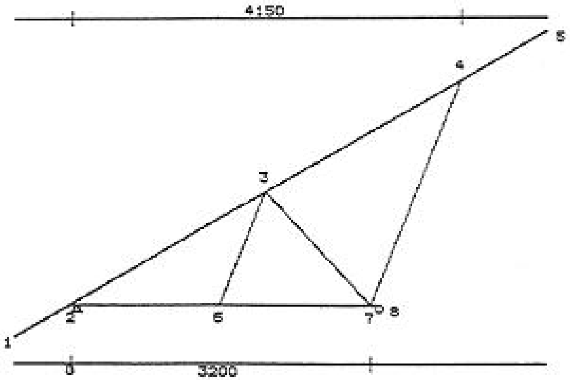
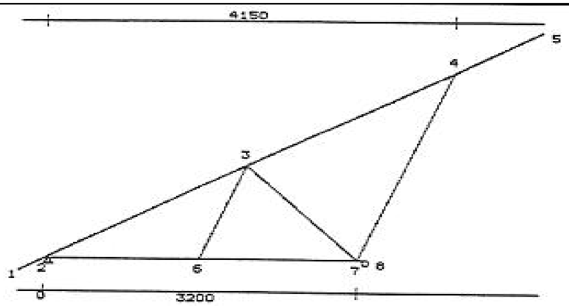


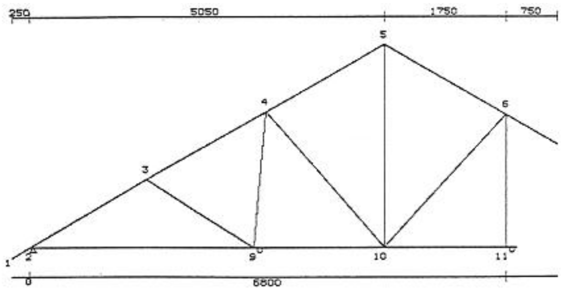
(b) Roof Plan for Block1

Figure C2: Roof Truss Layout for the Project 2.

Table C2: Summary of the Result of the Roof Truss Design Analysis for the Project 2.

Truss Mark	Geometry and Loading Diagram	Member	Size (Depth)	Applied Elementary Loads	Critical Values
COT1	 Span: 10 100 mm Overhang: 600 mm (Left); 750 mm (Right) Cutoff: 2 600 mm (Left)	T1 T2 B1 W1 W2 W3 W4 W5 W6	150 100 100 75 75 75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -3.069 kN at W1 and 1.362 kN at Panel 3 of B1 from LC2. M: 0.516 kNm at T1 from LC2. S/F: 0.76 kN at W3 from LC1. D: 7 mm at T1.

HT1	 Span: 3 200 mm Overhang: 600 mm (Left); 900 mm (Right)	T1 B1 W1 W2 W3	100 75 75 75 100	- Full Strip UDL on T1 and B1.	F: -3.025 kN at W3 and 1.287 kN at Panel 2 of T1 from LC2. M: 0.316 kNm at both panels of T1 from LC2. S/F: 0.43 kN at W2 from LC1. D: 6 mm at the both panels of T1.
HT1A	 Span: 3 200 mm Overhang: 250 mm (Left); 900 mm (Right)	T1 B1 W1 W2 W3	100 75 75 75 100	- Full Strip UDL on T1 and B1.	F: -3.025 kN at W3 and 1.287 kN at Panel 2 of T1 from LC2. M: 0.316 kNm at both panels of T1 from LC2. S/F: 0.43 kN at W2 from LC1. D: 6 mm at the both panels of T1.

COT2	 Span: 10 100 mm Overhang: 250 mm (Left); 750 mm(Right) Cutoff: 3 300 mm	T1 T2 B1 W1 W2 W3 W4 W5 W6	100 100 100 75 75 75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -2.948 kN at W2 and 1.260 kN at Panel 1 of B1 from LC2. M: 0.263 kNm at T2 from LC2. S/F: 0.86 kN at W2 from LC1. D: 4 mm at T2 and the Panel 1 of B1.

