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Scaffolding Systems in Hong Kong – Current Practice and Development Of MBMSS
香港棚架系統 – 竹通混合棚的現況及發展

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Abstract

Scaffolding is widely used in the construction industry. Traditional bamboo scaffolding has a long history and metal scaffolding has been in use for nearly 100 years. To meet safety requirements, address the problems involved in high rise building construction and take advantage of modern building technology, a new design scaffolding system has been invented. The Metal Bamboo Matrix Scaffolding System (MBMSS) takes advantage of the merits of both bamboo and metal scaffolding. Drawing support from academic research, and in conjunction with a standardised operational process and management protocol, MBMSS has been developed into a flexible scaffolding system that fulfils the requirements of various scenarios in the construction industry. The system has been patented in Europe, Hong Kong and China, and has been used in construction projects since 1998. The live load of MBMSS is less than metal scaffolding, and the new system has better safety features than bamboo scaffolding in terms of structural calculation and a standardised working environment. A new calculation approach, NAF-Nida, has been adopted, and safety has been further improved by considering the imperfection of alignment and deformation of the scaffold members; taking the nylon safety net vibration induced by wind into consideration, anchoring intervals and safety precautions during typhoons have also been reviewed. A modern operation and management scheme has also been developed to ensure the system's safety standards and address quality assurance and cost control. MBMSS is an integrated system and its performance has been proven by hundreds of projects implemented in actual environments and various working scenarios.

Acknowledgements

I wish first to thank my supervisor Professor S Kitipornchai for many discussions and thoughtful comments during my research and the preparation of this thesis. Although the idea presented in this thesis and the subsequent development of the MBMSS was my work alone, I benefited from the assistance and support of Mr Roger Lin, Mr Sunny Yau and Mr Stanley Lam of WLS Holdings Ltd. Finally, I would like to express my gratitude to the members of my family who offered their moral support during the years spent on this work, especially my wife, who has been a source of support in both happy and difficult moments.

List of Content

List of Appendices

Chapter 1 Introduction

Bamboo scaffolding has a long history. In the past 30 years it has been developed significantly and applied in many different applications. Metal scaffolding, in contrast, has only been used for 100 years, but there are now a number of different types of metal scaffolds. Despite the evolution of bamboo and metal scaffolding, recent concerns about safety, increasingly high buildings and operating cost and flexibility constraints have paved the way for the invention of a new scaffolding system. This study will introduce the current scaffolding system used in Hong Kong and the design, implementation of a new scaffolding system Metal-Bamboo Matrix System Scaffold (MBMSS) will be presented.

Before the establishment of the Construction Industry Training Authority in 1976, scaffolder was trained by traditional apprentice-master approach, the training period was usually long and the progress was closely monitored by the master stage by stage. There is no unified training and the knowledge was always conveyed without any theory or a strong academic support. It can be understood that due to the material properties of natural bamboo, a systematic design of bamboo scaffold like the metal scaffold is not available. Despite a long history of bamboo scaffold, a systematic study was begun in 1981 by Janssen (1981). Since bamboo is a natural product, the material properties are not consistence and it is strong relied on the experience of the scaffolder to make judgement when carry out his work. Due to the constraints of the material properties, it is difficult to obtain a theoretical analysis of a bamboo scaffold. A full scale experiment and numerical simulation of bamboo scaffold were conducted by Chang & Yu (2002) and the deviation of these two results was about 30%. The author, a practitioner in bamboo scaffold, has a profound experience in the scaffold industry and leading his own scaffold company, is able to share his experience and to test his idea in actual environment, to push forward the evolution of the bamboo scaffold into a new dimension.

The objective of the research reported here was to design an integrated scaffolding system that could improve on the performance of bamboo scaffolding, but also maintain bamboo's good reputation as being cheap, flexible and efficient. The research drew support from academic studies in an attempt to ensure that the scaffolding system designed could be deployed in various scenarios. A management protocol was also established to ensure the system's safety and efficient operation.

The scope of this research will review the current scaffold industry; the configuration of existing bamboo scaffold and the metal scaffold; the requirement of the building and construction industry as well as the legislation and regulation. Based on the advantage and disadvantage, a new scaffold system that could comply with the tightening legal requirements for bamboo scaffolding in Hong Kong will be designed. A key requirement was that the system had to be acceptable to Hong Kong's construction industry and take into account all current forms of malpractice. It had to be a system capable of eradicating all human error, wilful damage and inadequate workmanship. Most obviously, it had to be a system that was strong and rigid enough to support itself and provide service to others without much trouble. Yet to ensure its attractiveness to the industry, the system also had to be economical, flexible and fast to erect in a safe manner. The research will also present the application of the new scaffold system in different site conditions and the benefit in term of the safety, cost, and operation effectiveness.

In describing the development of that integrated scaffolding system, the rest of this dissertation proceeds as follows. Chapter 2 reviews the history of the scaffolds. Chapter 3 presents the configuration and design of traditional scaffolding, including the general features and components of bamboo and metal scaffolding, the loading and safety requirements and recent research into scaffolding. Chapter 4 then presents the design philosophy of the new scaffolding system. It covers the advantages and disadvantages of traditional scaffolding, the engineering problems encountered and the need for change. The chapter also presents a design based on the functional and safety requirements described in Chapter 3 and outlines the process by which that design was developed into an integrated scaffolding system, the Metal Bamboo Matrix Scaffolding System (MBMSS).

Chapter 5 demonstrates the implementation of the MBMSS starting from patent application. Further improvement of the MBMSS through collaboration with academics to study a numerical simulation algorithm and conduct aerodynamic testing is then described. The establishment of safety and operation management protocol is then discussed, followed by case studies of different applications of the new scaffolding system. Chapter 6 discusses the MBMSS system in terms of safety, cost, operation and application, and compares it to other metal bamboo scaffolding systems used in China. Finally, conclusions are drawn in Chapter 7, and recommendations are made for further study.

Chapter 2 History of Scaffolding in Hong Kong

Scaffolding is a very common structure and has been applied in many ways. Fu (1993) and So and Wong (1998) reported that bamboo scaffolds are commonly employed in building construction to provide temporary access and work platforms for construction workers and supervisory staff. Chung and Siu (2002) reported that single and double layered scaffolds were the most typical applications of bamboo scaffolding in building construction. Tong (1998) studied bamboo scaffolds for other applications. Recently, Scaffolding is indispensable to construction work, being used in the erection of new buildings, renovation work, and the repair and maintenance of old buildings. Before the 1980s in Hong Kong, the author have seen some local contractors even used it as a protective measure in open cut work, blasting and other civil engineering operations. It was also reported by Waters (1998).

Based on the material used, scaffolding can be classified as bamboo scaffolding, metal scaffolding and other scaffolding.

2.1 Bamboo Scaffolding

In ancient China, scaffolding was used in building houses and even in building the Great Wall. Bamboo scaffolding was introduced to the building industry in Hong Kong immediately after colonisation. Before the 1950s, it was used in building houses and multi-storey buildings of up to three or four stories high, and for other forms of construction such as the temporary sheds used for Cantonese Opera performances and the race course pavilion in Happy Valley that burned down in 1918 as shown in Figure 2.1.

Figure 2.1 Temporary shed on fire in Happy Valley racing court (reported by Hong Kong Telegraph in 1918, photo from http://en.wikipedia.org/wiki/File:HappyvalleyfireHK1918.jpg #filelinks)

Bamboo scaffolding has been widely used in Hong Kong's building industry, with bamboo pieces forming work platforms, means of access and egress, gangways and step-ladders. As reported by Chang and Yu (2002), bamboo scaffolds has been used when building new houses, erecting neon-signs, repairing sewage pipes outside buildings, renovating building facades. The various uses of bamboo scaffolding is illustrated in Figure 2.2 as reported by Fu (1993).

(a) Bamboo house

(b) Cantonese opera shed

(c) Building a new house

(d) Truss-out

Figure 2.2 Application of bamboo scaffolding in various fields

Bamboo could be easily cut to suit different shaped features within a short period, was a highly flexible material and cost little.

At that time, few regulations and safety measures covered bamboo scaffolding. The use of bamboo in this way was a little-studied handicraft involving knowledge of various types of bamboo and bamboo skin. The type of bamboo scaffolding used depended strongly on the training method experienced.

2.1.1 Training for building bamboo scaffolding

Bamboo scaffolds had to be built by skilful workers. The training involved an apprenticeship system with limited chances of entry into the field. It usually took a minimum of three years for the apprentice to learn the basic skills of scaffolding from his master. The apprentice also had to undertake other work, such as washing clothes for all masters and elders and cooking the meals for the team. After the apprenticeships, and according to whether or not the master was satisfied, a 'graduation' ceremony was held for the apprentice and he was accepted by the other workers. Most scaffolding companies today maintain the worship of the three ancient masters of scaffolding: Wah Kwong Master 華光先師 – the master of Chinese Drama; Yau Chau Master 有巢氏先師 – the master of netting in trees; and Luk Pan Master 魯班先師 – the master builder. The General Merchants' Association of Bamboo Scaffolders still celebrates the birthdays of these figures in memory of their contributions to the scaffolding industry every year.

It was reported by Waters (1998) that the first year of the traditional apprenticeship covered most of the general labouring work in scaffold building. It made the apprentice familiar with bamboo and trained him in identifying good and bad pieces, and selecting the correct piece of bamboo to be used in a particular area. At times, the apprentice was given the opportunity to practice by tying the unimportant areas of a bamboo scaffold.

Figure 2.3 shows the twisting method of securing bamboo pieces together that has been used for hundreds of years. The technique and skill has proven to be very effective but it has always been very difficult to examine. Assessing the quality of work is very subjective because it may vary from person to person and it depends heavily on the physical fitness and skill of the individual scaffolder. The traditional apprentice needed to spend over 6 months just to learn how to create a reliable twist.

Figure 2.3 Twisting of a nylon tie to secure bamboo and metal tube.

The second year of the traditional apprenticeship covered the erection of scaffolds. The apprentice worked side by side with the master, learning what was critical and dangerous on the job site, the correct ways of using the material, and gaining a feel for the whole task. The learning process was a mixture of art and sensation. The skill of tying the bamboo skins with the bamboo piece was very personal. The rigidity and strength of the scaffold relied heavily on whether or not the ties were tight enough. Those who could not gain aptitude in this process had to prolong their apprenticeships for up to a year.

The final year of training concentrated on setting up different kinds of scaffolds. The foundation and initial set-up or footing of bamboo scaffolds are the most important parts, ensuring that collapse is not possible. The traditional master always worked side by side with the apprentice or the two worked together as a team with other senior scaffolders. After that, the apprentice became a professional scaffolder himself. To gain status in the trade, the fresh graduate would work for the master for another three to four years, improving his efficiency, leadership and artistic outlook. Then he would either be promoted to senior scaffolder with a salary increase or move on to another crew.

The coverage and depth of the traditional apprenticeship was very comprehensive. Failure mode or collapses of scaffold with injuries were rare, and no safety belts or body harnesses were provided. Scaffolding practitioners today still marvel at the success of traditional apprenticeship training, even though they might regard it as having been harsh.

2.1.2 Changes in bamboo scaffolding

The methods used in bamboo scaffolding have changed over time. In the early 1960s, galvanized zinc sheeting replaced some of the natural materials in Cantonese Opera sheds. Galvanized wire mesh also replaced bamboo skin sheeting in safety screens. Traditional bamboo scaffolders relied on their own skill with the material in creating a pull-log anchorage system, but pull-logs were later replaced by mild steel bars of 6mm in diameter.

One of the drastic changes took place in 1978 when the co-polymer (a composition of polypropylene (p.p.) and polyethylene (P.E.)) or plastic nylon tie was invented by the author to replace the traditional bamboo skin as a tying method. In the past, both bamboo scaffolders and the public did not like the use of bamboo skin because bamboo skin ties were potentially weak and needed watering before use. The new nylon tie had undergone the elongation and tensile strength test. The breaking point was certified to be 119 kg, which is much higher than the required 50 kg as specified in the Code of Practice for Bamboo Scaffolding Safety (2001 and 2009). In 1983, Material Laboratory (Hong Kong) Ltd., a testing laboratory, certified that the nylon tie was an effective means of securing bamboo scaffolding. Gradually the nylon tie has been incorporated into bamboo scaffolding all over the world, particularly in Asia. Unfortunately, the patent of this product was not processed on time and the author missed the opportunity of registering the invention.

2.1.3 Current bamboo scaffolding

Training in the construction of bamboo scaffolding has changed a great deal from that offered by the traditional apprenticeship. The Construction Industry Council Training Academy (CICTA) and the Vocational Training Institute now take on the responsibility of training bamboo scaffolders (as shown in course prospectus CICTA (2009)). The Construction Industry Training Authority (CITA) was set up in the 1980s, and was re-organised into the Construction Industry Council Training Academy (CICTA) in 2007. Bamboo scaffolding is one of the subjects taught under its auspices in various centres. Experienced scaffolders are employed as lecturers and instructors, and apprentices are recruited and receive an allowance during their training. They are trained in classes and practice in outdoor areas at the centres. Notes and handouts are given to the students. After one year of training in the centre, students are deployed to scaffolding companies as trainees or apprentices for another two years. A trade test is conducted by the CITA upon completion of the 3-year apprenticeship programme. Successful candidates acquire professional scaffolder status.

This modern, scientific training has eliminated the exploitation and hardship of the traditional apprenticeship system, but it has also destroyed the close relationship between the master and the apprentice, which was essential in developing skills and safety awareness. Traditional one-to-one training was much more intensive and in-depth than modern lectures, which fail to identify the weaknesses of individual students.

The short-sighted attitude of CITA graduates has caused many problems in the bamboo scaffolding industry, with the overall standard of bamboo scaffolding having been downgraded, e.g. the fresh graduates always sustains injuries or lost their lives because of insufficient experience or negligence in their course of work. It gives a bad reputation and image to the public that scaffolding is a very dangerous job. Many façade scaffolds have become deformed after construction due to sub-standard workmanship. Scaffolders abandoned the use of timber as the main poles in scaffolding when China stopped commercial logging in 1998. It was announced by Mr. Lei Jiafu (1998), vice-director of the State Forestry Administration (SFA), after devastating floods on the Yangtze region in that summer, and 'Mao Jue' bamboo, which is thinner, was selected for ease of use.

Most buildings in Hong Kong are now high-rise, and the heavy dead load/self load of a bamboo scaffold used on such buildings without intermediate steel bracket support is likely to cause buckling or collapse. In the past, the master would definitely not have allowed his crew to build such dangerous structures.

Given these conditions, and as bamboo scaffolding remained popular in the construction industry, the Labour Department tightened its control over the practice after 1995. Besides the existing legislation, the Construction Site (Safety) Regulations (CSSR) and the Factories and Industrial Undertakings Ordinance, the government introduced the Code of Practice for Bamboo Scaffolding Safety in 2001. (Details of legislative measures on bamboo scaffold safety will be discussed in Section 2.2.2.)

The code of practice has a special legal status. Although failure to observe any of its provisions is not itself an offence, that failure may be taken by a court in criminal proceedings as a relevant factor in determining whether or not a person has breached the relevant safety and health legislation under the Factories and Industrial Undertakings Ordinance.

In view of the tighter safety control and the deteriorating quality of work in bamboo scaffolding, in 1996 many property developers and major contractors invited suggestions for improving the quality and workmanship of bamboo scaffolding. In response, traders offered metal scaffolds in various forms: e.g., the crab system, the cup-lock system, the beauty frame system and even the metal tubular scaffolding system. These metal scaffolding systems had been offered as a promotional exercise in Hong Kong during 1980, but they were not accepted due to the cost and skill required. Now, developers and major contractors tried to use them extensively, especially in government projects like the Chep Lap Kok International Airport, hospitals and school rehabilitation projects as shown in Figures 2.4 to 2.6. This was the first time that bamboo scaffolds had faced a challenge, and it led to demand for improvement in bamboo scaffolding.

Figure 2.4 Metal scaffold for freight terminal.

Figure 2.5 Metal scaffold for air traffic control tower.

Figure 2.6 Metal scaffold for school rehabilitation project.

2.2 Metal scaffolding

When the Hong Kong government looked into the safety of bamboo scaffolding in 1995, metal scaffold safety was also under consideration. A code of practice for metal scaffolding safety was introduced at the same time as its counterpart for bamboo in 2001, defining scaffolding as:

> Any temporarily operations or works to which the construction site (safety) regulations (CSSR) apply, and any temporarily provided structure which enables persons to obtain access to or which enables materials to be taken to any place at which such work is performed, and includes any working platform, gangway, run, ladder or step-ladder (other than an independent ladder or step-ladder which does not form part of such a structure) together with any guard-rail, toe board or other safe guards and all fixings, but does not include a lifting appliance or a structure

used merely to support such an appliance or to support other plant or equipment.

Figure 2.7 Metal scaffold

Metal scaffolding is now popular because it has the advantages of easy fabrication, installation and dismantling. As shown in Figure 2.7, steel and aluminium are often used in scaffolds, mainly due to their uniform mechanical properties and good corrosion resistance. However, the overall cost is much higher than for bamboo scaffolds. Usually, hollow section metal tubes with thinner walls are used to reduce self weight. The hollow steel sections are either hot-dip galvanised or paint coated tubes. Details of the configuration and design of various types of metal scaffolds will be discussed in Section 3.1.2.

2.3 Other work platforms

2.3.1 Mixed bamboo and metal scaffolding

Other than pure bamboo and pure metal scaffolding structures, 楊嗣信 (1992) reported scaffolding structures comprised of two different materials. A mixed scaffolding structure that used both bamboo poles and metal tubes was considered in China in the early 1990s, for use on a high-rise building called 廣東國際大廈. Metal tubes of 51 mm in outer diameter with 3.5 mm wall thickness were to be used as the load bearing parts of the scaffolding structure, and bamboo poles were to be used as railings. For both the inner and outer layers, the spacing of the vertical members was to be 2 m and the spacing of the horizontal members was to be 1 m. Steel wires of 12 mm in diameter were to be used to stabilise the structure at every fifth floor. However, the calculations for the scaffolding were based on the assumption that the maximum height would be 39.7 m, but the actual height of the project was 50.5 m. 楊嗣信 thus suggested applying double vertical tubes in the lower portion of the scaffolding. However, he offered no clearly detailed design drawing, and the method statement was not included in the publication. As no support documents are available for this particular project, or for the mixed scaffolding structure in general, it is doubtful the structure was successfully built. In addition, the use of double vertical tubes was not practical in China in the early 1990s due to the high cost of steel in comparison to bamboo.

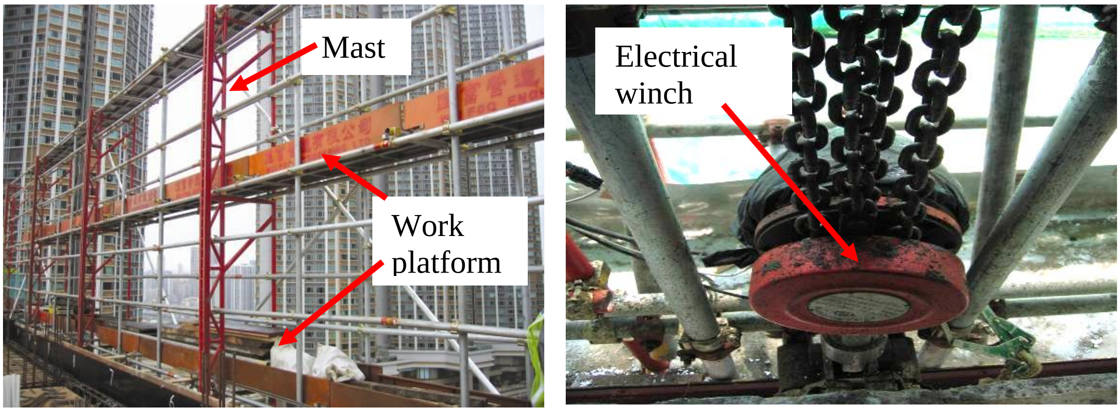
Another type of mixed scaffolding structure was mentioned by 建築工程手冊編委會 (1994). This structure comprised wooden and bamboo poles, with no metal involved. It was very similar to traditional bamboo scaffolding, but with 'Mao Jue' replaced by wooden poles.

Scaffolding is one means of providing a work platform, and is commonly used all over the world. Besides conventional scaffolding, other work platforms are utilised at heights, such as computerised self-climbing work platforms, gondolas, and mast climber work platforms. These types of platforms are usually powered by electricity.

2.3.2 Computerised self-climbing work platform

Computerised self-climbing work platforms are commonly used in China, and were introduced to Hong Kong in 2004. Since that time they have been widely accepted as alternatives to conventional scaffolding for high-rise buildings.

The key mechanism of the computerized self-climbing work platform is a number of winches installed on the façade. As shown in Figure 2.8, masts installed 3 m to 4 m horizontally apart on the façade act as railings, with electrical winches on every mast pulling the work platform. The computerized self-climbing work platform itself is a metal scaffolding system with a maximum height of around 20m, which is four to five storeys high.



(a) Computerised self-climbing work platform

(b) Electrical winch

Figure 2.8 Major components of computerised self-climbing work platform

The platform is controlled by a central control box connected to a laptop computer on site or by remote control at other locations such as the site office. The advantage of the computerised self-climbing work platform is cost savings for high-rise building construction.

2.3.3 Gondolas

Gondolas are mechanical work platforms powered by electricity, most often used as building maintenance units. There are two types of gondola, one is temporary and is usually rented out for construction or renovation work and the other is permanently installed on a particular building or structure for regular maintenance work.

As shown in Figure 2.9(a), a typical temporary gondola includes a metal work platform. Two electric hoists, as shown in Figure 2.9(b), are controlled by an authorised operator to move the gondola up and down. The control box, shown in Figure 2.9(c), is positioned inside the work platform. Figure 2.9(d) shows the safety locking device that stops the gondola from falling in case of hoist failure. The support anchorage is shown in Figure 2.9(e), and is fixed on the roof or the top of the building to ensure that the gondola can only move in a vertical direction. The location of the support anchorage can be changed, but each relocation must be certificated by a professional engineer.

The ascension speed of a gondola depends on the type of hoist installed, but according to the manufacturer’s specification (Tractel 2004), it is usually up to 10 metres per minute for construction use. The length of the working platform can be specially design for almost any shape of building or structure.

(a) Temporary gondola

(b) Electrical hoist

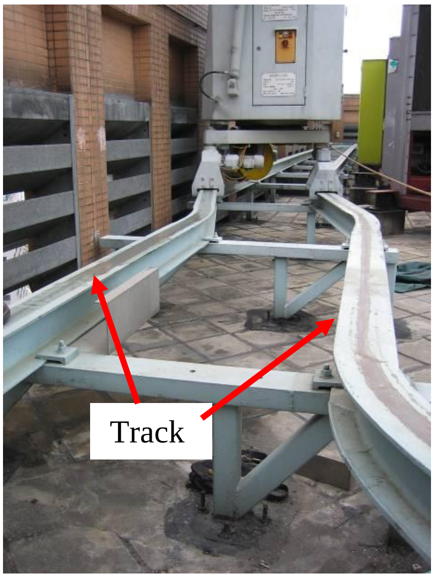
(c) Central control box

(d) Safety locking device

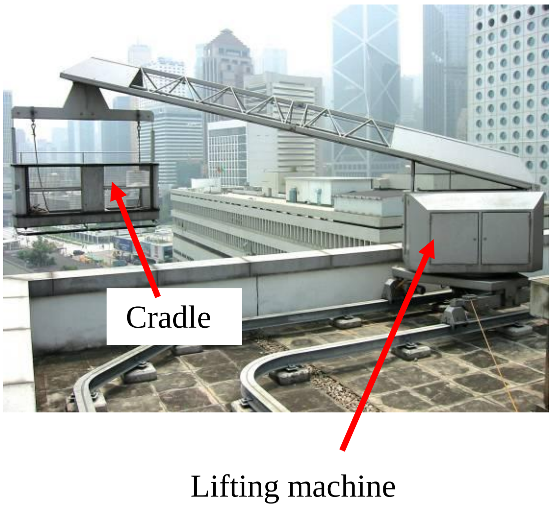
(e) Anchorage

Figure 2.9 Temporary gondola and its major components

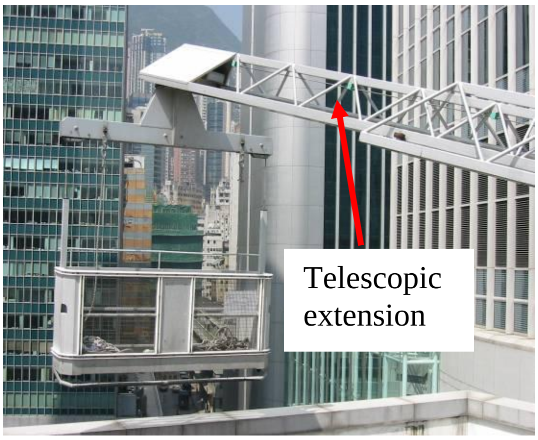
The advantages of the temporary gondola are that it reduces the number of labourers required and the erection time needed in comparison to a conventional scaffolding system. The disadvantages are that the work platform can only be moved in a vertical direction and that workers can only work in one area at a time. Monorail system introduced later in the market in late 90's solved this problem.



(a) Tracking system



(b) Lifting Machine and Cradle



(c) Telescopic extension

Figure 2.10 Permanent gondola and its major components

As shown in Figure 2.10, permanent gondolas are usually installed on the roofs or the tops of structures. Their main purpose is to provide access for workers to perform maintenance work. This type of gondola is not used for construction work, and is installed after the completion of the building or structure. It comprises a railing or tracking system as shown in Figure 2.10(a) and a computerised lifting machine and a cradle as shown in Figure 2.10(b). Permanent gondolas are designed to suit the shapes or contours of particular buildings or structures. Figure 2.10(c) shows that telescopic extensions can be tailored to suit the building profile.

Figure 2.11 shows the types of gentries used as work platforms. They are specially designed for single structures, and can be applied in many areas for maintenance such as on bridges (Figure 2.11(a)), or highway soundproofing glass panels (Figure 2.11(b)).

	
(a) Stayed cable	(b) Curved shape for noise barrier

Figure 2.11 Gantries for different applications

2.3.4 Mast climber work platforms

Another form of work platform powered by electricity is called the mast climber working platform (MCWP), as shown in Figure 2.8. MCWPs are automated access systems that provide safe, fast and efficient access for workers and materials to construction or renovation projects. Double mast (Figure 2.12(a)) and single mast (Figure 2.12(b)) MCWPs can go to 100 m. MCWPs are used for external cleaning and maintenance work on high-rise buildings, cladding and curtain walling, window installation, painting and cleaning, concrete and remedial repair, brick laying and roof edge protection, amongst others.

(a) Double mast	(b) Single mast

Figure 2.12 Mast climber work platform

Chapter 3 Configuration and Design of Traditional Scaffolding

3.1 Basic Structural Configuration

Based on the type of application, the design of bamboo and metal scaffolding has to comply with the codes of practice mentioned below.

3.1.1 Bamboo scaffolding

Bamboo scaffolding comprises several materials: bamboo, nylon ties, nylon netting and galvanized zinc sheets. The properties of each material are discussed as follows.

<u>‘Mao Jue’ and ‘Kao Jue’</u>

Bamboo is the basic material used in scaffolding in Hong Kong. Each year, over 10 million pieces of bamboo are imported into Hong Kong purely for scaffolding. There are differences species of bamboo, depending on climate and soil characteristics, with the northern Chinese species growing thicker. These are called ‘Phyllostachys Pubescens’ or ‘Mao Jue’(毛竹). In the south, the bamboo is much thinner, and it is called ‘Bambusa Pervariablilis’ or ‘Kao Jue’ (篙竹). Although there are 70 genera and 1200 bamboo species in the world, Mao Jue and Kao Jue, as shown in Figure 3.1, are the most commonly used on construction sites as stated in Waters (1998) and 江澤慧 (2002).

Figure 3.1 Mao Jue (毛竹) and Kao Jue (篙竹)

Because of differences in climate and soil characteristics, all bamboo species are quite different from one to another, and they lose their original characteristics when transplanted in different regions. Bamboo that grows in sandy and poor soil tends to be thicker in the shell, whereas bamboo that grows in fertile soil seems to be thinner and grows fasteras reported by 江澤慧(2002). Only two kinds of bamboo species in Guangdong and Guangxi are suitable for scaffolding in construction. These have a rough surface that provides more fiction in the contact, and the fibre is stronger than in other species. They have a growth period of 3-4 years before being cut for consumption. At that time, the line content and fibre context are at their best composition. If the growth period is shorter, the fibre content is not strong enough. When the growth period is longer, the bamboo pieces start to build up starch, which makes them too brittle and too dangerous to use in scaffolds for the building industry Hui and Yang (2002). Bamboo species from northern China tend to be bigger and can be used in scaffolding as the main poles or major standards.

The life span of a bamboo used in scaffolding is around seven years. Yu and Chung (2001) tested the mechanical properties of bamboo in detail. It has a very strong bending and elasticity strength when freshly cut, with that strength decreasing as time goes by. Bamboo tends to lose its resin, and it may crack after 18 months without any prior indication. Thus, bamboo scaffolding is extremely hazardous if it is in place for more than 18 months. There are many ways to protect the bamboo as reported by Hui and Yang (2002), for example inject synthetic resin into bamboo to restore its strength. Some have suggested that this may be successful if three times atmosphere pressure is applied; the natural resin may come out, leaving the long tissue fibre behind, after which the synthetic resin could be applied. That could preserve the bamboo for over 10 years. However, the process is still hypothetical and further consideration is needed.

As stated in the Guidelines for the Design and Construction of Bamboo Scaffolds (2001), the effective diameter of Mao Jue in Hong Kong should be no less than 75mm with a wall thickness of 10 mm, and for Kao Jue the effective diameter should be no less than 40 mm.

Nylon tie

The nylon tie is one of the components of the scaffold, connecting the bamboo pieces. It is a co-polymer PE/PP product that was introduced to scaffolding in Hong Kong in 1978 and is commonly used elsewhere in China. The product is modified from nylon packaging ties. Anti-UV and Anti-aging materials are added into the PE and PE mixture during the extrusion process. It has a bearing capacity of up to 119 kg for one simple round as stated in the tensile strength test in Section 2.1.2. Tests have confirmed that it has a bearing capacity of multiple tons for six rounds.

Nylon nets/sheets

Safety nylon nets or sheets are used on the outside of bamboo scaffolding to prevent falling objects from hitting people nearby. They also prevent workers from falling from heights.

Galvanized zinc sheet

Galvanized zinc sheets of 0.11 mm in thickness or nylon sheets are used as covers of catch-fans or horizontal work platforms. The object is again to prevent materials from falling.

Structure of bamboo scaffold

A bamboo scaffold consists of horizontal bamboo (i.e. ledgers/transoms) and vertical bamboo posts that are connected by plastic ties. The Guidelines for the Design and Construction of Bamboo Scaffolds include a general description of bamboo scaffolding, as shown in Figure 3.2. Two examples for the design of bamboo scaffolds and a detailed description of bamboo scaffolding and its major components are available in Appendices A.3.1 and A.3.2. According to the Guidelines, Mao Jue should be used for all standards and ledgers of the first lift of the scaffold, and the wall thickness of these members should be no less than 10 mm. Vertical bamboo posts can be either rest on the ground or on steel brackets at an elevated level. The steel brackets, which are fabricated by steel section (i.e. angle and channel) in a triangular shape as shown in Figure 3.3, support and transmit the vertical load to adjacent reinforced scaffolding beams on the columns of the building. For other standards, transom, ledgers and bracing, the smaller bamboo Kao Jue can be used. Tie wires of 6 mm in diameter with anchorage in reinforced concrete wall/beams are used to the tie back the scaffold to prevent it from being expelled outwards.

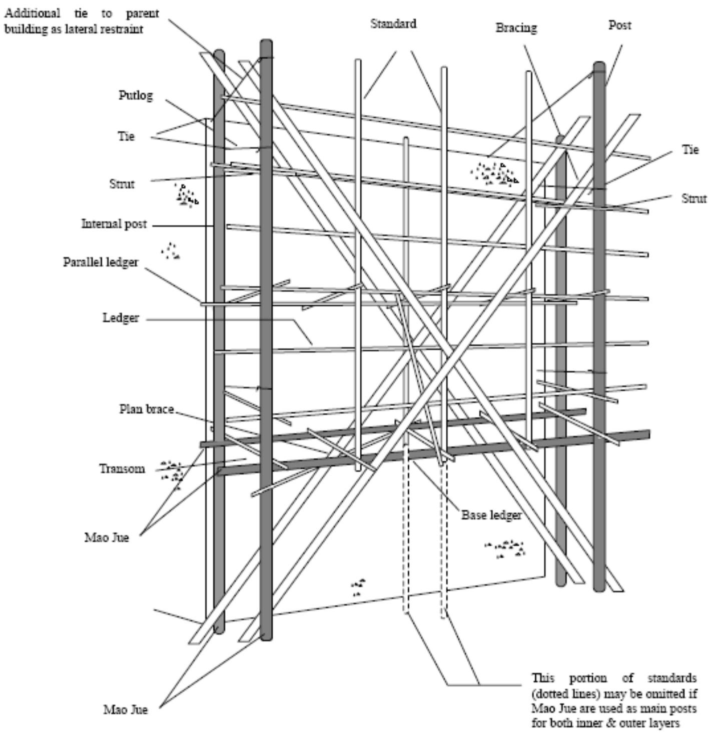
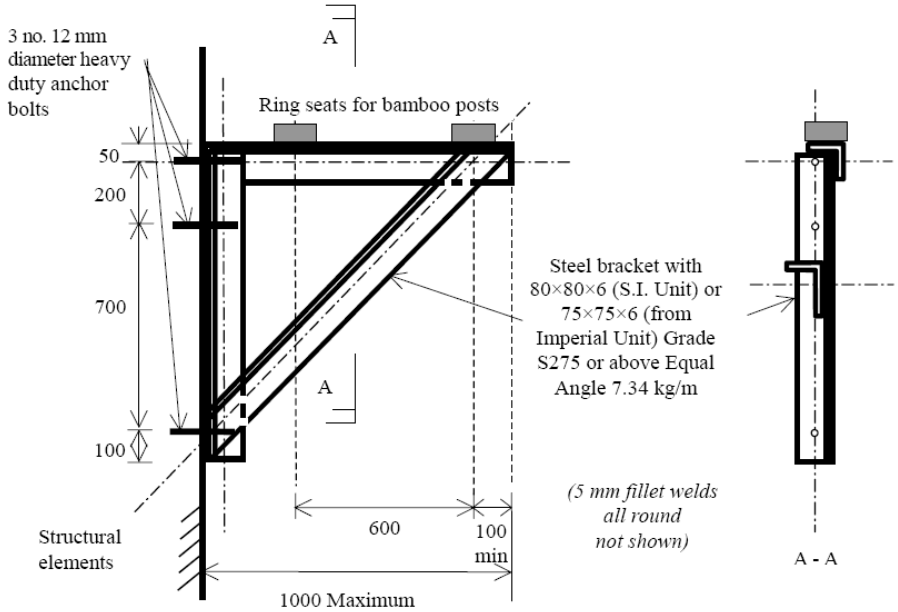
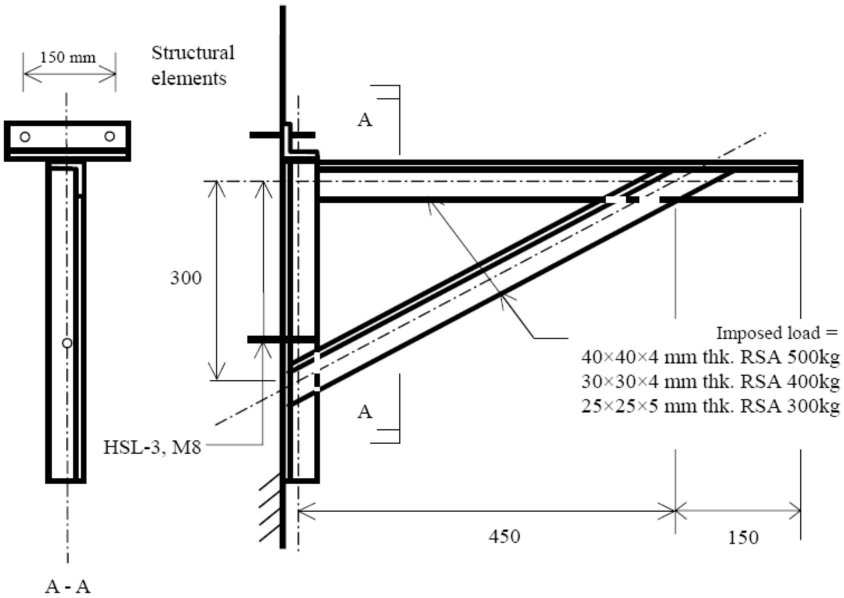


Figure 3.2 A recommended standard for double layer bamboo scaffolding (not to scale). (Guidelines for the Design and Construction of Bamboo Scaffolds 2006)



(a) Base support for general construction



(b) Base support for truss-out scaffold

Figure 3.3 Steel bracket

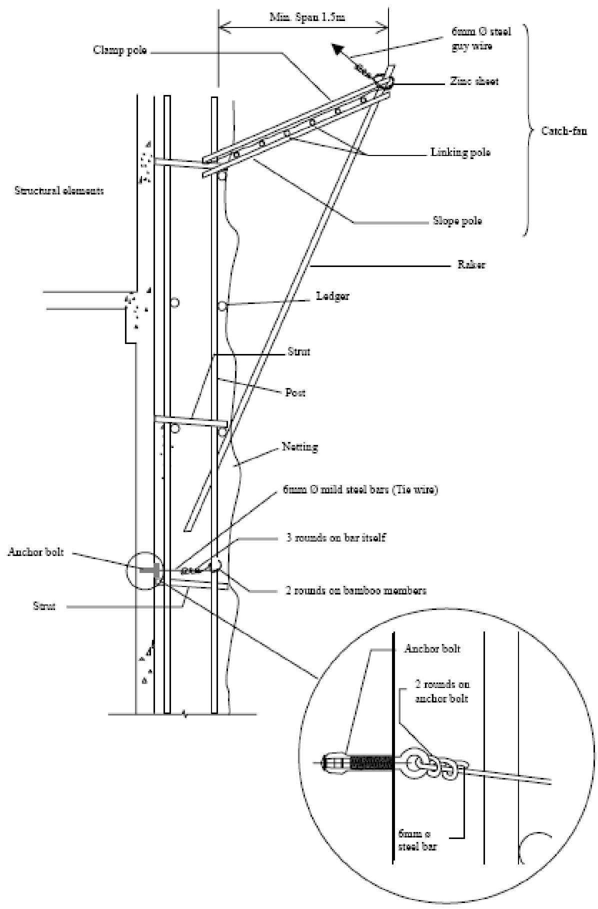


Figure 3.4   Details of putlog and catch-fan for double-layered bamboo scaffolding

To stabilise the scaffold, putlogs are installed. Catch-fans are also installed to prevent objects from falling off the scaffold. The design of the putlog and catch-fan are illustrated in Figure 3.4.

Due to its mechanical properties, bamboo scaffolding is used for light duty and inspection. Tong (2002) categorised bamboo scaffolds into the following types: typical single-row bamboo scaffolding, as shown in Figure 2.2(c) of Section 2.1; typical double-row bamboo scaffolding; bamboo scaffolding for signage, as shown in Figure 3.5(a); bamboo scaffolding for temporary performance stages, as shown in Figure 2.2(b) of Section 2.1; truss-out bamboo scaffolding, as shown in Figure 2.2(d) of Section 2.1; fir pole platforms; scaffolding for demolition work; and scaffolding for lift shafts. Other bamboo scaffolds are shown in Figure 3.5.

(a) Signage

(b) Slope

(c) Ceiling platform

Figure 3.5 Examples of bamboo scaffolding for different applications

The design of bamboo scaffolds involves the careful selection of bamboo members for their strength. Reference can be referred to later Section 3.3.1 on materials properties.

3.1.2 Metal scaffolding

Metal scaffolding can serve different purposes in different construction activities. It is commonly used as support scaffolding in falsework systems because it can withstand heavier live loads and dead loads during construction of the upper deck. Steel and aluminium are used for the metal tube and coupler. Fixed-angle steel couplers and rotational couplers fix the vertical members to the bracing, as shown in Figure 3.6. The mechanical properties and testing of these scaffolds should comply with the international standard BS 1139.

Figure 3.6   Metal coupler connecting two metal tubes.

Structure of metal scaffolding

The design and construction of metal scaffolding in Hong Kong must comply with BS 5973 or other equivalent national/international standards. Metal scaffolding is also subject to the Code of Practice for Metal Scaffold Safety (2001). Figure 3.7 shows a typical independently tied metal scaffold. The details of metal putlog scaffolds, anchors, mobile access towers, ties, bracing, flip locks and base plates, the connection of metal scaffolds, the layout of plane frame access scaffolds and some types of proprietary clamping or wedging arrangements for metal scaffold are available in Appendix A.3.3

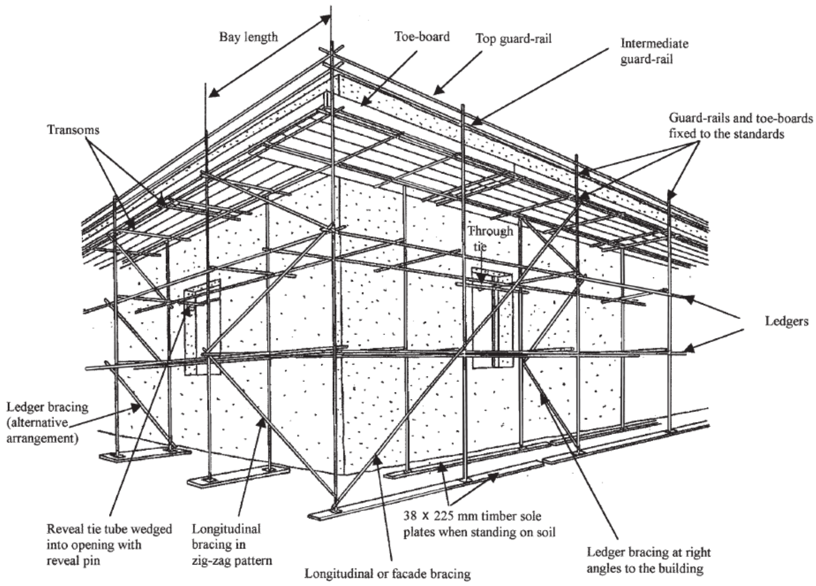


Figure 3.7 Typical independently tied metal scaffold (Code of Practice for Metal Scaffold Safety 2001)

A typical double-row metal scaffold was shown in Figure 2.4 of Section 2.2. As shown in Figure 3.8, medium to heavy duty metal scaffolds can be used for slopes, renovation work and performance stages. Other uses include the provision of access to lift shafts and ceilings, and as work platforms.

Due to the rigidity of the steel tubing, the flexibility of metal scaffolding is much less than that of bamboo. However, safety is improved by preventing workers to cut the posts easily and freely. Steel scaffolds are usually designed off-site. It is not easy to make changes or modifications in case amendments are made to some part of the project. This further limits the flexibility of steel scaffolds. Moreover, the unit weight of each steel post is much heavier than that of bamboo. The larger the scaffold, the heavier the dead load will be. Hence, scaffolders in Hong Kong tend not to use metal scaffolding.

(a) Metal slope scaffold

(b) Climbing scaffold

(c) Performance stage

Figure 3.8 Examples of metal scaffolding for different applications

3.2 Legislation and Codes of Practice

Legislation and codes of practice for scaffolding cover two areas: safety requirements for working on scaffolding and design loading requirements for scaffolding. In Hong Kong, safety issues are covered by the Factories and Industrial Undertakings Ordinance, Chapter 59 (Construction Sites (Safety) Regulations), regulations 38A to 38J (1978, 2003). Safety management and loading requirements are detailed in the Code of Practice for Bamboo Scaffolding Safety (2001), the Code of Practice for Metal Scaffolding Safety, the Guidelines on the Design and Construction of Bamboo Scaffolds (2004), the Guide to the Provisions for Safe Place of Work under Part VA of the Construction Sites (Safety) Regulations (2004), and the Code of Practice and Explanatory Materials on Wind Effects in Hong Kong (1983, 2004).

3.2.1 Safety requirements for working on scaffolds

In the 2003 amendment, the Construction Sites (Safety) Regulations (CSSR) 38A to 38J lay down legal requirements to ensure the safety, health and welfare of workmen on construction sites. The Code of Practice for Bamboo Scaffolding Safety (2001) provides practical guidance for compliance with the Factories and Industrial Undertakings Ordinance. Those provisions can be summarised into three categories: (a) the general duties of the proprietor of the industrial undertaking to protect the safety and health of the workers or employees under his employ; (b) stipulation of the design, erection, maintenance and management of a scaffold; and (c) stipulation of the general duties of employees in relation to the safety and health of themselves and each other in compliance with Chapter 59, sections 6A and B, of the Ordinance.