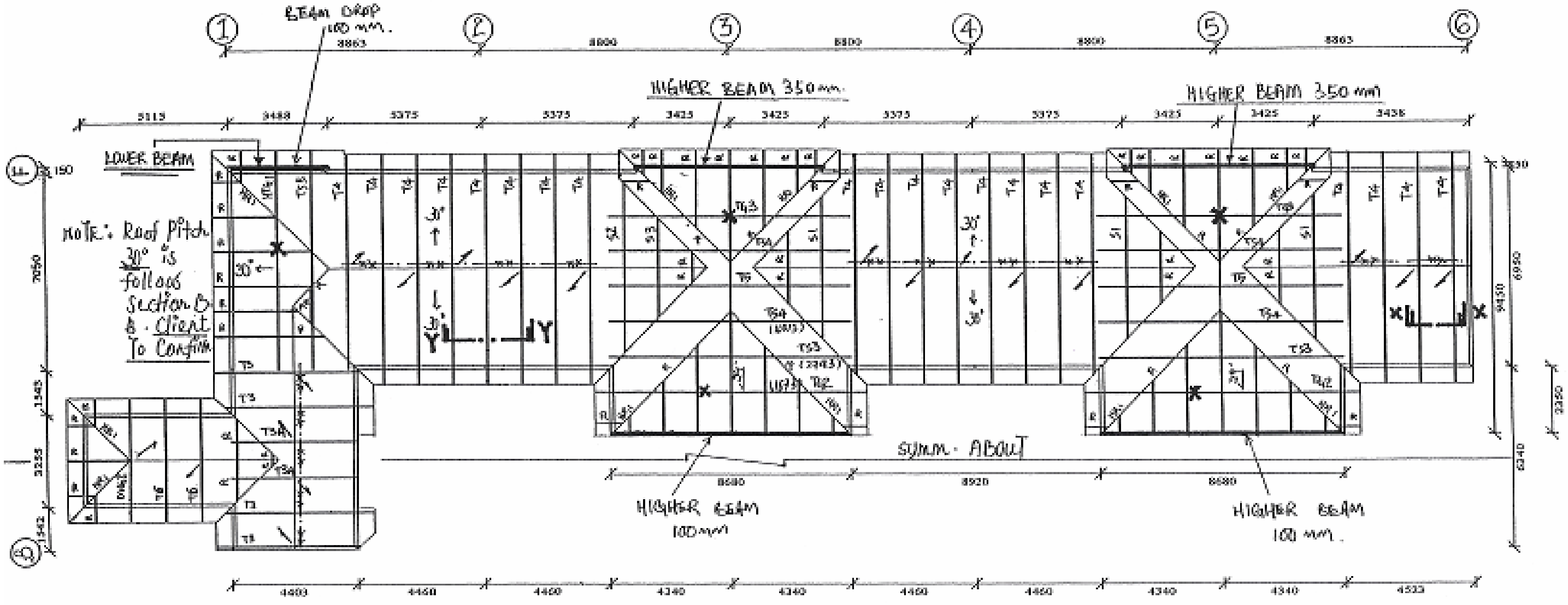
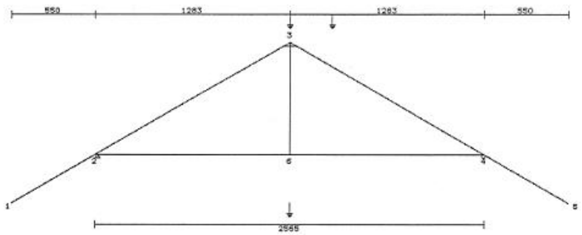
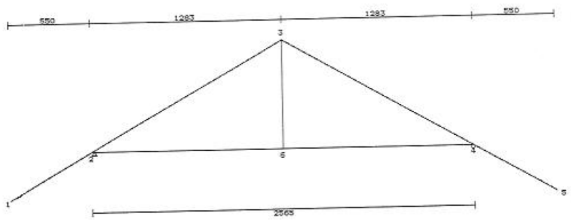
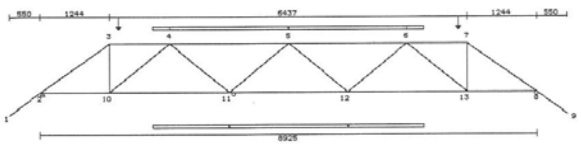
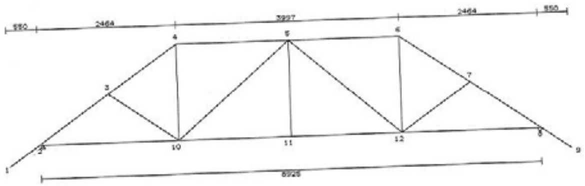


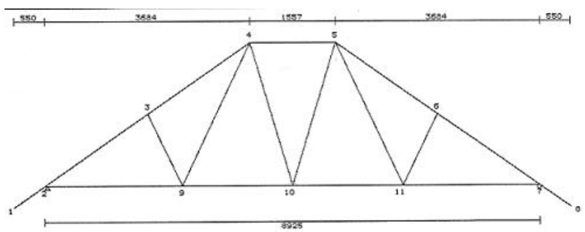
Figure C3: Roof Truss Layout for the Project 3.

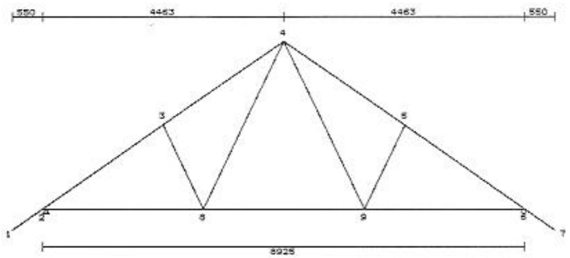
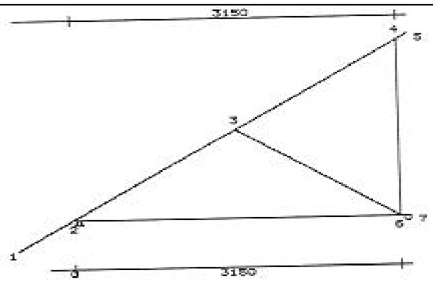
Note: The plan shows the only half of the whole roof plan. The building is symmetrical about the line that is shown above.

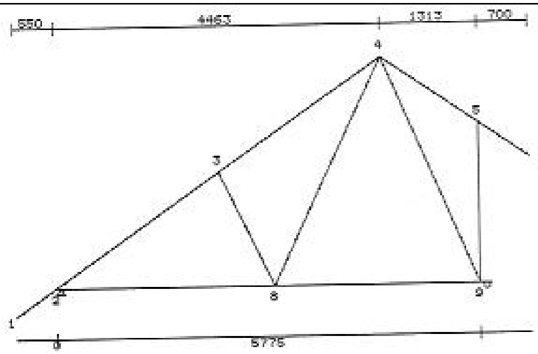
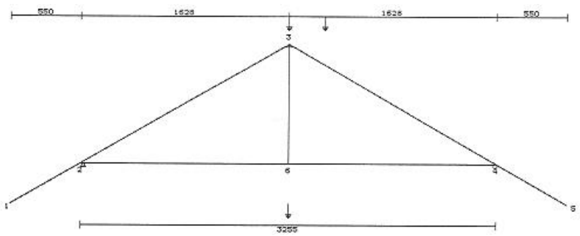
Table C3: Summary of the Result of the Roof Truss Design Analysis for the Project 3.