The proprietor has the general duty under the Ordinance to provide a safe work place and ensure the safety of each worker. Safety netting or safety belts should be provided to prevent falls and safety helmets must be provided to all workers, who must wear them at all times. Workers should not throw remains or debris, tools or other articles from a scaffold, and should not place loose articles on the work platform or other parts of the scaffold.

Bamboo truss-out scaffolding is often used in residential building repair and maintenance. To improve the safety standards for such scaffolding the Construction Industry Institute – Hong Kong (2007) recommended safety education and training, and the imposition of a mandatory licensing system. It also proposed the use of a rapid demountable platform to ensure safety at work.

3.2.2 Loading requirement for scaffold design

The Code of Practice for Bamboo Scaffolding Safety (2001), Guidelines on the Design and Construction of Bamboo Scaffolds (2004) and the Code of Practice for Metal Scaffolding Safety (2001) are used as references in calculating the design loading of the scaffold's platform. The Code of Practice on Wind Effects in Hong Kong (1983) published by Building Department and revised in 2004, is also pertinent. The Explanatory Materials on the Code of Practice (2004) were published to further elaborate the Code.

Table 3.1 Minimum imposed loading for different types of use (Code of Practice of Bamboo Scaffolding Safety and Code of Practice of Metal Scaffolding Safety 2001).

Minimum Imposed Loads			
Duty	Use of platform	Distributed load on platform	Concentrated load to be applied on plan over any square with a 300mm side and at the end portion of a cantilever
Inspection and very light duty	Inspection, painting, stone cleaning, light cleaning and access	0.75 kN/m^2	2 kN
Light duty	Plastering, painting, stone cleaning, glazing and pointing	1.5 kN/m^2	2 kN
General purpose	General building work including brickwork, window and mullion fixing, rendering, plastering	2 kN/m^2	2 kN
Heavy duty	Blockwork, brickwork, heavy cladding	2.5 kN/m^2	2 kN
Masonry or special duty	Masonry work, concrete blockwork and very heavy cladding	3 kN/m^2	2 kN

As stated in the Code of Practice for Bamboo Scaffolding Safety and the Code of Practice for Metal Scaffolding Safety, all decking units of work platforms should have adequate strength to meet the recommendations for the appropriate use as specified in Table 3.1. The distributed loads on platforms vary from 0.75 kN/m^2 to 3 kN/m^2, depending on the application.

Bamboo scaffolding

For bamboo scaffolding, the Code of Practice for Bamboo Scaffolding Safety provides practical guidance regarding structural safety and stability. The Guidelines on the Design and Construction of Bamboo Scaffolds (2004) further proposes a step by step procedure for the design and erection of bamboo scaffolds. Technical requirements for scaffold components, such as putlogs, nylon strips, drilled-in anchors and steel brackets, are also given, with configurations for double-layered bamboo scaffolds with heights of 15 m and 19 m also illustrated. Appendix A.3.2 provides typical bamboo scaffold designs, along with putlog and catch-fan, truss-out bamboo scaffolds, bamboo scaffolds for signboards, the base support for general construction scaffolds and the base support for truss-out scaffolds.

The Guidelines on the Design and Construction of Bamboo Scaffolds (2004) propose a full scale test or performance-based design approach when the design of a bamboo scaffold does not follow their recommendations. The performance-based design approach must be based on second-order stability analysis, specific load factors and wind effects.

Metal scaffolds

The design strength of metal scaffolds is much higher than that of their bamboo counterparts (4 kPa versus 1.45 kPa). Design calculations for the heights of steel tubular scaffolds are determined according to the information given in Table 3.2, which has been extracted from the Code of Practice for Metal Scaffolding Safety (2001).

Table 3.2 Design specifications for different types of work platform

Duty	Max. number of platforms	Commonly used widths using 225mm boards	Max. bay length (m)
Inspection and very light duty	1 working platform	3 boards	2.7
Light duty	2 working platforms	4 boards	2.4
General purpose	2 working platforms + 1 at very light duty	5 boards or 4 boards + 1 inside	2.1
Heavy duty	2 working platforms + 1 at very light duty	5 boards or 5 boards+ 1 inside or 4 boards + 1 inside	2.0
Masonry or special duty	1 working platform +1 at very light duty	6 to 8 boards	1.8

Note: (a) The boards are timber scaffold boards of nominal cross sections 38mm X 225mm. Decking units of other types or dimensions but with equal or greater strength can also be used.

(b) The normal lift height for works such as brickwork is 1.35m, and for walk-through scaffolds is 2.0m. For greater lift height or different loading conditions, reference should be made to the design criteria in BS 5973 or other equivalent national/international standards or provisions.

The Code also provides a protocol for the design, erection and maintenance of metal scaffolds.

Wind effects

The Code of Practice on Wind Effects in Hong Kong (1983, 2004) and the Explanatory Materials on the Code of Practice (2004) provide general calculation methods for determining the wind loads that act on the structural design of buildings or parts of buildings. Based on peak gust velocities from the last 50 years and the normal wind loads on complete buildings, the Code gives permissible design wind pressures at different heights. From the design wind pressure, the force acting on complete buildings can be obtained. For the static force, an equation for dynamic effects is also given. The 2004 revision of the Code further elaborated the topographical factor, total pressure coefficients for individual elements and dynamic force analysis. The Explanatory Materials gave detailed explanations of and outlined specific applications for the equations.

Structures are affected by local wind velocity, and the local wind is determined by the prevailing wind velocity and direction, as well as elements of the surrounding environment such as nearby buildings and the landscape. In additional to the local landscape, Hong Kong is exposed to extreme wind loads during typhoons, in which structures face wind gusts of up to 240 km/h. Hence, it is always difficult to determine the local wind conditions without an actual site measurement. The Code of Practice and the Explanatory Materials assist the designer in evaluating the wind effect on the structure. Wind characteristics near the ground are described by the hourly mean wind velocity profile, peak gust wind velocity profile, turbulence intensity profile, and directional distribution of the wind speed. Based on the wind characteristics in Hong Kong and reference wind speeds since 1884, the Explanatory Materials propose the hourly mean wind velocity profile, the gust wind velocity profile and the turbulence intensity. Based on that information, the design velocity and pressure profiles can be calculated. The Explanatory Materials also explain the terrain and topographic effect, and the wind speed can be corrected when the speed-up ratio is considered.

Other than the static loading due to wind velocity, the dynamic response of structures is also significant. The Explanatory Materials propose that when a building has a height exceeding five times its shortest horizontal dimension or a height that is greater than 100 m, the dynamic response of the structure should be considered. Two components of the wind-induced dynamic force on a tall structure should be studied: the along-wind response and the cross-wind and torsional response.

After considering the designed wind profile, the total wind force can be calculated. The Explanatory Materials also propose wind tunnel testing to provide an experimental approach to obtaining the wind force on the structure.

3.3 Research on Scaffolding

Research into scaffolding has focused on the mechanical properties of the materials, full-scale laboratory testing and computer simulation.

3.3.1 Material properties

Although bamboo scaffolds are often used to support work platforms for site personnel in the Hong Kong construction industry, they have not attracted much research attention in universities, and few articles in the engineering literature cover their use.

Early in 1978, a report on the study of bamboo as a construction material was conducted by Au et al. (1978) and Janssen (1981). Janssen (1991, 1995, 2002) reported the mechanical property testing of bamboo and SWOT analysis for the design of structural joints in the material. Arce-Villalobos (1993) studied bamboo trusses and frames, and Amada et al. (1997) studied bamboo as a natural composite material. Chung, Yu and

Chan (2002) conducted systemic testing of bamboo’s compression, bending strength and column buckling.

Janssen (1995) proposed that there is a relationship between density and permissible stress in bamboo, as shown in the following table.

Table 3.3 Allowable long-term stress (N/mm^2) per unit volume (kg/m^3)

	Axial Compression (No Buckling)	**Bending**	**Shear**
Air dry	0.013	0.020	0.003
Green	0.011	0.015	-

The allowable bending stress for air dried bamboo with a density of 530 kg/m would be 0.02 x 530 = 10.6 N/mm^2. Janssen further suggested that increasing factors of 1.25 and 1.5 are applicable to medium and short-term loading, respectively. These guidelines provide basic technical data in estimating the strength of bamboo.

Yu and Chung (2000a, 2000b and 2001) and Yu et al. (2002) published results obtained from a relatively large statistical analysis of over 500 compression and 200 bending tests of two bamboo species, Kao Jue and Mao Jue. Table 3.4 presents the results obtained by Yu and Chung (2000a and 2000b).

Chung et al. (2002) researched the effect of variation in relative humidity in the range of 60%, 75%, 90% and 98% in bamboo on its compressive strength and Young’s modulus. The maximum stress and deformation in bamboo for different load cases with impact loads were also studied to emulate accidental falls from scaffolding.

Table 3.4 Proposed mechanical properties of structural bamboo

Bambusa Pervariabilis (Kao Jue)	Compression			Bending		
		Dry	Wet		Dry	Wet
Characteristic strength (N/mm^2) (at fifth percentile)	$f_{c,k}$	79	35	$f_{b,k}$	80	37
Design strength (N/mm^2) ($\gamma_m = 1.5$)	$f_{c,d}$	53	23	$f_{b,d}$	53	25
Design Young's modulus (kN/mm^2) (Average value)	$E_{c,d}$	10.3	6.8	$E_{b,d}$	22.0	16.4

Phyllostachys Pubescens (Mao Jue)	Compression			Bending		
		Dry	Wet		Dry	Wet
Characteristic strength (N/mm^2) (at fifth percentile)	$f_{c,k}$	117	44	$f_{b,k}$	51	55
Design strength (N/mm^2) ($\gamma_m = 1.5$)	$f_{c,d}$	78	29	$f_{b,d}$	34	37
Design Young's modulus (kN/mm^2) (Average value)	$E_{c,d}$	9.4	6.4	$E_{b,d}$	13.2	9.6

Notes: Dry condition m.c. < 5% for Kao Jue and Mao Jue.
Wet condition m.c. > 20% for Kao Jue, and
m.c. > 30% for Mao Jue

It can be observed that moisture content is an important factor in defining the mechanical properties of both species of construction bamboo.

For metal scaffolding, the quality of the steel tubes is well assured and has been accepted over decades due to compliance with stringent international standards covering raw materials, processing and quality control over finished products. Data on standardised mechanical properties are readily available from product suppliers, which is convenient when an engineer needs to design of scaffold.

3.3.2 Full scale experimentation and simulation

(a) Bamboo scaffolding

Not many studies on bamboo scaffolds have dealt with full scale experiments and simulation, due to the relatively large variation in the mechanical properties of bamboo when compared to those of steel. Other factors such as differences in species, non-uniform cross sections and variation of moisture content make potential investigations even more complicated.

Chan and Chung (2002) and Chung, Chan and Yu (2002) conducted full-scale testing and simulation using nonlinear integrated design and analysis. Poon et al. (2002) conducted field tests and reviewed metal work platforms used on slopes. Wong (2002) conducted a systematic and detailed engineering analysis of the safety and reliability of bamboo scaffolding, including full-scale laboratory tests and computer calculation using the finite element method.

One of the leading studies, that of Chan et al. (1998), presented an empirical design for bamboo scaffolding that used a computerised methodology, and tested it on a double-layer scaffolding system with dimensions of 9 m high x 9 m long x 0.7 m wide for verification. Later, Chung and Chan (2002) presented practical design data and formulas with working examples of bamboo scaffolds.

Wong (2002) tested the mechanical properties of both bamboo and the fastening ties used on bamboo scaffolds. He also conducted full-scale testing of double-layer scaffolds with dimensions of 4.98 m high x 3.6 m long x 0.6 m wide under uniform distribution load and impact load. Detailed dimensions of the bamboo scaffold are shown in Figure 3.9. Wong compared his experimental results with his finite element result using SAP2000, and the simulation results were smaller by 30%. He also studied maximum stresses and deformations at critical locations of the scaffold under different combinations of dead and live loads, an impact load applied at some intersections and the ultimate load-carry capacity of the scaffoldings under different combinations of dead loads, live loads and impact loads. Some of the results are shown in Figures 3.10 and 3.11

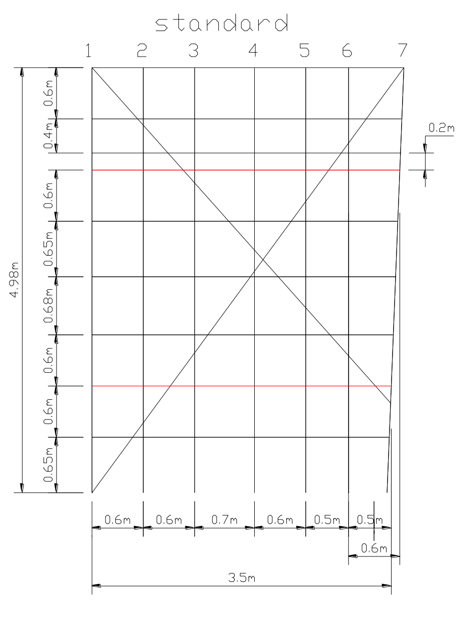


Figure 3.9   Dimensions of the simulated scaffold (Wong 2002)

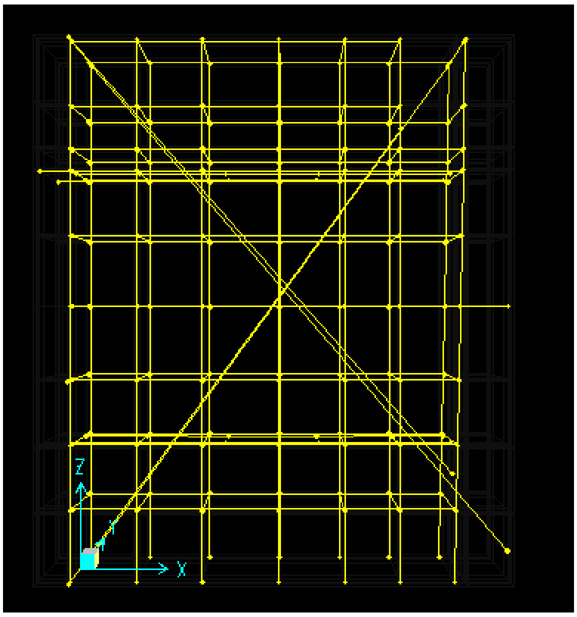


Figure 3.10 Finite element model of the scaffold (Wong 2002)

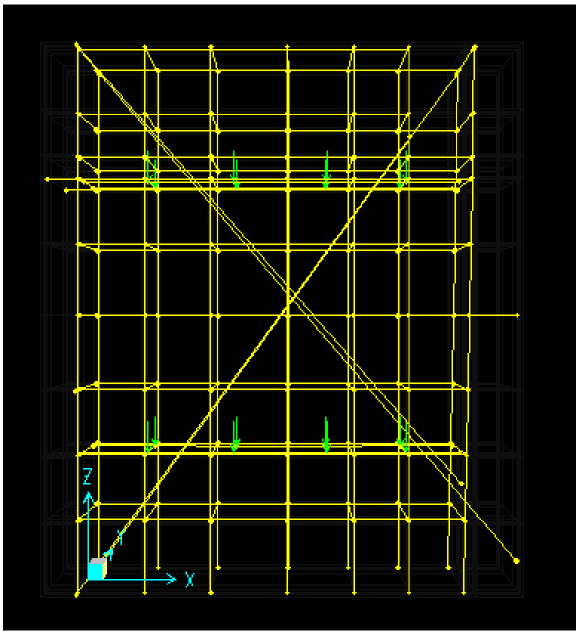


Figure 3.11 Loading of the uniform distributed load testing (Wong 2002)

(b) Steel Scaffolding

Metal scaffolding is commonly encountered in temporary engineering structures. Steel members are assumed to be without initial curvature. All joint connections were assumed to be fixed. First-order linear elastic analysis and its associated design method are used for the design of conventional steel frames. In a linear analysis, the axial shortening of a column is proportional to the applied axial force, and this assumption is applicable when the axial force is small and the steel column is short. When the axial force is large is comparison to the slenderness of the column, the column will buckle before it is shortened to reach its failure stress.

As a modular metal scaffolding system is slender and non-linear effects are important, secondary instability caused by both overall stress and deformation of the structure must be considered in assessing the overall frame and local member buckling capacity.

The new Hong Kong limit state design steel code (HKSC)[1] stipulates the requirement for considering the P-△ effect due to frame sway, as shown in Figure 3.12, and the P-δ effect due to member bow, as shown in Figure 3.13. Both figures are extracted from the work of Chan and Law (2005). As most structural analysis software only allows consideration of the P-△ functions and not the initial imperfection of the member, P-δ, NIDA software was purposely developed for inclusion of the P-δ effect. Chu and Chan carried out computer simulation of metal scaffolding of the dimensions 30m high x 20m wide x 1.3m deep using the NIDA software with the aim of proposing a reliable design method. The validity of the proposed method was confirmed by comparison with the test results of seven 3-storey scaffolding units. The NIDA software was used to validate the loading capacity of MBMSS as presented in Section 5.1.2 (a).

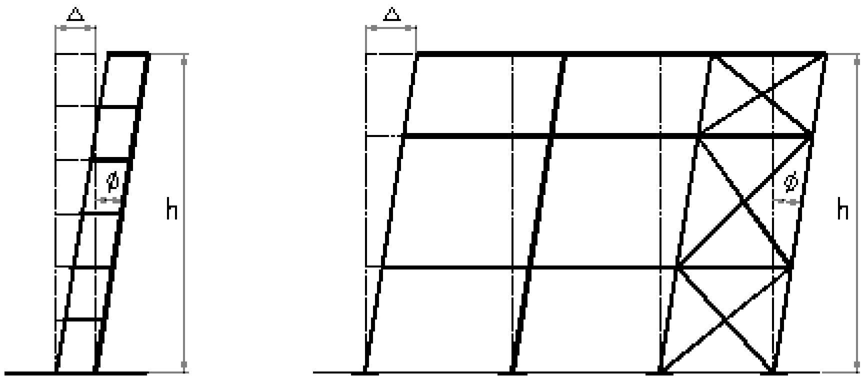


Figure 3.12 P-Δ_0 imperfection in Eurocode[2] with Φ taken as 1% for scaffolds (Chan and Law (2005))

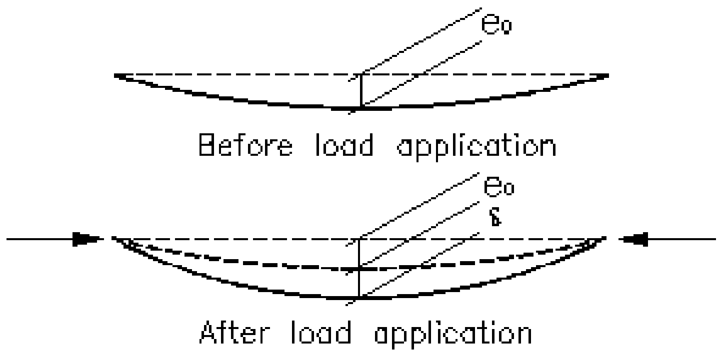


Figure 3.13 P-δ effect and P-e_0 imperfection with e_0 indicated in Table 6.1 (Code of Practice for the Structural Use of Steel (2005)) with deflection (Chan and Law (2005))

This Chapter outlined the basic configuration and design of the scaffolds. It also presented the material properties and some major research works in the last 15 years. It demonstrated the beauty as well as the constraints of the existing bamboo and metal scaffolds. The next Chapter will show the new design, which fulfill the existing requirement and also improve the performance of the bamboo and metal scaffolds.

Chapter 4 Design Philosophy

A new scaffolding design was initialised in 1994 when the author was studying for his Master degree at the Hong Kong Polytechnic University. Benefiting from his experience in the scaffolding industry and pressure for a new generation of scaffolding to meet safety and building environment requirements, the author combined his newly acquired academic knowledge and the resources of his company to realise and validate his ideas.

This chapter reviews the advantages and disadvantages of traditional scaffolding systems and analyses the problems and challenges that led to the need for change. Specifications for a new scaffold design are then defined based on functional and safety requirements, and essential components are redesigned for different work environments. A general description of the new integrated scaffolding system is then presented, based on the experience of the author in the scaffolding industry and taking into consideration operational conditions from the erection to the dismantling of scaffolds, the availability of the materials in the market, the cost involved and other issues.

4.1 Advantages and Disadvantages of Traditional Scaffolding

The long history of using bamboo and metal scaffolding has demonstrated its advantages and contributions to the construction industry in Hong Kong. However, given the industry's evolution and its safety requirements, weaknesses have become obvious in the traditional technology, operation and management of scaffolding. In the following sections, the advantages and disadvantages of the traditional methodology are introduced and a new design is unveiled.

4.1.1 Reasons for the widespread use of bamboo scaffolding in the Hong Kong construction industry

Bamboo is the favoured material for scaffolding in the local construction industry. Its advantages over other materials extend to unique characteristics such as weight, cost, ease of use and storage, feasibility and ease of repair and maintenance.

(a) Bamboo is light: the total weight of a 7 metre piece of bamboo is less than 9 kg dry, compared with hollow metal tubing of the same length with ϕ48.6 mm and a wall thickness of 2.3 mm, for which the weight is 17 kg.

(b) Economical: The price of a 7 m piece of grade ‘A’ bamboo is about HK$10, which is approximately 5% of the price of metal tubing; for metal scaffolding, 2 m of tubing costs approximately HK$250.

(c) Efficient: Given its low weight, workers can easily install and dismantle bamboo scaffolding in comparison to metal scaffolding. Installing and dismantling bamboo scaffolding is five times faster than metal scaffolding. In Hong Kong, time is very important to developers, and short building periods have significant implications for their finances. The sooner a project can be completed and ready for sale, the quicker development costs, such as interest, can be reduced. Bamboo scaffolding can save more than one month of construction lead time.

(e) Easy to store and dispose of: Bamboo is easy to store and scaffolding businesses can simply dump the whole consignment after one use. They can either set fire to it in a dumping compound designated by the authorities or leave it there to rot as it is organic.

(f) Flexible: Bamboo scaffolding can be erected on any ground under any conditions. It can be erected in shallow seawater near the shore or on sliding slopes. With sufficient compression on the ground surface, the major poles can be erected on top of a wooden plank resting on the soil. Even on ground that is uneven, the level of the horizontal ledgers and work platform can be adjusted to suit the actual situation. Bamboo scaffolding is also easy to cut and modify. If an opening is required in a scaffold for the movement of equipment into a building, as shown in Figure 4.1, it can be cut easily, which is not the case for metal scaffolding.

Figure 4.1 Opening in a bamboo scaffold.

(g) Easy to repair and maintain: Bamboo scaffolding can be repaired easily, by simply taking out a broken piece and replacing it with another. For the spell-out part of a bamboo scaffold, a hand-driven pulley can be applied. The scaffold can then be re-instated in its original position without difficulty. Moreover, bamboo scaffolding will not collapse easily even if the pull-push ties have been removed because the weight of the untied scaffolding is diverted and shared by other ties. Other forms of scaffolding collapse in similar situations.

4.1.2 Engineering problems associated with bamboo scaffold and metal scaffolding

In Hong Kong, high humidity in summer and low humidity in winter have adverse effects on bamboo scaffolding. Chang and Yu (2002) reported that bamboo cracks under low humidity and its strength is reduced in highly humidity. This behaviour can render scaffolding susceptible to collapse without proper maintenance.

With the application of new technology in building construction, such as the use of high-strength concrete, the height of high-rise buildings has increased to over 240 m measured from ground level. The erection of bamboo scaffolding to such heights, however, would generate problems involving inadequate structural strength for resisting high wind pressure and compliance with the stringent requirements of site safety.

Although pure metal scaffolding appears to be one solution for use in high-rise building construction, the self-weight of steel scaffolding remains a critical problem in erection and dismantling. The greater the number of scaffolding layers, the heavier the dead load will be. Relatively large-scale temporary steel structures are also required to support metal scaffolding, which increases construction costs and lengthens construction schedules for most projects.

4.2 The Need for Change

During the last decade of the 20th Century, bamboo scaffolding was heavily criticised by the public, the media and major contractors for its poor quality and workmanship. There has always been a problem with the deformation and breakage of bamboo members, which is a major cause of worker falls. To ascertain why the quality of bamboo scaffolding deteriorates, the following factors should be considered: (a) safety of the scaffold; (b) the material properties of bamboo; (c) whether the supply of skilful labour is adequate; (d) damage to the bamboo by other trades; (e) damage to the bamboo by fire; (f) lack of scientific support for professional engineering calculation at the design stage and (g) the level of safety awareness amongst workers on construction sites and whether the concept of total quality management is used in the scaffolding industry.

Wui Loong Scaffolding Company Ltd (1998) conducted a survey on the overall service quality, documentation and logistics of its scaffolding business. Of the 28 questionnaires distributed, 18 were returned. The 18 respondents were site managers representing 10 major developers in Hong Kong that operated more than 70% of the total construction and building projects it the city at the time. For all of the questions, the score was between 5.33 and 6.22 on a scale that ranged from ‘0’ for not satisfied to ‘10’ for completely satisfied. The results indicated that the performance was just satisfactory and that there was room for improvement. Individual comments from the respondents included that there had been a ‘decline in skill’; ‘insufficient site supervision’; ‘high turnover rate of scaffolders’, ‘shortage of scaffolders’, ‘lack of management skill’ and ‘overall performance decline in the last 10 years’. These comments reflected in the shortcomings in the skilled labour supply and also the management system.

(a) Scaffold Safety

Safety is always the most important issue in the scaffolding industry. Awareness of the need for it directly influences accident rates and injuries, can delay the work process and induce financial losses, such as through increased insurance premiums, medical cost and interest payments, and can cause intangible losses, such as social impact and damage to corporate reputations, etc.

Safety has a close relationship with the scaffold itself, the workers, and operation and management. If any link in this chain fails, accidents will happen. In relation to the scaffold itself, safety is determined by its design, application and materials. For the workers, proper training and experience are important. In terms of operation and management, regular inspection, safety awareness and coordination with other trades are essential to maintaining safety in scaffolding. This section will discuss the causes of accidents in the scaffolding industry, and also scaffolding materials, workers, operation and management.

When the quality of the material used in bamboo scaffolding deteriorates, the overall quality of the scaffolding tends to drop, and accidents happen. From 1990 to 1992, there were 43 accidents directly related to the use of bamboo scaffolding in Hong Kong, as shown in Tables 4.1 to 4.3. Of these 43 accidents, 6 were fatal.

Table 4.1 shows that most of the accidents (83.7%) happened on construction sites and 74.4% happened in single layer bamboo scaffolds. Tables 4.2 and 4.3 indicate that 6 fatal accidents (13.9%) occurred during the period, all on single layer bamboo scaffolds. Although there was no significant correlation between the accidents and the provision of work platforms in these 43 accidents, in 5 of the 6 fatal cases work platforms were not provided.

Table 4.1 Analysis of the 43 accidents – use of bamboo scaffolds on building or maintenance sites. (Policy Paper 1994, Labour Department)

	Construction	Maintenance	Total
Single layer scaffolds	26	6	32
Double layer scaffolds	10	1	11
Total	36	7	43

Table 4.2 Analysis of the 32 accidents involving the use of single layer bamboo scaffolds. (Policy Paper 1994, Labour Department)

	Sub-standard platform provided	Platform not provided	Total
Fatal	1	5	6
Non-Fatal	12	14	26
Total	13	19	32

Table 4.3 Analysis of the 11 accidents involving the use of double layer bamboo scaffolds. (Source: Policy paper 1994, Labour Department)

	Sub-standard platform provided	Platform not provided	Total
Fatal	0	0	0
Non-fatal	9	2	11

Total	9	2	11

One of the key factors in these accidents was the sudden breakage of bamboo poles, and the improper use of the bamboo scaffolding may also have contributed. Another interesting observation is that although double layer scaffolds may help to save lives, they cannot entirely prevent accidents. Likewise, double layer scaffolds may help to prevent falls, but the bamboo poles can still deteriorate. In single layer scaffolds this inescapable fact can lead to even more accidents. Hence, the use of safety belts with independent safe-lines may be needed to prevent falls from single layer scaffolds.

(b) Material properties of bamboo

The bamboo used in scaffolding is strong, flexible and light weight. Unlike steel, however, it is a natural material and thus not uniform in terms of strength, weight and density. Calculating the total weight of bamboo scaffolding and projecting its live load and maximum bearing load are more difficult than for steel. In Hong Kong, structural engineers tend to assume that bamboo scaffolding is unreliable because its strength is not measurable.

Ko et al. (2002) summarised research that had been conducted on the mechanical properties of bamboo used in scaffolding (Chang and Yu, 2002; Chung and Siu, 2002; Jansen, 1991) and concluded after conducting many tests that bamboo is reliable and strong. The tests focused on the mechanical properties at different locations (top, middle and bottom, on bamboo pieces and at different growth periods (1-7 years). The mechanical properties tested were tensile strength, bending strength and press strength.

In general, the percentage of lime and water in bamboo determines the strength of its fibre. When the hydration percentage is between 10% and 22%, the bamboo is at maximum strength. Once the hydration percentage decreases below 10%, the bamboo becomes dry and cracks appear. 楊嗣信 (1992) reported that at one year after cutting, the water content inside bamboo will reduce to 7%; when it reaches 0%, the bamboo piece is not safe to use.

Lime content affects the bamboo's strength and rigidity, and the fibre content affects its bending and tensile strength. 楊嗣信 reported that a bamboo piece 3-4 years old has 50-58% fibre content and 1.5% lime content. After that time, the fibre content decreases and the lime content increases, rendering the bamboo rigid and easily broken. Hence, the best time for bamboo harvesting for construction should be at 3-4 years. After cutting, it can be safely used for 1 year, or at most one and a half years. There is an idiom in China regarding bamboo cutting: 'retain at 3, cut at 4 and never 7'.

Recently in Hong Kong, bamboo material used in scaffolding has deteriorated very quickly. Because of the rapid economic growth in China and huge consumption rate, bamboo is cut at 1.5 to 2 years old. The wall thickness of the pre-mature bamboo is very thin, which means that the bamboo pieces can suddenly break without warning. This gives rise to a great deal of maintenance and remedial work. Improvement of material quality is one of the inevitable issues that the scaffolding tradesman has to tackle.

(c) Insufficient skilled labour supply

According to Hong Kong Construction Industry Council, there are total 253 registered scaffolding subcontractor companies in Hong Kong up to now.

According to Manpower Survey Report Building and Civil Engineering Industry by Building and Civil Engineering Training Board, Vocational Training Council (2005 and 2007), the total number of scaffolding workers actually decreasing during 2005 – 2007 as shown in Table 4.4

Table 4.4 Number of skilled and semi-skilled worker in Hong Kong

	Number of skilled and semi-skilled workers	
Types of scaffolds	Year 2005	Year 2007
Bamboo Scaffolding	1009	560
Metal Scaffolding	338	272

According to the data from Hong Kong Yearbook 2006 and 2007 by HKSAR, there were total 868, 911 and 946 construction sites in Hong Kong from 2005 - 2007 respectively. These data indicated that there were increasing numbers of construction sites every year.

However, the scaffolding workers were decreasing especially the bamboo scaffoldings workers. Moreover, according to the Annual Report 2007 by CICTA, there were only 7 graduates from Construction Scaffolding Works and 60 graduates from Metal Scaffoldings. Thus, with over 250 registered scaffolding subcontractors and over 900 construction sites, and with the government's pledge to push ahead with ten major infrastructure projects to stimulate the local economy, there will be more construction activities for the coming years, therefore, the scaffolding industry is having a major shortage of skilled and semi-skilled workers now and for future years.

(d) Damage by other trades

Bamboo scaffolding is commonly found on construction sites and in renovation works. For renovations, damage done to the scaffolding by other trades is very minimal, for the following reasons.

(i) Renovations are usually conducted on buildings that already have occupants and tend to be smaller in scale than construction sites, so the scope of possible damage is small.

(ii) Renovations usually last less than a year. Thus, the condition of any bamboo scaffolding used is not a critical consideration and the material is still within its life cycle period. The fibre is strong enough to sustain the loading incurred.

(iii) No bulky or massive operations: renovation work involves no re-bar, formwork or concreting work, all of which can damage a bamboo scaffold because it is very common for workers in these areas to saw or otherwise cut the bamboo pieces whenever they cause inconvenience.

(iv) Self-awareness amongst workers: renovation workers seem to be more conscientious than those on construction sites. They wear safety belts at their own initiative and do not throw objects from heights. They realise that the workplace is not private, and other people can be at risk. Hence, the quality of work and the workmanship of bamboo scaffolding used in renovations are better than those used on construction sites.

On construction sites, the condition of bamboo scaffolding is totally different. It is often damaged at various stages by various trade workers.

(i) During the formwork stage: bamboo scaffolding tends to be cut and sawn by formworkers when it is obstructing their progress, as shown in Figure 4.2(a). When they set up their external wall panels, formworkers nail their guard rails or stepping planks on to the scaffold, again damaging the bamboo. This seriously affects the stability and reliability of the bamboo and hence the safety of the scaffold as a whole.

(ii) Damage by re-bar workers is not as serious. These workers only damage the bamboo ledger when lifting the 12-metre reinforced steel bars. If, however, they cannot handle the lifting properly, the heavy re-bars moved by the tower crane can damage the whole scaffold. Some workers also tend to unload the bars onto the scaffold members, which causes further damage.

(ii) Damage caused by concreting workers: such damage is again not as significant, but it does take place when the workers fail to take enough care in lifting their containers, which hit the surrounding bamboo.

(iv) Finishing stage: this stage consists of ground work, as shown in Figure 4.2(a). Rendering workers usually damage the scaffold the most. As noted previously, the positioning of a bamboo scaffold relies heavily on the pull-logs and tie bars that are affixed to the building walls. These are made up of 6mm mild steel bars and short bamboo transoms. In the course of their work, renderers usually untie the pull-logs and tie bars for their own convenience. Some even chop off the 6mm tie bar just to gain a better outlook for their rendering and to avoid double handling. This causes the bamboo scaffold to loss its anchorage. Due to the outward momentum for the brace bamboo and the standard bamboo, a bamboo scaffold without the anchorage will shift outwards. The self load plus the live load of the scaffold will cause the bamboo members (including the standard and the ledger) to bend, sometimes inward. This is why much of the bamboo scaffolding used on construction sites is deformed in a zig-zag shape when projects near completion.

(v) Damage by window frame workers and drainage pipe workers: these workers usually cut holes in the scaffold to move their materials into the building, as shown in Figure 4.2(b). It is not uncommon to see that during the construction period, drainage workers cut away the double layered scaffold to move in the pipes for their own convenience regardless of safety. When the internal layer of a double layer scaffold is removed, no one can ever work on it again.

(vi) Scaffolds with water pipes attached: bamboo scaffolds with temporary water pipes affixed are dangerous because the areas around the pipes are often wet, which causes the bamboo to deteriorate and rot. The scaffold can also become very slippery, and thus hazardous to workers.

(a) Damage during ground work

(b) Opening in scaffold

(c) Damage by debris

Figure 4.2 Photographs illustrating damage by other trade workers

(vii) Scaffolds are often damaged when debris is dumped. A particular point must be allocated for workers to dump waste. Before the invention of the debris plastic passageway, all debris was moved to the ground by either a wooden channel hanging from the top floor to the ground floor or by a steel tube. Very often, the debris would escape from the channel or tube and hit the scaffold and thus damage the bamboo, as shown in Figure 4.2(c). Scaffolds badly damaged in this way become hazardous to workers, and are very difficult to repair. In such circumstances, workers dismantling the scaffold have to wear safety belts attached to independent life lines and work downwards from the top, piece by piece. They may step on the damaged pieces, which break instantly.

(e) Bamboo scaffolds can easily catch fire. During winter, the bamboo members are dry can catch fire if welders are careless.

(f) Lack of scientific support for professional engineering calculation in the design stage. In the tender process, managements usually rely on experience to determine what costs and pricing are required for a project. In terms of scaffolding, they may know what the required height should be, or the live load and dead load of the scaffolding. These issues are usually left to the supervisor of the scaffolding team, which is not an adequate, scientific defence against future accidents.

(g) Lack of safety awareness of workers on construction sites. Most construction workers, even those with few skills, consider themselves as professional and presume they can handle any problems arising on a construction site as a matter of course. However, construction sites contain many traps and hazardous. Accidents occur when people think they know the hazards they face but do not, and thus fail to take the safety of others into consideration.

(h) Lack of understanding of total quality management in most scaffolding companies. From the WLS survey (1998), it indicated that there was a lack of management skill and a proper management system. It reflected that most of the senior management of scaffolding companies are not well educated. Some of them became self-employed and proprietors after they had acquired sufficient knowledge of scaffolding or when they had established their own connections in the field. They have no idea about total quality management, such as how to manage material from purchase to use, how to detect deterioration in material, the sort of quality control that should be exercised on bamboo members and how the material should be maintained. Lack of understanding in these areas is a significant reason for failure in bamboo scaffolding.

4.3. Design Specification

As discussed above, to cope with advances in building technology a new type of scaffolding system, which combines the advantages of bamboo and metal scaffolding, is necessary. This should be a flexible system, with the components easily integrated. Several specific areas need to be considered: the functional requirements, loading requirements, safety requirements, structural elements, anchorage mechanism, support mechanism and accessories.

4.3.1 Functional and Safety Requirements

As the scale of scaffolding for renovation work is usually small and there is less involvement with other trades, a scaffold system for construction work only will be studied.

On a construction site, scaffolding begins before the concrete of the building is cast. At this stage, to suit the formwork process, a scaffold is erected at a distance from the casting fixture. This is required for transporting materials such as the wooden formwork or aluminium formwork panels and building the casting fixture itself. The main contractor normally commences rendering work when the concrete has been cast to a certain height, e.g. up to 15 floors. At this stage, the scaffold is moved closer to the building façade, usually within 200mm of the internal scaffold for the façade, so that workers can carry out their rendering work. The rendering is conducted in two phases, namely, cement mortar bedding and the finish (either mosaic tiles or smooth rendering), at two different levels. Therefore, to meet the main contractor’s requirements, the scaffold should be erected in double layers up to 8 floors high, protected by a protective horizontal screen installed above.

In layman’s terms, the expected live load should be two workers with 3 buckets of cement mortar and 3 boxes of mosaic titles at 2 metre intervals. The estimated labour force may be up to 3 layers of work at the same time. Hence, the maximum imposed load should be 3.0 kPa with a load factor of 1.6.

The new system could be designed to take up more imposed load than a traditional bamboo scaffold. All decking units of the work platform should have adequate strength to meet the recommendations for the appropriate duty, as specified in Table 3.1 of Chapter 3.2.2.

The design should comply with the safety regulations, the Code of Practice for Bamboo Scaffolding Safety (2001) and the Code of Practice for Metal Scaffolding Safety (2001) as stated in Chapter 3.2.1. The material life of bamboo should be considered, especially when a scaffold is erected in an extreme environment, such as near the sea or in areas of high humidity. In addition, new features such as an anchorage system, a support system and accessories should be designed and integrated to ensure reliability and safety.

4.3.2 Integrated Scaffold System

To meet the functional, loading and safety requirements, a new integrated scaffold system should be considered. An integrated system should use existing materials in a new way, incorporating components and accessories to achieve the required performance and to facilitate use. In terms of structural elements, if metal members (including the load bearing poles and fittings) are to be used to maintain reliability and rigidity, this will increase the self load. Thus, bamboo members should be used for the rest of the components to reduce the overall load. The primary scaffold should consist of steel components for the vertical standards, and secondary bamboo elements for the horizontal guard rail ledgers.

The new design should be a standardised system equipped with an anchorage mechanism and support system that is sufficiently flexible to fit different work scenarios. As scaffolding can only be erected to a limited height due to its own weight and the required live loading, it must use a support system to provide a work platform on high-rise buildings. A standardised support for the new system should be able to be erected on the façade of a building. It must support the scaffold and transfer the loading from the posts to the building. To maintain the stability and performance of the system, a standard anchorage system will be considered here.

Scaffolding provides a work environment for different trades during the construction process. Usually that environment is not maintained properly, as shown in Figure 4.3. Accessories for the new system should thus be provided to enhance occupational safety and improve the work environment. Evolving from the design of metal scaffolding, a stable work platform that can support the loading of both workers and materials should be provided. A staircase, cat ladder, guard rail and toe-board will be considered for easy access and to protect the workers on the work platform.

Figure 4.3 Traditional work platform for bamboo scaffolding

4.4 The Metal-Bamboo Matrix System Scaffold (MBMSS)

Based on the above requirements, a new integrated system, the Metal-Bamboo Matrix System Scaffold (MBMSS), using metal and bamboo as base materials was designed and adopted by the construction industry. Drawing on traditional knowledge of bamboo scaffolding, the new system not only considers the structural and hardware side of scaffolding, but also the software side, such as theoretical support, engineering support, quality and cost management.

The MBMSS bill of materials is listed in Appendix A.4.1. The system comprises steel pipes and bamboo poles, and the layout of the bamboo and steel members of the MBMSS follows the traditional bamboo scaffolding layout. In the typical layout of the external scaffold, each vertical steel post is 3 m apart and there are 3 vertical bamboo standards 750 mm apart between 2 vertical steel posts. Horizontal steel ledgers are 2 m apart and there are 2 horizontal bamboo guard-rails approximately 600 mm apart between 2 horizontal steel ledgers. In the typical layout of the internal scaffold, each vertical steel post is 3 m apart and there is 1 vertical steel standard between 2 vertical steel posts. Horizontal steel ledgers are 2 m apart, and it is not necessary to install horizontal bamboo guard-rails if the gap between the façade and the internal scaffold is less than 200mm, preferably 150mm.

The selection of the steel tubing is based on the technical specifications, price, durability and delivery time. The decision of the size is determined from the practical handling of the metal tube, then the size and thickness is double checked with structural calculation. Besides, MBMSS scaffolding is currently constructed with steel tubes manufactured in South Korea. Previously, tubes from India and China were used, but their durability and the delivery time did not fulfil operational requirements

The specification and inspection certificate of the steel tube currently being used in the MBMSS system are attached in Appendix A4.2.

For a typical 30 m x 30 m MBMSS main frame, the quantities of key materials used are as follows.

Steel Tube 6 m	460 pieces
Kao Jue 8m	330 pieces
Clamps	580
Pipe Joints	220
Nylon Ties	6000

The ratio of steel tube to bamboo is around 6:4.

The MBMSS is an optimised design for loading capacity, material weight and wind resistance, as shown in the Table 4.5, with a standardised configuration using metal tubes and bamboo pieces as the main structure. The table compares steel scaffolding, the MBMSS and bamboo scaffolding.

Table 4.5 Comparison of different scaffolding system.

	Steel Scaffold	MBMSS	Bamboo Scaffold
Loading Capacity 0.75 kPa	✓	✓	✓
Material weight	1.4	1	0.5
Strong wind	✓	✓	✗

The MBMSS also uses the anchorage and support systems that have been adopted by the scaffolding industry, which enhances its capabilities in terms of height and loading and ensures greater safety than traditional bamboo scaffolding.

Incorporating other components, such as standardised catwalks, toe-boards and staircases, the system provides a stable and safe working environment, allowing access for external wall workers in full compliance with various construction regulations.

In general, the procedure for erecting the MBMSS is similar to that for bamboo scaffolding. A temporary scaffold is erected first for the installation of steel support brackets on the façade of the building. The MBMSS is then erected on the support brackets. Nylon nets are placed over the outer layer of the scaffold (the work scaffold). The procedure for erecting the inner-layer scaffold, catch fan and protective platform will vary according to the requirements of the client, and hence is not standardised.

Other than the hardware side, unlike traditional scaffolding, which relies on the experience and skill of the scaffolders, the MBMSS draws on academic knowledge. The next chapter discusses system experimentation, simulation and implementation from an academic standpoint. Apart from research support for the conceptual design, a standard calculation for the MBMSS is required for every project, to ensure the performance of the scaffold and that it satisfies safety requirements.

(a) The double-layer MBMSS

The MBMSS is a double layer scaffold that consists of steel pipes and bamboo poles for the main structure. The steel pipes are used as the main posts and ledgers to support the loading. This structure can provide a much more stable, secure and reliable scaffold for workers than a bamboo-only scaffold.

Bamboo poles are used in the MBMSS to reduce the loading of the scaffold and to increase its flexibility. The MBMSS provides flexibility and adaptability to various building structures with different requirements, resulting in enhanced productivity and efficiency in comparison to that offered by metal scaffolds.

The double layer MBMSS consists of an outer layer and inner layer. The outer layer provides suitable guard rails during the initial construction period. It is connected to inner layer of the scaffold to provide a work platform for workers.