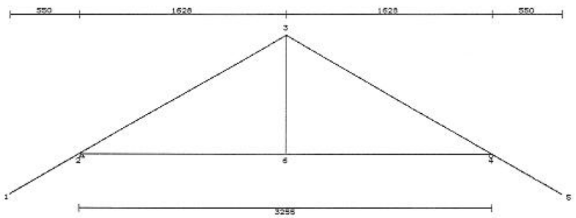
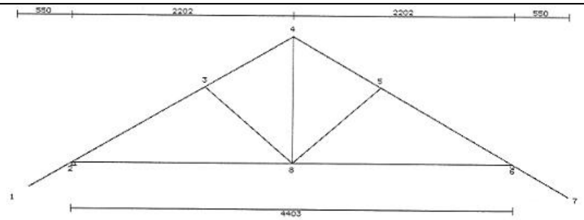
Truss Mark	Geometry and Loading Diagram	Member	Size (Depth)	Applied Elementary Loads	Critical Values
DHG1 Pitch: 30°	 Span: 2 565 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 B1 W1	100 100 100 75	- Full Strip UDL on T1, T2 and B1; and - Point Loads are subjected on T1, T2 and B1.	F: -1.773 kN at the T1 and T2 and 1.535 kN at the both panels of B1 from LC2. M: 0.228 kNm at T1 and T2 from LC2. S/F: 0.25 kN at T1 and T2 from LC1. D: 2 mm at T1 and T2.
T2 Pitch: 30°	 Span: 2 565 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 B1 W1	100 100 75 75	- Full Strip UDL on T1, T2 and B1.	F: -1.369 kN at the T1 and T2 and 1.186 kN at the both panels of B1 from LC2. M: 0.120 kNm at T1 and T2 from LC2. S/F: 0.14 kN at T1 and T2 from LC1. D: 1 mm at T1 and T2.

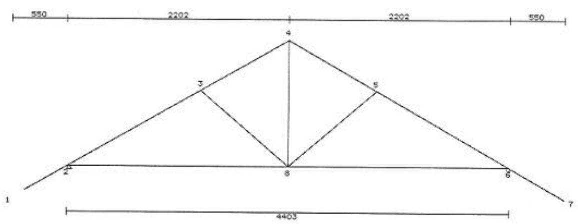
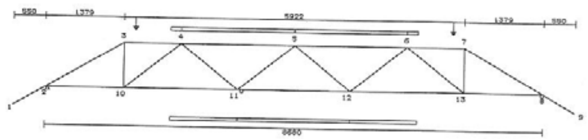
TG1 Pitch: 35°	 Span: 8 925 mm Overhang: 550 mm(Left); 550 mm (Right)	T1 T2 T3 B1 W1 W2 W3 W4 W5 W6 W7 W8	100 100 100 100 75 75 75 75 75 75 75 75	- Full Strip UDL on T1, T2, T3 and B1; - Point Loads are subjected on T2 for the Panel 1 and 4; and - Additional UDL on all of the panels on T2 and all of the internal panels of B1.	F: -5.631 kN at the W4 and 4.100 kN at the Panels 4 of B1 from LC2. M: 0.473 kNm at Panels 2 and 3 of T2 from LC2. S/F: 0.55 kN at the Panel 3 of T2 from LC1. D: 8 mm at Panels 2 and 3 of T2.
TS2 Pitch: 35°	 Span: 8 925 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 T3 B1 W1 W2 W3	100 100 100 100 75 75 75	- Full Strip UDL on T1, T2, T3 and B1.	F: -7.230 kN at the Panel 2 of T3 and 6.151 kN at the Panels 2 and 3 of B1 from LC2. M: 0.374 kNm at both panels of T2 from LC2. S/F: 0.74 kN at the W3 and W5 from LC1.

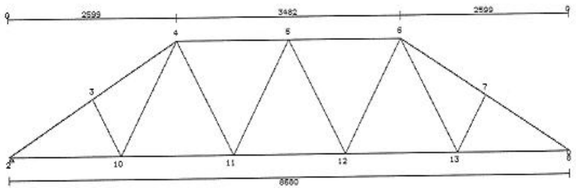
		W4 W5 W6 W7	75 75 75 75		D: 5 mm at both panels of T2.
TS1 Pitch: 35°	 Span: 8 925 mm Overhang: 550 mm(Left); 550 mm(Right)	T1 T2 T3 B1 W1 W2 W3 W4 W5 W6	100 100 100 100 75 75 75 75 75 75	- Full Strip UDL on T1, T2, T3 and B1.	F: -6.967 kN at the Panel 1 of T1 and the Panel 2 of T3 and 5.707 kN at the Panels 1of B1 from LC2. M: 0.368 kNm at both panels of T1 and T3 from LC2. S/F: 0.60 kN at the Panel 1 of T1 and Panels 2 of T3 from LC1. D: 7 mm at both panels of T1 and T3.

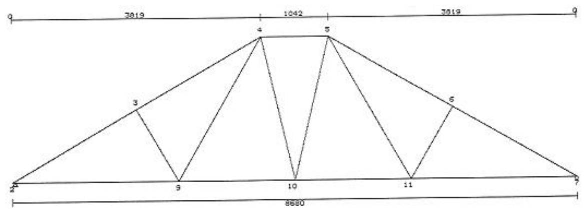
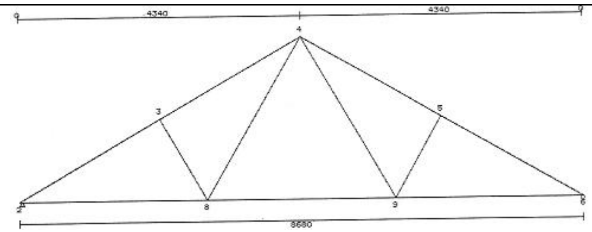
T1 Pitch: 35°	 Span: 8 925 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 B1 W1 W2 W3 W4	100 100 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -6.609 kN at the Panel 1 of T1 and the Panel 2 of T2 and 5.414 kN at the Panels 1 and 3 of B1 from LC2. M: 0.353 kNm at both panels of T1 and T2 from LC2. S/F: 0.79 kN at the Panel 1 of T1 and Panels 2 of T2 from LC1. D: 9 mm at both panels of T1 and T2.
HT1 Pitch: 35°	 Span: 3 150 mm Overhang: 550 mm (Left); 100 mm (Right)	T1 B1 W1 W2	100 100 75 75	- Full Strip UDL on T1 and B1.	F: -1.488 kN at the Panel 1 of T1 and the W1 and 1.219 kN at the B1 from LC2. M: 0.184 kNm at both panels of T1 from LC2. S/F: 0.44 kN at the W1 from LC1. D: 10 mm at B1.

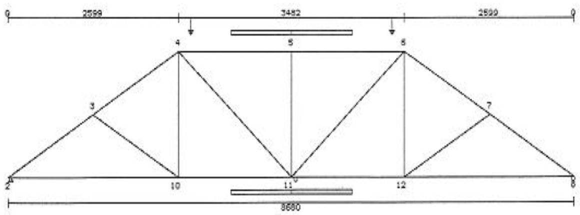
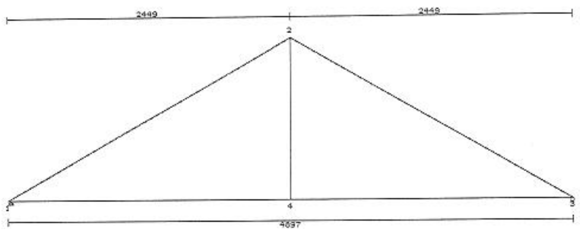
COT1 Pitch: 35°	 Span: 8 925 mm Overhang: 550 mm (Left); 700 mm (Right) Cutoff: 3 150 mm (Right)	T1 T2 B1 W1 W2 W3 W4	100 100 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -3.554 kN at the Panel 1 of T1 and 2.911 kN at the Panel 1 of B1 from LC2. M: 0.369 kNm at both panels of T1 from LC2. S/F: 0.78 kN at the W3 from LC1. D: 10 mm at the both panels of T1.
DHG2 Pitch: 30°	 Span: 3 225 mm Overhang: 550 mm (Left); 550 mm(Right)	T1 T2 B1 W1	100 100 100 75	- Full Strip UDL on T1, T2 and B1.	F: -2.566 kN at the T1 and T2 and 2.222 kN at the both panels of B1 from LC2. M: 0.367 kNm at T1 and T2 from LC2. S/F: 0.42 kN at T1 and T2 from LC1. D: 6 mm at T1 and T2.