The design of the double layer MBMSS is given in Figure 4.4. The main layer of the MBMSS has approximately the same design as the external layer. At the two ends are two vertical poles. To maintain the same load bearing strength, these poles have to be metal tubes of 48.6 mm in diameter and 2.3 mm in wall thickness. The two inner tubes are connected to each other by a metal tube ledger. The connection between the tubes is achieved using metal couplers, each of which bears a loading of 2 kN. The inner fold of the MBMSS is connected to the external fold by means of two pieces of bamboo transom of similar size in diameter and wall thickness at the two ends of the scaffold. The length of the transom will depend on the required width of the internal passageway.

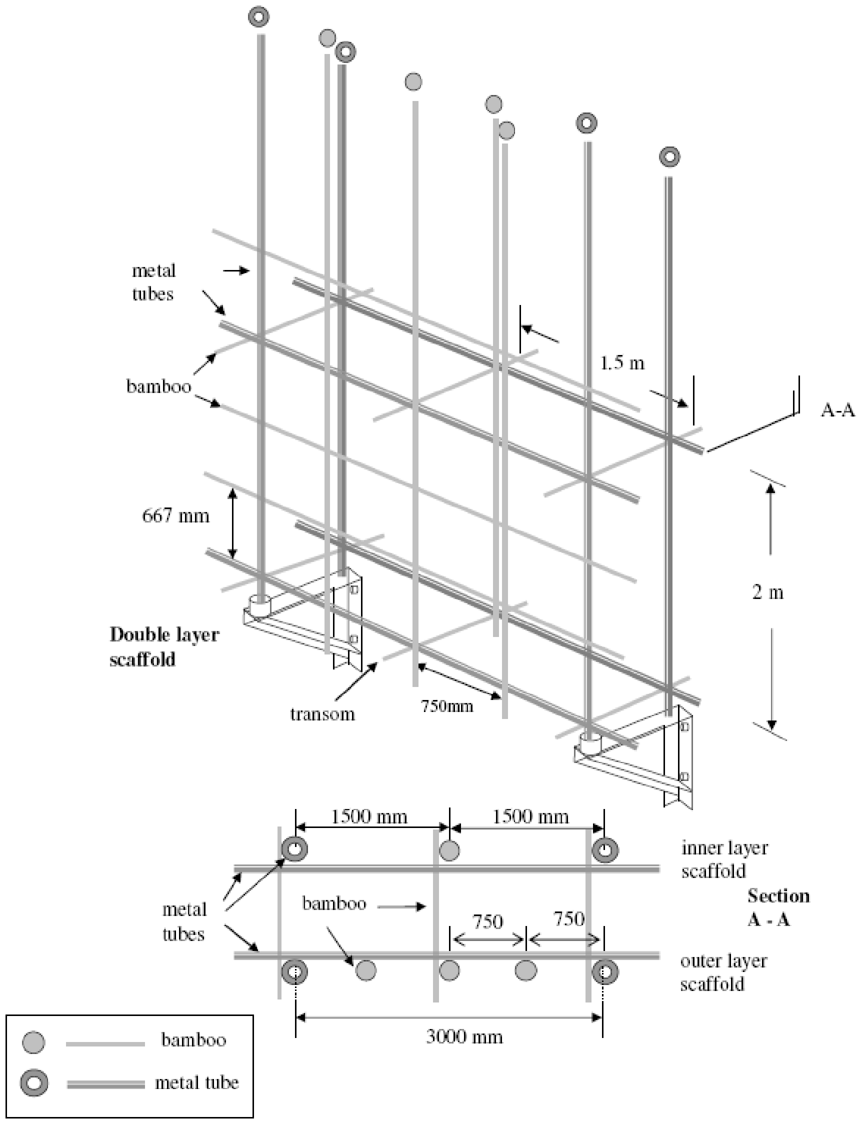


Figure 4.4 MBMSS double layer scaffold, with section

As there is a external bracing layer, there is no need to erect a bracer for the internal layer. Some site managers or safety officers who do not understand the concept behind the design may insist on the installation of internal bracers, but that would increase the self load of the scaffold, and may hinder rendering workers at later stages of the construction project. Just like the internal guard rail for the inner layer scaffold, when the rendering workers find that these members are obstructing their work, they will dismantle them. To avoid infringing on safety regulations, the distance between the external façade scaffold and the reinforced concrete face should be no more than 150 mm. The scaffold is anchored to the reinforced concrete wall by a L-shape steel bar anchor specifically designed for this purpose. The whole set-up is illustrated in Figure 4.4. The solid circles in the figure represent bamboo and the open circles represent metal tubing. The spacing of the metal tubes and bamboo is optimised for the loading capacity and to ensure adequate safety.

This standardised metal and bamboo structure also allows other features to be added to the system to enhance safety and provide a better work environment.

(b) Anchorage system

To maintain stability, a standardised anchorage system should be applied to the scaffold. An L-shape pull-log anchorage is affixed from the major steel poles at both ends to the concrete wall at minimum intervals of 7 m x 4 m, as stipulated by the Code of Practice for Bamboo Scaffolding Safety (2001) and the Code of Practice for Metal Scaffolding Safety (2001). After the installation of the pull-log anchor onto the concrete wall or flow slab, as shown in Figure 4.5, a new type of scaffold (MBMSS) is formed.

Figure 4.5 Put-log

(c) Support System

With the abovementioned loading design, the MBMSS can be erected to a height of 24 to 30 metres, depending on what is needed on site. It should either be erected from ground level or stand on the triangular steel bracket. Scaffolds more than 24 metres high should separate the excess into another zone by installing another bracket at a higher level. To avoid the unexpected settlement of soil on construction sites, the MBMSS should rest on steel brackets installed in the concrete wall at 2 metres above ground level, as shown in Figure 4.6.

For use with internal or external renovations, the MBMSS can rest on solid ground. The setting out and levelling of the brackets must be conducted during the installation stage to maintain the stability and reliability of the MBMSS system.

(d) Other components of the MBMSS

To improve safety and the work environment, other MBMSS components, such as a guard rail, work platform, staircase, catwalk and toe board have been designed.

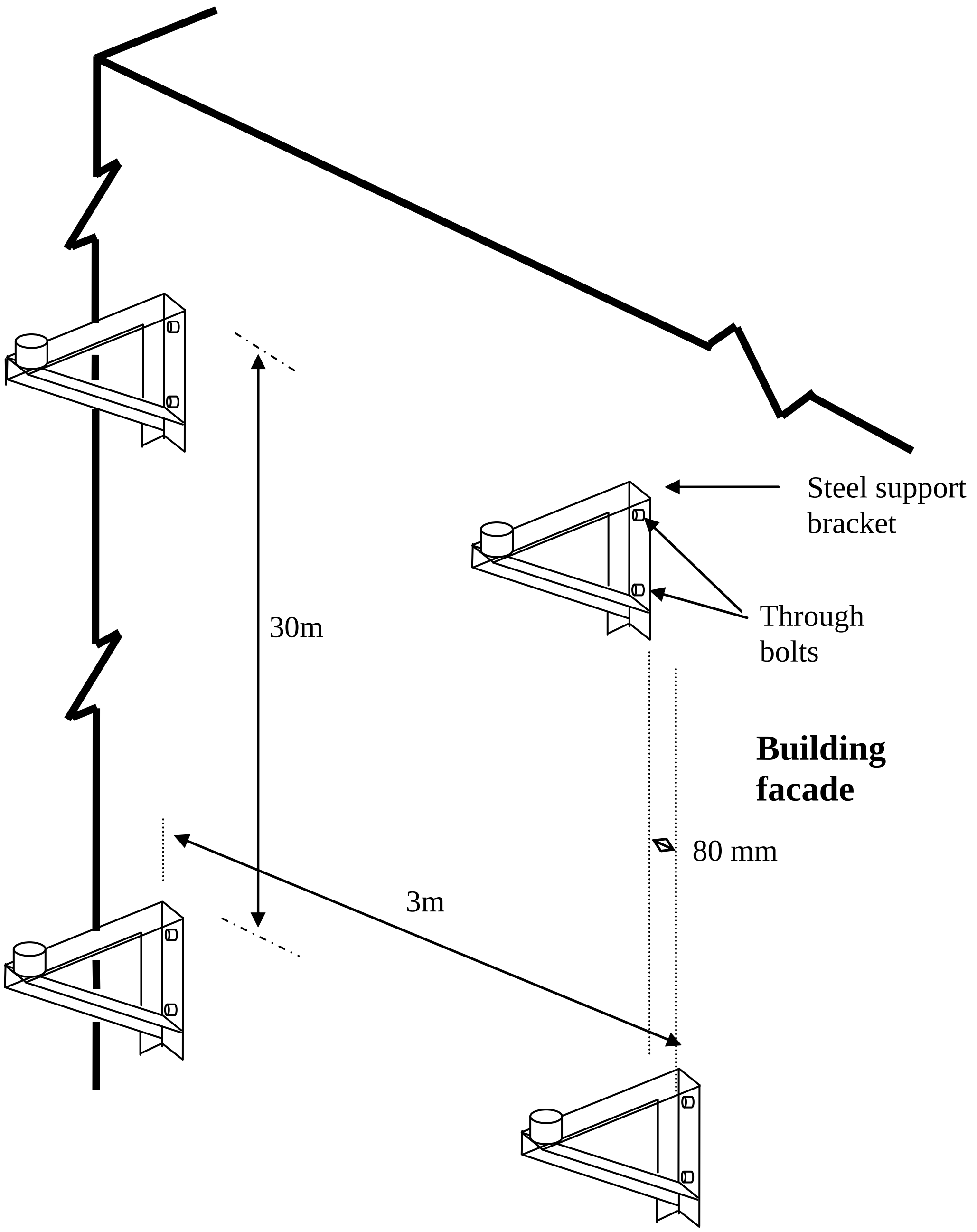


Figure 4.6 Installation of triangular steel bracket supports

As shown in Figure 4.7(a), for the safety of workers on the work platform a bamboo guard rail is installed. The work platform is a piece of metal catwalk manufactured specifically for the MBMSS. It can be of various lengths, but has a constant width of either 250mm or 500mm. Unlike the traditional work platform, the connecting hinge is on both sides instead of at both ends. Positioning the hinge on the side shortens the load bearing arm and increases the platform's rigidity and strength. The length of the work platform is shortened for the same reason. The overall performance of the platform has been increased to the extent that it does not allow any vibration and all of the load is transferred to the metal tubes at both sides, thus indirectly transferring the load to the vertical metal poles and supporting steel bracket.

Two toe-board holders, each 200 mm high as shown in Figure 4.7(b), are welded to the work platform on both sides. If the work conditions allow, a 500 mm width catwalk can be installed. If the actual situation does not provide the required width, then a minimum width of 250mm catwalk can be installed. All of these fittings must be designed, calculated and endorsed by a professional structural engineer, fulfilling legal safety requirements. The performance of the MBMSS and its fabrication were tested at the University of Queensland in Australia, with the edge beam certified as taking a maximum vertical load of 6 kN and the centre beam as taking a maximum vertical load of 9.5kN. The certificate of testing is attached in Appendix A.4.3 for reference. To allow access and egress, the MBMSS can provide cat-ladders or staircases, as illustrated in Figure 4.7.

For access between two levels, a separate staircase tower or cat ladder can be erected upon request, as shown in Figure 4.7(c) to (f). In this design, the total outlook of the scaffold is rigid and safe, allowing it to meet the expectations of the end-user and the authorities.

In this Chapter, the problem and challenge of the traditional scaffold were illustrated.

In order to comply with these requirements, a new integrated system was proposed. The principle and the hardware of the MBMSS were demonstrated. The success of the system was also relied on the software supports. In the next Chapter, it will demonstrate the validation of the MBMSS system by numerical simulation; the acquisition of engineering supports; establishing a total quality management system; and of course, implementation and feasible to suit different commercial application.

	
(a) Guard rail	(b) MBMSS work platform with toe-board
	
(c) MBMSS staircase	(d) MBMSS staircase

	
(e) Cat ladder	(f) Cat ladder

Figure 4.7 Other components of the scaffolding system

Chapter 5 Implementation of the MBMSS

5.1. From Theory to Reality

Once the MBMSS concept was formulated in 1998, the next step was its implementation. Research was conducted to determine the suitable materials and how the required items – including couplers, metal tubes, work platforms, toe-boards and steel brackets – would be manufactured, and to fine tune the design. Overseas manufacturers and suppliers were interviewed to determine the best approach.

In parallel with the procurement process, suitable sites for experimental installation were investigated. The conceptual skeleton structure was first applied in 1998 at a construction site in Yuen Long under the management of Hsin Cheong Construction Company Limited. The pilot erection was successful, but some problems were identified. The design was improved in the second stage of the experiment. The major problems were the instability of the putlog system that caused instability of the scaffold, misplacement of the staircase that made certain work platform areas inaccessible and the inadequacy of the toe-board fixing method that had the potential to cause hazards. The details of improvements made to rectify these problems are given as follows.

The rigidity of the MBMSS relies heavily on its pull-log anchoring system. In the first project, the pilot team used a steel bar 6 mm in diameter that was cast on-site into a concrete slab. However, the bar did not hold the MBMSS firmly, and moved freely with the movement of the workers. That movement also caused instability of the vertical metal tube. The dead load of the entire 10-storey-high MBMSS did not rest on the steel bracket as had been anticipated. Rather, it rested on the tube itself because of the vibration. Some of the vertical poles bent because of heavy self-load. In addition, some 6 mm ties were found to have been removed by other workers. This alerted the pilot team to the necessity of installing a strong anchor that could not easily be untied or dismantled.

It was also found that to increase the rigidity of the MBMSS, metal work platforms needed to be installed at all levels to prevent the two layers (both the internal and external scaffold) from shifting against each other when the system was under pressure from above and laterally.

The staircase is one of the key features of the MBMSS. Traditional bamboo scaffolds do not provide stair access for the workers, who can only climb up or climb down on the internal or external scaffold to reach different work areas. As a result, the chance of accidents is high. In the MBMSS, metal staircases are used for access between different levels of the work platform on the scaffold. In the first project, eight-step inclined metal staircases were used, as shown in Figures 5.1 (a) to (c). The problem of using this kind of staircase inside the main scaffold was that workers could not move along the work platform where the staircase was installed. In the later projects this problem was solved by putting the staircase tower outside the main scaffold, as shown in Figure 5.1 (d). Even though his staircase tower did not obstruct the work platform, it was very expensive to install. The author thus developed the cat-ladder system that consists of a cat-ladder and operable work platforms, as shown in Figures 5.2 (a) to (e). The advantage of this system is that no extra scaffold needs to be erected, thus saving in material cost and labour cost. However, the disadvantage is that workers need to use both hands to hold the rungs to climb up or down, which is not as convenient as using a staircase tower.

(a)

(b)

(c)

(d)

Figure 5.1 Staircase: (a) to (c) original staircase; (d) improved staircase

(a)

(b)

(c)

(d)

(e)

Figure 5.2 Cat ladder

Toe-boards must be installed for the scaffold's work platform according to the Code of Practice for Metal Scaffolding Safety Section 4.4.1(b). The minimum height of the toe-board is 200mm (Third Schedule to the CSSR). During the pilot project, the fixing of toe-board to the work platform was achieved using two U-shape connectors with screws to hold the wooden toe-board and then using the pins below the U-shape cups to go through the holds on the work platform to complete the fixing, as shown in Figures 5.3 (a) to (d). After this first pilot project, the author found that the disadvantage of this kind of insertion fixing method was that the connections were not stable because the installed toe-board would move back and forth freely, and as shown in Figure 5.3 (d) workers needed to use a plastic strip to stable the toe-board. After identifying this problem in the first pilot project, the author solved this problem in the later projects by using a new fixing design for the toe-board as shown in Figures 5.3 (e) and (f). The fixing method was totally redesigned, with the use of the U-shape connection pin abandoned. The author used two L-shape metal angle brackets that were welded to the work platform, as shown in Figure 5.3 (f), to hold the toe-board. The advantages of this kind of insertion method are that it is fast and stable and does not require extra add-on accessories because the L-shape metal angle brackets are welded during the production of the work platform by the manufacturer. Unlike the old method, there is no need to use a plastic tie to fix the connection because the toe-board is already stable enough by itself. In addition, the lack of accessories means that the chance of losing material is reduced, thus saving both labour and material costs.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 5.3 Toe-board

In the second phase of the pilot study, two Sun Hung Kai Property Limited (SHK) projects were selected, one in Ha Yau Tin in Yuen Long, and the other in Tseung Kwan O (TKO), Lot 55, Phase I. These projects required the installation of work platforms, and the project in TKO also required toe-boards. The Hai Yau Tin project covered only one block of the lower portion of a building 10 storeys high, whereas the TKO project involved four blocks of buildings 52 storeys high, with full-scale application. The results from both pilot sites were very encouraging and drew the attention of the senior management of the SHK Group as no injuries or accidents related to the scaffolding system were reported. In September 1999, a significant event took place: Typhoon York hit Hong Kong and Typhoon Signal No. 10 was hoisted. The TKO project was in the direct path of the typhoon. All of the bamboo scaffolds at the sites neighbouring the TKO site, which were under the management of the same scaffolding company, collapsed, whereas the MBMSS in place at TKO 55 was unaffected save for minimal damage. It took more than a month to restore the bamboo scaffolds to their original condition in the neighbouring projects, but only three days to replace the missing catch and nylon safety net of the MBMSS. The senior management of the SHK Group were impressed by the greater efficiency and reliability of the MBMSS, and the system was incorporated into the Group's scaffolding policy.

5.1.1 Patent Application and Registration

As all of the components and filing details had been confirmed by trial and error, the next step was to apply for a patent. Protection of intellectual property has two meanings. First, an invention must be registered with a recognised authority. Second, an invention has the obligation to educate and teach those who want to use it in the future, under the management of the inventor.

A legal firm undertook the registration of the patent in New Zealand for the European Patent (a copy of the Grant of the Patent is attached in Appendix A3.1). Upon the granting of the European Patent, another patent application was made through the Hong Kong Productivity Centre for registration in the Patent Office of the Intellectual Property Department of the Hong Kong government. After nine months of examination and study by the relevant authority, a short-term patent of eight years, a standard patent of eight years and a standard patent of 20 years were finally granted in March 2001 (see Appendix 3.1b) for the design of a proprietary product, the Metal Bamboo Matrix Scaffolding System, and its application worldwide. As there are many similar combined metal-bamboo scaffolding systems in China, a similar registration process was initiated in the People's Republic of China in the same period. It took the relevant Chinese authority more than five years to examine the patent application. Finally, a patent for design and application was granted in 2006 (see Appendix 3.1c). The registration of the patent in Europe, Hong Kong and finally, in China involved lengthy legal proceedings and a number of legal disclaimers, which are discussed in a later chapter.

5.1.2 Support from Other Research

"In parallel with the patent registration and on-site implementation of the MBMSS, the author initiated several research studies by external parties to improve and reinforce the new design. The studies focused on two areas, the loading capacity of the scaffolding and the effect of wind on acting on a scaffold.

Scaffolding design has traditionally been based on live loading and wind effects. Before Chang and Yu's (2002) study there had been no numerical simulation of bamboo scaffolding. They reported that there was a deviation of 30% between experimental and numerical simulation results. Although the design of the MBMSS was based on experience, it had to be validated by a theoretical or engineering approach. The simulation of the live loading of a metal scaffold under perfect conditions can be done easily. In reality, however, imperfections always occur, with small deformations of the metal tubes and tube misalignment. The effects of these imperfections are not known, and a search for a better simulation method was conducted by Chu and Chan (2005).

In terms of wind effects, scaffolding design must follow the Code of Practice on Wind Effects (1983, 2004). The Code is based on the aerodynamic forces acting on an object, and the flow pattern surrounding a building is not considered. Hong Kong suffers from typhoons, and most scaffolding collapses occur because of the strong winds they create. To understand the basic effects of aerodynamics on the MBMSS, a study was conducted by an external adviser (Fung 2005).

(a) Simulation

As mentioned in chapter 3, the main frame of the MBMSS is a metal scaffold composed of 46.6 mm x 2.3 mm (circular hollow section) tubes. The MBMSS was validated by numerical simulation and the results gave lower bound solutions to practical design problems.

Metal scaffolding is a common temporary engineering structure used worldwide; however, a relatively high number of collapses are reported every year. Chu et al. (1996) assert that the design of metal scaffolding is based on experiments combined with judgment. However, a theoretical treatment of the design of this type of structure is not yet available as failure of this sort is normally due to buckling, particularly when the scaffolding system is more than three storeys high.

A modular metal scaffold system is a slender steel structure for which the non-linear effects are important. The initial out-of-straightness before loading and eccentricity of the applied load are sources of imperfections in metal scaffold systems. The stability problems of these systems can be as addressed through elastic critical load and second-order analyses.

It has been found that the elastic critical load method alone is not sufficient to provide adequate information on the occurrence of system failure as it ignores imperfections and load concentration and large deflection effects. However, second-order P-△-δ elastic analysis can fill this gap by investigating the equilibrium and stability conditions of frame structures. The latter method also takes into consideration the second-order effects due to changes in geometry, member curvature and stiffness of each member.

Chu and Chan (2005) proposed a reliable design method for the practical design of a metal scaffold. The effect of initial geometrical imperfection was simulated using NAF-NIDA by assuming initial imperfection of 0.001 of the member length but this effect was found to be quite insignificant. This was not surprising since the influence of joint eccentricity would be far more significant than the influence of initial geometrical imperfection. The validity of the proposed method was confirmed by comparison with the test results of seven 3-storey steel scaffolding units and the design of a 30 m (height) x 20 m (width) x 1.3 m (depth) three-dimensional scaffolding system.

Second-order analysis traces the load deflection path of a structure by applying the load incrementally onto the structure, with large deflection p-Δ and p-δ effects considered. The advantage of this method is that it provides virtual strain gauges attached to every member in a scaffold structure.

To validate the proposed computation method, Chu and Chan (2005) used the test results of seven 3-storey steel scaffolding units that had been obtained by Weesner and Jones (2001). The dimensions of the four types of units are given in Figure 5.4, and their detailed dimensions can be found in the original paper. The material yield is 350 MPa, and Young's modulus of elasticity is 200 kN/mm^2. The results of the computed design capacity of the four types of 3-storey scaffolding system using Chu and Chan's (2005) second-order analysis are given in Table 3.1, together with the test results. It can be seen that the design load capacity ranges from 80.4% to 98.9% of the tested failure load. The present computed loads are always below the test failure load, which indicates the suitability of the proposed method as a reliable tool for giving lower bound solutions to practical design problems.

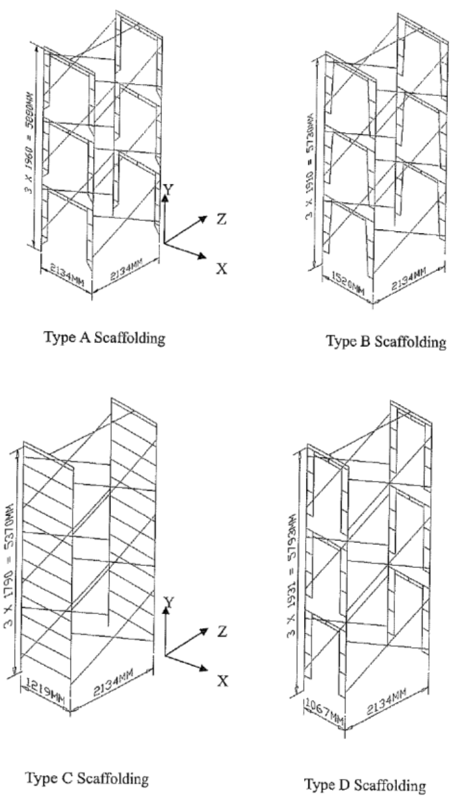


Figure 5.4. Geometry of test specimens.

Table 5.1. Results from experiments and computer analysis

Frame Serial Number	Experimental Results Load (kN)	Computed Design Load (kN)	$\frac{Theory}{Test}$ x100%
1	195.1	192.9	98.8
A2	201.9		95.5
B1	184.4	170.6	92.5
B2	190		89.8
C1	502.4	422.2	84.8
C2	525.3		80.4
D	180.9	157.9	87.3

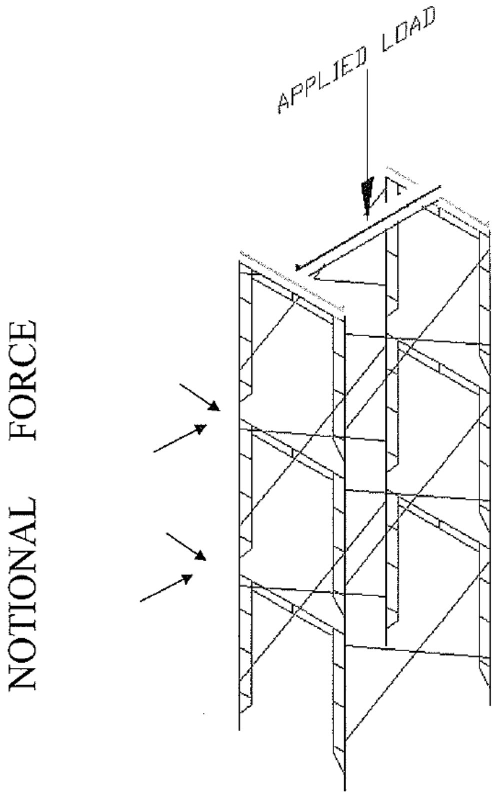


Figure 5.5. Arrangement for the loading test of a scaffold specimen.

Figure 5.5 shows the simulation of the expected imperfect curvature of the complete system through applying the notional force at the junction between each scaffolding unit. This modelling approach is simpler than using the imperfect geometry of the system.

Chu and Chan (2005) proposed that a second-order analysis method be carried out using the NAF-Nida computer program for the design of a 30 m (high) x 20 m (wide) x 1.3 m (deep) three-dimensional scaffolding system, as shown in Figure 5.6. The scaffold structure is simulated using circular hollow sections (CHSs) 32 mm in diameter and 4.5 mm thick as standards, ledgers and ties to the façade, and CHSs 56 mm diameter and thickness 4mm as transoms. Young's modulus of elasticity is taken as 200kN/mm² and a yield stress of 190 kN/mm² is assumed in the analysis. The structure is under a vertical load of 3 kPa at the top five storeys and a uniform 0.2 kPa at all other levels. Wind pressure in the lateral direction is 0.75 kPa. All joints between members are assumed to be rigid but connections to the ground support are pinned. The analysis shows that the member at the bottom of the scaffolding system fails at an axial load of 58 kN with the implication of an effective length factor (Le/L) of 2.32. These failure loads and the effective length factor are larger that the quoted values of 33.61 kN and 3.72, respectively, for axial load at failure obtained from conventional elastic critical load analysis (Godley & Beale 1997). The difference shows that a more economical design can be obtained using the proposed second-order analysis method as it gives a lower bound solution to the actual failure load.

After the study by Chu and Chan (2005), the author adopted the NAF-Nida software and included it in the engineering design manual of the MBMSS. The NAF-Nida software has been accepted by the Buildings Department of the HKSAR for non-linear analysis and design under the Code of Practice for the Structural Use of Steel 2005.

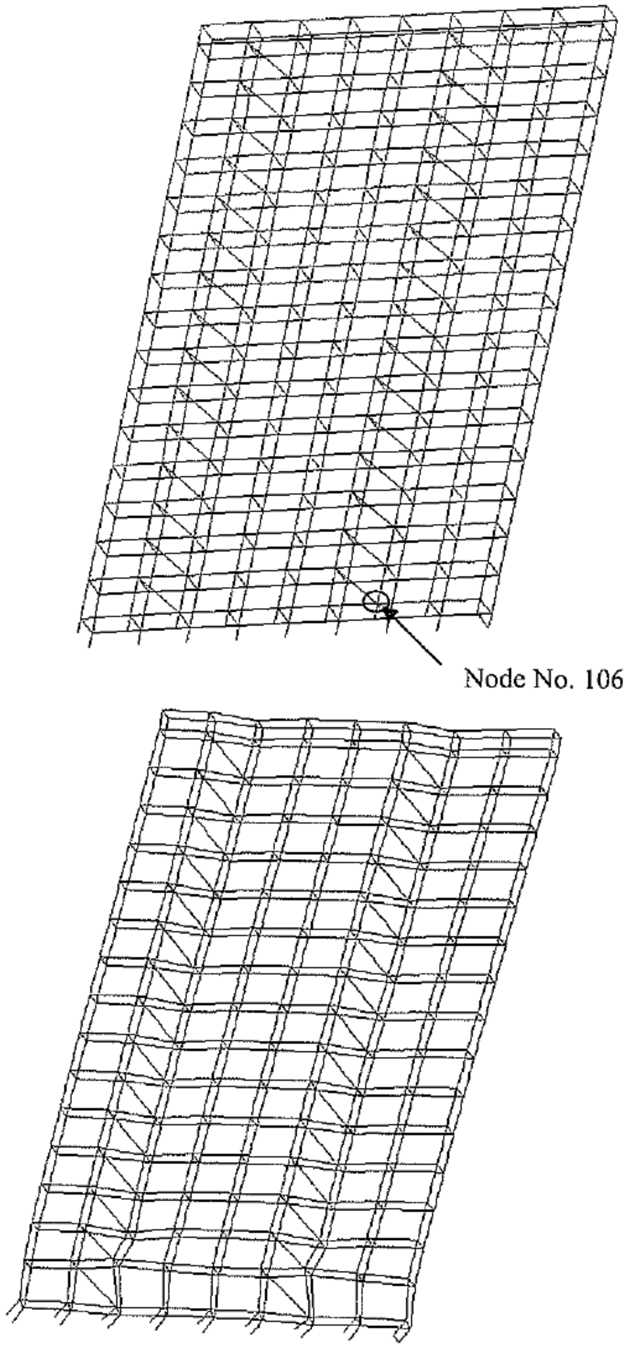


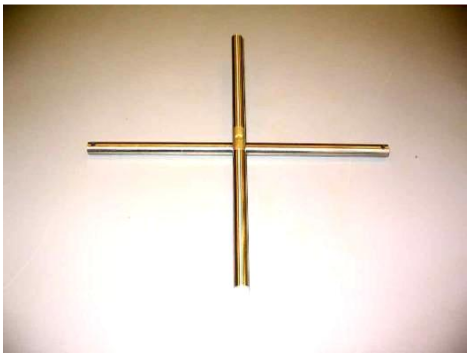
Figure 5.6 Undeformed (top) and deformed (bottom) shape of a 30 m x 20 m x 1.3 m scaffolding system.

(b) Aerodynamic Forces

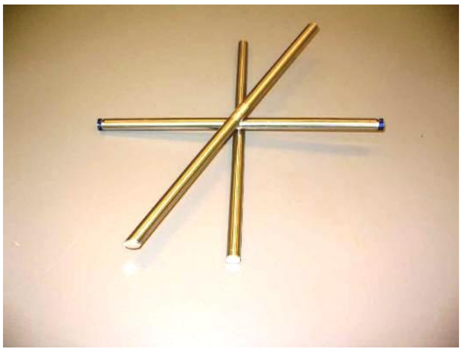
When a scaffold is rigidly mounted on a building, wind loading is mainly taken up by the building structure. The aerodynamic force of the scaffold was calculated by professional engineers according to the Code of Practice on Wind Effects (1983, 2004). The wind pressure increases when the height increases. In the design calculation of MBMSS, the wind pressure varies from 1.2 kPa for the height less than 10m and 2.2 kPa for 10m to 30m. In the following section, the aerodynamic forces and vibration induced due to the local flow pattern acting on the scaffold are discussed.

The number and duration of typhoons that hit Hong Kong from 1956 to 2007 are shown in Appendix A3.2. The strong winds and gusts of typhoons threaten the stability and safety of scaffolding, especially that which is attached to high-rise buildings, which have become more popular in the past two decades. Hence, knowledge of the aerodynamic forces acting on scaffolding and the wind profiles around buildings can provide fundamental information on wind effects.

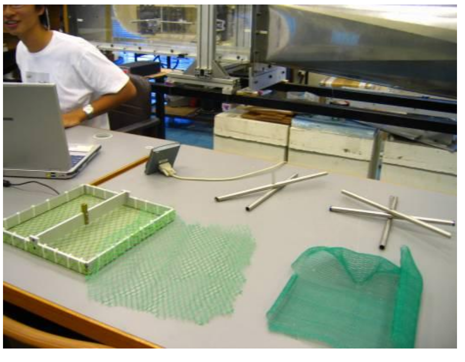
The drag coefficient acting on a circular tube can be found in general fluid mechanics books. The author involved the Fluid Mechanics Laboratory in Hong Kong Institute of Vocational Education (Tsing Yi) in 2004 and observed a wind tunnel demonstration on circular tubes as shown Figure 5.7(e). Based on the results of the Fung (2005), an experiment was conducted to demonstrate the drag coefficient of a single tube using a 90-degree crossed tube, 45-degree crossed tube, triple crossed tube and several nylon safety nets, as shown in Figure 5.7. The experiment was conducted in a 300 mm x 300 mm wind tunnel, with a variable speed up to 30 m/s. The test was limited by the dimension and the wind velocity of the wind tunnel. The drag coefficients of different tube configurations were slightly lower than the theoretical results but agreed in general, as shown in Figure 5.8. Hence, the trends of the result will follow the theoretical drag coefficient. However, the drag force of the nylon safety nets was 30N, which was three times higher that of the 90 degree + 60 degree specimen tubes, as shown in Figure 5.7.



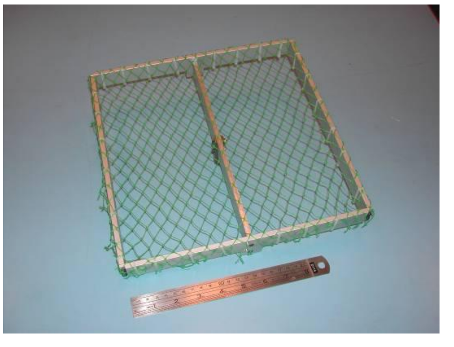
(a) 90 degree



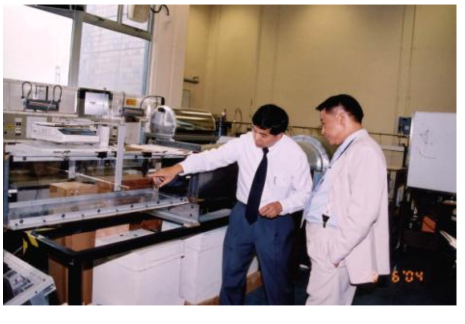
(b) 90 degree + 60 degree



(c) Different nylon safety nets



(d) Mounting of a nylon safety net for wind tunnel testing



(e) Author involved in experimental demonstration

Figure 5.7 Specimen used in wind tunnel testing and author involved in experimental demonstrated

The experiment revealed that the nylon safety nets shown in Figures 5.7(c) and (d) have a higher drag than the tube. As the scaffold is rigidly fixed to a building but the nylon net is hanging on the scaffold, the nylon net will flap under strong wind conditions and the resultant drag force will bring down the scaffolding. The results indicated that the operational procedure for during typhoons had to be improved.

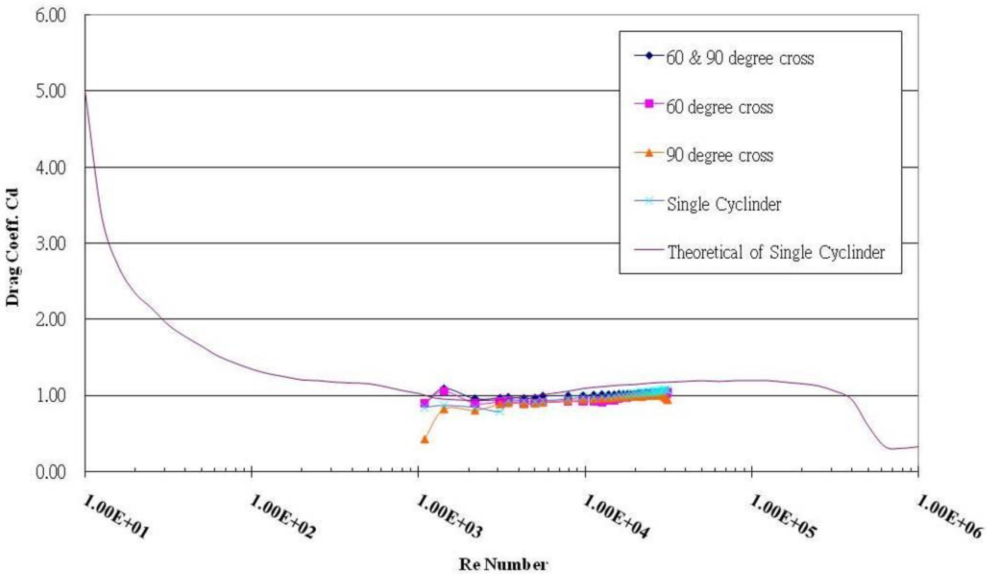


Figure 5.8 Drag coefficient of experimental result

As scaffolding is attached to a building, it is affected by the wind patterns around the building, as indicated in Figures 5.9 and 5.10 (ASHRAE Handbook 1993).

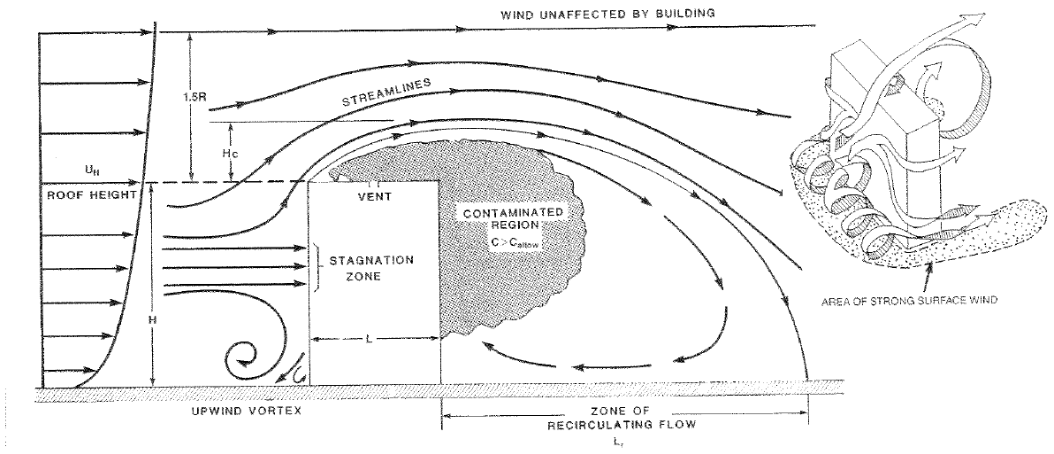


Figure 5.9. Flow patterns around a rectangular building (ASHRAE Handbook 1993).

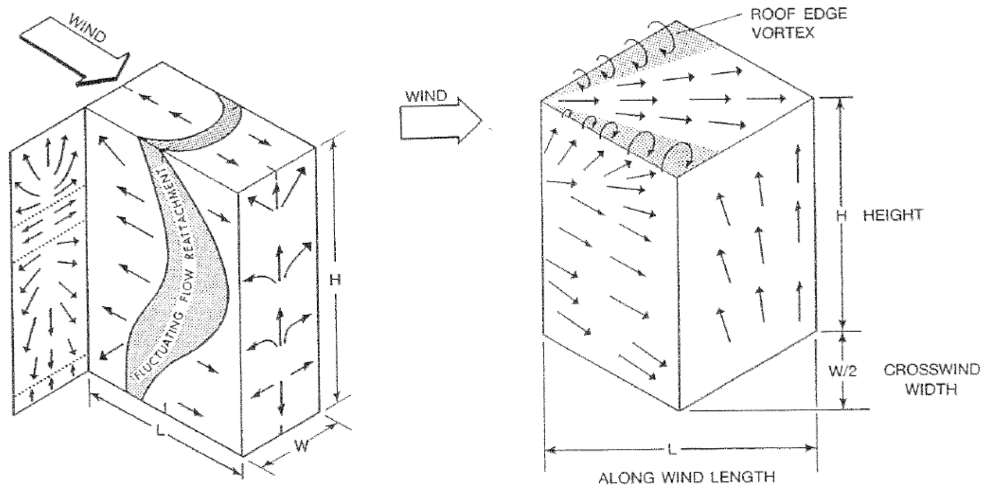


Figure 5.10. Surface flow patterns and building dimensions (ASHRAE Handbook 1993).

As shown in Figure 5.9, wind approaches the building with a stagnation zone at about mid-height of the building. Near the roof, the air flow accelerates at a higher velocity near the edge of the building, and will apply a strong wind load at the top of a scaffold, especially during the construction period when the poles of the scaffold with the nylon safety net are high above the roof. Near the ground is a region with a strong rolling surface wind, which creates what is called a horse-shoe vortex. The wind travels downward near the building and can cause damage to the catch fan.

Figure 5.10 shows the surface flow patterns, and indicates the flow directions along the surface of the building. As a scaffold is attached to the surface of a building, the flow direction will generate an additional aerodynamic force on the scaffolding system. The aerodynamic study conducted by Fung (2005) showed that the effect of aerodynamic force acting on a nylon net is more significant than metal tubes of the scaffold. A clause was thus added in the management manual of the MBMSS to the effect that the nylon net has to be lowered and tied up when there is strong wind or a typhoon.

It was also observed that the air flow pattern around the building affects the stability of the scaffold. For example, the downward wind due to the horse-shoe vortex at a lower level will affect the stability of the catch-fan. However, the Code of Practice for Bamboo Scaffolding Safety (2001 & 2009) states that the catch fan is compulsory and no action could be taken in that regard. The scaffold also suffered higher wind loading near the roof and at the edge when the wind velocity was accelerating at the corner of the building. Further study of the spacing of put-logs and the anchorage system thus had to be conducted.

5.2 Operation and Management

The key to safety management is knowing how to identify and control hazards and applying key managerial principles so that workers can work safely every day that they are on the job. A good safety management system not only minimises the risk of accidents, but also improves job efficiency. The next subsection briefly discusses the five major components of safety management.

5.2.1 Safety Management

A. Responsibilities

In Hong Kong, according to the Code of Practice on Safety Management, Factories and Industrial Undertakings (Safety Management) Regulation under Schedule 3 of Factories and Industrial Undertakings Ordinance (Chapter 59AF), any construction contractor with an aggregate of 50 or more workers a day working on a single construction site or more than one construction site must develop, implement and maintain a safety management system. However, most scaffolding companies usually have fewer than 50 workers a day working at two or more construction sites. The few scaffolding companies that have more than 50 workers working each day, such as the author's company, need to comply with the Safety Management Regulation to develop, implement and maintain a safety management system (as listed in the first eight elements in section C).

B. Developing, implementing and maintaining a safety management system

The development of a safety management system involves both planning and developing. Planning is the process of determining in advance what needs to be accomplished. The contractor of the industrial undertaking is required to identify in advance what safety and health objectives should be accomplished by the safety management system, prioritise those objectives, devise ways of achieving them, and estimate the financial and other resource implications arising from the accomplishment of those safety and health objectives.

The contractor should conduct an initial status analysis of the existing arrangements for managing safety and health. It should carry out risk assessment to decide on priorities and objectives for hazard elimination and risk control, establish performance standards for monitoring performance and conduct periodic status analyses of the safety management system in operation. Risk assessment is used to estimate an industrial undertaking's overall risk profile. The findings of the assessment provide the basis for the contractor to formulate risk control strategies, set out safety and health objectives and define standards and priorities. The basic steps include the identification of hazards and the determination of risk. After risk assessment, the following actions should be taken to eliminate or control the risks identified: (i) development of safety procedures and risk control measures, (ii) implementation and maintenance of safety procedures and risk control measures and (iii) review of safety procedures and risk control measures. The contractor should appoint a competent person to carry out this assessment.

Development is the process of determining how the safety and health objectives should be realised. The contractor is required to define, document and endorse a safety policy to spell out the safety and health objectives identified in the planning stage. To carry out the safety policy, the contractor should prepare an effective safety plan.

The safety plan should be established by the industrial undertaking's senior management, with the advice and assistance of safety and health personnel. As far as reasonably practicable, all levels of managers, supervisors and workers should be involved in developing the plan. In general, the plan should spell out the safety policy, along with the objectives and standards to be achieved, the statutory and contractual obligations to be fulfilled, the risks to be tackled and the safety procedures and measures to be adopted. Where necessary, further details can be spelled out in safety manuals, method statements and so on. All managers, supervisors and employees should know the plan and the role they play in its implementation. Establishing an effective communications system within the organisation is thus essential. Finally, the safety plan should be regularly reviewed and, where necessary, modified in the light of experience.

The implementation of a safety management system involves both organisation and implementation. Organisation involves prescribing formal relationships between people and resources in the organisation to accomplish objectives. The contractor is required to ensure that occupational safety and health is fully integrated across the industrial undertaking and into all of its activities, whatever the size or nature of its work, and to set aside an adequate budget commensurate with the relevant industrial undertaking's size and nature for implementing the policy and for properly establishing and maintaining the elements of the safety management system. It is also important to structure the industrial undertaking properly so that it can put the safety policy and plan into practice effectively. In addition, the contractor is required to allocate safety and health responsibilities and to make arrangements for the formation and operation of a safety committee, a safety department/unit/group and the appointment of a safety officer, adviser or director.

Implementation involves carrying out or putting into practice the plans, with appropriate control to ensure proper performance. The contractor is required to determine and execute operation plans to control the risks identified, meet legal and other requirements for safety management and provide adequate and effective supervision to ensure that the policies and plans are effectively implemented. It also needs to prepare and maintain sufficient documentation to record and monitor the progress of the implementation of the policies and plans and to have emergency response plans in place and maintain a high level of emergency preparedness.

The maintenance of a safety management system involves measuring and auditing or reviewing, through which the contractor knows whether the safety management system of his relevant industrial undertaking is working well or needs improvement.

Measuring is the process of checking performance against standards to ascertain the improvement needed, and a means of monitoring the extent to which policies and objectives are being met. This stage provides a feedback loop for the development and implementation stages, helps the industrial undertaking reinforce and maintain its ability to reduce risks and ensures the continued efficiency, effectiveness and reliability of the safety management system.

Auditing or reviewing is carried out to assess performance and routinely monitor occupational safety and health concerns. Auditing or reviewing is the feedback loop of the planning stage, allowing the industrial undertaking to reinforce, maintain and develop its ability to reduce risks and ensure the continued efficiency, effectiveness and reliability of the safety management system. In addition, information should be flowing between the development, implementation and maintenance stages and the auditing/reviewing stage to ensure the correct operation of the safety management system.

The development, implementation and maintenance of a safety management system is summarised in the management model in Figure 5.11.

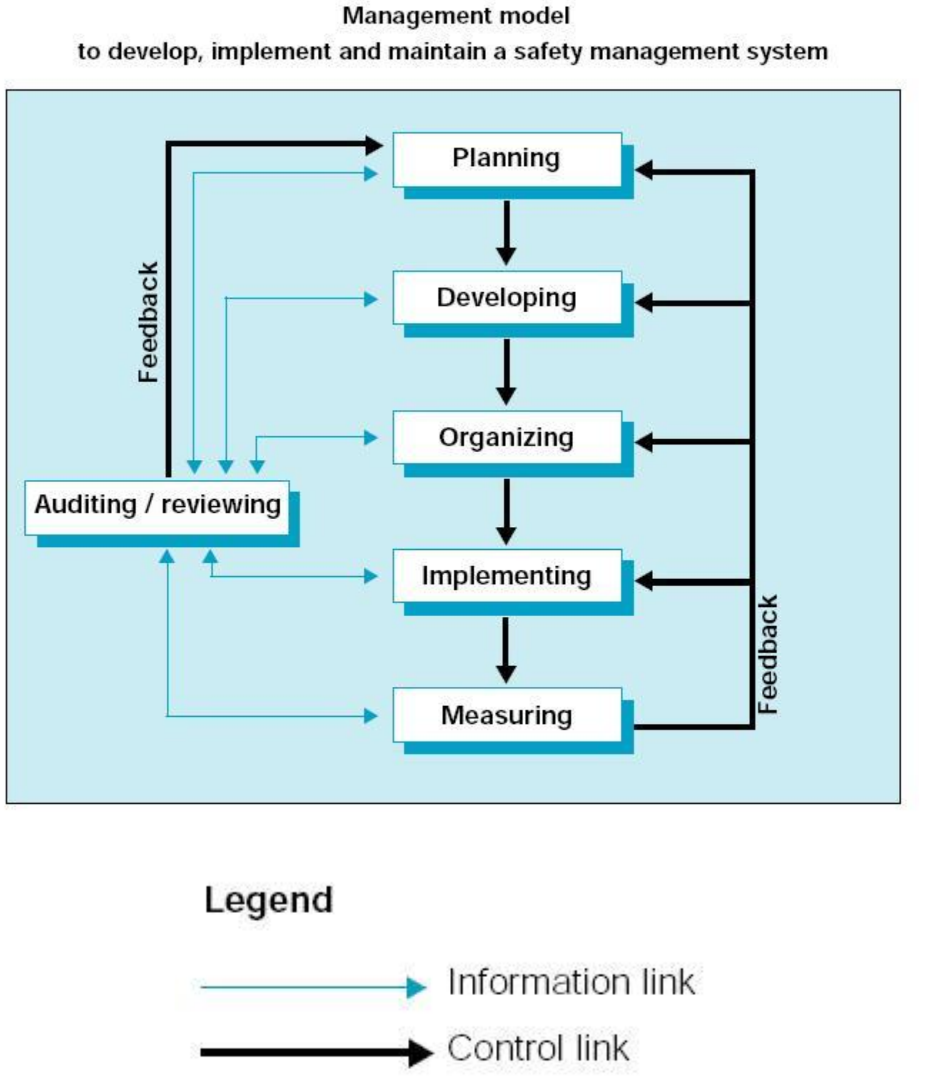


Figure 5.11 Safety management model.

C. The elements of a safety management system

The 14 elements of a safety management system are as follows.

1. A safety policy that states the contractor's commitment to safety and health at work
2. A structure to assure implementation of that commitment

3. Training to equip personnel with knowledge to work safely and without risk to health
4. In-house safety rules to provide instruction for achieving safety management objectives
5. A programme of inspection to identify hazardous conditions, and to rectify those conditions at regular intervals or as appropriate
6. A programme to identify hazardous exposure or the workers' risk of such exposure and provide suitable protective equipment as a last resort where engineering control methods are not feasible
7. Investigation of accidents or incidents to determine the cause of any accident or incident and to develop prompt arrangements to prevent recurrence
8. Emergency preparedness to develop, communicate and execute plans that prescribe the effective management of emergency situations
9. Evaluation, selection and control of sub-contractors to ensure that they are fully aware of their safety obligations and are actually meeting them
10. Safety committees
11. Evaluation of job-related hazards or potential hazards and development of safety procedures
12. Promotion, development and maintenance of safety and health awareness in the workplace
13. A programme for accident control and the elimination of hazards before workers are exposed to any adverse work environment
14. A programme to protect workers from occupational health hazards

D. Safety Audit

A safety audit constitutes a feedback loop that enables the industrial undertaking to reinforce, maintain and develop its ability to reduce risks to the fullest extent and ensures the continued effectiveness of the safety management system. Under the Safety Management Regulations, the main duties of the contractor specified in Parts 1 or 3 of Schedule 3 of the Safety Management Regulations, Chapter 59AF Factories and Industrial Undertakings (Safety Management) Regulation, in relation to safety audits include the following:

- Appointment of a registered safety auditor to conduct safety audits (Section 13 of the Safety Management Regulations);
- Provision of facilities, etc., for safety audits (Section 14 of the Safety Management Regulations); and
- Action to be taken on safety audit reports submitted by a safety auditor (Section 16 of the Safety Management Regulations).

A safety audit involves collecting, assessing and verifying information on the efficiency, effectiveness and reliability of a safety management system and considering improvements to the system. Based on the audit findings, the overall performance of the safety management system should be assessed. If inadequacies or nonconformities are identified, then recommendations should be made to improve the system. The audit should also identify the system’s strengths and suggest how to build on them.

A plan based on the audit findings for improving the safety management system should be developed and drawn up. This plan should contain the necessary remedial measures and actions to rectify the inadequacies and non-conformities identified, complete with a description of responsibilities, completion dates and reporting requirements. Follow-up monitoring arrangements should be established to ensure the satisfactory implementation of the plan.

If the safety audit report contains recommendations for improving the safety management system, then the contractor has to devise a written plan complete with a description of the remedial measures, responsibilities, completion dates and reporting requirements, and so on, for the implementation of the recommended improvements, within 14 days of receiving the report.

E. Safety review

A safety review is a feedback loop that enables the industrial undertaking to reinforce, maintain and develop its ability to reduce risks and ensures the continued effectiveness of the safety management system. Under the Safety Management Regulations, the main duties of the contractor include the following:

- Appointment of a safety review officer to conduct safety reviews (Section 19 of the Safety Management Regulations);
- Provision of facilities, and so on, for safety reviews (Section 20 of the Safety Management Regulations); and
- Action to be taken on safety review reports submitted by a safety review officer (Section 22 of the Safety Management Regulations).

A safety review involves reviewing the effectiveness of the safety management system and considering improvements to its effectiveness. Based on the review findings, the overall performance of the system should be assessed. If inadequacies or non-conformities are identified, then recommendations should be made to improve the system. The review should also identify the system's strengths and suggest how to build on them. A plan based on the review findings for improving the safety management system should be developed and drawn up. This plan should contain necessary remedial measures and actions to rectify the inadequacies and non-conformities, complete with a description of responsibilities, completion dates and reporting requirements. Follow-up monitoring arrangements should be established to ensure the satisfactory implementation of the plan.

The safety review report contains recommendations to improve the safety management system. As with the safety audit report, the contractor should devise a written plan including a description of the remedial measures, responsibilities, completion dates and reporting requirements, and so on, for the implementation of the recommended improvements, within 14 days of receiving the report.

5.2.2 Operational Management

5.2.2.1 Design Stage

A construction project should be designed with safety in mind. This approach makes it possible to eliminate or minimise work hazards by proper planning and design of the methods of construction, sequences of activities and co-ordination.

During the design of a scaffold, attention should be paid in the following areas.

(a) A safe scaffold and its erection/alteration/dismantling for all stages of construction should be designed and planned well beforehand.

(b) The safe method of scaffolding devised should be kept under continual review.

(c) The strength and stability of the scaffold throughout all stages of scaffolding should be ensured.

(d) The strength of scaffolding members such as tubes and couplers should be ensured. Reference should be made to the procedures laid down in relevant standards of the International Organisation for Standardisation or equivalent procedures for their sampling and mechanical testing.

(e) Realistic assessment of loadings on the scaffold at all work stages should be made. When considering the wind load on the scaffold, reference should be made to the latest edition of the Code of Practice on Wind Effects, Hong Kong.

(f) Safe access to and egress from the working places should be provided.

(g) An effective bonding system to the ground should be provided for the scaffold.

(h) Additional features such as attachment points for ladders, work platforms, guard-rails and toe-boards should be provided for the protection of scaffolders. Safety nets and safety belts should also be provided for the protection of scaffolders.

(i) Scaffolding components/materials/equipment should be handled, lifted, stored, stacked and transported safely.

(j) The time at which the scaffold is to be erected and dismantled should be decided in the design and planning stage. The scaffold should be dismantled as soon as it is no longer required.

In most cases, whenever tenders for MBMSS scaffolding works are awarded, design calculations and drawing submissions for the works are requested by the main contractor. In-house consultants are notified to prepare submissions for the projects.

Before the commencement of the design work and drawings, a site meeting with site personnel including the main contractor, site supervisor from the scaffolding company and an in-house consultant is requested. The meeting is used to clarify the required live loads imposed on the scaffold and any special site conditions to be considered in the design of the scaffold and supporting steel bracket at elevated levels. For example, large openings in a scaffold to allow a projected out-loading platform may be required.

After confirmation of the design live load and clarification of the site conditions, a design submission is carried out by the in-house consultant. The design submission normally has two parts. The first part includes the structural design calculations for the MBMSS using the second-order analysis computer program NAF-Nida, and the conventional steel design for the associated steel support brackets at elevated levels. The second part is the drawing submission, which includes the elevations of the MBMSS, the layout of the steel brackets around the perimeter of the building and details of the steel brackets and anchor bolts. Figures 5.12(a) to (h) show the elevations of the MBMSS, the layout plans of the steel brackets and details of the steel brackets, respectively, for the Venetian project in Macau, completed by the author’s company.

The abovementioned design calculations and drawings are submitted to the main contractor for approval before the MBMSS is erected. After approval is obtained, a set of design calculations and drawings is retained on site for reference as requested by an officer of the Buildings Department of the Hong Kong government.

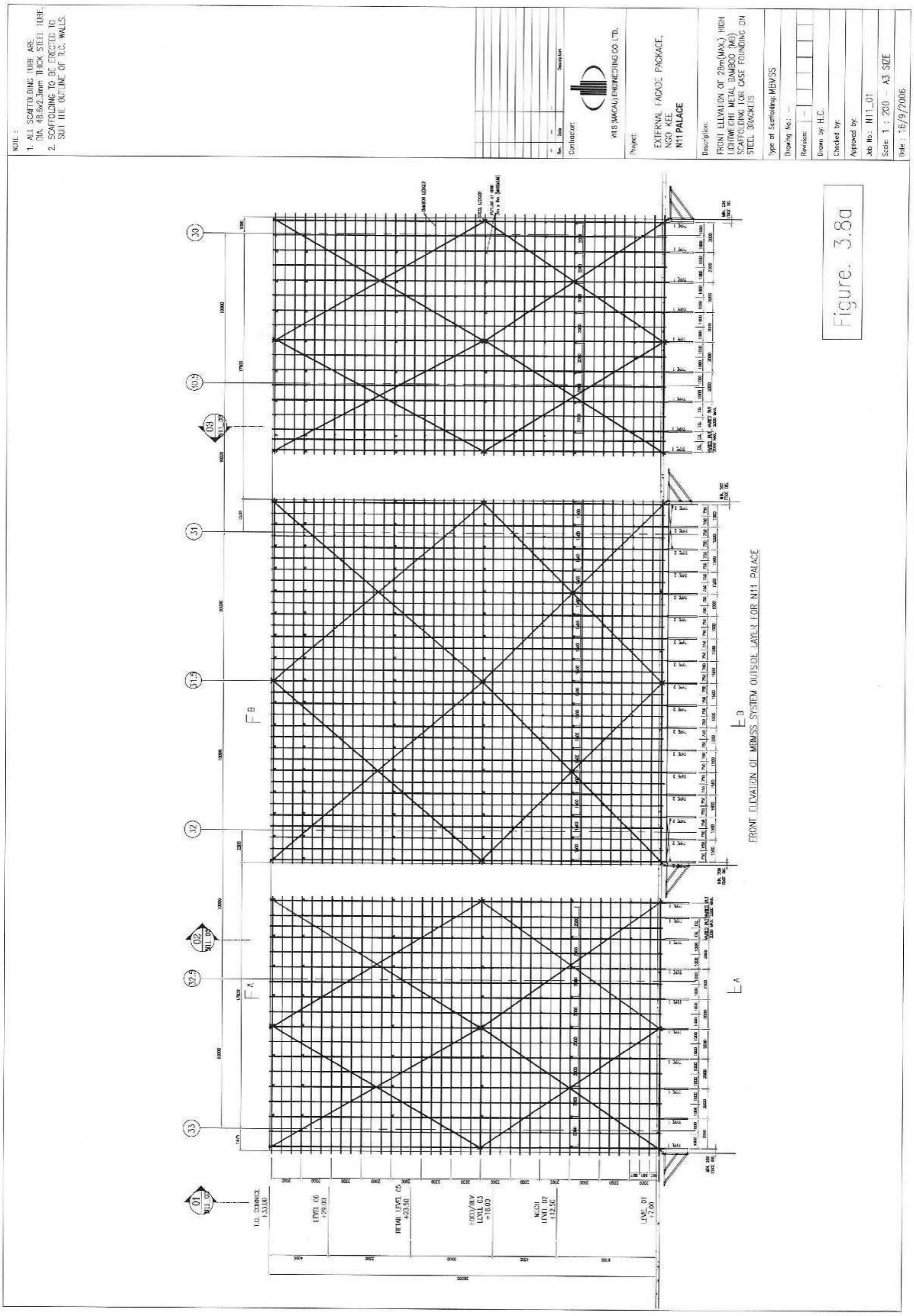

NOTE :
1. ALL SCAFFOLDING TUBE ARE DIA. 48.6x2.3mm THICK STEEL TUBE.
2. SCAFFOLDING TO BE ERECTED TO SUIT THE OUTLINE OF R.C. WALLS.
EXTERNAL FACADE PACKAGE,
NGO KEE
N11 PALACE
FRONT ELEVATION OF MBMSS SYSTEM OUTSIDE LAYER FOR N11 PALACE
Figure. 3.8a

Figure 5.12(a)

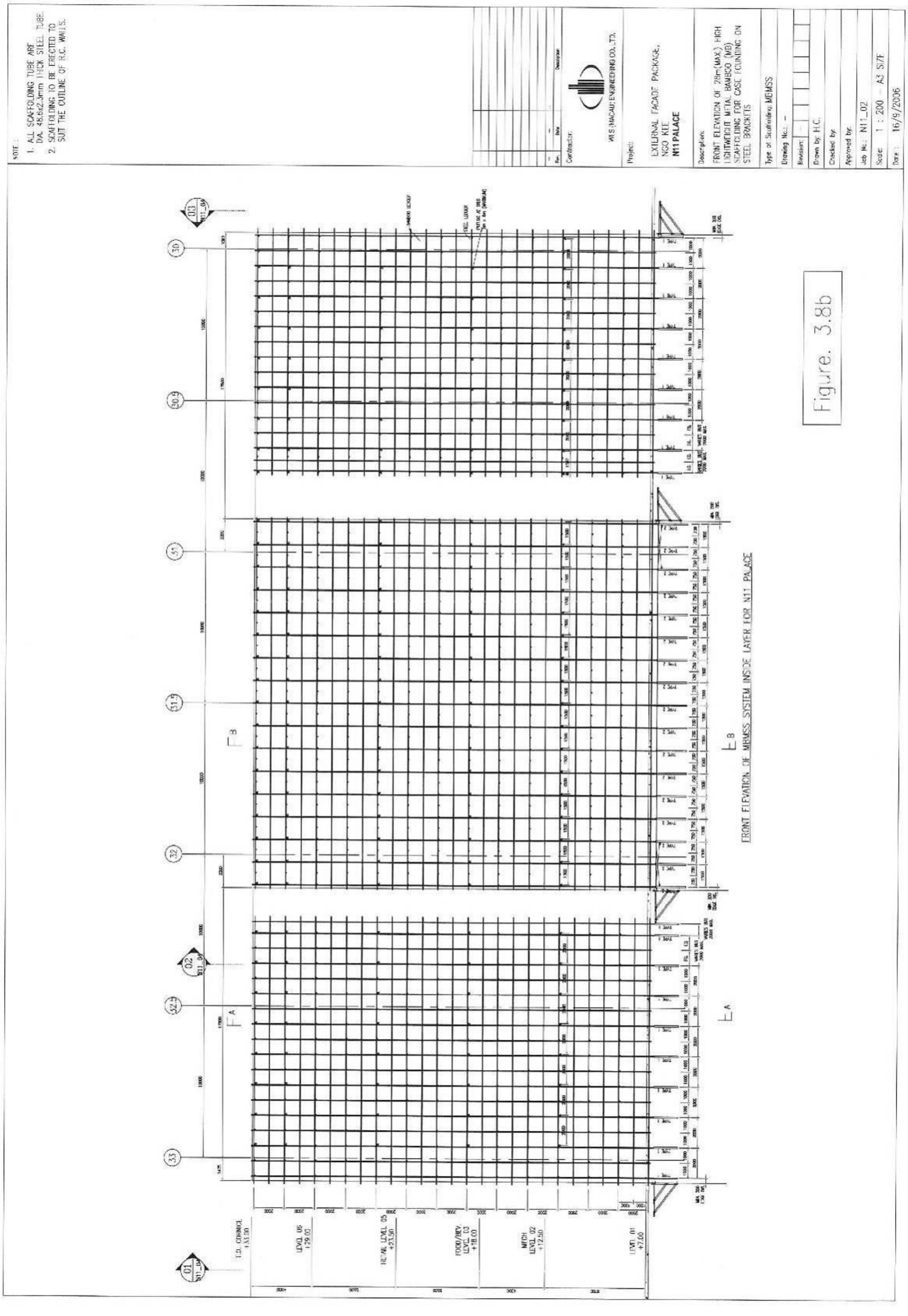


Figure. 3.8b
FRONT ELEVATION OF MBMSS SYSTEM INSIDE LAYER FOR N11 PALACE
EXTERNAL FACADE PACKAGE,
NGO KEE
N11 PALACE
Type of Scaffolding: MBMSS
Drawn by: H.C.
Job No.: N11_02
Scale: 1 : 200 - A3 SIZE
Date: 16/9/2006

Figure 5.12(b)

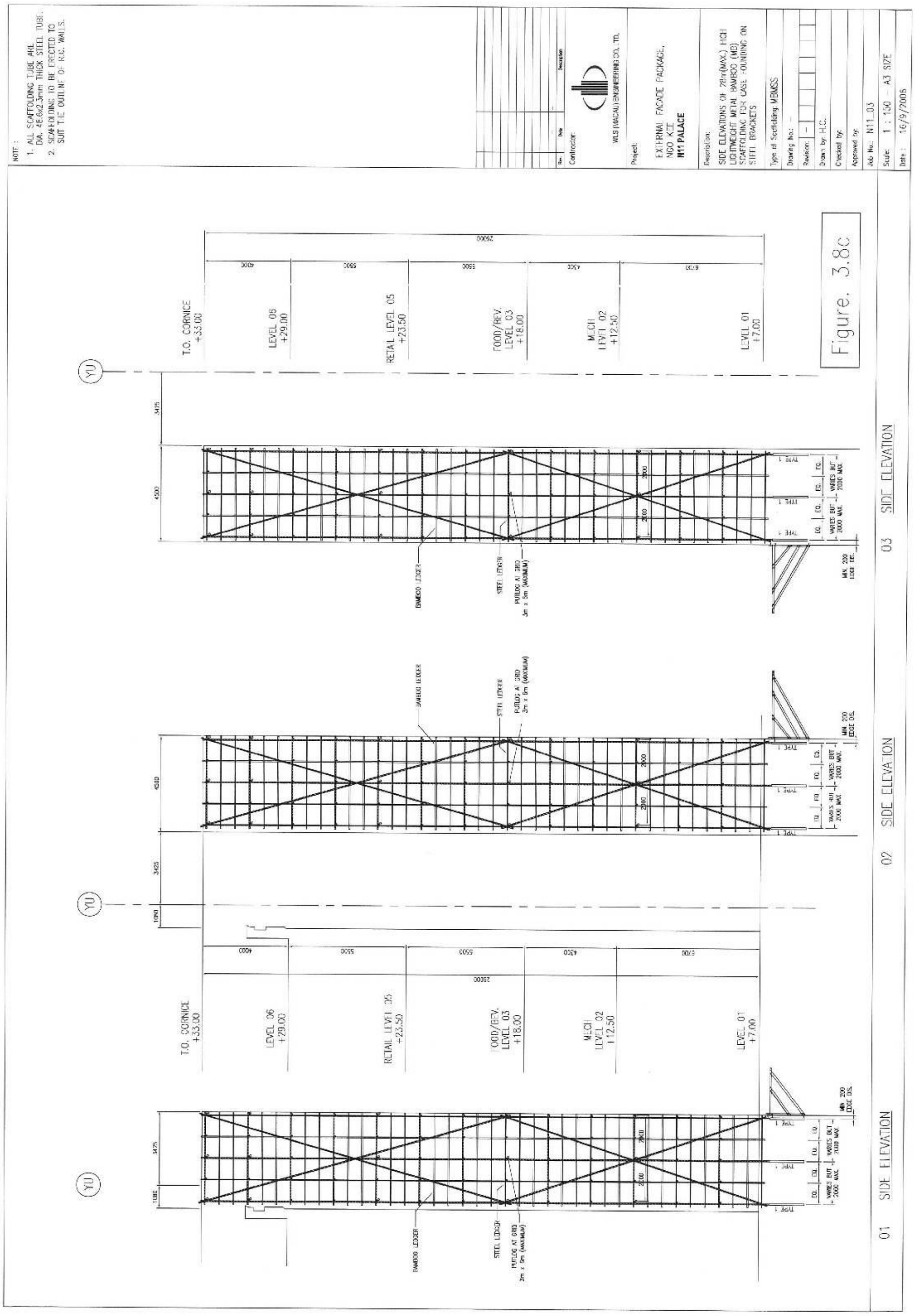

NOTE :
1. ALL SCAFFOLDING TUBE ARE DIA. 48.6x2.3mm THICK STEEL TUBE.
2. SCAFFOLDING TO BE ERECTED TO SUIT THE OUTLINE OF R.C. WALLS.
EXTERNAL FACADE PACKAGE, NGO KEE
N11 PALACE
SIDE ELEVATIONS OF 28m(MAX.) HIGH LIGHTWEIGHT METAL BAMBOO (MB) SCAFFOLDING FOR CASE FOUNDING ON STEEL BRACKETS
Type of Scaffolding MBMSS
Drawn by: H.C.
Job No.: N11_03
Scale: 1 : 150 A3 SIZE
Date: 16/9/2006
Figure. 3.8c
T.O. CORNICE +33.00
LEVEL 06 +29.00
RETAIL LEVEL 05 +23.50
FOOD/BEV. LEVEL 03 +18.00
MECH LEVEL 02 +12.50
LEVEL 01 +7.00
BAMBOO LEDGER
STEEL LEDGER
PUTLOG AT GRID 3m x 5m (MAXIMUM)
YU
01 SIDE ELEVATION
02 SIDE ELEVATION
03 SIDE ELEVATION

Figure 5.12(c)

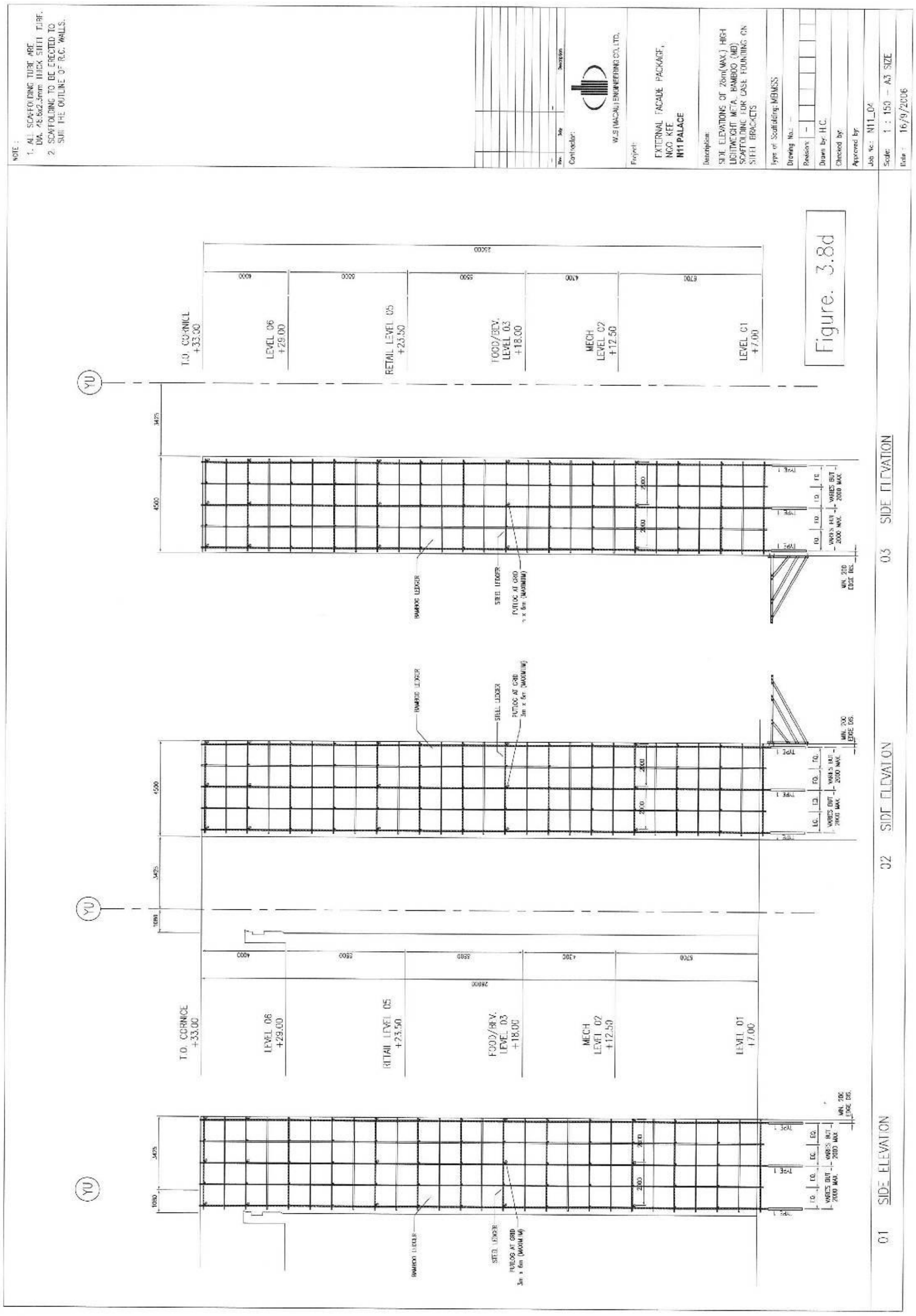


Figure. 3.8d
01 SIDE ELEVATION
02 SIDE ELEVATION
03 SIDE ELEVATION
T.O. CORNICE +33.00
LEVEL 06 +29.00
RETAIL LEVEL 05 +23.50
FOOD/BEV. LEVEL 03 +18.00
MECH LEVEL 02 +12.50
LEVEL 01 +7.00
EXTERNAL FACADE PACKAGE, NGO KEE N11 PALACE

Figure 5.12(d)

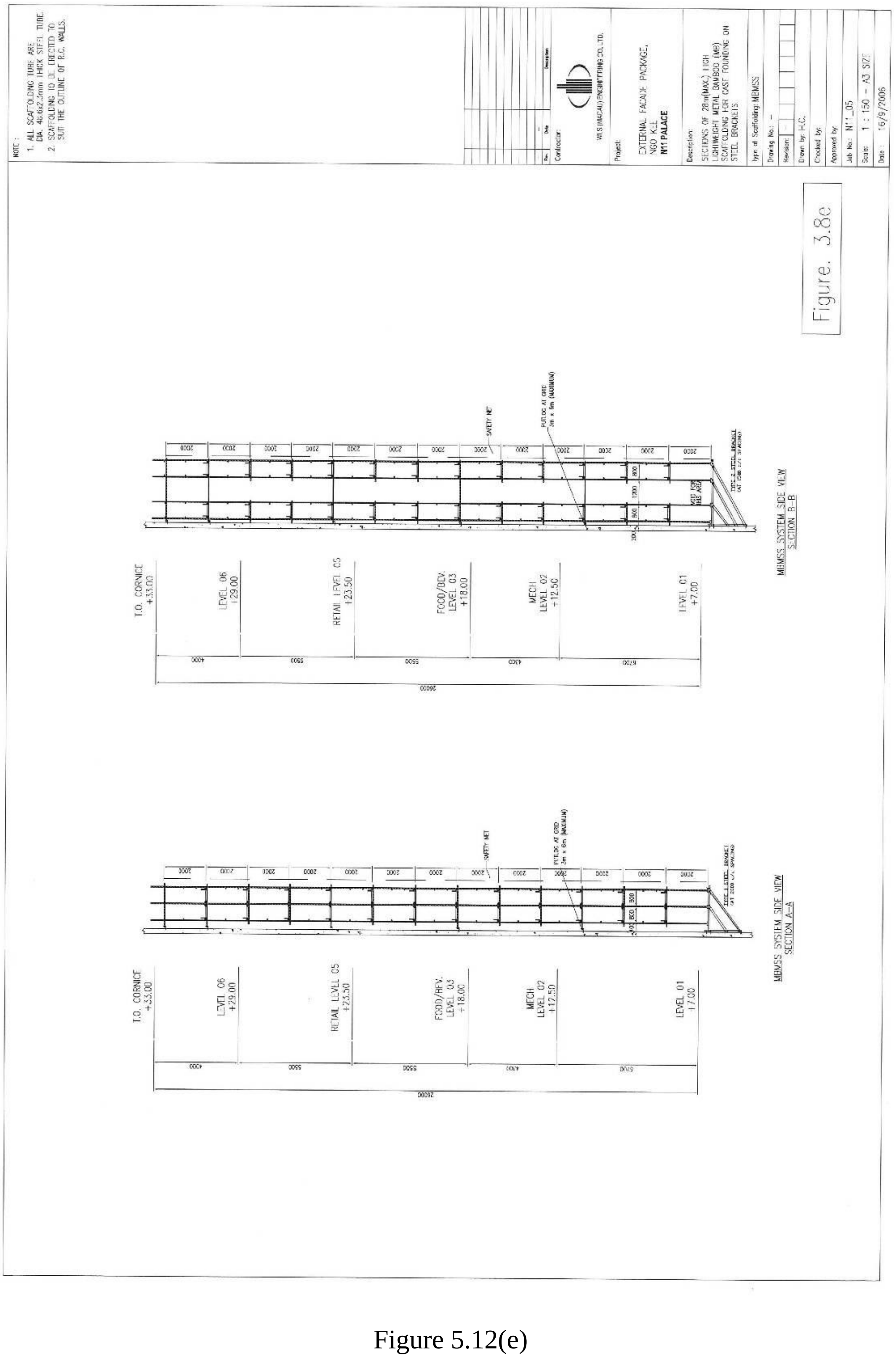


Figure 5.12(e)

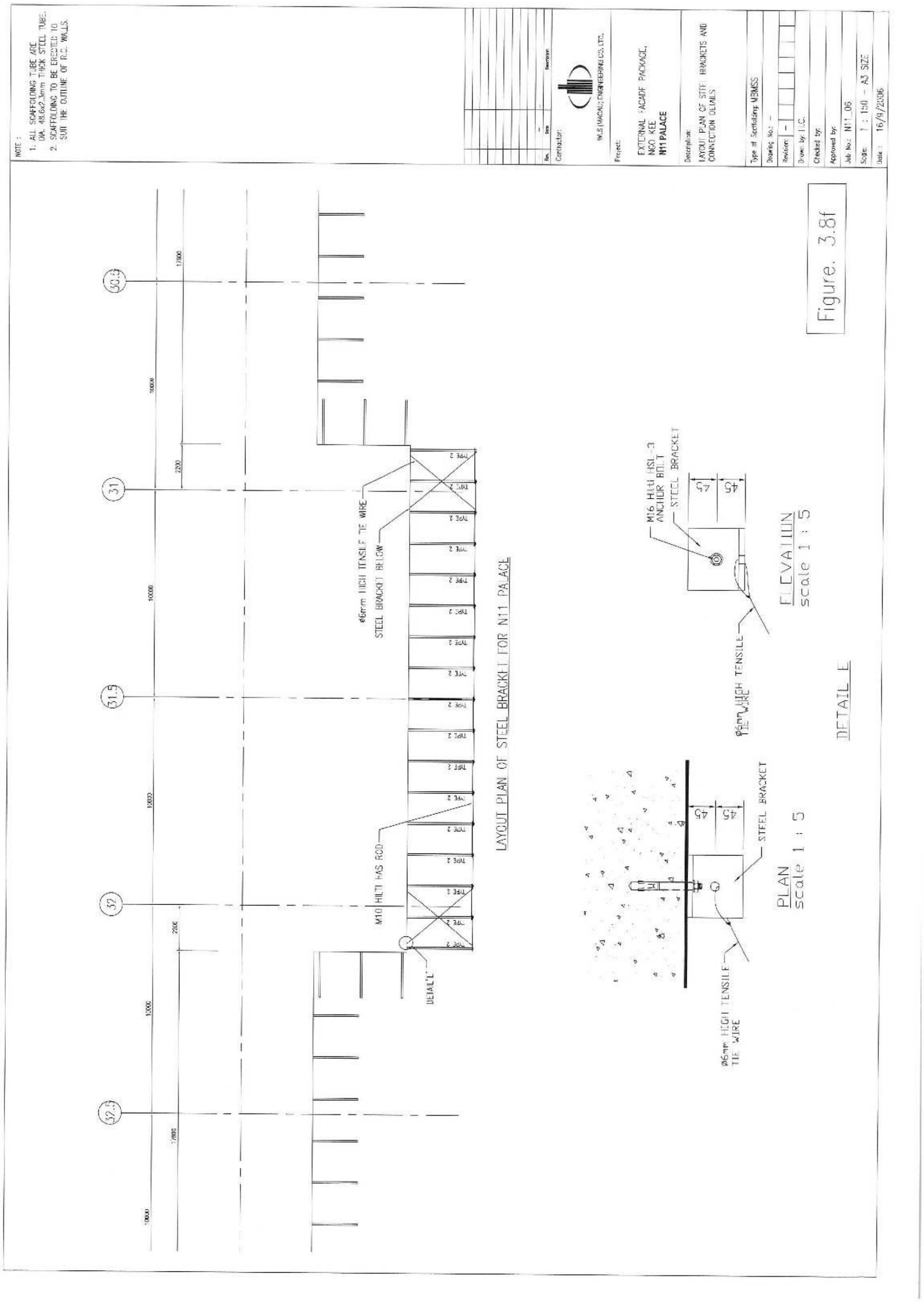
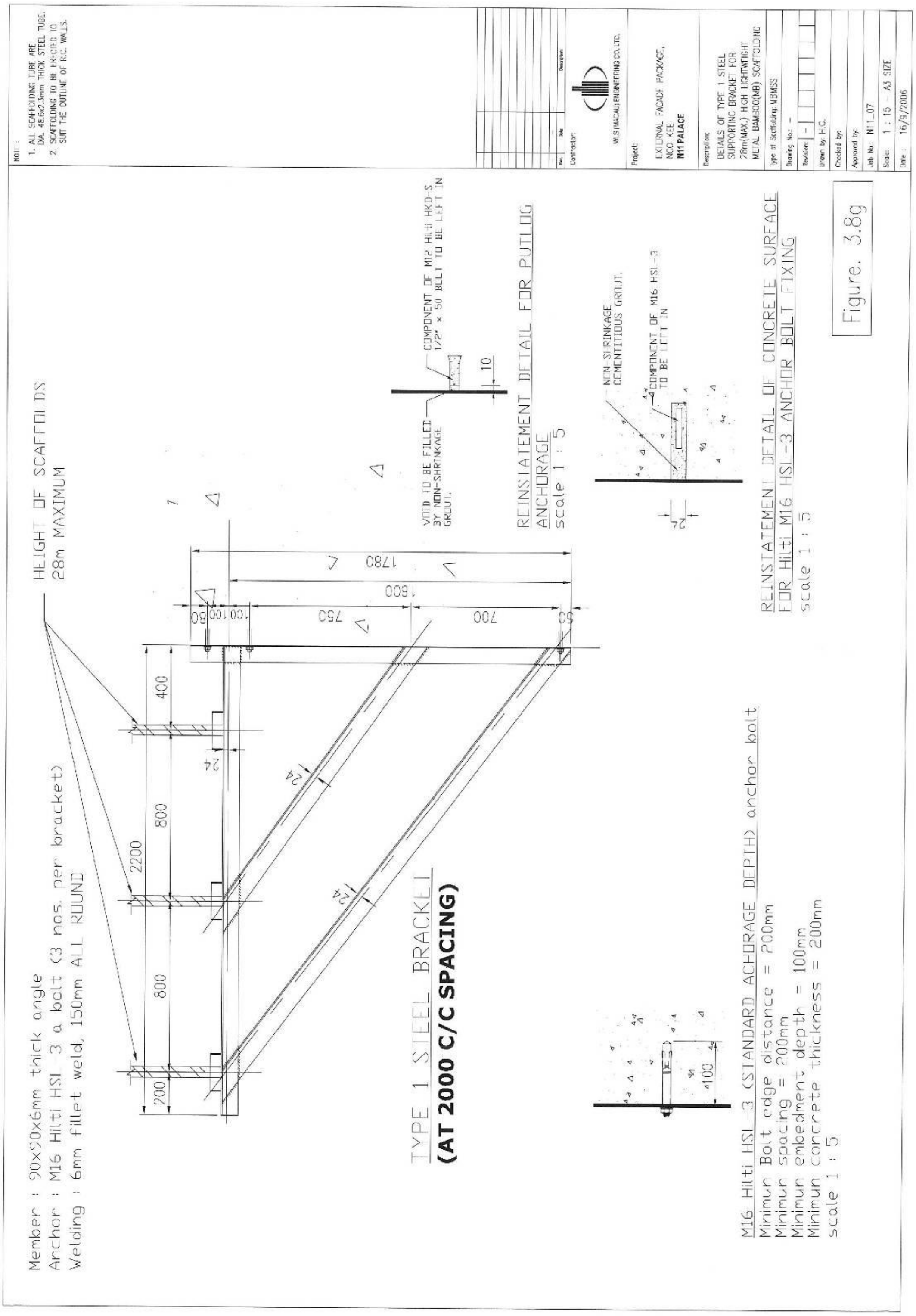


Figure 5.12(f)



Member : 90x90x6mm thick angle
Anchor : M16 Hilti HSL-3 a bolt (3 nos. per bracket)
Welding : 6mm fillet weld, 150mm ALL ROUND
HEIGHT OF SCAFFOLDS
28m MAXIMUM
TYPE 1 STEEL BRACKET
(AT 2000 C/C SPACING)
M16 Hilti HSL-3 (STANDARD ACHORAGE DEPTH) anchor bolt
Minimum Bolt edge distance = 200mm
Minimum spacing = 200mm
Minimum embedment depth = 100mm
Minimum concrete thickness = 200mm
scale 1 : 5
REINSTATEMENT DETAIL FOR PUTLOG ANCHORAGE
scale 1 : 5
REINSTATEMENT DETAIL OF CONCRETE SURFACE FOR Hilti M16 HSL-3 ANCHOR BOLT FIXING
scale 1 : 5
Figure. 3.8g
EXTERNAL FACADE PACKAGE, NGO KEE
N11 PALACE

Figure 5.12(g)

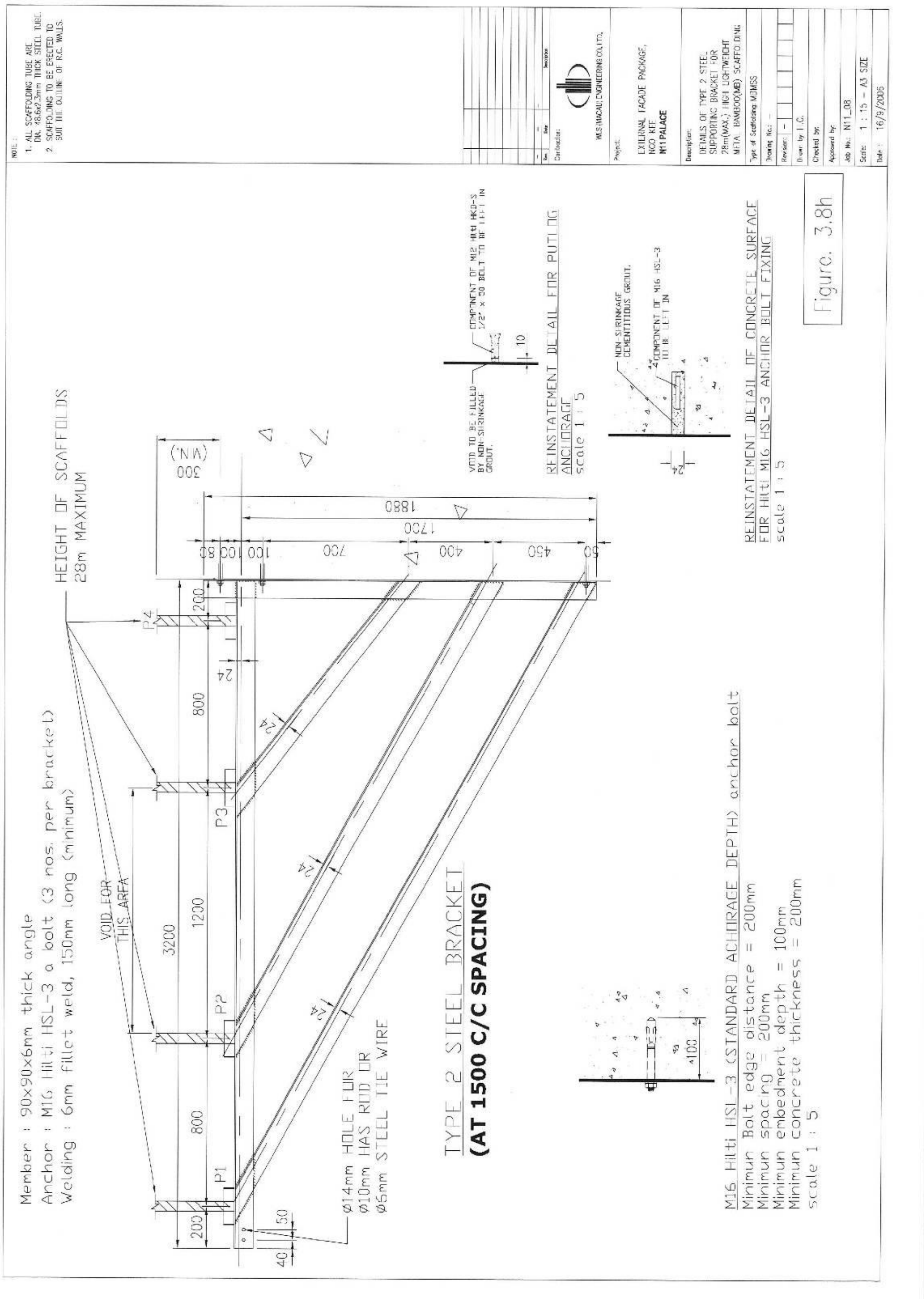


Figure 5.12(h)

Figure 5.12 MBMSS Drawings for Venetian Cotai Macau, External Façade – MFT Package 3224 Supply and Installation of Scaffolding Works.