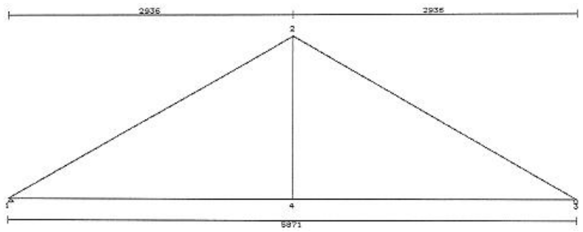
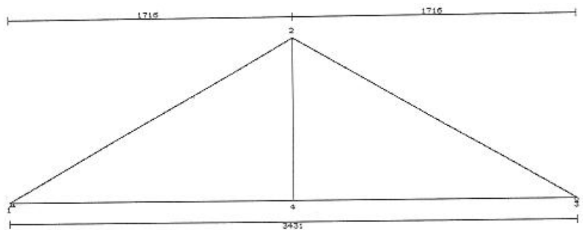
T6 Pitch: 30°	 Span: 3 255 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 B1 W1	100 100 75 75	- Full Strip UDL on T1, T2 and B1.	F: -1.769 kN at the T1 and T2 and 1.532 kN at the both panels of B1 from LC2. M: 0.200 kNm at T1 and T2 from LC2. S/F: 0.23 kN at T1 and T2 from LC1. D: 3 mm at T1 and T2.
T3 Pitch: 30°	 Span: 4 403 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 B1 W1 W2 W3	100 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -3.336 kN at the Panle 1 0f T1 and Panel 2 of T2 and 2.889 kN at the both panels of B1 from LC2. M: 0.117 kNm at Panel 1 of T1 and Panle 2 of T2 from LC2. S/F: 0.18 kN at Panel 1 of T1, Panel 2 of T2 and both panels of B1 from LC1. D: 2 mm at both panels of B1.

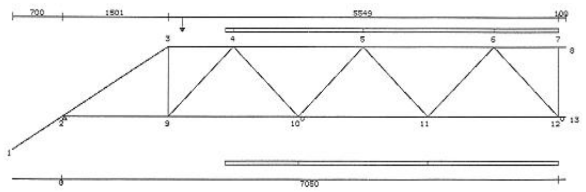
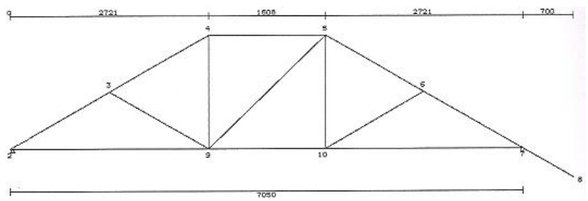
T4 Pitch: 30°	 Span: 7 050 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 B1 W1 W2 W3	100 100 100 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -5.437 kN at the Panle 1 0f T1 and Panel 2 of T2 and 4.708 kN at the both panels of B1 from LC2. M: 0.310 kNm at Panel 1 of T1 and Panle 2 of T2 from LC2. S/F: 0.56 kN at Panel 1 of T1 and Panel 2 of T2 from LC1. D: 6 mm at the Panel 1 of T1, Panel 2 of T2 and both panels of B1.
TG2 Pitch: 30°	 Span: 8 680 mm Overhang: 550 mm (Left); 550 mm (Right)	T1 T2 T3 B1 W1 W2 W3 W4	100 100 100 100 75 75 75 75	- Full Strip UDL on T1, T2, T3 and B1; - Point Loads are subjected on the Panel 1 and 4 of T2; and - Additional UDL on all of the panels of T2 and the internal panels of B1.	F: -5.984 kN at W4 and 4.415 kN at Panel 4 of B1 from LC2. M: 0.062 kNm at the Panel 3 of B1 from LC2. S/F: 0.74 kN at W4 from LC1. D: 1 mm at the internal panels of B1.

		W5 W6 W7 W8	75 75 75 75		
TS3 Pitch: 30°	 Span: 8 680 mm	T1 T2 T3 B1 W1 W2 W3 W4 W5 W6 W7 W8	100 100 100 100 75 75 75 75 75 75 75 75	- Full Strip UDL on T1, T2, T3 and B1.	F: -8.151 kN at Panel 1 of T1 and Panel 2 of T3 and 7.059 kN at Panel 1 and 5 of B1 from LC2. M: 0.294 kNm at the both panels of T2 from LC2. S/F: 0.70 kN at both panels of T2 from LC1. D: 3 mm at the both panels T2.

TS4 Pitch: 30°	 Span: 8 680 mm	T1 T2 T3 B1 W1 W2 W3 W4 W5 W6	100 100 100 100 75 75 75 75 75 75	- Full Strip UDL on T1, T2, T3 and B1.	F: -7.679 kN at Panel 1 of T1 and Panel 2 of T3 and 6.650 kN at Panel 1 and 4 of B1 from LC2. M: 0.392 kNm at the both panels of T1 and T3 from LC2. S/F: 0.61 kN at Panel 1 of T1 and Panel 2 of T3 from LC1. D: 7 mm at the both panels T1 and T3.
T5 Pitch: 30°	 Span: 8 680 mm	T1 T2 B1 W1 W2 W3 W4	100 100 100 75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -7.305 kN at Panel 1 of T1 and Panel 2 of T2 and 6.326 kN at Panel 3 of B1 from LC2. M: 0.330 kNm at the both panels of T1 and T2 from LC2. S/F: 0.71 kN at Panel 1 of T1 and Panel 2 of T2 from LC1. D: 7 mm at the both panels T1 and T2.

TG3 Pitch: 30°	 Span: 8 680 mm	T1 T2 T3 B1 W1 W2 W3 W4 W5 W6 W7	100 125 100 100 75 75 100 100 100 75 75	- Full Strip UDL on T1, T2, T3 and B1; - Point Loads are subjected on the both panels of T2; and - Additional UDL on all of the panels of T2 and the internal panels of B1.	F: -5.639 kN at W3 and W5 and 2.807 kN at both panels of T2 from LC2. M: 0.717 kNm at the both panel of T2 from LC2. S/F: 0.46 kN at the both panels of T2 from LC1. D: 4 mm at both panels of T2.
S1 Pitch: 30°	 Span: 4 987 mm	T1 T2 B1 W1	75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -1.518 kN at W1 from LC2. M: 0.694 kNm at T1 and T2 from LC3. S/F: 0.82 kN at the both panels of B1 from LC3. D: 4 mm at both panels of B1.

S2 Pitch: 30°	 Span: 5 871 mm	T1 T2 B1 W1	100 100 75 75	- Full Strip UDL on T1, T2 and B1.	F: -1.820 kN at W1 from LC2. M: 0.998 kNm at T1 and T2 from LC3. S/F: 0.99 kN at the both panels of B1 from LC3. D: 4 mm at both panels of B1.
S3 Pitch: 30°	 Spans: 3 431 mm	T1 T2 B1 W1	75 75 75 75	- Full Strip UDL on T1, T2 and B1.	F: -1.595 kN at W1 from LC2. M: 0.766 kNm at T1 and T2 from LC3. S/F: 0.90 kN at T1 and T2from LC3. D: 4 mm at both panels of B1.

HTG1 Pitch: 30°	 Span: 7 050 mm Overhang: 700 mm(Left); 100 mm (Right)	T1 T2 B1 W1 W2 W3 W4 W5 W6 W7 W8	100 100 100 75 75 75 75 75 75 75 75	- Full Strip UDL on T1, T2 and B1; - Point Loads are subjected on the Panels 1 of T2; and - Additional UDL on all of the panels of T2 and the Panels 2, 3 and 4 of B1.	F: -3.980 kN at W4 and 1.921 kN at the Panels 2 of T2 from LC2. M: 0.400 kNm at the Panel 2 and 3 of T2 from LC2. S/F: 0.49 kN at W4 from LC1. D: 5 mm at Panels 2 and 3 of T2.
TS5 Pitch: 30°	 Span: 7 050 mm Overhang: 700 mm (Right)	T1 T2 T3 B1 W1 W2 W3 W4 W5	100 100 100 100 75 75 75 75 75	- Full Strip UDL on T1, T2, T3 and B1.	F: -6.308 kN at the Panel 1 of T1 and 5.463 kN at the Panels 1 and 3 of B1 from LC2. M: 0.314 kNm at T2 from LC2. S/F: 0.49 kN at T1 from LC1. D: 5 mm at T2.