5.2.2.2 Site management

The site supervisor plays an important role in site management. Before any scaffolding work commences, the site supervisor needs to prepare a detailed method statement. The complexity of this statement depends upon the size and/or complexity of the work, with a simple job requiring only a simple method statement and repetitive tasks covered by standard sheets. A preliminary method statement produced at the planning stage should be developed into a detailed method statement to be incorporated into the detailed scaffolding plan. The whole method statement should be reviewed and updated as necessary, and it should be distributed to all of those concerned with the supervision of the scaffolding work.

Coordination and liaison amongst parties should be maintained throughout the job. Any changes in procedures previously agreed to must be verified as safe by the person responsible for coordination before they are implemented. Matters that pertain to safe scaffolding work, such as the availability of information, plants and manpower and the quality and supply of materials, should also be coordinated. To ensure that the precautions outlined in the method statement are followed, lines of communication should be clearly designated, with the responsibility for implementing the method statement well defined.

Weather conditions such as rain, high winds, lightning or typhoons that could have an adverse effect on scaffolding work, and those causing poor visibility such as fog, mist or glare, should be constantly monitored. If a decision is made to stop work, measures should be taken to maintain the scaffold’s stability and that of all plants, equipment and works erected on it. All personnel should be safely and efficiently evacuated from the scaffold. After the adverse weather, the scaffold should be inspected and certified as being in safe working order by a competent person and all of the plants, equipment and works erected on the scaffold should be checked and confirmed as being in order before work is restarted.

The results of the previously mentioned aerodynamic force experiment indicate that the collapse of a scaffold under strong wind conditions during a typhoon is mainly due to the high drag force from the safety net. Therefore, the nylon safety net at the top level should be lowered and tied up when there is typhoon or strong winds, as shown in Figure 5.13.

Figure 5.13. Safety net is lowered and tied up at the top level of the scaffold.

Under Regulation 38E of the Construction Sites (Safety) Regulations (CSSR), a site supervisor must ensure that no scaffold is erected on the site or substantially added to, altered or dismantled except under the immediate supervision of a competent person and by trained workmen with adequate experience. Training should be a continuing process with on-the-job instruction and formal training sessions provided as appropriate.

5.2.2.3 Inspection and maintenance

Under Regulation 38F of the CSSR, a scaffold must not be used on a construction site unless it has been inspected by a competent person before use for the first time and at regular intervals no more than 14 days immediately before each use. The scaffold also cannot be used on a construction site unless it has been inspected by a competent person after any substantial addition, partial dismantling or other alteration (Regulation 38F of the CSSR).

The scaffold must also be inspected by a competent person because exposure to weather conditions such as heavy rain and storms is likely to have affected its strength or stability or to have displaced its parts (Regulation 38F of the CSSR). The person should check the strength and stability of the scaffold and determine whether it is safe for workers to stay on or needs to be repaired. Inspection may be conducted more frequently depending on the use and condition of the scaffold.

Defects found during the inspection should be rectified immediately. The scaffold must not be used unless a report has been made on a standard form (Form 5 of Regulation 38F of the CSSR), which specifies the location and extent of the scaffold on the site and includes a statement that the scaffold is in safe working order. Copies of the form should be displayed in prominent positions on the scaffold. Unsafe scaffolds should be marked to show that they are unsafe, and they should not be used.

5.2.2.4 Dismantling of scaffolds

The dismantling of scaffolds is considered to be of higher risk than their erection. Dismantling must be conducted by trained workmen under the immediate supervision of a competent person (Regulation 38E of the CSSR), and the site supervisor should make sure the main contractor provides sufficient time for the dismantling to be conducted safely. The scaffold to be dismantled should be checked for strength and stability beforehand. No components should be removed, which could endanger the stability of the remaining structure. Unless necessary precautions have been taken, all of the ties and bracings should remain secured in their position.

If dismantling has reached the stage at which a critical member such as a tie or a brace has to be removed, the stability of the structure should be assured by fixing a similar or otherwise adequate member in place lower down before the member to be taken out is removed. All of the stacked materials and debris placed on the scaffold should be removed.

The dismantling sequence should be planned and the sequence should be logical and determined with due consideration of the safety of scaffolders. Dismantling should be carried out according to the plan. Because changes may have been made in a scaffold structure during its working life, it is not safe to assume that dismantling can be carried out in the reverse order of erection. The procedure should proceed generally from the top in horizontal sections. If the scaffold is defective, then it should be made good before dismantling commences.

Safe access to and egress from the place of work should be provided for scaffolders. The scaffold to be dismantled should be fenced off at the ground level or in public areas to prevent people from entering the work area, and warning notices should be posted up in the vicinity. Steps must be taken to ensure that scaffolding materials are not thrown, tipped or dropped from a height where they are liable to cause injury to any person on or near the construction site. Were practicable, they should be properly lowered by means of a lifting appliance or lifting gear (Regulation 49 of the CSSR).

All materials should be lowered to the ground and not stored on the scaffold. When the pavement cannot to be obstructed and scaffolding materials have to be stored on the lowest lift awaiting collection, that lift should be stiffened and fully braced or propped by rakers, using the materials recovered from the upper lifts. Every scaffolder involved in the dismantling work at height should wear a safety belt attached to suitable and sufficient anchorage with suitable fixing arrangements, such as an independent lifeline that extends from an independent anchorage point to which a lanyard of a safety belt is attached using a fall arresting device. Scaffold members should not be used for anchorage purpose. Whenever practicable, safety nets for fall protection should be used.

All of the trades on the site should coordinate and collaborate closely with the contractor engaging in scaffold dismantling to ensure that safety precautions are taken during the various stages of the work.

5.3 Case Study Demonstrating Applications of the MBMSS in Different Scenarios

As a temporary work platform at height, the MBMSS has the characteristics of a traditional bamboo scaffold and an advanced metal system scaffold, such as flexibility and reliability. In addition, because of its design, the MBMSS can be applied in various areas to suit for different jobs, such as new high-rise building construction, existing building renovation, internal renovation works in shopping malls, and so on. This section demonstrates the strength and advantages of the MBMSS in various applications. A comprehensive comparison with other scaffolding systems is also discussed.

In Hong Kong, the demand for traditional bamboo scaffolding for new building construction is very high because of its flexibility and low cost compared with metal scaffolding. In most cases, the total cost of traditional bamboo scaffolding is only half that of metal scaffolding; moreover, the construction time required for the former is much less than that for the latter. However, traditional bamboo scaffolding is currently considered to constitute a high-risk work environment because of the high accident rate and numerous fatalities associated with it. Therefore, the author developed a new scaffolding system, the MBMSS, which is not only as good as bamboo scaffolding but also as safe as metal scaffolding.

5.3.1 Application of the MBMSS for High-Rise Building Construction

The first case of the application of the novel MBMSS demonstrated in this section is a new construction job site of a high-rise residential development in Tseung Kwan O Area 55, “Ocean Shores” Phase One, in 1999. This was a private development project, and the main contractor was Sun Hung Kai Properties Limited. Originally, traditional bamboo scaffolding was to be used. However, the author introduced the MBMSS to the main contractor's senior management, explained to them the shortcomings of bamboo scaffolding related to this particular project and provided detailed technical information and calculations to their engineers. The senior management then agreed to try the MBMSS. The project comprised five blocks of buildings, each 50 stories high. The main contractor decided to use the MBMSS for the first 20 storeys of blocks 1, 2 and 3, and to retain the traditional bamboo scaffolding for the rest of the storeys and the other two blocks because of budget concerns.

The main contractor agreed to use the MBMSS as part of the overall scaffolding system for three reasons: the site environment, the weather and safety. Obviously, cost was also a key factor but is not discussed in this section. A comparison of the costs of bamboo scaffolding, the MBMSS and metal scaffolding is given in the next chapter.

The MBMSS used at this job site was the first generation and its design is shown in Figure 5.14. The layouts of blocks 1, 2 and 3 are shown in Figures 5.15(a) to (c). In the first stage of this project, the engineers needed to tailor the layout of the scaffold to suit the shape of the buildings. The difficulty that they faced was the bay window areas around the buildings, as the first-generation design of the MBMSS did not take into consideration the application of the work platform for such areas. Therefore, the engineers needed to find a way to develop suitable work platforms for these areas that would provide a safe environment for site workers. After serious consideration of modification of the overall design and several meetings with the main contractor, the engineers finally decided to modify the inner scaffold layout, as shown in Figure 5.16, to provide extra work platforms for the bay window areas. This was the safest and most suitable method at that time. However, the modification was not only time consuming but also costly compared to the original, first-generation MBMSS design.

As mentioned previously, one reason that the main contractor decided to use the MBMSS instead of pure bamboo scaffolding was the site environment. The site was located along the shoreline of Tiu Keng Wan, as shown in Figure 5.17. Continuous high humidity during the 18-month construction period of this project could be expected, which meant the scaffolding bamboo would become mouldy or damaged by bacteria, as shown in Figure 5.18. The main contractor decided to use the MBMSS for the lower portion of the three blocks of buildings because this section of the scaffold would remain standing for the longest period. Bamboo scaffolding was expected to suffer serious damage during the construction period and the consequences were a dangerous working environment and unstable scaffolding structure. In addition, any scaffold repair works such as replacement of the damaged bamboo could take a long time and delay the overall construction period. It is believed that the senior management of the main contractor took the author's advice because the cost that would be incurred by the delay of progress was unpredictable and would likely be more than the cost of adopting the MBMSS. They also wanted to minimise the risk of delaying the project's completion and to prevent or lower the probability of overall scaffold collapse due to bamboo scaffold failure.

During the construction period, a few typhoons passed through Hong Kong. Typhoon York was the strongest in 1999, and the strongest in 10 years. Typhoon Signal No. 10 was hoisted on 16 September for 11 hours during the typhoon's passage directly through Hong Kong. Detailed information, including maximum gust peak speeds and maximum hourly mean winds, is shown in Table 5.2. The damage done by Typhoon

York was enormous. More than 500 people were injured, 11 of them seriously. A total of 800 signboards collapsed, over 4 000 trees were uprooted and about 90 roads were rendered impassable. York shattered the curtain walls of several buildings. A crane was blown down and struck a nearby flat before crashing onto Jaffe Road in Wan Chai. A mobile office in a transport container was blown into the harbour by high winds, and found floating near Queen's Pier. Photos of the damage are shown in Figures 5.19(a) to (c). One might think that, given these extremely high winds, all of the scaffolds would have collapsed. However, this was true only of the bamboo scaffolds. At the TKO 55 Phase One project, two blocks of bamboo scaffolding around 15 storeys high were in place, and three blocks of MBMSS scaffolding around 10 storeys high. The two blocks of bamboo scaffolding were seriously damaged, as shown in Figures 5.19(a) and (b), whereas the three blocks of MBMSS scaffolding were only slightly damaged, as shown in Figure 5.19(c). As mentioned previously, repair of the latter took much less time than did that of the former, causing only a short delay in work. The MBMSS not only minimised the time wasted but also material and labour costs. This, its overall efficiency was much higher than that of the bamboo scaffolding. This real case study proved that the MBMSS is a much safer and more reliable scaffolding system than is traditional bamboo scaffolding.

Another key factor that the author believes impelled the main contractor of the TKO project to adopt the MBMSS is the safety of the system. This contractor is the top-ranked construction company in Hong Kong, and safety is the management's primary concern. Before the author introduced the MBMSS to them, they did not have a choice for a better scaffolding system. Their only option at that time was high-cost metal scaffolding, which was not a viable option as the cost exceeded their planned budget and the installation time was much longer than the planned master programme. The MBMSS fully complies with the requirement of the Hong Kong Factories and Industrial Undertakings Ordinance (FIUO) and the Construction Sites (Safety) Regulations (CSSR). Furthermore, it has been designed and checked by experts at Hong Kong Polytechnic University using a second-order analysis method. Therefore, in terms of safety, the MBMSS is as good as metal scaffolding but is less costly and requires less erection and dismantling time.

The stability and reliability of the MBMSS were well proven in this TKO project when it suffered only minimal damage under severe weather conditions. However, another advantage of the MBMSS was also demonstrated in this project. The substitution of steel tubes for Mao Jue pieces as the load-bearing members in the scaffold system ensured that the stability of the scaffold would not be affected by the surrounding environment, such as the high level of humidity and rain. After being in place for 18 months, the MBMSS portion of the scaffolding for the TKO project was still in good working condition. Today, the advantages of using the MBMSS for high-rise building construction are well known in the construction industry in this region, and it is widely accepted as the best scaffolding system by most major construction companies in Hong Kong.

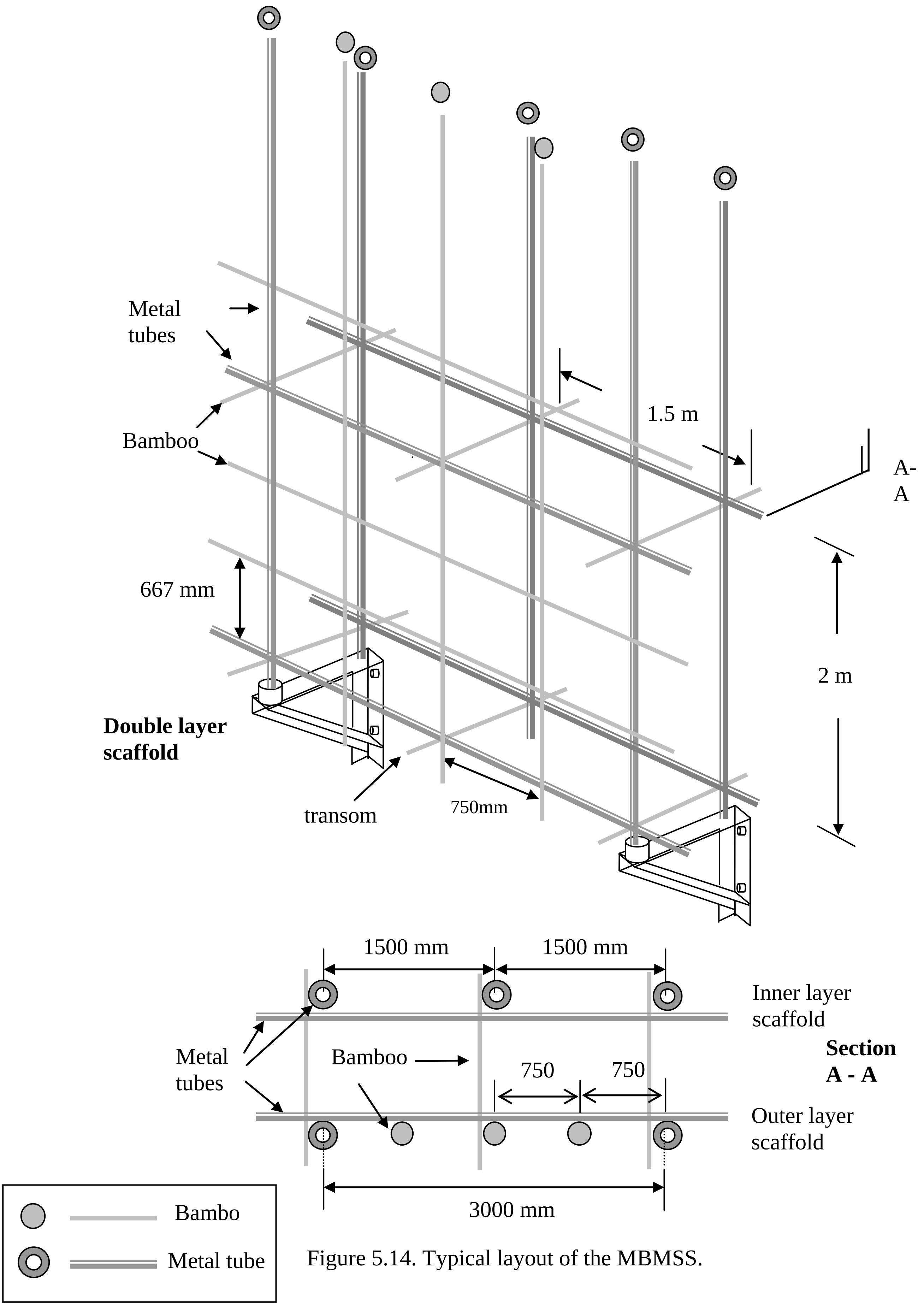


Figure 5.14. Typical layout of the MBMSS.

Figure 5.15(a). Block 1.

Figure 5.15(b). Block 2.

Figure 5.15(c). Block 3.

Figure 5.16. Modified inner scaffold.

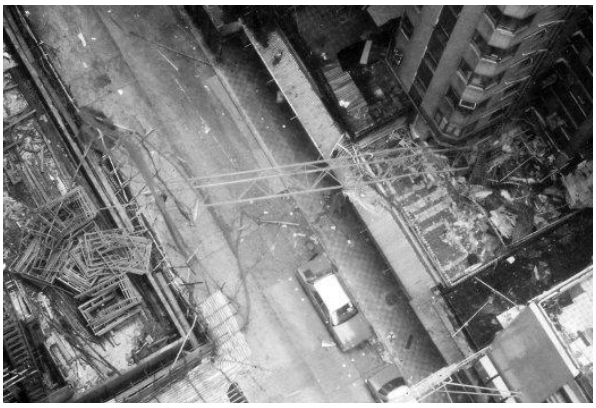
Figure 5.17. Site located near the seashore.

Figure 5.18. Mouldy bamboo in humid conditions.

Table 5.2. Wind speed during Typhoon York.

在約克影響下，本港各站在熱帶氣旋警告信號懸掛時所錄得的最高陣風、最高每小時平均風速及風向
Maximum gust peak speeds and maximum hourly mean winds with associated wind directions recorded at various stations during the hoisting of the tropical cyclone warning signals for York

站	Station	最高陣風 Maximum Gust 風向 Direction	風速(公里/小時) Speed (km/h)	日期/月份 Date/Month	時間 Time	最高每小時平均風速 Maximum Hourly Wind 風向 Direction	風速(公里/小時) Speed (km/h)	日期/月份 Date/Month	時間 Time
中環	Central	東南偏東 ESE	161	16/9	1416	東 E	77	16/9	1500
中環廣場	Central Plaza	- -	198	16/9	0614	- -	133	16/9	0800
赤鱲角 (機場)	Chek Lap Kok (Airport)	北 N	113	16/9	0720	北 N	76	16/9	0800
長洲	Cheung Chau	東北 NE	182	16/9	0838	西南偏南 SSW	112	16/9	1600
長沙灣	Cheung Sha Wan	東北偏北 NNE 東北 NE	113 113	16/9 16/9	0739 0925	東北 NE	40	16/9	0900
京士柏	King's Park	東北偏北 NNE	149	16/9	0738	東北偏北 NNE	65	16/9	0800
流浮山	Lau Fau Shan	北 N	158	16/9	0910	北 N	104	16/9	0800
西貢	Sai Kung	東北偏北 NNE	211	16/9	0645	東北偏北 NNE	108	16/9	0700
沙螺灣	Sha Lo Wan	東北偏北 NNE	151	16/9	0915	東北偏東 ENE	85	16/9	1100
沙田	Sha Tin	北 N	153	16/9	0912	北 N	51	16/9	0800
石崗	Shek Kong	東北偏北 NNE 東北偏東 ENE	137 137	16/9 16/9	0944 1155	東北偏北 NNE	68	16/9	1000
天星碼頭	Star Ferry	東南偏東 ESE	149	16/9	1324	東南偏東 ESE	70	16/9	1300
打鼓嶺	Ta Kwu Ling	東北 NE	121	16/9	1043	東北 NE	58	16/9	1100
大尾篤	Tai Mei Tuk	北 N	180	16/9	0805	北 N	112	16/9	1000
鰂魚湖	Tsak Yue Wu	東北偏北 NNE	122	16/9	0505	東北偏北 NNE	43	16/9	0600
青衣	Tsing Yi	東南 SE	182	16/9	1409	東南偏南 SSE	101	16/9	1700
屯門	Tuen Mun	東北 NE	133	16/9	0927	東南偏南 SSE	49	16/9	1700
橫瀾島	Waglan Island	東北偏北 NNE	234	16/9	0514	東北偏北 NNE	151	16/9	0600
黃竹坑	Wong Chuk Hang	東北偏東 ENE	146	16/9	0801	東北偏東 ENE	54	16/9	0800


(i)


(ii)

Figure 5.19(a). Damage done during Typhoon York.

Figure 5.19(b). Damage done during Typhoon York.

Figure 5.19(c). MBMSS only slightly damaged.

5.3.2 Application of the MBMSS for Infrastructure Works

The first application of the MBMSS for an infrastructure project was in 2001, for the West Rail Line project in Hong Kong. Nine stations were being built, and the MBMSS was used as the external work platform for two of them: Tuen Mun Station (Kowloon-Canton Railway Corporation Contract No. CC213) and Siu Hong Station (Kowloon-Canton Railway Corporation Contract No. CC212). The main contractor for both these projects was HK ACE JV (Hong Kong Construction-AMEC China Railway Construction Corp-China Everbright Joint Venture).

At the tendering stage, the MBMSS was not considered an option as HK ACE JV preferred to use a metal work platform system. It was not hard to understand the reason for this preference: some of the engineers and senior-level members of the management came from Western countries and did not want to use something they had never used before, especially bamboo poles, in work platforms. The common perception was that bamboo was not a reliable material, and there was no scientific support document for the engineers to check regarding the stability of bamboo structures. However, the detailed MBMSS presentation given by the author to the senior management of the contractor together with a registered professional engineer’s technical report by Professor SL Chan (1998) from the Hong Kong Polytechnic University changed their minds, and the MBMSS subcontractor was allowed to bid on the two projects. With a cost advantage because of the use of bamboo and the stability and reliability of metal scaffolding, the MBMSS was chosen for the two projects.

The design of the MBMSS for these projects was different from the standard design. The main contractor required a work platform of at least 700 mm wide. The standard requirement for the minimum width of a work platform according to the Code of Practice for Metal Scaffolding Safety is only 400 mm, and the width of the standard MBMSS work platform is 500 mm.

To increase the width between the inner and outer scaffolds, the whole design of the MBMSS had to be modified. As the scaffolding requirements for these two contracts were basically the same, only the scaffolding for Tuen Mun Station will be discussed here.

Tuen Mun Station is located in Tuen Mun in Hong Kong's New Territories, and is the West Rail Line northern terminus. The station is elevated over the Tuen Mun River, near the centre of Tuen Mun New Town, as shown in Figure 5.20. Therefore, high humidity was expected during the construction period. The shape of the station is rectangular, so the design of the scaffolding should not have been difficult. However, as mentioned in the previous paragraph, the employer requirement for the scaffolding work platform was non-standard, so the MBMSS engineers had to re-design the MBMSS.

The typical scaffolding layout design of this MBMSS project is shown in Figure 5.21. The MBMSS engineers increased the distance between the inner and outer scaffolds by using longer transoms and larger steel support brackets and placed two work platforms alongside each other inside the scaffolding, one 500 mm in width and the other 250 mm in width. The total width of the combined work platform after installing both of the work platforms was 880 mm, measuring from edge to edge on both sides and including the gap between the two work platforms. The outlook of the combined work platform is shown in Figure 5.22. The work area for site workers increased nearly 80% compared to a standard single work platform. The advantages of the wider work platform were a wider work area and safer work environment for scaffolding end-users, especially those from Western countries as they were not only taller but also bigger than the local Hong Kong workers. As the distance between the inner and outer scaffolds was greater, the steel support brackets at the bottom also needed to be larger to support the inner and outer scaffolds. These brackets, shown in Figure 5.23, were designed by a registered professional engineer to ensure the safety and efficiency of the scaffolding system.

In addition to the non-standard work platform, there were some atypical scaffolding areas in this project, such as the cantilever work platform, shown in Figures 5.24(a) to (c), and internal ceiling work platform, shown in Figures 5.25(a) to (d). It is not unusual to see bamboo or metal cantilever scaffolding. However, it was proved in this project that MBMSS cantilever scaffolding could go up over 10 meters, with a full set of work platforms installed. The erection method was similar to that of traditional bamboo cantilever scaffolding. Therefore, the scaffolding workers could easily build the MBMSS cantilever platform at the same speed as they would a bamboo scaffold. Steel tubes were used as load-bearing members on the bottom and their function was the same as that of steel support brackets, to transfer the load to the scaffolding below. Putlogs were also installed on the cantilever structure to stabilise the scaffolding.

This cantilever scaffolding was constructed on the outside of the station. A special application of the MBMSS, a ceiling work platform, was used inside the station. Such platforms are very useful for internal ceiling work, especially for ceilings over 20 m high as traditional mobile tower scaffolds are inadequate for the job. The erection method was similar to that of bamboo ceiling work platforms except that steel tubes were used instead of Mao Jue as the load-bearing members. For this project, the main contractor used internal ceiling work platforms in various locations such as the elevator ceiling area, as shown in Figure 5.25(b), and for uneven ceiling cladding, as shown in Figures 5.25(c) and (d).

The overall comments on the MBMSS from the main contractor were quite positive, especially from the Western employees. They did not trust bamboo scaffolding but the MBMSS was accepted as a lower cost, more flexible alternative to metal scaffolding.

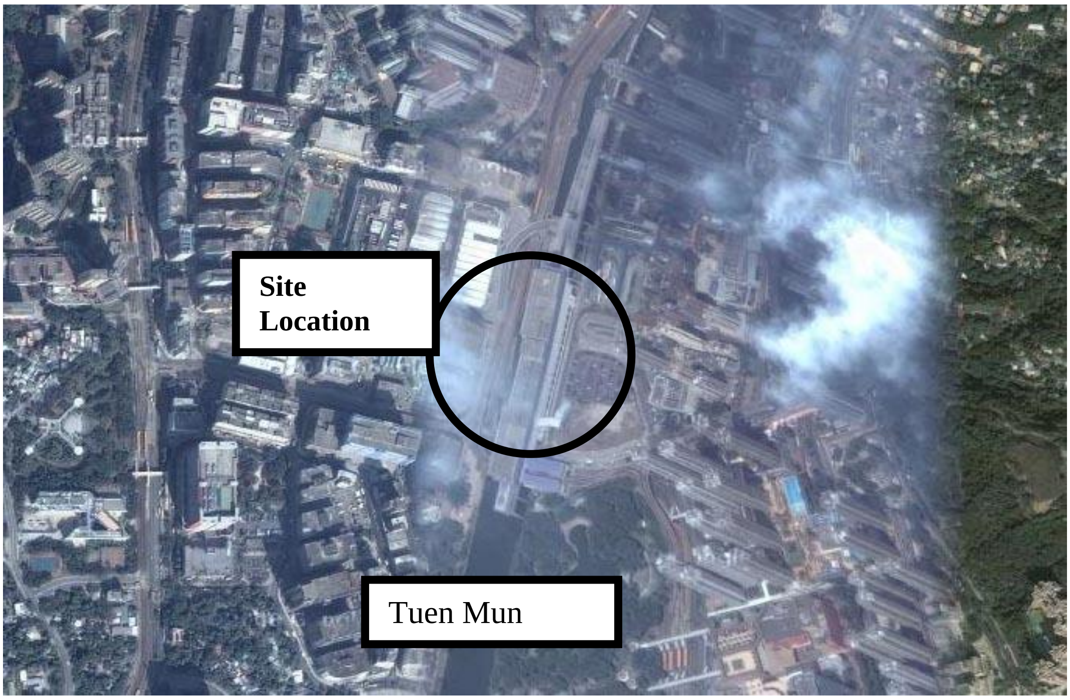


Figure 5.20. Location of Tuen Mun Station.

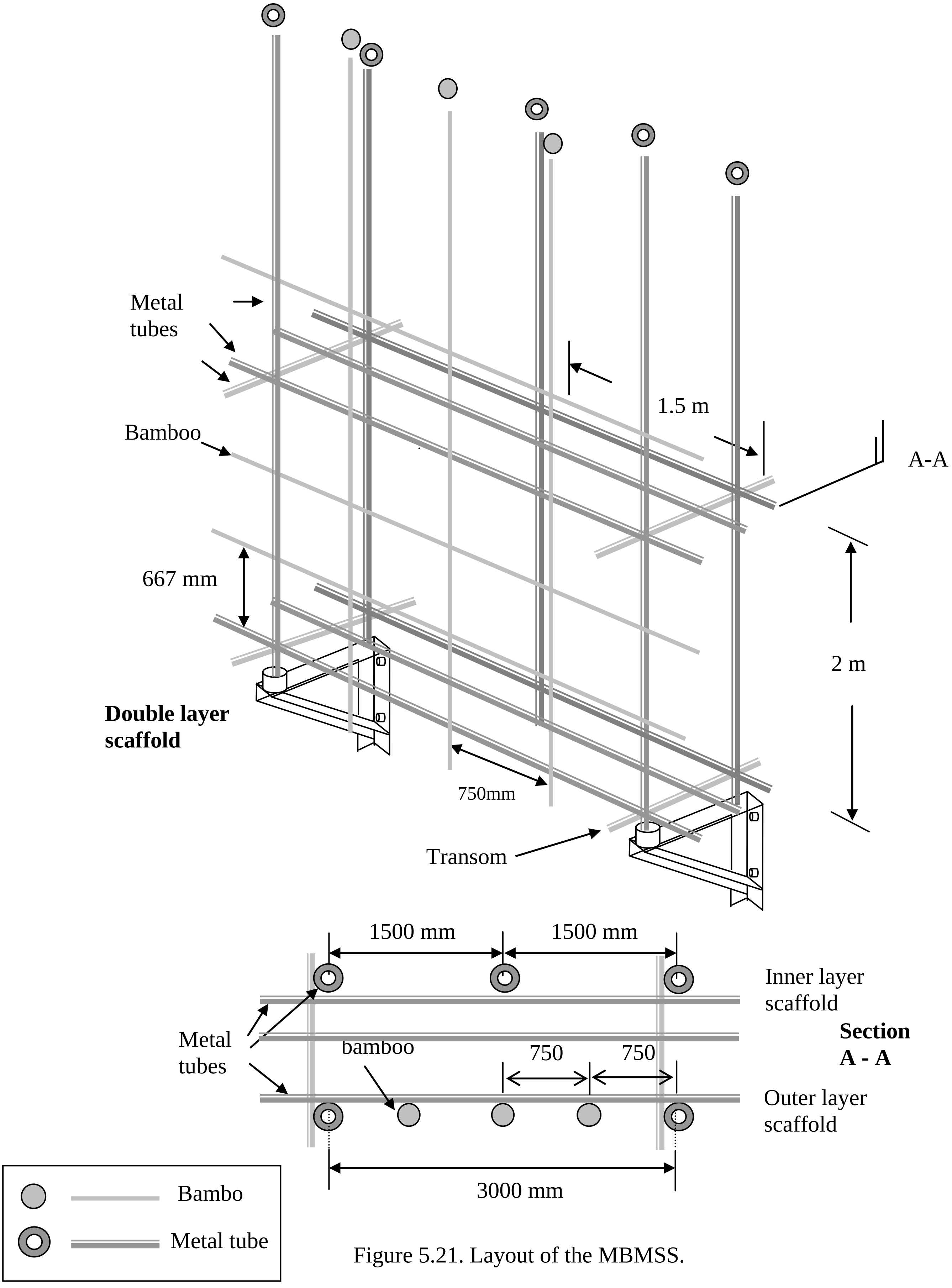


Figure 5.21. Layout of the MBMSS.


Figure 5.22. Double work platform.


Figure 5.23. Steel support brackets.

Figure 5.24(a). Cantilever scaffolding.

Figure 5.24(b). Cantilever scaffolding.

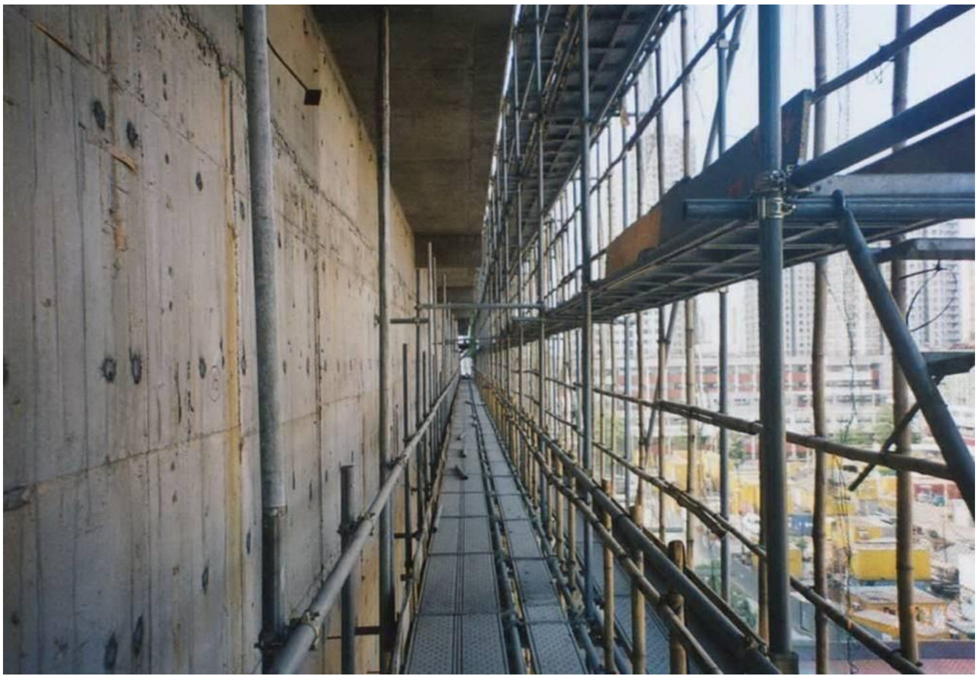


Figure 5.24(c). Cantilever scaffolding.

Figure 5.25(a). Ceiling work platforms.

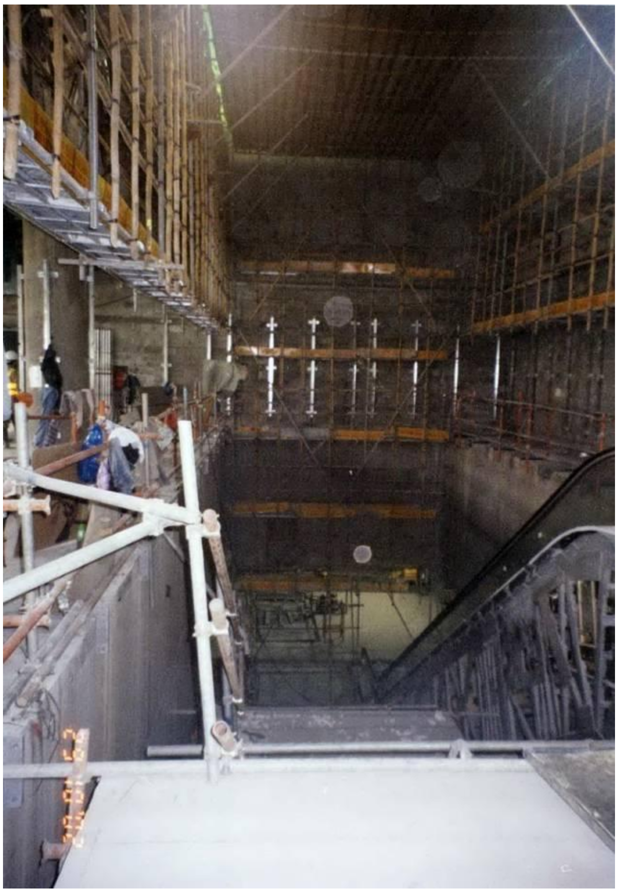


Figure 5.25(b). Ceiling work platforms.

Figure 5.25(c). Ceiling work platforms.

Figure 5.25(d). Ceiling work platforms.

5.3.3 Application of the MBMSS for Large-Scale Internal Renovations

In Hong Kong, the most commonly used scaffolding for large-scale internal renovations is bamboo scaffolding because of its flexibility and cost advantage. However, the high number of bamboo scaffolding-related accidents has led to safety and quality concerns. Therefore, metal scaffolding platforms had become the only alternative for contractors before the MBMSS appeared on the market.

In 2005, the Shatin New Town Plaza, one of Hong Kong's major shopping malls, underwent major internal renovations. The most significant project of this large-scale renovation was the replacement of the existing cladding panels on the more than 25-metre-high ceiling. Right below the ceiling were elevators, shops and crowded areas. Therefore, safety was the first priority. Because the renovations were being done inside an existing shopping mall, they could only be carried out overnight. As a result, the time for this project was very limited and every procedure had to be well planned.

The highlight of this project was the large-scale suspended ceiling work platform. Its dimensions were approximately 14 m (long) x 30 m (wide) x 28 m (high). The completed structure is shown in Figure 5.26(a). The maximum load for the suspended work platform was 1.5 kPa. Steel tubes were used as the load-bearing members, and bamboo poles were used as the fencing and supplementary members. The surface of the work platform was covered with steel catwalks, and the base was covered with canvas, as shown in Figures 5.26(b), (c) and (d). The whole work platform was suspended by metal wires that were fixed to the ceiling, as shown in Figure 5.27(a). The wires were evenly distributed 1 m apart throughout the work platform, as shown in Figure 5.27(b).

The erection method for this suspended ceiling work platform was different from that of a standard suspended work platform. As mentioned, the renovations could be carried out only at night so that the normal shopping mall activities were not affected. The traditional erection method uses vertical single-layer scaffolds to support the platform during its erection. However, such scaffolds require much ground space and would have not only affected the people accessing the areas but also posed an accident risk. Second, it was impossible to erect single-layer scaffolds within the limited time period and working hours given by the main contractor. Therefore, the MBMSS engineers designed the work platform so that it required support only from hanging wires fixed to the ceiling. The existing gondola was used to fix all of the support hooks into place, and then the work platform was installed, starting from the edge and moving gradually outward to ensure that every installed work platform was supported by the hooks. The whole work platform was built within 14 days without affecting the normal shopping mall activities.

For this project, the MBMSS was also used as a ceiling platform for replacing the skylight, a ceiling platform for replacing the bottom panels of elevators, a work platform for replacing fencing and lighting, and so forth. Photos of some of these scaffolding installations are shown in Figures 5.28, 5.29 and 5.30. Once again, the MBMSS demonstrated its advantages over traditional bamboo or metal scaffolds, such as flexibility, reliability, efficiency and applicability. The whole scaffolding project was successfully finished on time without any delay of work or complaints or reports of damage from the main contractor or shopping mall owner.

Figure 5.26(a). The suspended ceiling work platform.

Figure 5.26(b). Surface of the ceiling work platform.

Figure 5.26(c). Surface of the ceiling work platform.

Figure 5.26(d). Surface of the ceiling work platform.

Figure 5.27(a). Metal wires.

Figure 5.27(b). Distribution of the metal wires.

Figure 5.28. Work platforms for the base of an elevator.

Figure 5.29. MBMSS for a shopping mall.

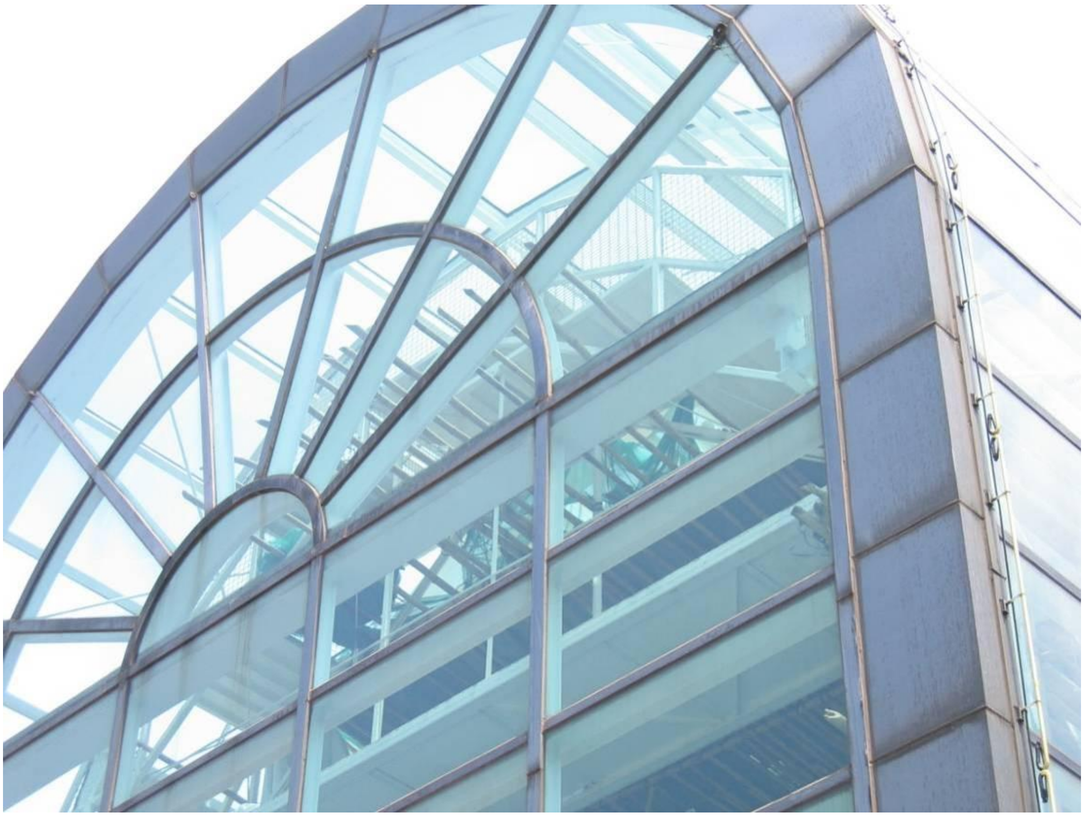


Figure 5.30. Work platform for a skylight.

In this Chapter, the implementation of MBMSS was demonstrated. The system started from initial idea, then launched in commercial market and patent was registered. The system has undergone continuous improvement though the experience learnt from actual site works and external advisers, and it was also validated by computer simulation. The popularity of MBMSS in the construction industry also came from the establishment of operation and management manual, which is important for the MBMSS to ensure the safety and quality of the system. Other than the software support, MBMSS is also flexible and capable to suit different scenario which made the system welcome by the construction industry.

Chapter 6 Discussion

In this chapter, the performance of MBMSS is compared with traditional bamboo scaffolding and metal scaffolding in term of safety, cost and operation. Some applications will be demonstrated to show the powerful capability of MBMSS in different scenarios. Finally, other scaffold systems used in China will be presented to show the trends in the scaffolding industry.

6.1 Comparison of the Safety, Cost, Operation and Application of the MBMSS with those of Traditional Scaffolding

6.1.1. Safety

The metal bamboo matrix scaffolding system (MBMSS) has been used by Hong Kong's building industry since its launch in 2001. Hundreds of blocks of buildings have been completed using the MBMSS. Most of the major construction companies know the system and employ the MBMSS in their projects. Some well-known developers have even requested its use for all of their high-rise building projects. Since the introduction of the MBMSS, not one industrial accident related to the system has occurred. Of course, there may be some isolated cases involving minor injuries sustained by scaffolders who have cut fingers or hurt shoulders when transporting the material. However, such injuries have nothing to do with the design of the system.

When comparing the accident rate of the MBMSS with that of traditional scaffolding such as bamboo or metal scaffolding over the 2003-2007 period, statistics supplied by the Labour Department of the HKSAR government show that there were a total of 27 fatal cases related to bamboo or metal scaffolding. Among these cases, 10 were related to bamboo scaffolding, 13 to trussed-out scaffolding and 4 to metal scaffolding. So far, the MBMSS has a zero accident rate. The details of the fatal cases are shown in Table 6.1.

Table 6.1. Breakdown of fatal accidents for bamboo and metal scaffolding for the 2003-2007 period (Statistic Division, Labour Department, HKSAR)

	Number of cases
Bamboo scaffolding	10
Trussed-out scaffolding	13
Tubular (metal) scaffolding	4
Total	27

As no fatal cases have been related to the MBMSS, we can assume that the system is comparatively safer and more reliable in terms of fatality rate than traditional systems. Its safety performance is the outcome of scientific research, careful design and the calculations of a professional engineer who understands the site situation and has evaluated every possible aspect that may affect the safety of the MBMSS. Before the implementation of the work sequence at the operational level, the professional engineer briefs the working team on the design philosophy, site conditions and areas that require special attention, selection of materials, usage of specially designed material, support of the MBMSS and anchorage.

One could argue that the system's zero accident rate does not necessarily mean that it is safe and reliable. Other factors may affect other scaffolding systems and the MBMSS may not yet have been affected by such factors. Alternatively, the application of the MBMSS over only a few years may have been limited compared with that of other systems, which might have a larger market share and subsequently a higher accident rate.

Many factors contribute to the success of a system. Design and careful evaluation are two of the most important factors, but the importance of management and control must also be considered. No matter how good a system is, without a good management and control plan, the system is likely to fail. In addition to having reliable design, the MBMSS has a good control system. Take, for example, the recent tropical storm Kammuri in August 2008, which had an average wind speed of 180 km/hour and affected Hong Kong indirectly. Many bamboo scaffolds collapsed during the storm. Later in August 2008, a second severe tropical storm, Nuri, directly hit Hong Kong, with an average wind speed of over 180 km/hour. (The summary of the maximum gust peak speeds and maximum hourly mean winds for these two tropical cyclones are attached in appendices A6.1 and A6.2.) Once again, many bamboo scaffolds collapsed, blocking traffic on roads in urban areas. In Kowloon, one metal scaffold with an area 15 m x 30 m and 20 storeys high fell onto the street and damaged three vehicles. According to the Hong Kong Observatory, there were eight reports of collapsed scaffolding during this period, but none of the three MBMSS scaffolds suffered serious damage. Minor damage occurred in the form of loosened nylon safety nets or catch fans being torn away. Some MBMSS sites with other scaffolding accessories remained stable, with no loosened parts. These examples illustrated the strength of the MBMSS under extreme condition when comparing to traditional bamboo scaffolding.

The calculation and design of the system using computer simulation was originally put on trial in September 1999 by Typhoon York. At that time, the success of the MBMSS was under question, and attributed in part to coincidental factors. However, the system has maintained an excellent track record over the past nine years, and withstood other typhoons.

The removal of the nylon safety net above the ground level by management before the arrival of a typhoon is critical. This reduces the effect of wind on the MBMSS. The impact of wind on the remaining scaffold structure becomes insignificant, as it shifts away on both sides. The force from local aerodynamic flow is transferred to the specially designed anchorage system affixed to the concrete wall. The anchorage system can withstand a pull-out force of 7kN when the wind pressure is reflected back from the wall. The anchor bolts are evenly distributed at 3 m x 6 m instead of 4 m x 7 m as indicated by the codes of practice for both bamboo scaffolding and metal scaffolding safety. These features explain why the MBMSS is so strong that it can withstand severe storms. It is not coincidence but rather careful planning and design as well as effective management that make the MBMSS a success.

Regarding scaffolding system accessories, the MBMSS provides metal catwalks, cat ladders or staircases and toe-boards in accordance with the stipulations of the Labour Law. Metal scaffolding systems have similar features, whereas bamboo scaffolding systems provide no such accessories. The Labour Law requires that bamboo scaffolding systems and the MBMSS provide a nylon safety net, catch fan at intervals and protective horizontal layers. A comparison of the systems is given in Table 6.2. Based on the above data, the MBMSS is the safest and most reliable scaffolding system.

Table 6.2. Comparison of Advantages and Disadvantages of Different Scaffolding Systems.

Items provided	MBMSS		Bamboo Scaffold		Metal Scaffold	
Professional calculation/design	Yes	✓	No	X	Yes	✓
Catwalk or work platform	Yes	✓	No Wooden plank (portable)	X	Yes	✓
Toe-board	Yes	✓	Halfway		Yes	✓
Nylon safety netting	Yes	✓	Yes	✓	Yes	✓
Catch fan of any type at intervals	Yes	✓	Yes	✓	Yes	✓
Horizontal protective layer at intervals	Yes	✓	Yes	✓	No (only at the lowest level)	X
Staircase or cat ladder	Yes	✓	No No	X	Yes	✓
Previous fatal accident or collapse	Nil	✓	Yes	✓	Yes	✓

6.1.2 Cost

The cost of the MBMSS includes the cost of materials, accessories and labour, and the hidden cost of constructing a piece of the system.

The material cost of a traditional single layer bamboo scaffold 30 m (width) x 30 m (height) and the direct cost of labour and materials for an MBMSS and a double layer bamboo scaffold, based on quantity analysis by WLS Scaffolding Works Co. Ltd. in September 2008, are shown in Tables 6.3, 6.4 and 6.5, respectively.

Table 6.3. Material Cost of a Single-Layer Bamboo Scaffold 30 m x 30 m

Material	Total cost	Cost per square metre
Mao bamboo	HK$1,890	HK$2.1
Kao bamboo	HK$5,760	HK$6.4
Plastic ties	HK$747	HK$0.83
Total cost	HK$8,397	HK$9.33

Table 6.4. Direct Cost of an MBMSS Scaffold per Square Metre

Cost per square metre of an MBMSS scaffold without a work platform	
Material	HK$16.67
Labour (erection and dismantling)	HK$37.36
Transportation	HK$3.84
Cost per m^2	HK$57.87

Table 6.5. Direct Cost of a Double Layer Bamboo Scaffold per Square Metre

Cost per square metre of a double layer bamboo scaffold	
Material	HK$11.89
Labour (erection and dismantling)	HK$23.36
Transportation	HK$2.84
Cost per m^2	HK$38.09

Normally, a metal scaffolding system consists of a metal tubular, or metal frame, scaffold. In the comparative study, the data of the cost of the metal system were derived from the actual cost build up for an H frame scaffold III, developed by WLS Scaffolding Works Co. Ltd. The full scaffold set includes a work platform and toe-boards. However, in the comparison, neither a work platform nor a toe-board was included in the cost of the bamboo or MBMSS scaffolds. Therefore, only the cost of the frame structure of an H-frame scaffold III was taken into account. The cost breakdown of an H-frame metal scaffold III of the same dimensions (30 m by 30 m) as the other two scaffolds is shown in Table 6.6.

Table 6.6. Cost Breakdown of Labour and Materials for a General H-Frame Scaffold III.

	Full set	Frame only
Material cost per m^2 (frame) (work platform)	HK$29.32 HK$19.53	HK$29.32 -
Labour cost per m^2	HK$61.60	HK$38
Transportation (in/out) per m^2 (20kg/ m^2)	HK$8	HK$8
Allowing 10% wastage on material	HK$4.89	HK$2.93
Grand total cost per m^2	HK$123.34	HK$78.25

For a comparative study of the three scaffolding systems, four assumptions were made.

i) First, it was assumed that the bamboo material could be used only one time, with a maximum lifespan of 12 months. Beyond the specified period, the main contractor could ask specific sub-contractors to replace and repair the disintegrating bamboo at their own cost, so there is a hidden cost of repair and maintenance.

ii) It was assumed that all of the metal components of both the metal and MBMSS scaffolds could be used six times, with a maximum lifespan of 10 years.

iii) It was assumed that the total loading capacity of the transportation lorry was 8,000 kg, with a charge of HK$1,600 per trip for all types of scaffolding systems.

iv) For the metal and MBMSS scaffolds, allowance was made for 10% wastage of the metal components for wear and tear or repair.

Table 6.7 shows the cost comparison of the three types of scaffolding, taking into consideration all of the factors listed above.

A superficial comparison of the labour and material costs of the three types of scaffolds reveals that the traditional bamboo scaffold is the most economical. The cost ratio for the three types of scaffolds is 1:1.51:1.977 for the bamboo, MBMSS and H-frame scaffold, respectively. If a full scaffold set including a work platform and toe-board were installed, then the ratio would be 1:2.6:3.06. Hence, in terms of costs, the main contractors and property developers have a strong motivation to use bamboo scaffolding for their projects.

Table 6.7. Cost Comparison of Different Types of Scaffolding

	Bamboo	MBMSS	H-frame
Material Work platform and toe-board (full set)	HK$11.89 ---	HK$16.67 HK$19.53	HK$29.32 HK$19.53
Labour Work platform and toe-board (full set)	HK$23.36 ----	HK$37.36 HK$22	HK$38 HK$22
Transportation	HK$2.84	HK$3.84	HK$8
Total cost Work platform and toe-board (full set)	HK$38.09	HK$57.87 HK$99.4	HK$75.32 HK$116.85
Ratio Ratio for a full set	1 1	1.51 2.6	1.977 3.06

From the safety point of view, accidents related to bamboo or pure metal scaffolding are frequent and incur hidden costs. The direct payment of compensation to accident victims under legislation and common law amounts to a huge figure. For example, in February of 1991, there was an accident that a worker fell down from the bamboo scaffolds. The 37 year old worker climbed out of a window to investigate a leak, using scaffolding outside the building. The scaffolding collapsed so the worker fell and suffered injuries leaving him a quadriplegic. In October 1997, The High Court of Hong Kong delivered an judgment for the worker for over 25 million Hong Kong dollars damages (1995 No. P.I. 496). In addition, the penalties imposed by authorities jeopardise the reputation and image of a company, and represent another hidden cost. The delay in progress due to suspension of work while an incident is being investigated can lead to a loss of interest in the development budget, or opportunity loss in relation to project sales at peak times. It was demonstrated in 1999 with Typhoon York and again in 2008 with severe tropical storm Nuri that the minor damage to MBMSS scaffolds could be repaired within a day or two, whereas bamboo scaffolds required up to two months for repair. If risk management is taken into account, then the MBMSS provides another reason for client selection.

From the environmental point of view, bamboo is environmentally friendly as it is an organic material. However, it is not recyclable and creates much construction waste that has to be dumped into designated areas, which is another cost for contractors. Some argue that metal components are not environmentally friendly, According to Sources of Carbon Dioxide Emissions (2006), because much carbon dioxide is generated during their manufacture. However, they are recyclable and can be used for over ten years. The MBMSS represents a respectable compromise on these issues. The system reduces the quantity of metal used in the scaffolding set up, and by using bamboo material, contributes to the protection of the environment. Its use also reduces the overall amount of construction waste.

In summary, from the cost comparison in Table 6.7, in overall terms of safety, reliability and environmental concerns, the performance of MBMSS is better than that of traditional bamboo or metal scaffolding.

6.1.3 Operation

6.1.3.1. Design stage

The MBMSS is a scaffolding system that has a scientific design and detailed management scheme. Before commencement of the work, a registered professional engineer (RPE) or structural engineer studies the site and usage of the scaffold and then starts to plan the installation. The loading capacity of the MBMSS has to suit different types of tradesmen. The engineer also plans for any modification of the scaffold that might be necessary during the construction period. He submits a method statement and erection plan to the main contractor for coordination before work commences. Very often, he has to attend meetings with the structural engineers from the client.

For bamboo scaffolding, in Hong Kong, except for one or two reputable scaffolding companies, scaffolding contractors have to rely on the main contractors to give them direction and guidelines for the erection of scaffolding. The preparation of a method statement and its submission are the responsibility of the main contractor’s professional engineers. Normally, bamboo scaffolding practitioners do not need to calculate the structural strength of the scaffold, they just have to follow the Code of Practice for Bamboo Scaffolding Safety.

In contrast, all of the design data for metal scaffolding are provided by the manufacturer of the system. All that needs to be done is some adjustments in accordance with the site conditions. In the past ten years, some metal scaffolding players have employed structural engineers to design scaffolds on their behalf. Some have even sent their workers to attend metal scaffolding training courses organised by the Construction Industry Council Training Academy (CICTA) or Vocational Training Council (VTC). Hence, the quality of metal scaffolding work has improved. However, perhaps because of lack of experience, fatal accidents involving such scaffolding still occur (refer to the accident statistic provided by the Labour Department, HKSAR, for the 2003-2007 period as shown in Table 4.1).

6.1.3.2. Operation – preparation work

Preparation before the commencement of work is not necessary for bamboo scaffolding. All that needs to be done is to transport the bamboo material from the storage yard to the construction site and start the erection of the scaffold. The scaffold is erected on either solid concrete or steel brackets installed beforehand. The bamboo can be cut to exact measurements based on the site situation.

For metal and MBMSS scaffolds, contractors have to pick up the required items from the scaffold check list. The scaffold can only be erected in accordance with the layout plan designed by the structural engineer, who has already obtained approval from his counterpart from the main contractor. No deviation from the materials or dimensions specified is allowed in the erection process. In this respect, the construction of bamboo scaffolds has greater leeway than has that of either MBMSS or metal scaffolds.

However, the latter systems have a high degree of reliability and safety because of the rigidity of procedures, and there is less chance of human error. Differences in the skills of each individual can also weaken the quality of work in bamboo scaffolding. The MBMSS is better than metal scaffolding in that it has some flexibility, as bamboo elements are used in the scaffold. However, these components are controlled by the metal frame structure and have only a secondary function. In terms of erection and dismantling, the MBMSS and bamboo scaffolding require the same group of technicians and craftsmen, who have received the same sort of training from CICTA within the bamboo scaffold and metal scaffold categories. The construction of metal scaffolding requires workmen trained in the metal scaffold category, and it is easier to train up a metal rather than a bamboo or an MBMSS scaffolder. However, it is not difficult for a bamboo scaffolder to pick up the skills required for metal scaffolding work after training in this area. In contrast, it is rather difficult for a metal scaffolding worker to learn bamboo scaffolding work, and such training takes much longer. Hence, use of the MBMSS creates more employment opportunities for bamboo scaffolders who are proficient in both bamboo and metal scaffolding work.

6.1.4 Application

6.1.4.1. Problems with high-rise buildings

Since the launch of the MBMSS in 2001, a number of reputable developers and main contractors have used this system to test its efficiency, reliability and safety. Figure 6.1 shows scaffolders erecting an MBMSS along the external façade of a building under construction. Figure 6.2 shows an erected MBMSS in a building light well.

Figure 6.1. Erection of an MBMSS – external façade.

Figure 6.2. Erected MBMSS in a light well.

In Hong Kong, the height of buildings is steadily increasing. Buildings of up to 50 storeys are seen everywhere. Figure 6.3 shows an MBMSS for the Arch in Kowloon, which demonstrates the current trend in building design. The MBMSS is structurally sound, and strong enough to withstand strong wind from any direction. The use of a metal scaffolding system would create many problems, such as the dead load required to move the scaffold to a height of up to 500 metres above ground level. If the scaffold were divided into separate zones, then there would be the problem of setting up a steel structural platform to support the scaffold, which would be very costly. Second, there would be problems with the anchorage system used to hold the scaffold at a high level in a firm position. The attached catch-fan system under strong winds at a high level in open areas could loosen, creating a hazardous situation. All of these problems have led main contractors to hesitate to use metal scaffolding at high levels.

Figure 6.3. MBMSS for the Arch in Kowloon.

6.1.4.2 Acute areas

In addition, acute areas such as internal light wells, bay windows and projecting features cause difficulties in the erection of metal scaffolding. Some spaces are so narrow that moving in the basic materials is impossible.

Bamboo scaffolding for high-rise building projects has the advantage of being light, but as mentioned previously bamboo cannot withstand the strong wind pressure at high levels. The bamboo scaffold deforms after its erection, and requires constant rectification. Hence, main contractors have to look for alternatives on high-rise building projects.

The MBMSS is the solution to the abovementioned problems. It is lighter in weight and self load, and can be erected in the same narrow areas that bamboo scaffolding can be used in. It can be erected to suit acute features whether they are in a house or on an external façade. Like bamboo scaffolding, the MBMSS can be seated on separate steel brackets, so a big steel platform is not required. Computer modelling and structural calculations by professional structural engineers have shown that for each zone of the scaffold, the MBMSS can be erected to a height of 24 to 30 metres, with a loading capacity of 1.5 kPa and a safety factor of 2 depending on the nature of usage. Natural phenomena such as typhoons with speeds of over 160 km/hour in 1999 and 2008 proved that the MBMSS is strong enough to withstand high winds. Figures 6.4(a) and 6.4(b) show the severe damage to the bamboo scaffolding and minor damage to the MBMSS, respectively, in 1999 at Tseung Kwan O (TKO) sites.

Figure 6.4(a). Bamboo Scaffolding at TKO 62 – 1999.

Figure 6.4(b). MBMSS at TKO 55 – 1999.

6.1.4.3 Work platform

The MBMSS includes a metal work platform, which helps to reinforce the stiffness of the double layer scaffold. Figure 6.5 shows the first stage of the erection of the prototype MBMSS. The setting up of the bamboo transom allows the placing of a wooden plank, which acts as a work platform later on. There is still a hazard, as workers may place the wooden plank incorrectly, causing open traps or sudden falls by other tradesmen. In addition, the bamboo transom may disintegrate and break after a long period, which is common in bamboo scaffolding.

Figure 6.6 shows the essential features of the MBMSS work platform, with the bamboo transoms replaced by a steel work platform. There are many widths to suit different requirements. In addition to functioning as a work platform, the platform holds the internal and external layers of the scaffold firmly in position in one piece. The whole system is then bolted onto the concrete wall at even intervals of 3 m x 6 m.

Figure 6.5. Bamboo transom of the prototype MBMSS.

The significant difference between metal scaffolding and the MBMSS is that in the latter, the primary steel frame structure is backed up by secondary bamboo pieces as guard rails and vertical links to the second layer. The bamboo elements serve two purposes: to reduce the self load/weight of the whole scaffold and to provide a closer span for workers when they are moving up and down or horizontally between the standards and ledgers. Unlike most metal scaffolding systems, the span between metal members is quite wide, which reduces the weight, or dead load. In metal scaffolding systems, the width of the span between the ledgers and standards of the metal scaffold is too wide and beyond grip limits. When workers are tired or not in their best condition, these spanning widths may be too far for them to reach, which results in fatal accidents at times.

Figure 6.6(a). Metal work platform of an MBMSS.

Figure 6.6(b). Work platform of an MBMSS.

Figure 6.6(c). Work platform/wooden planks of a bamboo scaffold.

Figure 6.6(d). Wide span of members of a metal scaffold.

6.1.4.4 Humid areas and low-rise structures

The MBMSS has further advantages over the other systems, especially in humid areas and for low-rise structures with long construction periods.

Humidity is one of the factors that cause bamboo scaffolding to collapse after a short period. Areas such as humid and dark light wells, mountain sides and peaks or seafronts are the most unfavourable. Humidity can cause bamboo pieces to rot very rapidly. Chang and Yu (2002) have proven that under humid conditions, bamboo can rot easily and break at the rod area. Figure 6.7 shows rotten areas found on a new bamboo member after three months on a construction site on a mountain peak. This kind of situation applies to both Mao Jue and Kao Jue.

Figure 6.7. Rotten Bamboo Member.

The MBMSS overcomes this problem by using metal tubes as the load-bearing members. When the secondary bamboo members become rotten, they can easily be replaced, which keeps repair and maintenance costs to a minimum without causing the collapse of the scaffold. The same principle applies to low-rise scaffolding in areas such as the podium levels of multi-block projects, where scaffolding is kept until the end of construction, 36 months after its erection, before being dismantled. Bamboo members have to be renewed, but the steel structure remains safely in place. In terms of the overall cost, comparing the MBMSS with metal and bamboo scaffolding systems in the same circumstance, the former system is still the most economical.

The application of the MBMSS in Hong Kong has resulted in increased safety on construction projects. It has also had a great impact on existing bamboo scaffolding and metal scaffolding practitioners, who have started to think about how they can improve their services and products to retain their market positions. In general, there has been an overall upgrading of the scaffolding industry in Hong Kong, which had not been foreseeable before the introduction of the MBMSS.

6.2 Comparison of the MBMSS with Other Metal Bamboo Scaffolding Systems in China

Scaffolding has a long history of development in China, and there were other forms of metal bamboo scaffolding before the invention of the MBMSS in Hong Kong.. Jian Zhu Shi Gong Gong Yi Biao Zhun (1994) demonstrated a mixed metal-bamboo scaffold in China, it usually consists of a metal tube skeleton of Φ51 with a wall thickness of 3.5 mm or 4 mm and span of 2 metres. In between two metal tubes is a vertical bamboo pole (the standard). The inner layer of the scaffold has similar metal tubular poles in position, and the work platforms are made of wire mesh stretched across bamboo members and located at 2 metre intervals. The scaffold has a unique anchorage system. Wires of Φ12 mm are embedded inside a concrete slab and affixed to the external layer of the scaffold every five storeys. The space between the inner and external layers of the scaffold is one metre in width, wide enough for the movement of material by trolley.

The most significant difference between the Hong Kong patented MBMSS and the Chinese system is the size and weight of the metal tubing used. The size of the Hong Kong tubing is Φ48.60 mm with a wall thickness of 2.3 mm, and each section is 17 kg, whereas the Chinese tubing is 40 kg per section. The self-load of the latter is very heavy, and not all scaffolders in China are strong enough to move the sections alone. In fact, it can be dangerous to erect a metal or a mixed metal-bamboo scaffold in China. A photograph of the Chinese type of mixed metal-bamboo scaffolding is shown in Figure 6.8.

(a) (b)

Figure 6.8. Mixed metal-bamboo scaffold in China.

The Chinese scaffolding system requires more metal tubing and less bamboo, and is more expensive than the Hong Kong patented system. As the Construction Bureau of the PRC has banned the use of bamboo for scaffolding in all major cities in China, metal bamboo scaffolding is becoming increasingly rare, and is found only in second-tier cities or villages. Metal tubular scaffolding has replaced it in the market.

Different kinds of climbing scaffold systems have emerged in China for high-rise buildings. These systems employ a simultaneous climbing device that is controlled by a computer. A metal scaffold with a metal work platform and full set of accessories is attached to a climbing rail and lifted by a strong electrical winch. The system is illustrated in Figures 6.9(a)-(e).


SYP電腦遠程控制爬棚系統
SYP COMPUTER REMOTE CONTROL SCAFFOLD SYSTEM
主框架
MAIN FRAME
防傾防墜導座
IEAN AND FALLING PROTECTION GUIDANCE.

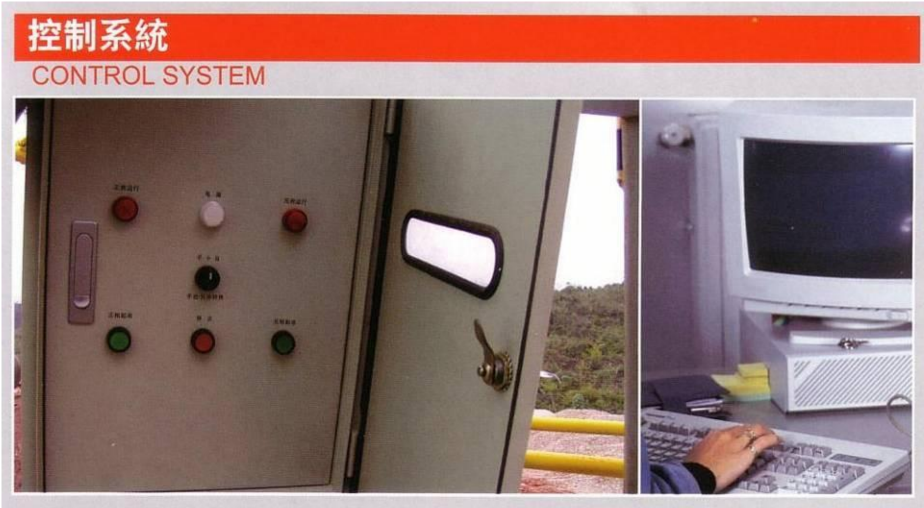
(a)


防墜系統
FALLING PROTECTION SAFETY DEVICE

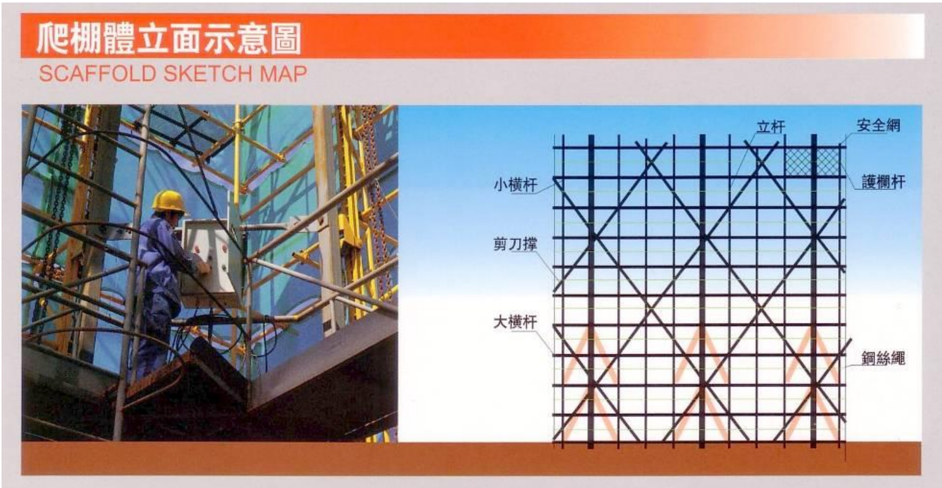
(b)


水平桁架
HORIZONTAL TRUSS
安全網、脚手板
SAFETY NET.SCAFFOLD PLATE
提升系統
LIFTING DEVICE

(c)



(d)



(e)

Figure 6.9. Climbing scaffold system of SYP Remote Control Scaffold, Sany Heavy Industry Limited Company.

As the system was introduced into China only two years ago, the technology and equipment are not yet fully developed, and accidents and failure have been recorded. In Hong Kong, different types of climbing scaffolds have been introduced for a number of projects, with some success and failures. In the latter case, the scaffold has had to be dismantled in the middle of the project and a bamboo scaffold erected in its place. Clearly, the climbing scaffolding system needs further improvement before it can be used extensively in Hong Kong.

A successful climbing scaffold project is illustrated in Figure 6.10. The climbing scaffold is located inside the green nylon safety net, and moves upward with the progression of the building work. Further illustrations of the system are presented in Figures 6.11(a)-(j).

Figure 6.10 A climbing scaffold system at Kowloon Station, Phase VI (covered by a green nylon safety net).

Figure 6.11(a) shows the sections of the main frame of the system. As requested by the main contractor, they were painted red. Each section is 4 metres in height and approximately 100 kg. A tower crane was used to assist in the installation of the main frame on the façade, as shown in Figure 6.11(b).

Figure 6.11(b) shows the main frame after installation. The vertical alignment of each single frame was checked and confirmed by a registered engineer to ensure the smooth operation of the climbing process.

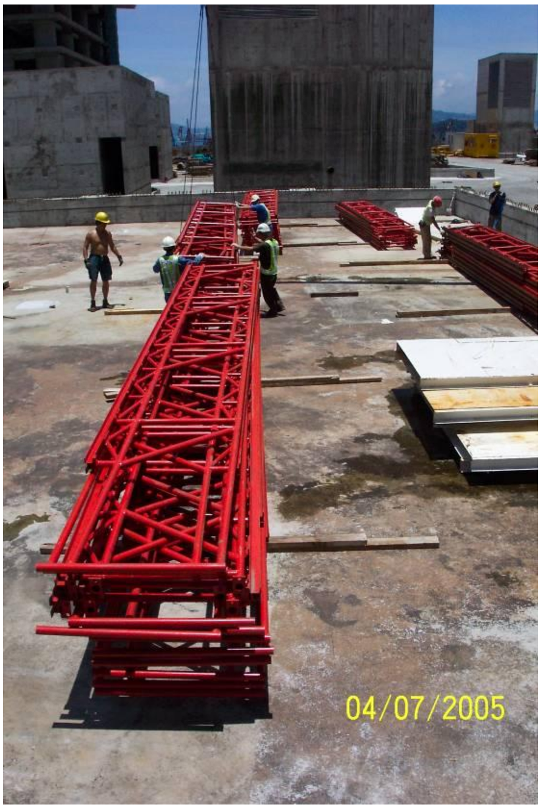


Figure 6.11(a). Frame assembly.

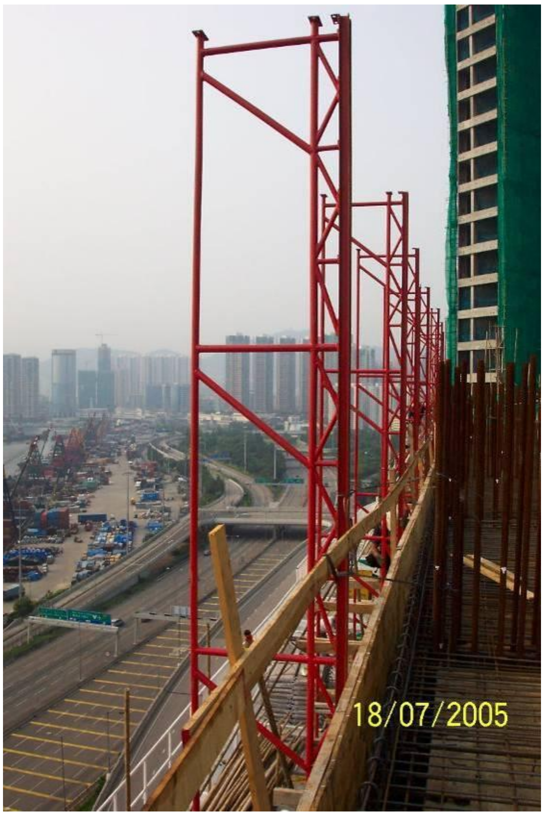


Figure 6.11(b). Installation of the frame.

Figure 6.11(c). Fall protection system.

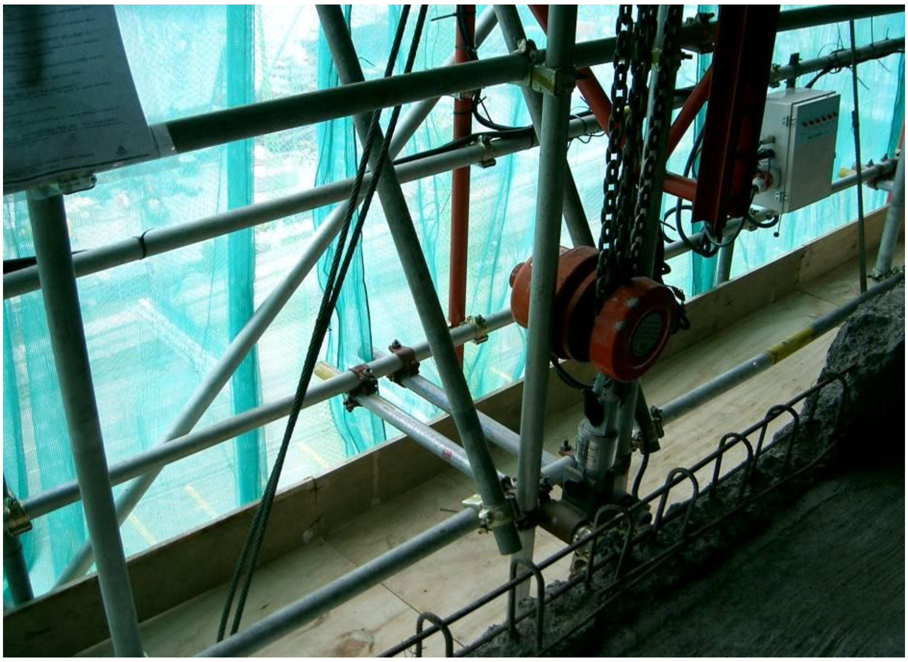


Figure 6.11(d). Lifting device (red) and weight sensor (below the lifting device).

Figure 6.11(e). Side view of the bottom part of the climbing scaffold.

Figure 6.11(d) shows the lifting gear and Figure 6.11(e) shows the bottom part of the climbing system. Moveable protective metal plates are used to prevent the fall of debris. The edges of the plates rest on the façade during the work stage and are lifted up during the climbing stage. A safety net underneath the base of the lowest level work platform prevents material and rubbish from falling to the ground.

Figure 6.11(f). The work platform and toe-board.

Figure 6.11(g). Movable protective plate.

Figure 6.11(h). Control box.

Figure 6.11(i). Control panel.

Figure 6.11(g) shows a moveable protective plate, which is connected to the work platform by means of hinges. The plate is fastened to the scaffold by a chain, and workers lift the plate by pulling the chain. Figures 6.11(h) and 6.11(i) show the control box and control panel for controlling the movement of the system and emergency stoppage.

In this chapter, the performance of MBMSS was compared with the traditional scaffold in term of the safety, cost, operation and application. The MBMSS together with its accessories show its strength and capable to achieve a safety and better working environment to the workers. The system also demonstrates its strength in high rise building , acute and humid area. Although there are some cases of mixed metal and bamboo scaffold in China, their functionality and self load are not favourable when compared with the MBMSS. Finally, the climbing scaffold is developing recently and further study is required to improve their performance.

Chapter 7 Conclusion

7.1 Review of the Major Findings

7.1.1 Major Achievement of MBMSS

Safety is the prime issue in the building and construction industry. Any scaffold must comply with the safety regulations, as mentioned in chapter 4. Safety is not limited to the structural loading capacity, but it also correlated with the working environment, operational procedure, management, worker training and other related aspects. The innovative MBMSS not only meets the safety requirements, but is also an integrated system equipped with other features and accessories to improve and enhance safety and the work environment.

The innovative MBMSS has a loading capacity higher than that of bamboo but at a lower cost than that of a metal scaffold. It is an integrated system, providing other features and accessories, such as the put-log system and anchorage system to improve the stability of the scaffold, and the work platform, cat ladder and toe-board to improve the work environment for workers.

The MBMSS system has a primary scaffold of steel components for the vertical standards and secondary bamboo elements for horizontal guard rail ledgers. The metal primary scaffold provides a higher loading capacity than the bamboo scaffold. Unlike natural bamboo, the mechanical properties of metal are reliable and consistent. It also has a longer service lifetime. Although bamboo is a natural material and grows very quickly, it is disposed of after a limited period, whereas metal tubing can be re-used over a longer period. As bamboo is used only as a secondary element in the MBMSS scaffold, less bamboo elements are used and the risk of fire is decreased.

Labour supply is affected by many factors, such as salary, the training period and the work environment. Technically, training for a bamboo scaffolder is more difficult than a metal scaffolder. The MBMSS has a primary metal scaffold and hence, both bamboo and metal scaffolders can work on it. In addition, the secondary bamboo elements are the guard rail and the setup is easier than a traditional scaffold. The MBMSS also provides a safer and better work environment than the traditional bamboo scaffold, together with a simplified skill requirement.

The MBMSS integrates access points and other special openings at the design stage to meet the needs of other trades. It provides the work platform, cat ladder and so on to facilitate access so workers can carry out their tasks easily without damaging the scaffold.

The MBMSS is more flexible than the other systems in allowing the transportation of equipment through the scaffold. Openings are made in bamboo scaffolds by cutting through the bamboo structure, which damages the scaffold. Once the scaffold has been repaired and re-positioned, it no longer retains its original form. As for metal scaffolding, such access must be provided for in the very early stage as a hole cannot be cut in the scaffold. In the case of the MBMSS, on one occasion an opening was created by popping out a metal tube with a span of 10 metres to move in a chiller machine. This resulted in neither deformity to the existing scaffold nor instability in the work platform above.

In the past, bamboo scaffolding was erected based on the experience of the scaffolder –

there was no academic support for the scaffolding industry. In the development of the MBMSS, external advisers were invited to provide support in terms of numerical simulation and determining wind effects. The numerical simulation validated the loading performance of the MBMSS by considering imperfections. Determining the wind effect provided a better understanding of the aerodynamics forces and flow patterns around buildings, indicating that nylon nets should be removed during strong winds.

The application of metal tubing with an outer diameter of 48.6 mm and wall thickness of 2.3 mm in the MBMSS structure is also a radical move. It decreases the fatigue factor for scaffolders and increases the safety factor in operation. The structural stability of the MBMSS remains unaffected, but its total weight is greatly reduced. The use of such tubing is reaffirmed by computer simulation and professional calculation.

A modern operation and management system is essential to ensuring the safety of the MBMSS. A systematic operation and management protocol plays an important role in guiding the workflow from the design stage in tendering to operation and quality management, and finally to dismantling the scaffold when the project is completed. The protocol also includes procedures for special scenarios, such as during typhoons. The principle concern is to arouse safety awareness amongst everyone involved in the scaffolding project, and to standardise their work processes.

7.1.2 Significant Improvement Adopted by Scaffolding Industry

In developing the new system, significant findings were made regarding the stability of bamboo scaffolding, metal scaffolding and the MBMSS. First, a scaffold must be erected on a solid and stable concrete surface. The scaffold will tend to deform if some of the supporting poles rest on uneven ground. If the scaffold is erected with a heavy live load, then the supporting ground becomes unstable. Hence, regardless of how solid the ground looks, it is better to rest the supporting poles on steel brackets installed on concrete columns or on beams supported by anchor bolts or full bolts. The steel brackets should be installed at least 2 metres from the ground to avoid impact from on-site traffic. Second, pull-up anchors must be installed at even intervals of 3 m x 6 m along the supporting poles in accordance with the actual site situation, and these anchors must be in line with the work platform, immediately beneath it. In many cases, the scaffold (bamboo, steel or matrix system) will thus not collapse even with the failure of the steel brackets because of the suspension function of the pull-up anchoring system.

These two factors are the major elements that make a scaffold strong and stable. The diagonal bracers are the third important element reinforcing the stiffness of the scaffold. They encompass the whole scaffold structure and prevent it from shifting. They also help to shift part of the vertical load back to the supporting poles. For both bamboo scaffolding and the MBMSS, diagonal bracers are projected 60^{o} from the supporting poles at the level of the steel brackets and angle up to the top in a cross-diagonal manner. In metal scaffolding, bracers are found at one bay of the frame structure, which makes this system weaker than the other two systems. That is why in many failure cases, accidents are due mostly to missing diagonal bracers. Thus, to prevent structural failure, it is best to install diagonal bracers to support the whole scaffold.

The level at which the supporting brackets should be installed depends on the type of scaffold. For bamboo scaffolds, the brackets should be installed every 15 metres, as stated in the Code of Practice for Bamboo Scaffolding Safety. For the MBMSS and metal scaffolding, the placement needs to be calculated by a professional structural engineer, and can extend as high as 100 metres.

7.1.3 Other Mixed Metal-Bamboo Scaffold in Hong Kong

The acceptance of the MBMSS and implementation of the system by major contractors has caused a series of reactions in the scaffolding industry in Hong Kong. First, because the system is protected by patent in Hong Kong, many scaffolding practitioners are trying to avoid patent infringement by introducing modifications to the MBMSS. Some simply use a metal tube to replace the Mao Jue as the load-bearing standard without affixing the metal ledger as shown in Figure 7.1. In addition, they do not use metal tube standards in the inner layer of the scaffold.

Figure 7.1 A mixed metal and bamboo scaffold

In the work platform area, some contractors affix a metal ladder frame to the scaffolding structure of the MBMSS and claim that this is a compatible system. Others weld a nut to the metal tubing at intervals to stop the slippage of bamboo members in the metal bamboo scaffold structure. Making modifications to the structure or changing the dimensions or the method of erection of the MBMSS has become the norm in the industry. Such efforts are risky, as most practitioners do not employ professional engineers for the design and calculation of the scaffolding structure. However, despite the many infringements, patenting has been important to the success of the MBMSS. It not only provides direct protection for the author's intellectual property, but has also spurred the development of scaffolding industry as competitors attempt to improve on the design enough to register their own patents.

7.2 Suggestions for Future Research

The MBMSS has been used by major developers and construction companies on many projects. However, further research is required. There is, as yet, no job reference involving renovation work with a poor concrete base. The MBMSS used for recent renovation work on the World Trade Centre in Hong Kong's Causeway Bay had a sound concrete bedding. Further consideration needs to be given to what would happen if the support of a concrete wall or column failed. How high could an MBMSS scaffold be erected with only one steel bracket installed? This can easily be answered by computer simulation. However, assuming that a no pull-up anchorage system has been installed or that such a system has failed, when will failure occur? Will it occur because of wind pressure or because of momentum from vibration caused by movement below? Future studies could investigate such issues.

Another significant question that will need to be asked is how much wind load or wind pressure can an MBMSS scaffold endure with and without an anchorage system installed? The installation of anemometers at intervals of 50 metres to test the effect of wind speed on the MBMSS has been considered, but there is no practical way of achieving this on site. Although wind tunnel tests can provide some data for analysis of the effect of wind on the MBMSS, testing on site would provide better data. In the future, academic researchers could obtain data from projects in progress to carry out this analysis.

With regard to material improvement, future research could investigate the replacement of bamboo by other building materials such as fibreglass reinforced epoxy tubing with plastic couplers. This could help to reduce the weight of the whole scaffolding structure. Researchers would need to determine whether such members would be as reliable as bamboo members, and whether they would create an even stronger structure with a greater live-load capacity. Another important consideration would be whether such a system would be economically feasible and accepted by the market. Market recognition is very important: regardless of how good an invention is, practicality and economic feasibility always come first. In addition, a study of patent applications should be conducted to gain a better understanding of intellectual property protection, as any oversight or omission can have far-reaching effects.

In conclusion, the MBMSS is a new invention in that the total weight of the scaffolding structure has been greatly reduced and the system has reached its maximum reliability and safety. It has proven its strength and stability even under adverse whether conditions. Computer simulation and calculation by professional structural engineers support the philosophy of the design and operation of the system. Nevertheless, further study is recommended to minimise the defects and address the issues mentioned in previous chapters.

References

1 *The Construction and Use of Basic Access Scaffolds*, Construction Industry Training Board, Hong Kong (1985).

2 *A Guide to the Provisions for Safe Place of Work under Part VA of the Construction Sites (Safety) Regulations (2004)*, Occupational Safety and Health Branch, Labour Department, HKSAR.

3 *Annual Report*. Construction Industry Council Training Academy, 2007

4 *ASHRAE Handbook – Fundamentals (1993).*

5 *British Standard 1139: Metal Scaffolding.*

6 *British Standard 2482: Specification for Timber Scaffold Boards.*

7 *British Standard 5507 Methods of Test for Falsework Equipment.*

8 *British Standard 5867: Specification for Fabric for Curtains and Drapes.*

9 *British Standard 5973: Code of Practice for Access and Working Scaffolds and Special Scaffold Structures in Steel.*

10 *British Standard 5975: Code of Practice for Falsework.*

11 *British Standard 5867: Part: 2 1980 Specification for Fabrics for Curtains and Drapes. Part 2. Flammability Requirements.*

12 *Code of Practice for the Structural Use of Steel*. Building Authority, HKSAR.

13 *Code of Practice on Wind Effects.* Building Authority, HKSAR, 1983 and 2004.

14 *Code of Practice for Bamboo Scaffolding Safety.* Occupational Safety and Health Branch, Labour Department, HKSAR, 2001 and 2009.

15 *Code of Practice for Metal Scaffolding Safety.* Occupational Safety and Health Branch, Labour Department, HKSAR, 2001.

16 *Comparative Study on Safety and Application of Bamboo and Metal Scaffolding in Hong Kong.* (Tsinghua-Gammon) Construction Safety Research Centre, 2001.

17 *Construction Safety Involving Working at Height for Residential Building Repair and Maintenance.* Construction Industry Institute Hong Kong, 2007.

18 *Construction Scaffolding Operations.* Guangzhou Publicity and Education Centre for Labour Protection, 1989.

19 *Course Prospectus.* Construction Industry Council Training Academy, 2009

20 *Explanatory Materials to the Code of Practice on Wind Effects in Hong Kong.* Building Department, HKSAR, 2004.

21 *Factories and Industrial Undertakings Ordinance, Hong Kong Law, Chapter 59 Section 6A & 6B, CAP59, Construction Sites (Safety) Regulations (CSSR) Regulation 38A and 38A, 38B to 38F, 38H, 38I, Regulation 48, 49, 52, Third Schedule.* HKSAR, 1997.

22 *Factories and Industrial Undertakings Ordinance, Hong Kong Law, Chapter 59AC (Suspended Working Platforms) Regulation.* HKSAR, 1997.

23 *Guideline for Design and Construction of Bamboo Scaffolds*. Buildings Department, HKSAR 2006.

24 *Guidance Notes on Classification and Use of Safety Belts and their Anchorage Systems.* Labour Department, HKSAR.

25 *Handbook on Construction Methods.* Publisher for Construction Industry, People's Republic of China, 1999.

26 *High Court Judgement 1995 No. P.I. 496*. High Court of Hong Kong, Hong Kong, 1997.

27 *Hong Kong Year Book*. HKSAR, 2005 & 2007

28 *Manpower Survey Report Building and Civil Engineering Industry* . Building and Civil Engineering Training Board, Vocational Training Council, 2005 & 2007.

29 *Rules for Safety Techniques of Construction and Installation Projects.* State

Council, People's Republic of China, 1956.

30 *Safety Techniques for Construction and Installation Workers: Pictorial Manual on the Operations.* Publisher for Construction Industry, People's Republic of China, 1988.

31 *Safety Techniques for Construction Scaffolding Operations*. Shanghai Municipality Publicity and Education Centre for Labour Protection, 1989.

32 *Singapore Standard CP 14 – Code of Practice for Scaffolds.1996*

33 *Sources of Carbon Dioxide Emissions*. U.S. Environmental Protection Agency, 2006.

34 *Technical Specification for Building Maintenance Unit, MARS models.* Tractel Group, 2004.

35 江澤慧 (2002) Bamboo and Rattan in the World, Liaoning Science and Technology Publishing House, 2002.

36 楊嗣信 (1992) *高層建築手冊* 中國建築工業出版社.

37 建築工程手冊編委會 (1994) *建築工程手冊* 地震出版社.

38 Amada S., Munekata T., Nagase Y., Ichokawa Y., Kirigai A., and Yang Z. (1997) The mechanical structures of bamboo in viewpoint of functionally gradient and composite materials. *Journal of Composite Materials*, Vol. 30, No. 7, 1997, 800-819.

39 Arce-Villalobos O.A. (1993) Fundamentals of the design of bamboo structures. PhD thesis, Eindhover University of Technology, Holland.

40 Au F., Ginsburg K.M., Poon Y.M. and Shin F.G. (1978) *Report on Study of Bamboo as a Construction Material.* Hong Kong Polytechnic, Hong Kong.

41 Champion S. (1996), *Access Scaffolding*, Chartered Institute of Building.

42 Chan S.L. and Chung K.F. (1998) *Technical Report No. WL-MB01*. The Hong

Kong Polytechnic University Department of Civil and Structural Engineering, Hong Kong.

43 Chan S.L. and Chung K.F. (2002) Stability design of scaffolds using circular hollow timber section – bamboo. *Proceedings of International Seminar Bamboo Scaffolds in Building Construction*, INBAR, 55-64.

44 Chan S.L., Wong K.W., So Y.S. and Poon S.W. (1988). Empirical design and structural performance of bamboo scaffold. *Proceedings of the Symposium on Bamboo and Metal Scaffoldings*, Hong Kong Institution of Engineers, Hong Kong, 5-22.

45 Chang C.C. and Yu T.X. (2002) *An Engineering Study for Improving Safety and Reliability of Bamboo Scaffoldings*. Occupation Safety and Health Council, Hong Kong.

46 Chu A.Y.T and Chan S.L. (2005) Numerical and experimental studies of metal scaffolding by the notational force method. *Proceeding of Technical Seminar on Advances in Design and Technologies in Scaffolding*, Hong Kong Institute of Steel Construction, Hong Kong 2005, 4-20.

47 Chung K.F., Chan S.L. and W.K. Wu (2002) Design of bamboo scaffolds. *Proceedings of International Seminar Bamboo Scaffolds in Building Construction, INBAR, 65-88.*

48 *Chung K.F. and Siu Y.C. (2002) Bamboo Scaffolds in Building Construction. Erection of Bamboo Scaffolds.* INBAR Technical R*eport No.24. Joint Publication of the International Network for Bamboo and Ratt*an and the Hong Kong Polytechnic University , 2002, 1-68.

49 Chung K.F., Yu W.K. and Chan S.L. (2002) Mechanical properties and engineering data of structural bamboo. *Proceedings of International Seminar*

Bamboo Scaffolds in Building Construction, INBAR, 1-24.

50 Fu W.Y. (1993) Bamboo scaffolding in Hong Kong. *The Structure Engineer*, Vol. 71, No. 11, 202-204.

51 Fung K.S. (2005) Private communication.

52 Godley M.H.R. and Beale R.G. (1997) Sway stiffness of scaffold structures. *The Structural Engineer*, 1997, 75, No.1, 4-12.

53 Hui Chaouao & Yang Yuming (2002) *A handbook of bamboo cultivation and utilisation in China*. China Forestry Publishing House, 2002.

54 Janssen J.J.A. (1981) Bamboo in building structures, PhD thesis, Eindhoven University of Technology, Holland, 1981.

55 Janssen, J.A. (1987) *Building with Bamboo*, Eindhoven, Netherlands

56 Janssen, J.A. (1991) *Mechanical Properties of Bamboo*, Kluwer Academic Publishers. Netherlands.

57 Janssen Jules J.A. (2002) Structural Joints in Bamboo. *Proceedings of International Seminar Bamboo Scaffolds in Building Construction*, INBAR, 25-30.

58 Jayanetti D.L. and Follett P.R. (2002) Bamboo in Construction – Trada's Experience. *Proceedings of International Seminar Bamboo Scaffolds in Building Construction*, INBAR, 43-54.

59 Jeary A P and Yip S (1994) *Signposts in Wind Codes*, City Polytechnic of Hong Kong, Building and Construction Department, Hong Kong.

60 Jian Zhu Shi Gong Gong Yi Biao Zhun (1994) publisher "Guangzhoushi Jian Zhu Zong Gong Si" April 1994, pp864-865.

61 Ko J.M. et al. (2002) *Bamboo Scaffolds in Building Construction. Design of Bamboo Scaffolds.* Joint Publication, Hong Kong Polytechnic University and

International Network for Bamboo and Rattan.

62 Lee H. K. (2002) Bamboo Scaffolds – Past, Present and Future from a Safety Practitioner's View. *Proceedings of International Seminar on Bamboo Scaffolds in Building Construction*, INBAR, 101-104.

63 Lei Jaifu (1998) (http://english.peopledaily.com.cn/200110/25/eng20011025_83160.html)

64 Poon S. W., Chan N.F., Au A.K.K., Kwong A.W.K. and Chan R.C.K. (2002) Performance of metal scaffolding used in slope work. *Proceedings of International Seminar on Bamboo Scaffolds in Building Construction*, INBAR, 95-100.

65 So Y.S. Francis (1996) Bamboo scaffold development in Hong Kong – A critical review. M.Sc thesis, Jointly organized by University of Warwick, UK and Hong Kong Polytechnic University, Hong Kong, 1996.

66 So Francis Y.S. (2002) Trade practice of bamboo scaffolds and mixed metal-bamboo scaffolds. *Proceedings of International Seminar on Bamboo Scaffolds in Building Construction*, INBAR, 89-94.

67 So Y.S. and Wong K.W. (1998) Bamboo scaffolding development in Hong Kong – A critical review. *Proceedings of the Symposium on Bamboo and Metal Scaffolding*, Hong Kong Institution of Engineers, Hong Kong, 63-75.

68 Stanley H.O. Lam (2004), *Behaviour of Bamboo Materials under Chemical Treatment.* Building and Construction Department, City University of Hong Kong.

69 Tong A.Y.C. (1998) Bamboo scaffolding – Practical application. *Proceedings of the Symposium on Bamboo and Metal Scaffolding*, Hong Kong Institution of Engineers, Hong Kong, 43-62.

70 Tong Albert Y.C. (2002) Bamboo scaffolding – Practical application.

Proceedings of the International Seminar on Bamboo Scaffolds in Building Construction, INBAR, 31-42.

71 Tong M.K. & Chan S.L. (2005) *Technical Seminar on Advances and Technologies in Scaffolding*, HKSTC.

72 Wong P.Y. (2002) Safety and reliability of bamboo scaffolding. MPhil Thesis, Department of Civil Engineering, Hong Kong University of Science and Technology, Hong Kong.

73 Wessner L.B. and Jones H.L. (2001) Experimental and analytical capacity of frame scaffolding. Engineering Structures, 23, 2001, 592-599.

74 Yu W.K. and Chung K.F. (2000a) Qualification test on Kao Jue under compression and bending. Technical Report, Research Centre for Advanced Technology in Structural Engineering, Hong Kong Polytechnic University, Hong Kong.

75 Yu W.K. and Chung K.F. (2000b) Qualification test on Mao Jue under compression and bending. Technical Report, Research Centre for Advanced Technology in Structural Engineering, Hong Kong Polytechnic University, Hong Kong.

76 Yu W.K., Chung K.F. and Chan S.L. (2002) Column buckling in structural bamboo for bamboo scaffolding. *Proceedings of the 17th Australasian Conference on the Mechanics of Structures and Materials*, Gold Coast, Australia.

77 Yu W.K. and Chung K.F. (2001) Mechanical properties of bamboo for scaffolding in building construction. *Proceeding of the International Conference on Construction*, Vol. 2, 19-21 June 2001, 266-272.

80 Waters, Dan (1998) The Craft of Bamboo Scaffolders, *Journal of the Hong Kong Branch of the Royal Asiatic Society*, vol. 37, 1998, p.19-38

Appendices

A.3.1 Recommended Configuration of Bamboo Scaffolding (Code of Practice for Bamboo Scaffolding Safety 2001)

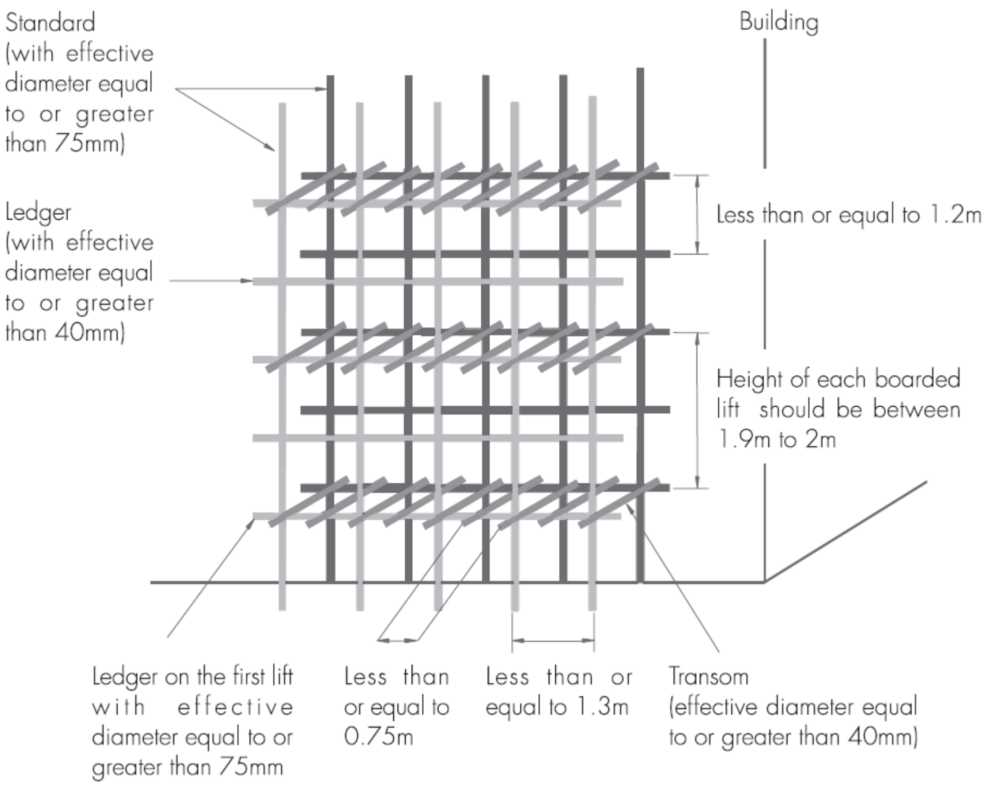
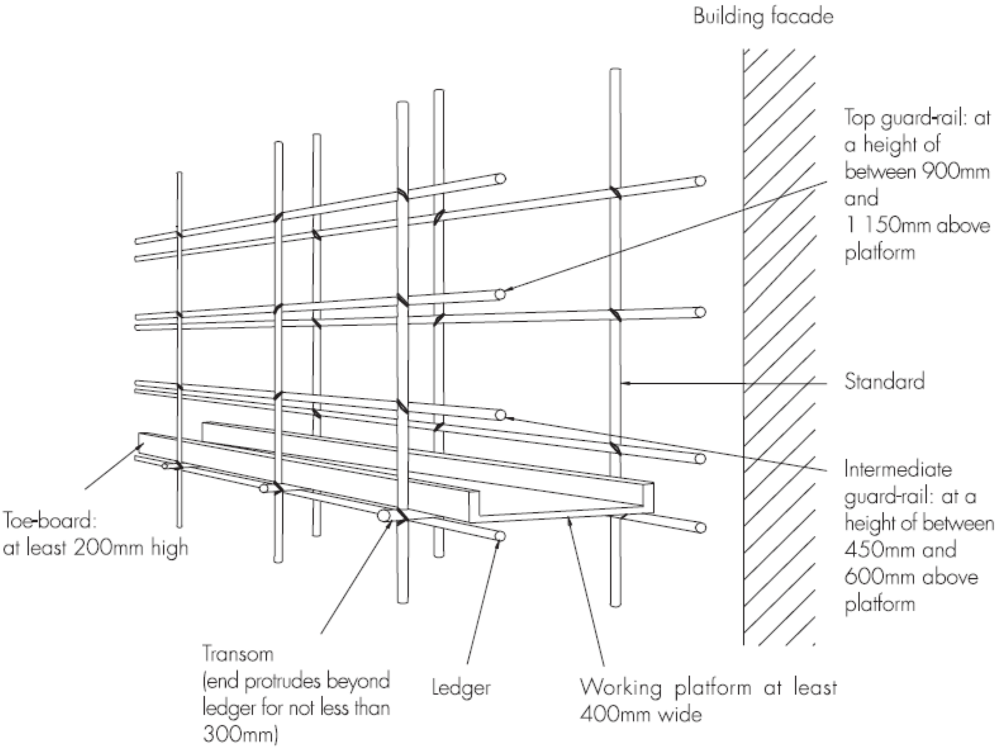


Figure A.3.1(a) A recommended standard for double layer bamboo scaffolding (not to scale)

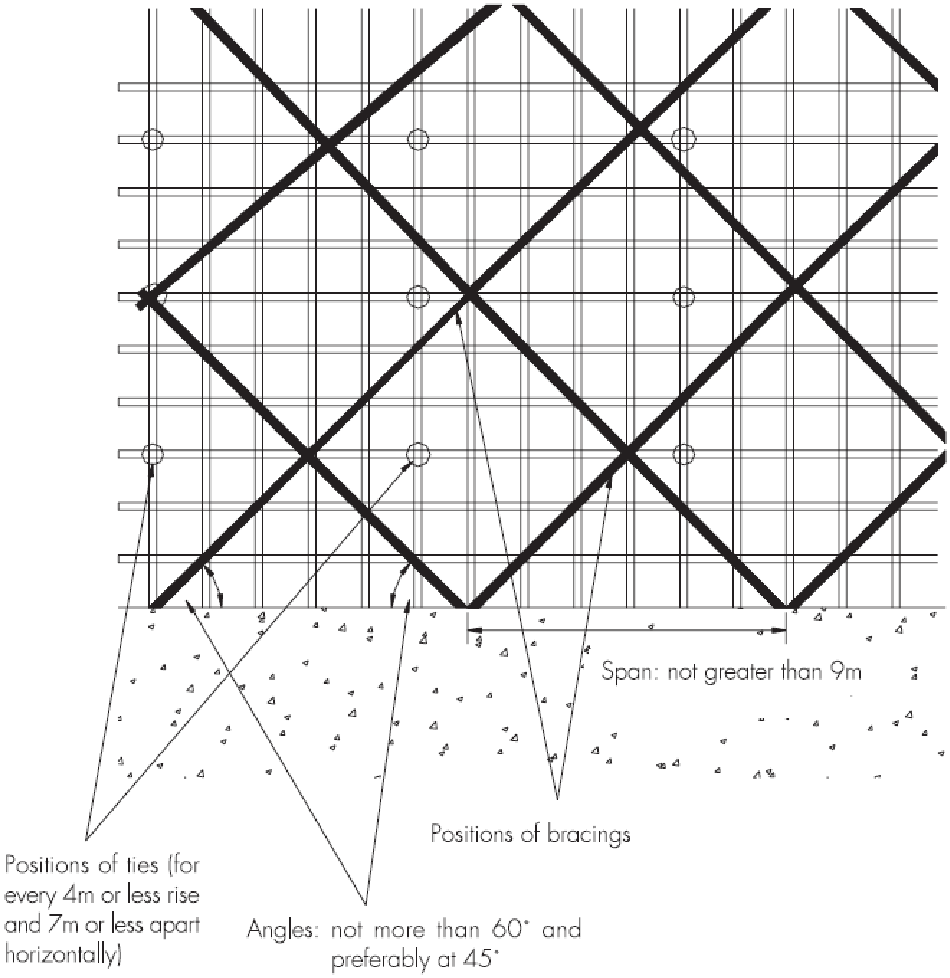


Note:

(i) Each scaffold board should be not less than 200mm in width and not less than 25mm in thickness or not less than 150mm in width when board exceeds 50mm in thickness.

(ii) Heght of guard-rails shall not apply to a working platform on a bamboo scaffold if the platform is protected by not less than 2 horizontal bamboo members of the scaffold spaced at intervals between 750mm to 900mm.

Figure A.3.1(b) Work platform of a double-row bamboo scaffold (not to scale)

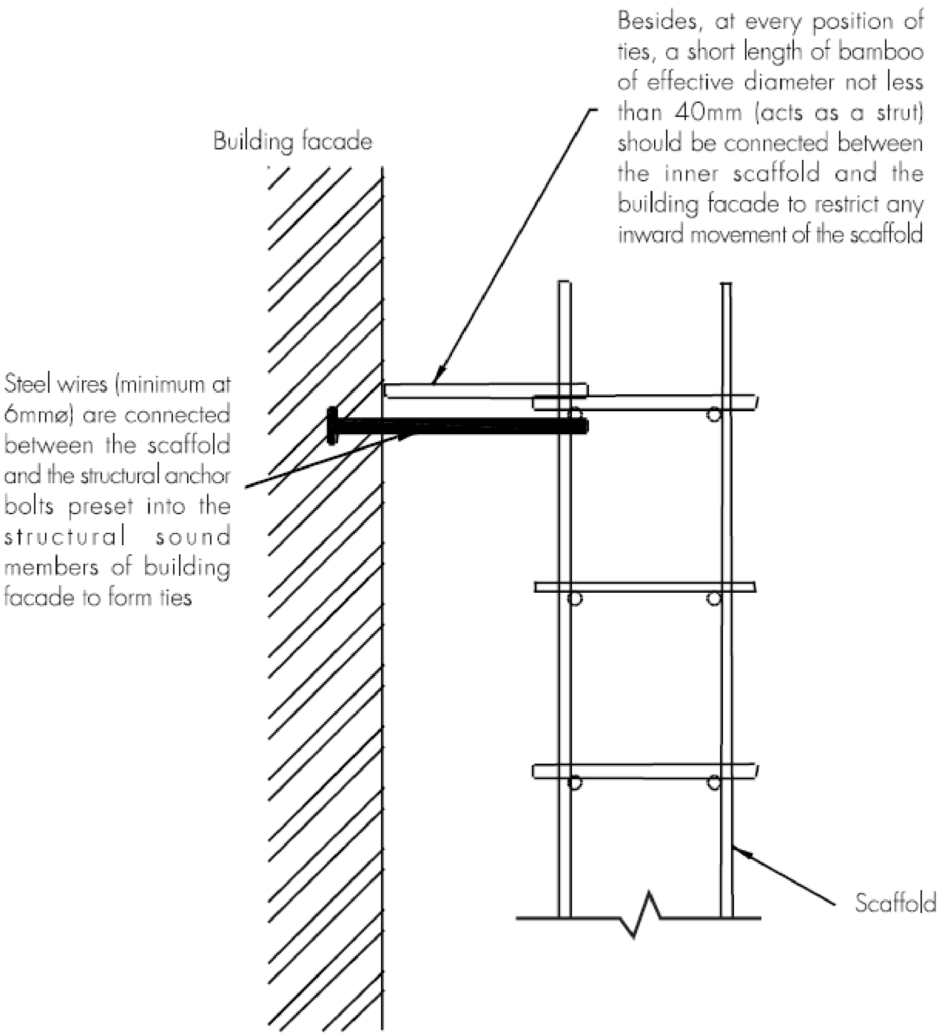


Note:

(i) Positions of transoms are not shown.

(ii) Ties should be fitted for bamboo scaffold of height greater than 7m.

Figure A.3.1(c) Positions of ties and bracing for bamboo scaffolding (front elevation, not to scale)



Note:

(i) For building under construction, structural anchors for the ties can be preset into the structural sound members of building facade.

(ii) For existing building, structural anchors can be provided by expansion type anchor bolts set into the structural sound members of building facade.

Figure A.3.1(d) Details of the tie/strut arrangement of a double-row bamboo scaffold (side elevation, not to scale)

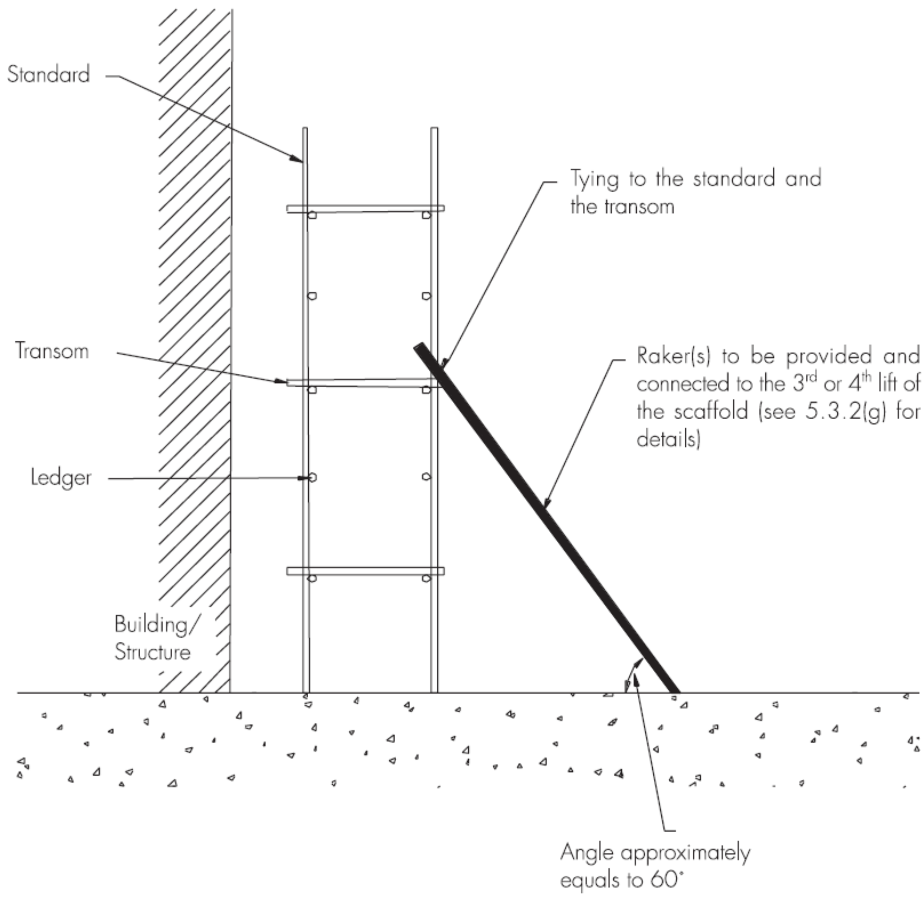


Figure A.3.1(e) The position of rakers for a bamboo scaffold up to 7 m in height

(side elevation, not to scale)

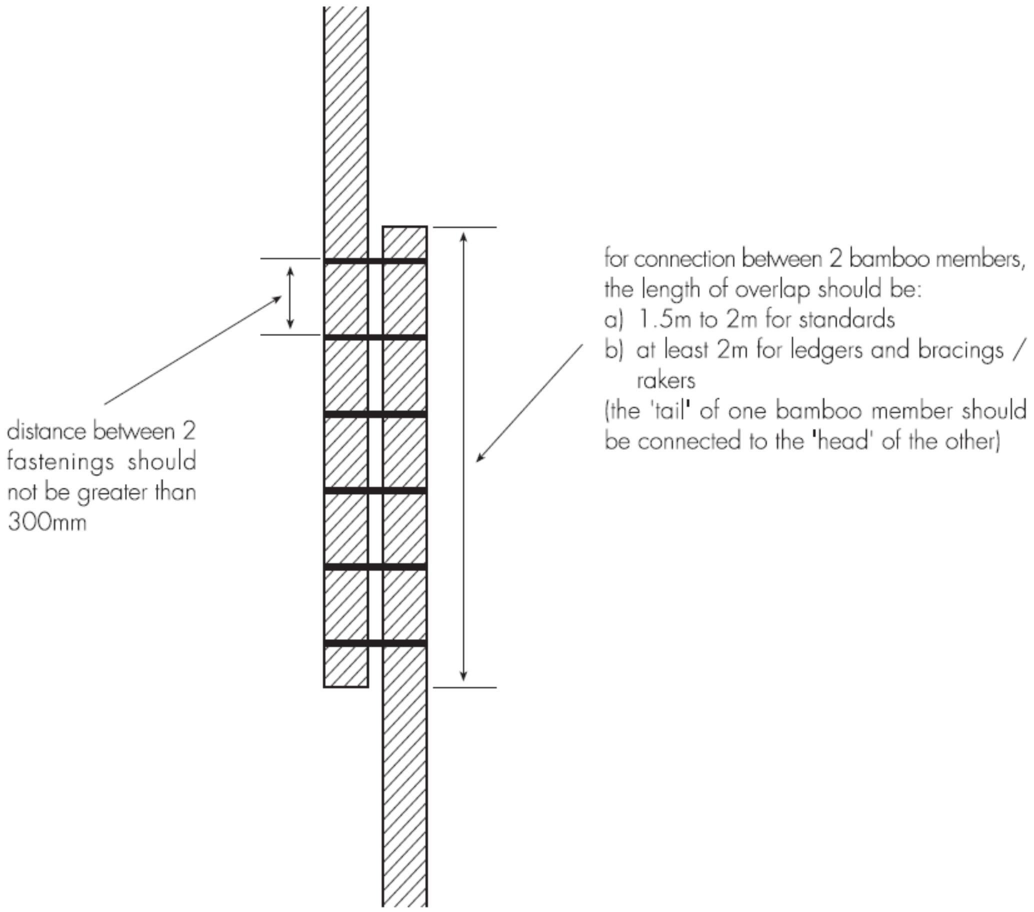
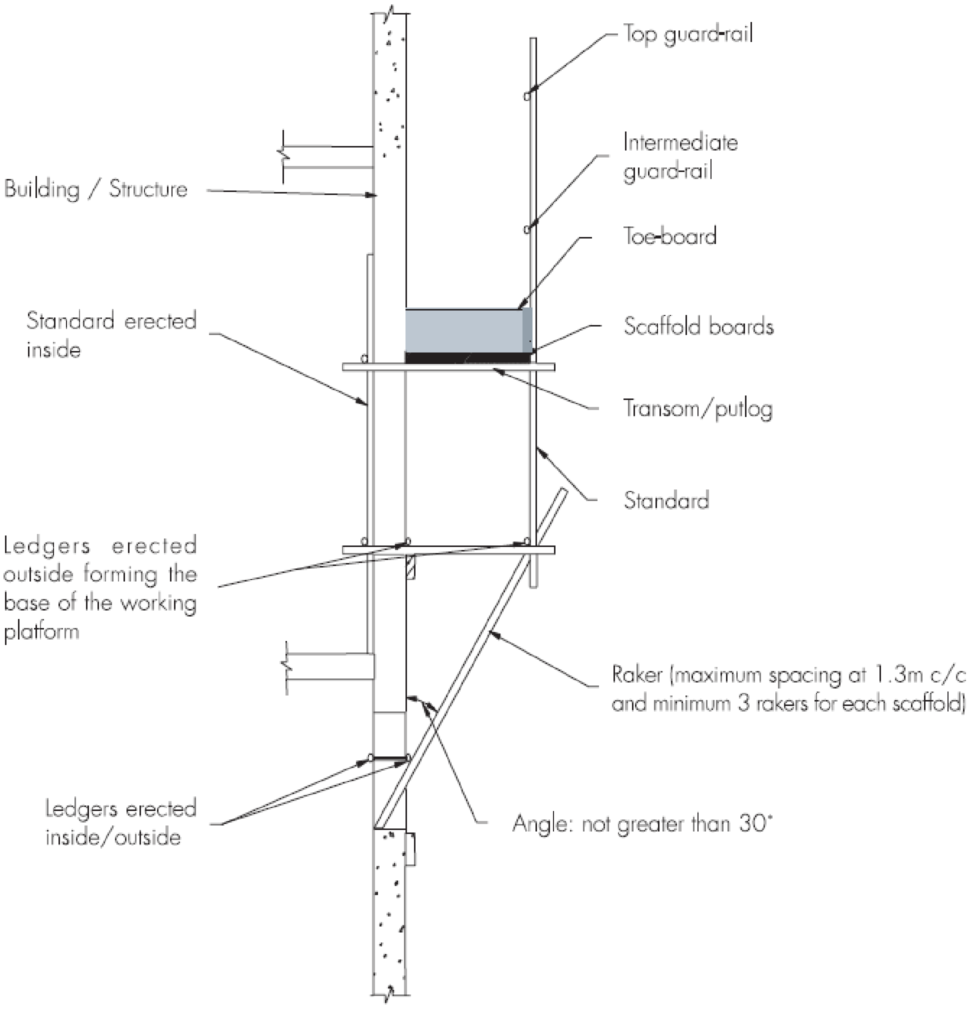


Figure A.3.1(f) The proper connection of bamboo members for bracings/rakers, ledgers and standards used in the erection of bamboo scaffolding (not to scale)



Note:

(i) For the top guard-rail: at a height between 900mm and 1 150mm above platform.

(ii) For the intermediate guard-rail: at a height between 450mm and 600mm above platform.

Figure A.3.1(g) Single lift type truss-out bamboo scaffold (side elevation, not to scale)

A.3.2 Recommended Guidelines for the Design and Construction of Bamboo Scaffolds (2006)

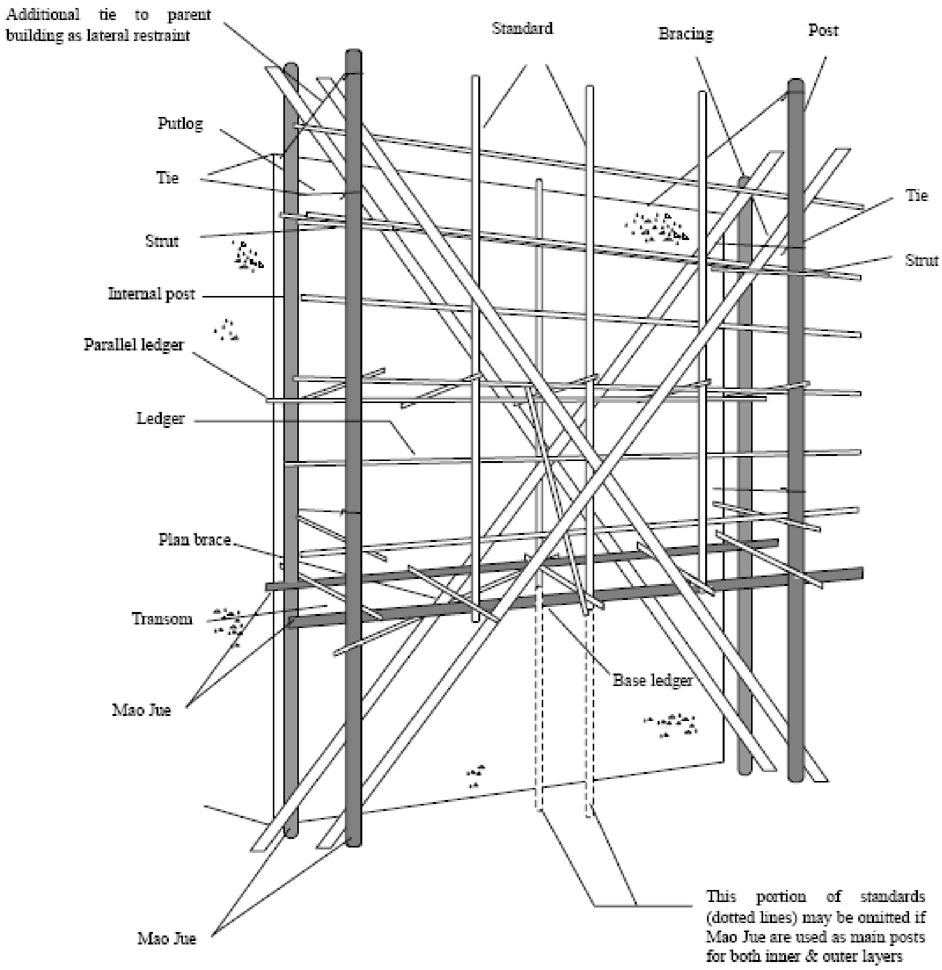


Figure A.3.2(a) Alternative arrangement for double-layered bamboo scaffold

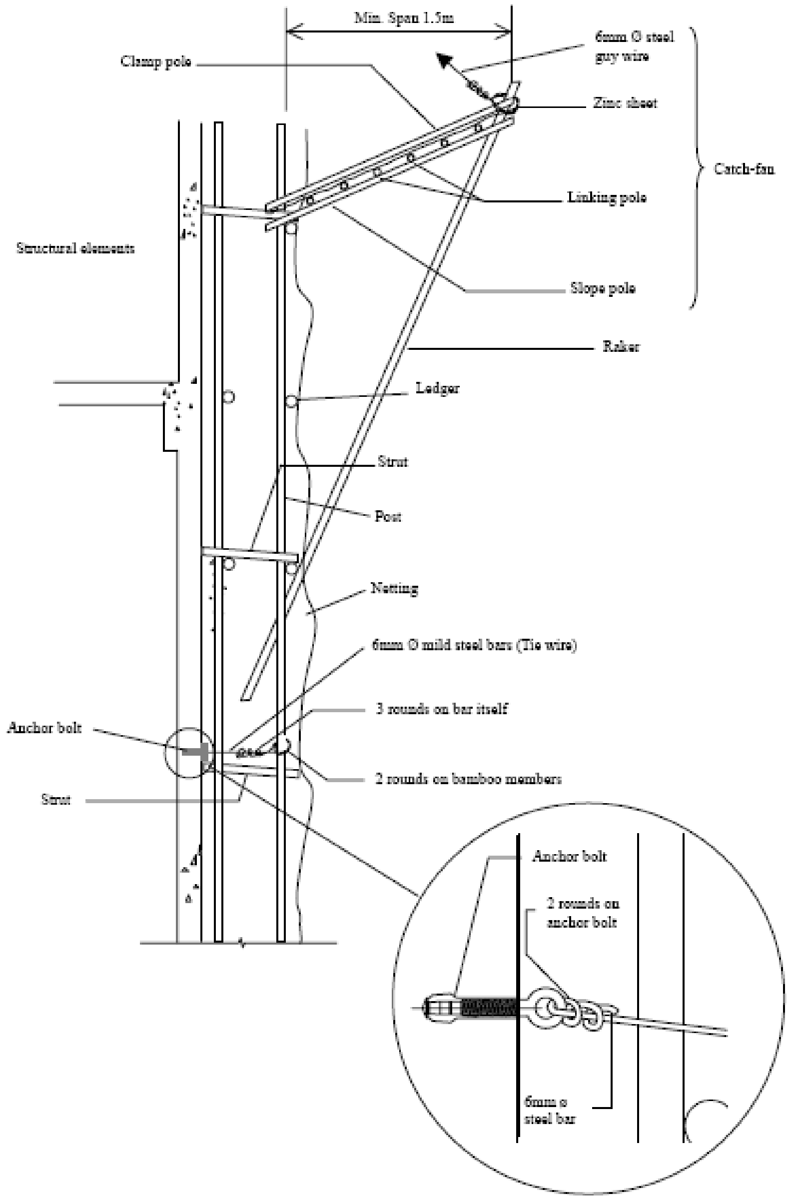


Figure A.3.2(b) Details of putlog and catch-fan for double-layered bamboo scaffold

One loaded platform (See Table 1)
L = 3.0 m ; h = 2.1m
Height (H) = 14.8m or 6@2.1 + 2.2
Inner layer KJ + MJ
Covered area per putlog = 3 × 2.1 × 3 = 18.9 m^2
Transoms not shown for clarity

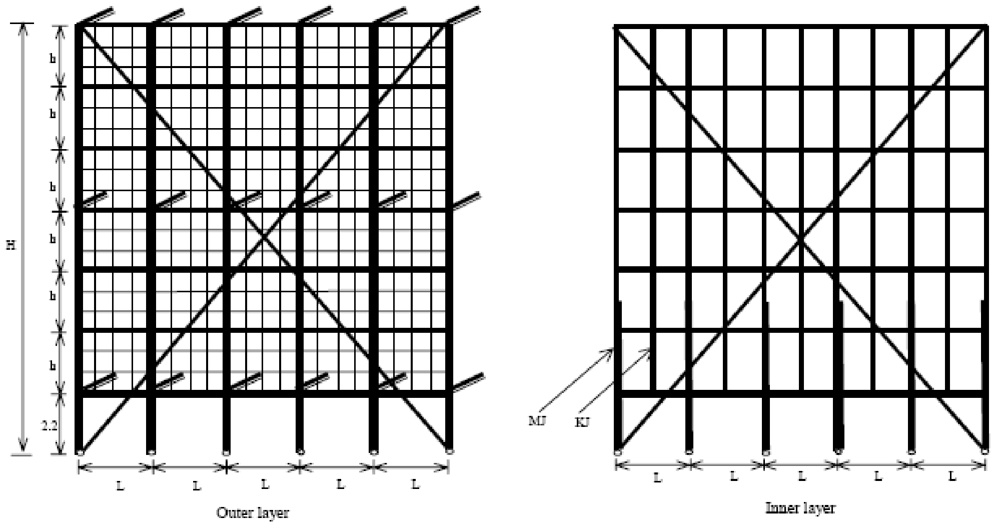


Figure A.3.2(c)   Configuration of double-layered bamboo scaffold 15 m high

(for reference only)

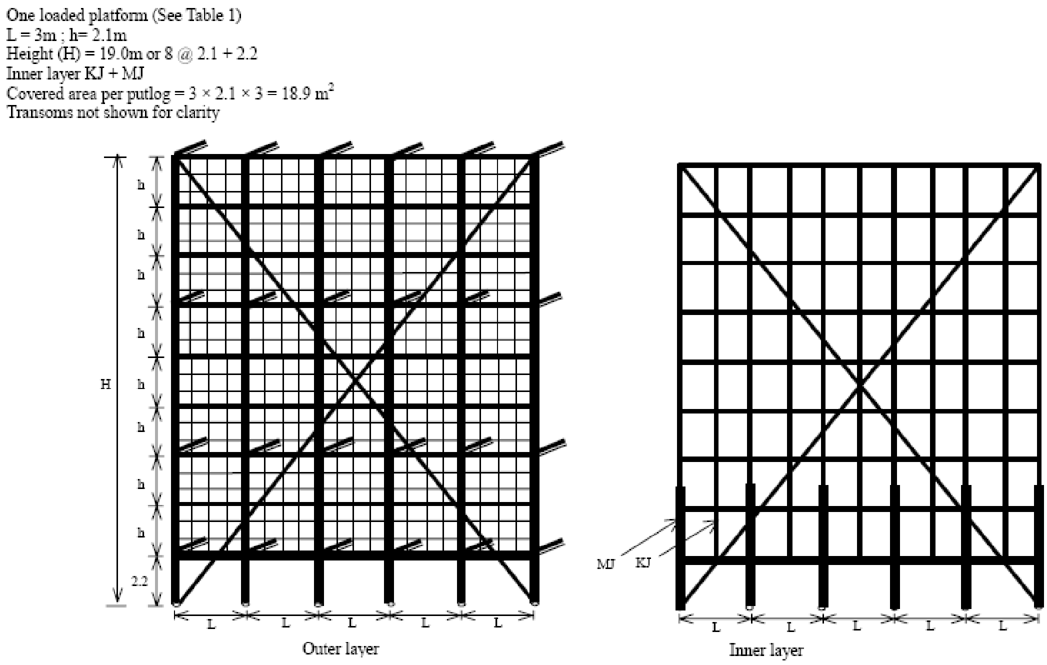


Figure A.3.2(d) Configuration of double-layered bamboo scaffold 19m high

(for reference only)

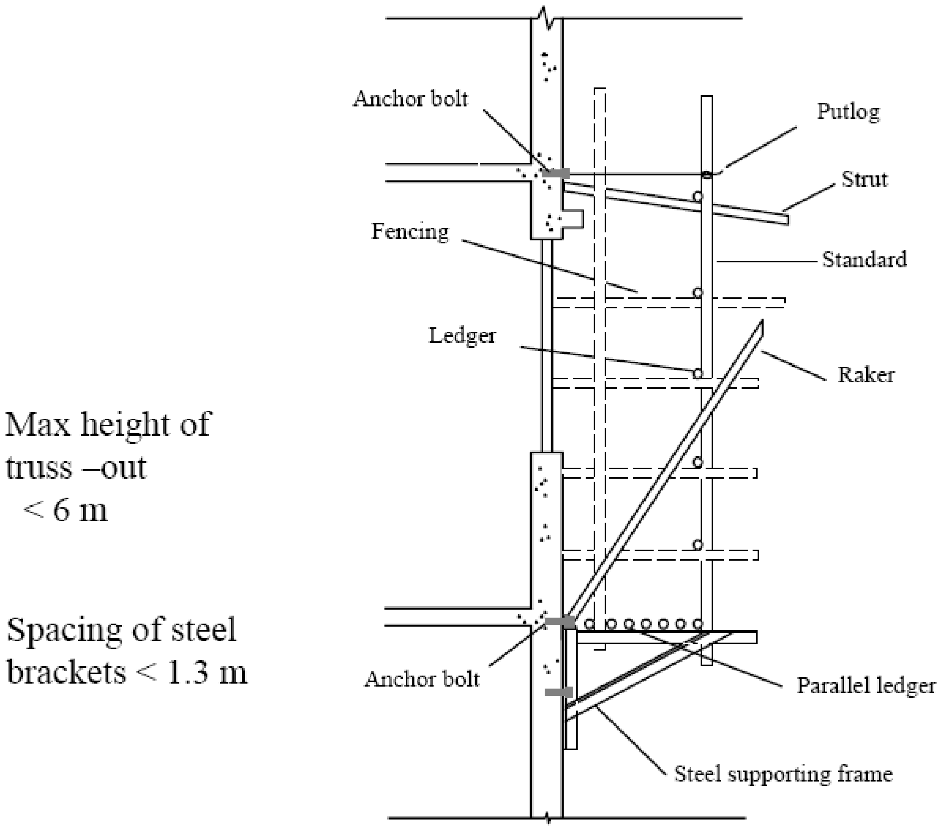


Figure A.3.2(e) Truss-out bamboo scaffold

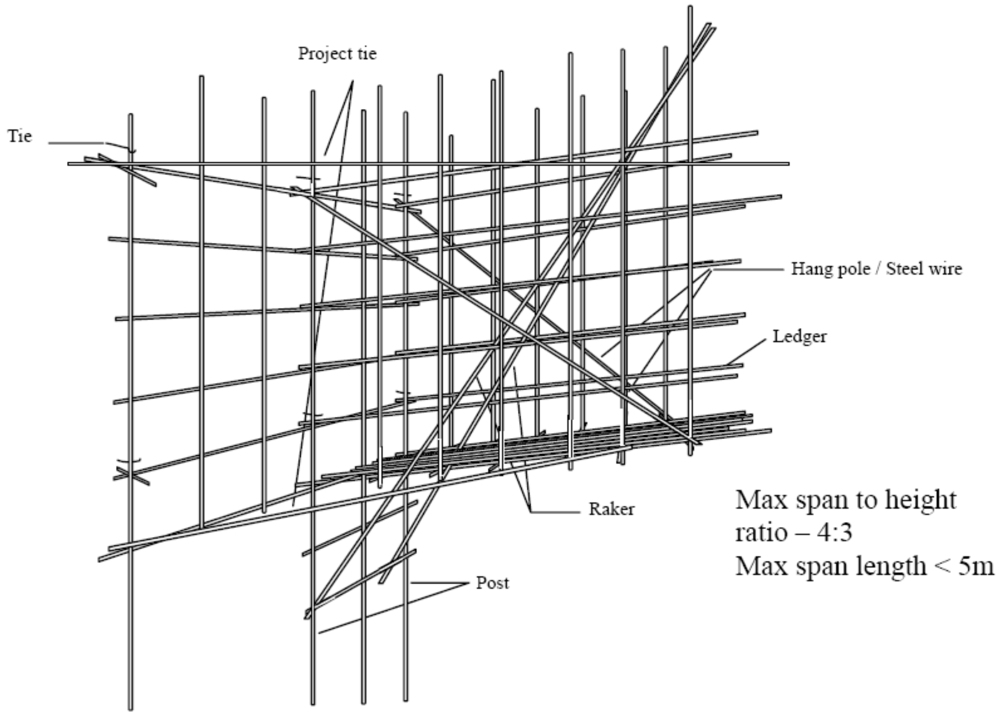


Figure A.3.2(f) Bamboo scaffold for signboard

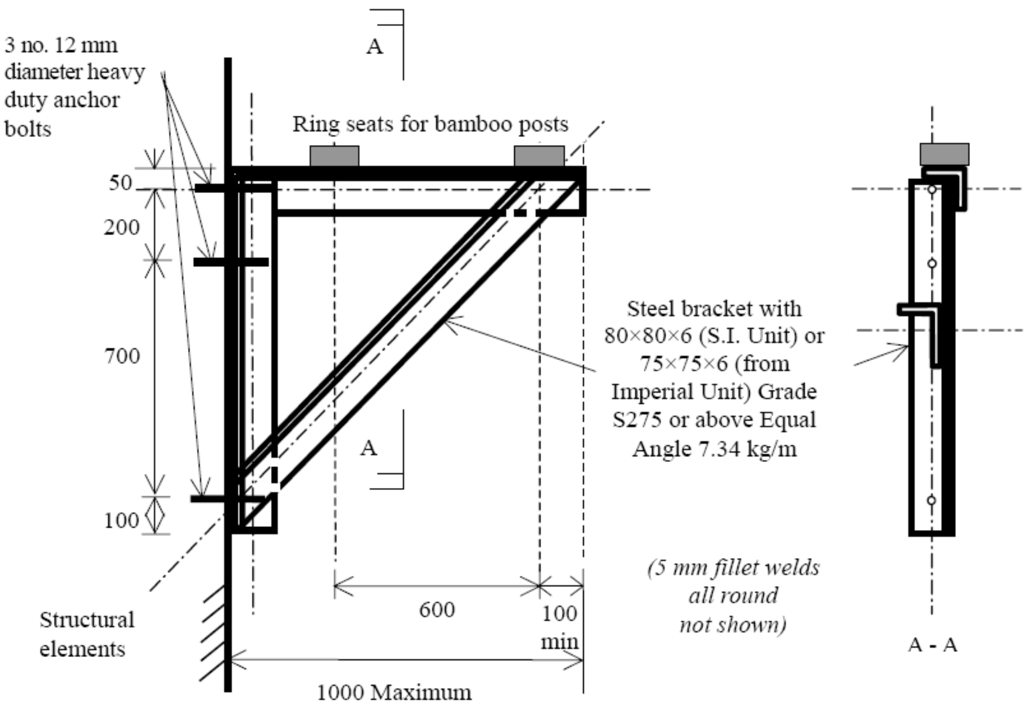


Figure A.3.2(g) Base support for general construction

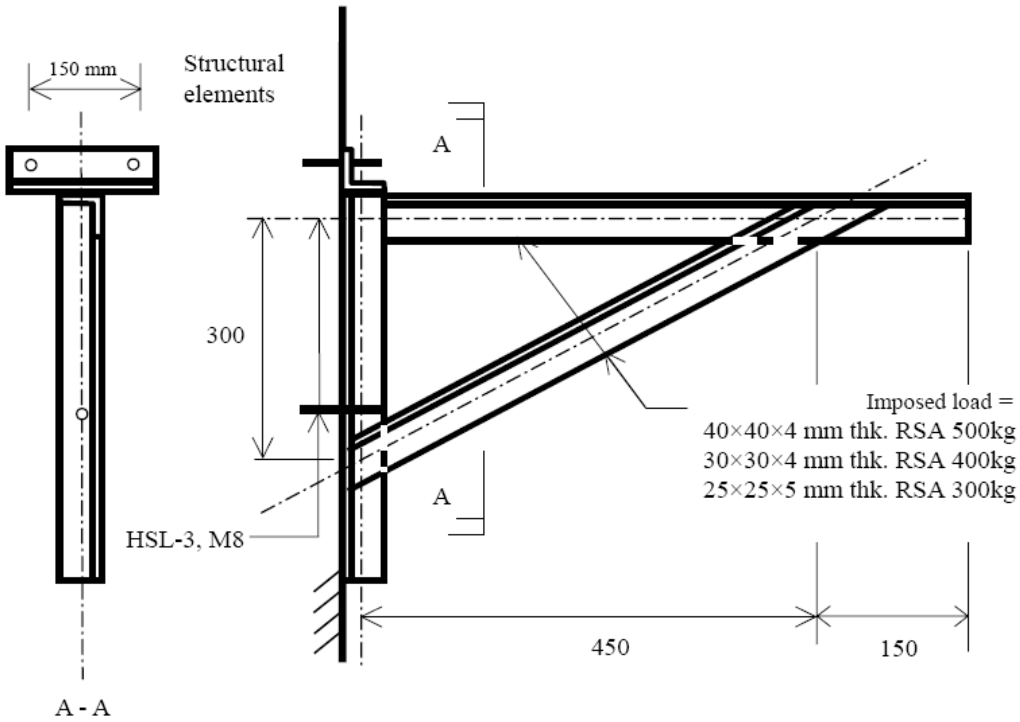


Figure A.3.2(h) Base support for truss-out scaffold

A.3.3 Recommended Configuration of Metal Scaffolding (Code of Practice for Metal Scaffolding Safety 2001)

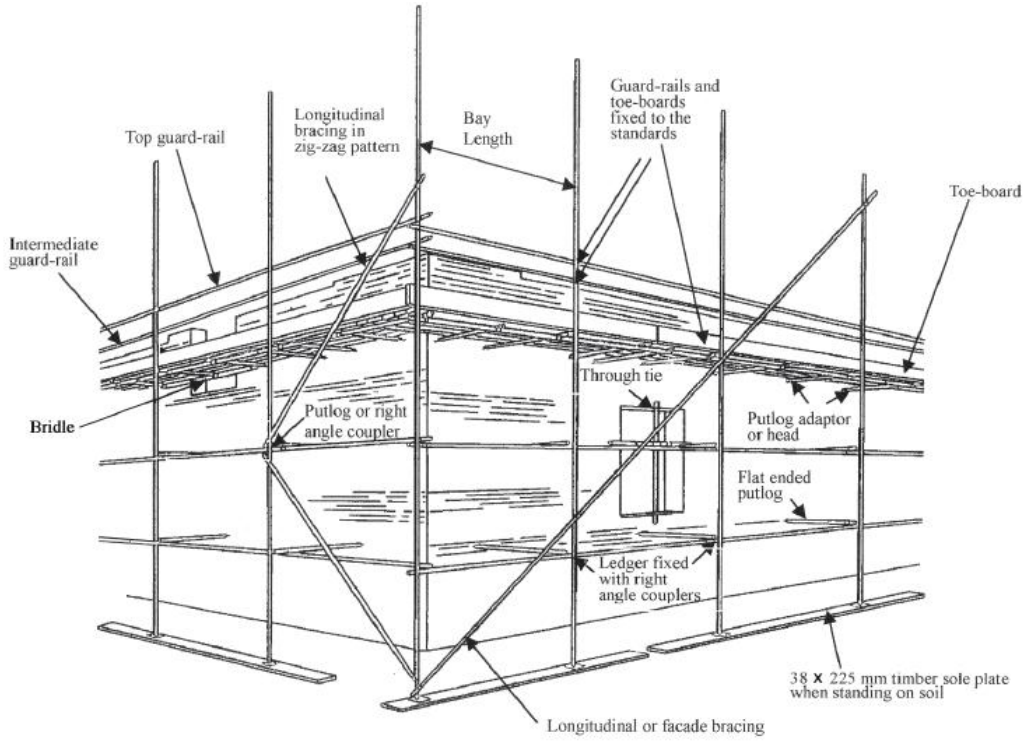


Figure A.3.3(a) Metal putlog scaffold

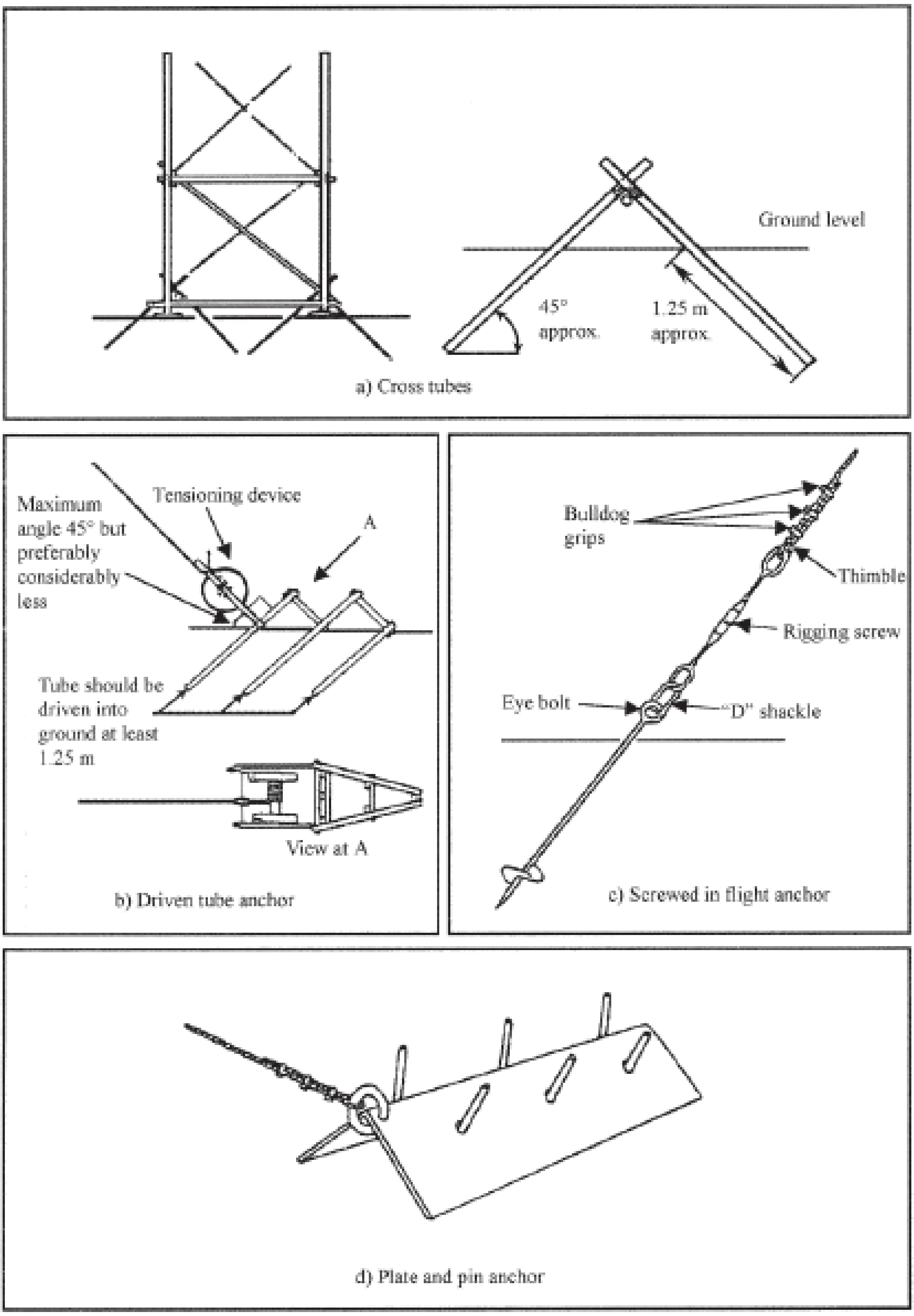


Figure A.3.3(b) Anchors

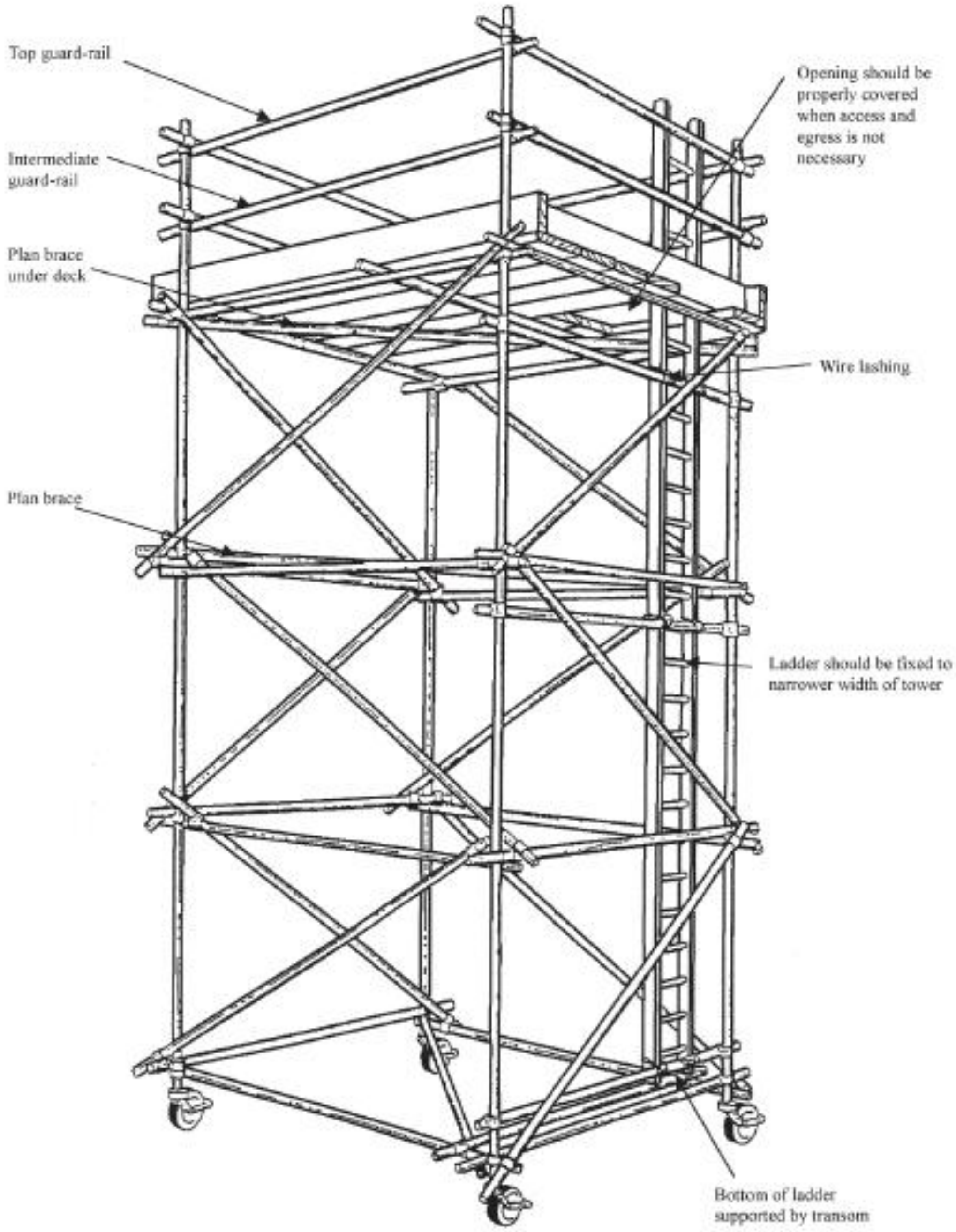


Figure A.3.3(c) Mobile access tower

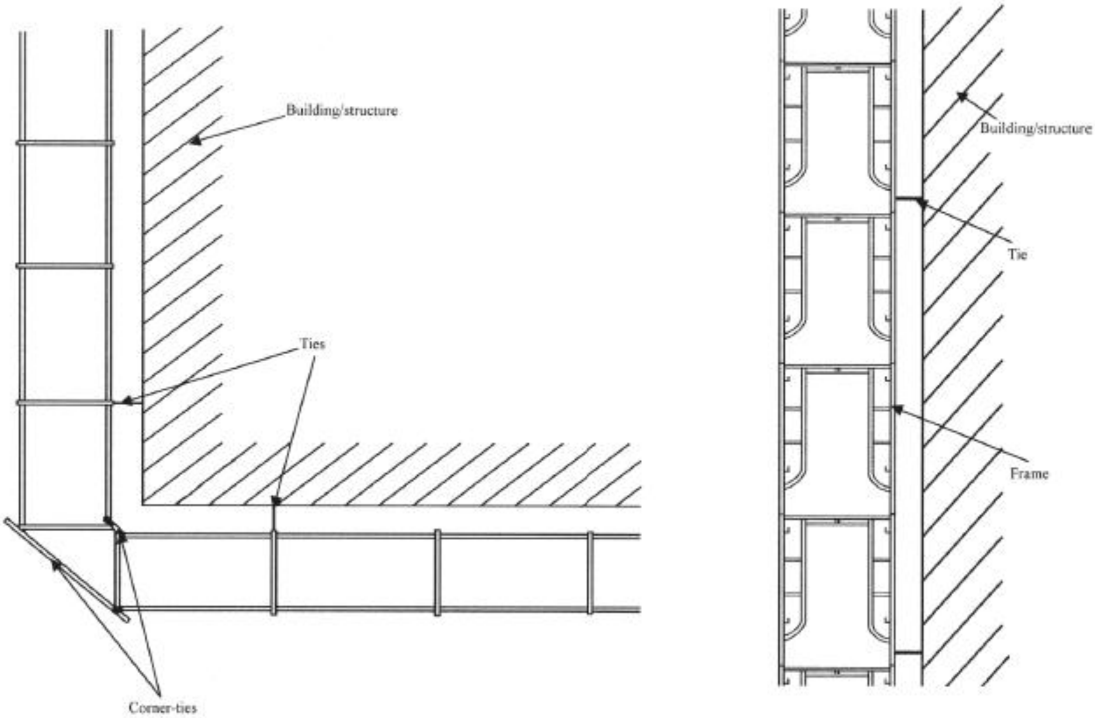


Figure A.3.3(d) Ties

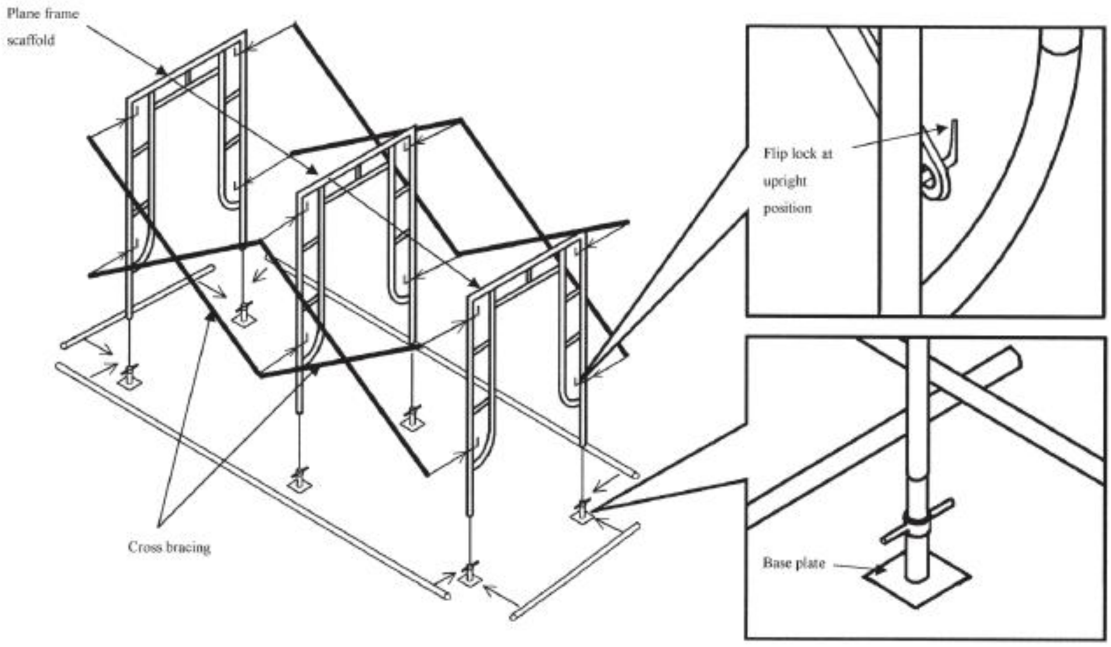


Figure A.3.3(e) Bracing, flip lock and base plate

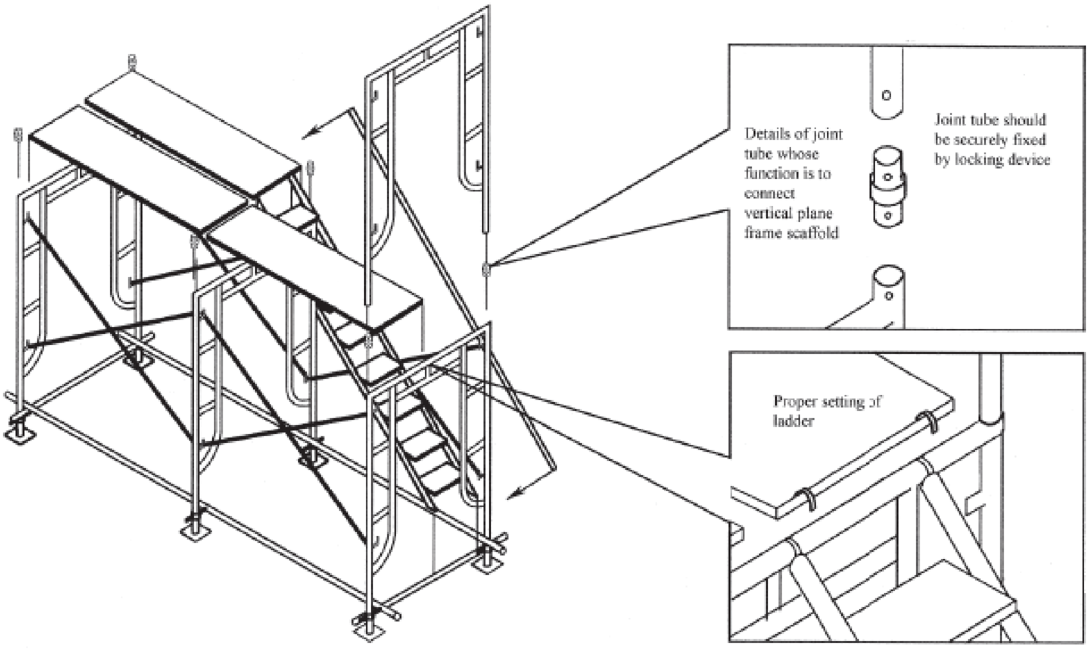
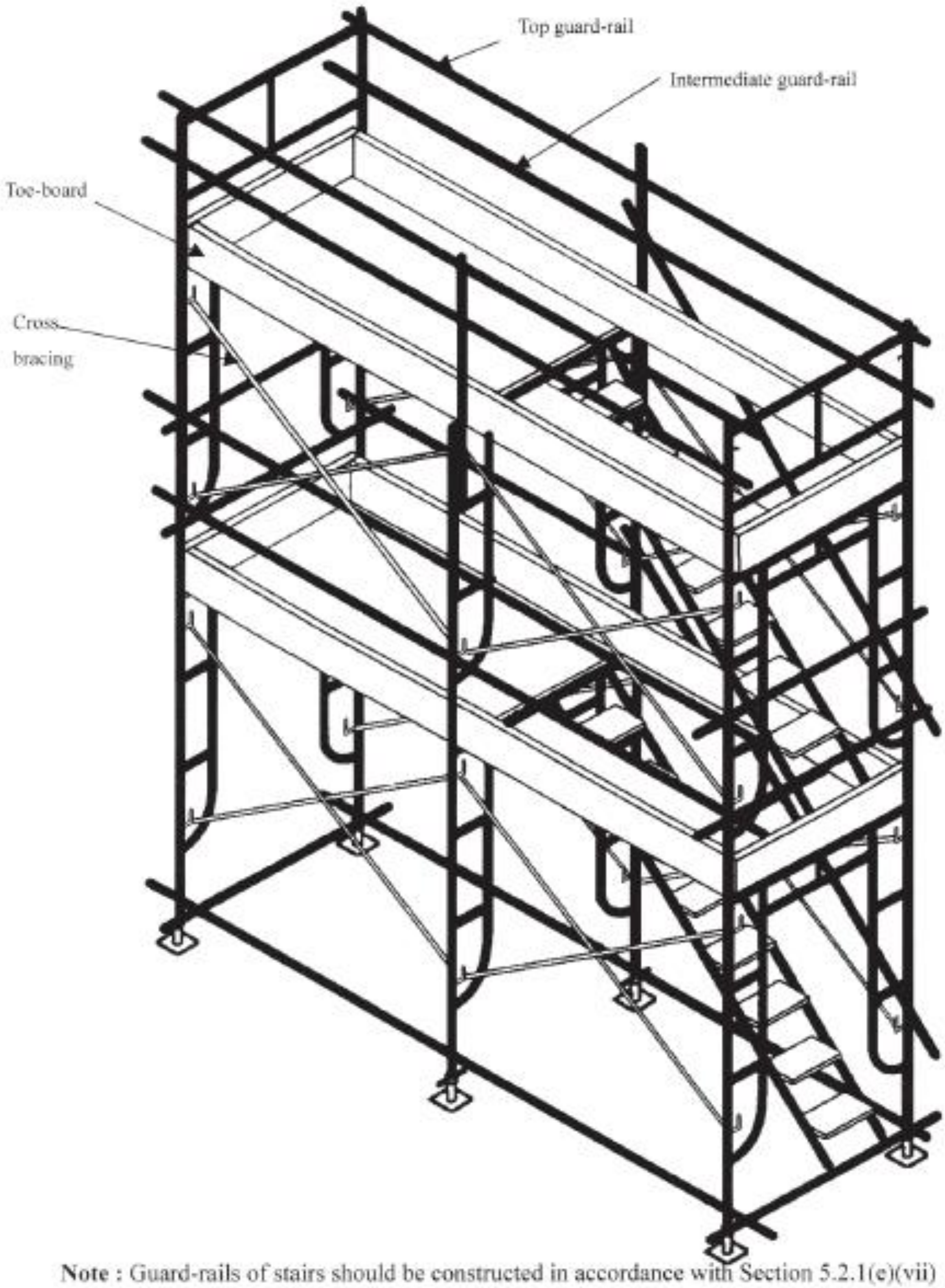


Figure A.3.3(f) Scaffold connections



Note : Guard-rails of stairs should be constructed in accordance with Section 5.2.1(e)(vii)

Figure A.3.3(g) Layout of plane frame access scaffold

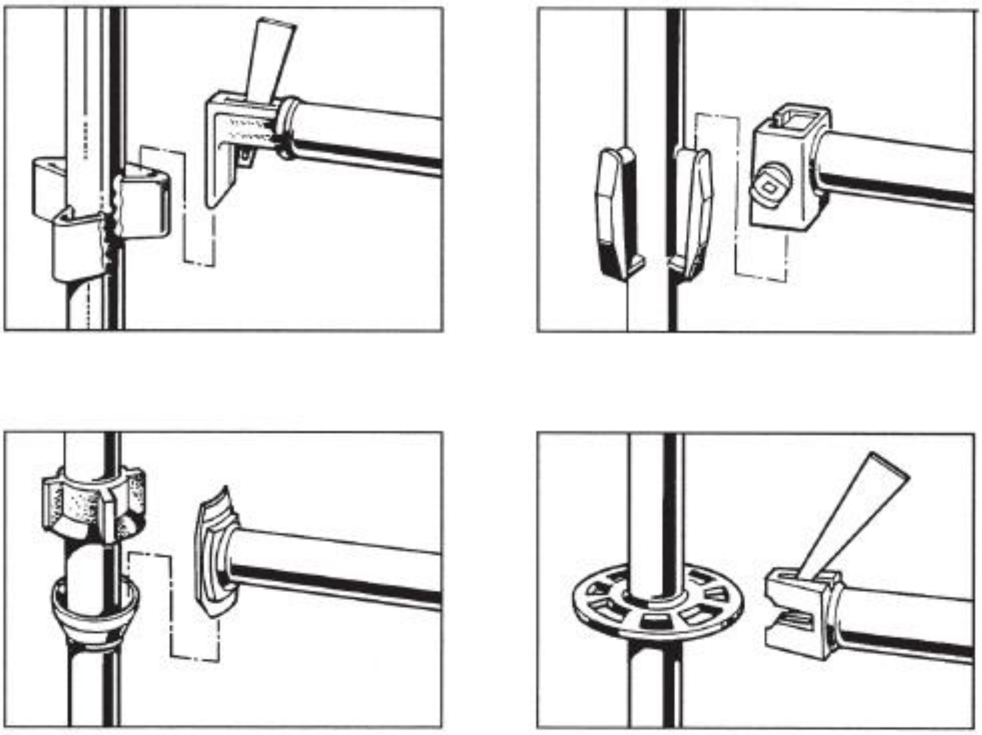


Figure A.3.3(h) Proprietary clamping or wedging arrangements

A3.4 Frequency and Total Duration of Display of Tropical Cyclone Warning Signals: 1956-2007 (Hong Kong Observatory)

Frequency and Total Duration of Display of Tropical Cyclone Warning Signals : 1956-2007

	Signals								Total Duration	
Year	1	3	8 NW	8 SW	8 NE	8 SE	9	10	hr	min
1956	5	4	0	0	0	0	0	0	191	25
1957	4	9	1	1	2	2	0	1	295	45
1958	4	5	0	0	1	0	0	0	214	5
1959	1	1	0	0	0	0	0	0	36	35
1960	11	7	0	2	2	2	1	1	432	35
1961	6	7	1	2	1	0	1	1	192	55
1962	4	3	0	1	1	0	1	1	158	10
1963	4	5	0	0	1	0	0	0	175	50
1964	11	14	1	3	5	3	3	2	570	15
1965	7	6	0	0	1	1	0	0	239	40
1966	6	5	0	0	2	2	0	0	284	40
1967	8	6	0	0	2	1	0	0	339	10
1968	7	7	0	1	1	0	1	1	290	10
1969	4	2	0	0	0	0	0	0	110	15
1970	6	8	2	1	2	0	0	0	286	45
1971	9	10	1	3	2	2	1	1	323	25
1972	8	6	0	0	1	1	0	0	288	20
1973	8	6	1	1	1	0	1	0	416	50
1974	12	10	0	0	2	1	1	0	525	20
1975	8	6	1	0	0	1	1	1	292	20
1976	6	6	0	0	1	2	0	0	351	30
1977	8	6	0	0	1	0	0	0	395	10
1978	8	9	1	1	3	2	0	0	462	10
1979	5	5	1	0	2	2	1	1	281	15
1980	10	8	0	0	1	1	0	0	414	5
1981	5	4	0	0	1	1	0	0	202	20
1982	7	4	0	0	0	0	0	0	247	35
1983	8	7	0	1	2	2	1	1	289	42
1984	6	6	0	0	1	0	0	0	280	2
1985	5	4	1	0	0	1	0	0	193	35
1986	6	7	0	1	1	0	0	0	305	0
1987	6	1	0	0	0	0	0	0	165	45
1988	6	4	0	0	0	0	0	0	204	10
1989	7	8	0	0	2	2	0	0	306	10
1990	6	4	0	0	0	0	0	0	245	10
1991	8	6	0	0	1	1	0	0	349	55
1992	5	5	0	0	1	1	0	0	167	5
1993	8	9	0	0	2	4	0	0	325	40
1994	4	3	0	0	0	0	0	0	138	10
1995	8	6	2	2	1	1	0	0	348	50
1996	7	2	0	0	0	1	0	0	189	0
1997	2	3	0	1	1	0	1	0	97	30
1998	5	2	0	0	0	0	0	0	188	35
1999	10	13	4	3	2	0	2	1	520	0
2000	7	3	0	0	0	0	0	0	329	5
2001	6	6	1	1	2	1	0	0	253	35
2002	3	2	0	0	0	1	0	0	144	25
2003	4	5	1	1	1	1	1	0	158	0
2004	3	2	1	1	1	0	0	0	77	35
2005	3	1	0	0	0	0	0	0	142	45
2006	10	3	0	0	0	0	0	0	317	50
2007	4	3	0	1	0	0	0	0	86	50
Total	329	284	20	28	54	40	17	12	13842	59
Mean	6.3	5.5	0.4	0.5	1	0.8	0.3	0.2	266	13

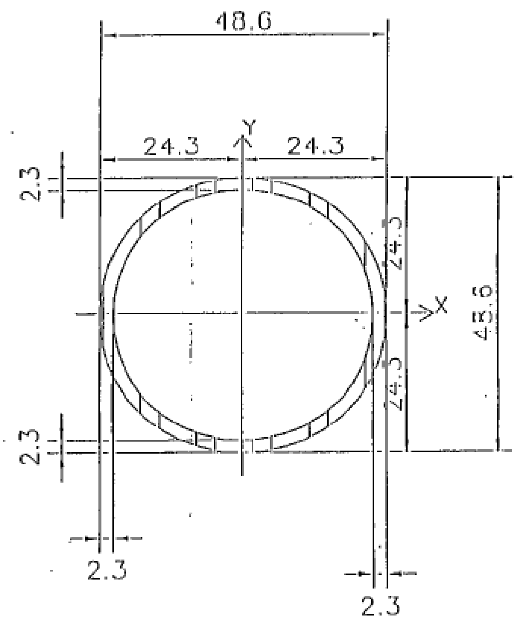
A.4.1 Bill of Materials for MBMSS

Type	**Standard size**	**Use**
Metal tube	● Length: 6 m ● Diameter: approximately 48.6 mm ● Thickness: 2.3 mm	● Main posts and ledgers ● Bracings
Bamboo 'Kao Jue '	● Length: approximately 7-8 m ● Diameter: approximately 37.5 mm (head of bamboo)	● Standards and ledgers ● Transoms (4') ● Catch fan (6')
Clamp	● ∅ = 48.6 mm	● Connect the metal tubes
Nylon tie	● Length: approximately 2 m ● Width: approximately 5 mm ● Tensile strength: 119 kg	● Fasten bamboo and connect bamboo and metal tubes
Pipe joint	● Length: 220 mm ● Diameter: approximately 43 mm	● Extension of metal tubes
Putlogs	● Length: 1 m	● Stabilise the scaffold
Steel tie rod	● Length: approximately 2 m ● Diameter: approximately 6 mm	● Stabilise the scaffold
Nylon net	● Length: approximately 19 m ● Width: approximately 2.5 m	● Cover the scaffold
Zinc sheet	● Length: approximately 2.2 m ● Width: approximately 0.9 m	● Cover the catch fans and protect work platforms
Staircase/ Cat-ladder	● Height: approximately 2.25 m	● Provide access for workers from one level of platform to another.
Catwalk	● Length: 0.5 m, 0.9 m and 1.5m ● Width: 0.5 m	● Provide work platform for workers ● For the installation of toe-boards
Toeboard	● Length: 0.53 m, 0.94 m and 1.55 m ● Height: 200 mm	● Prevent material from falling from catwalk
Steel support bracket	● 80 x 80 x 10L Grade 43, 1000 mm (W) x 700 mm (H) (Various sizes will be used subject to the actual site conditions) ● Fixed to concrete wall by two R20 through bolts.	● Support the scaffold loading

A.4.2 The specification and inspection certificate of the steel tube

APPENDIX

Dia. 48.6 x2.3mm thick g.m.s. CHS



INERTIA ABOUT X–X AXIS :	89867.2 mm^4	INERTIA ABOUT Y–Y AXIS :	89867.2 mm^4
SECTION MODULUS ABOUT X–X AXIS (MINIMUM) :	3698.2 mm^3	SECTION MODULUS ABOUT Y–Y AXIS (MINIMUM) :	3698.2 mm^3
PRODUCT OF INERTIA XY :	0 mm^4	TORSION CONSTANT :	
RADII OF GYRATION X : Y :	16.4 mm 16.4 mm	SECTION NO.:	
CHECKED BY :		SECTION AREA :	334.5 mm^2
APPROVAL BY:		WEIGHT :	2.61kg/m

Figure A.4.2 (a) Specification of tube

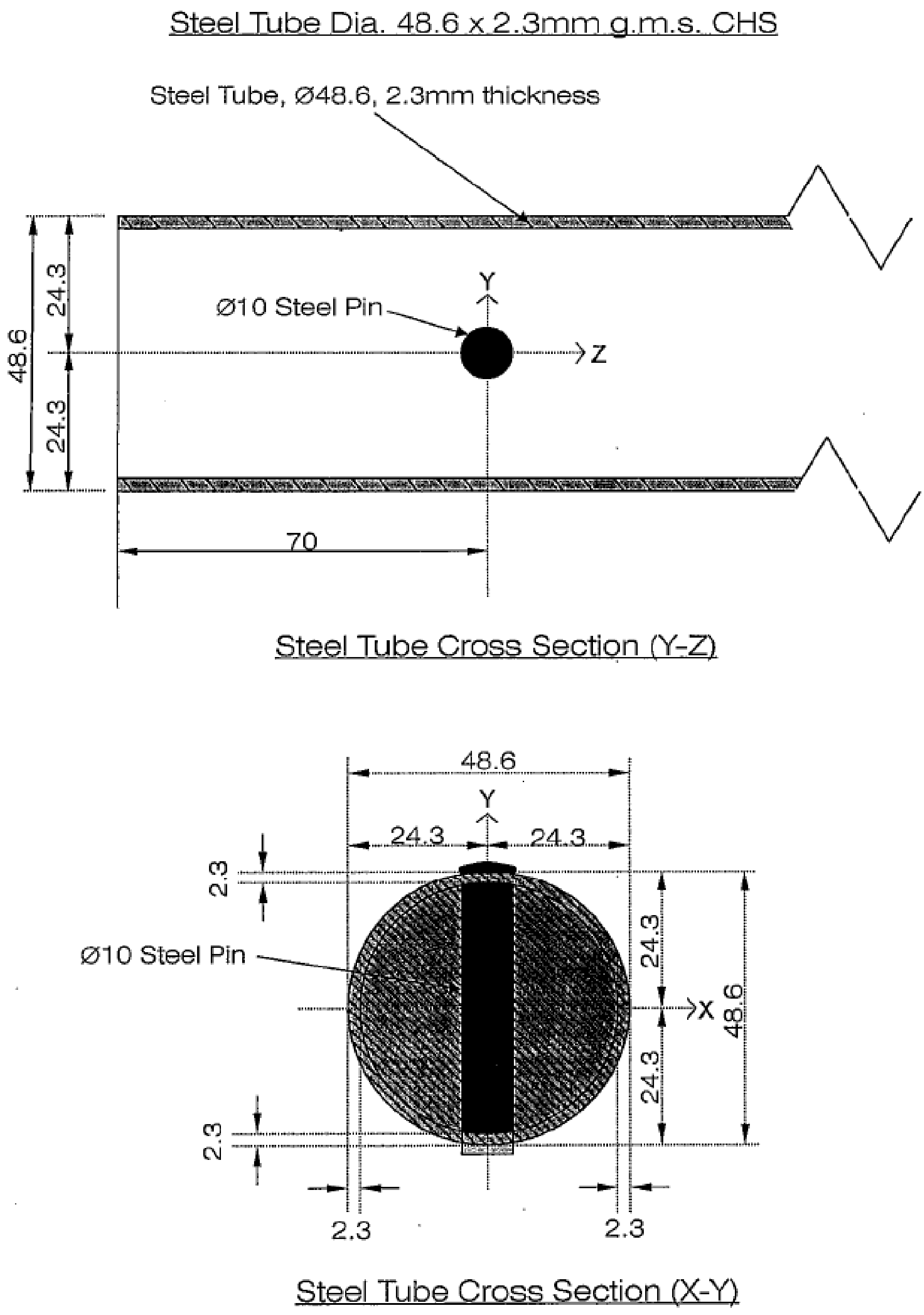


Figure A.4.2 (b) Specification of tube

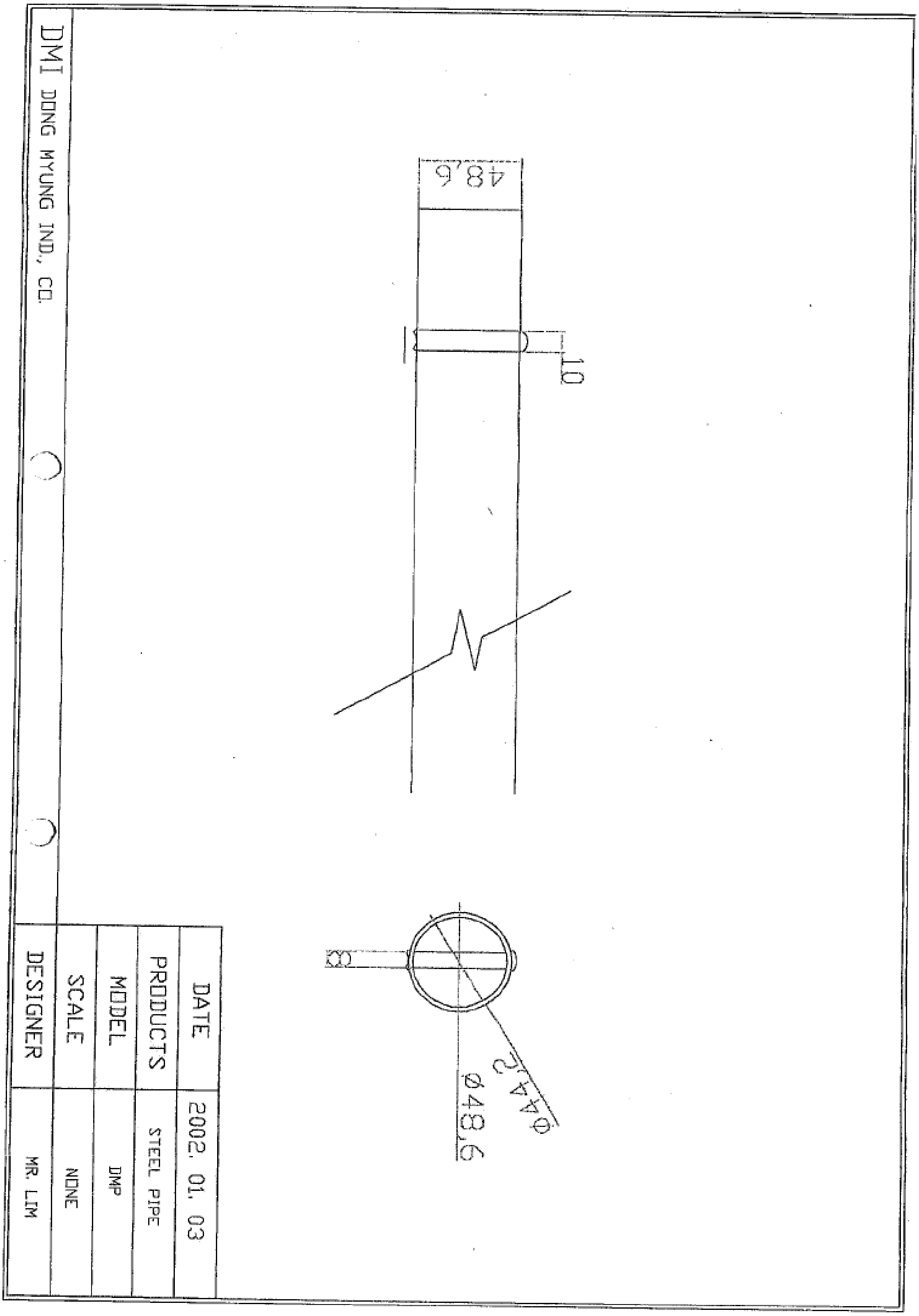


Figure A.4.2 (c) Specification of tube

INSPECTION CERTIFICATE

KOREA INDUSTRIAL SAFETY CORPORATION (KISCO)
ADDRESS : 34-4 Kusan-dong Pupyung-gu Inchon 403-711, Republic of Korea
Tel : 032-5100-500 Fax : 032-518-6484

Date : Jan. 22, 1999
Validity : Jan. 21, 2002
Item : Steel Pipe
Manufacturer : Dong Myung Industrial Co., Ltd.
16-1 Sa Chang Ri Yang Gam Myun Hwa Sung Gun Gyung Gi Do, Korea
Tel : 0339) 352-5260 Fax : 0339) 352-2702

ITEM	RESULT OF TEST		JUDGMENT
	CONTENTS	AVERAGE	
STEEL PIPE	MATERIALS	SPS 51	SPS 51
	THICKNESS	2.2mm	2.3mm
	OUT-DIAMETER	48.3mm	48.6mm
	YIELD POINT	33kg/mm²	35kg/mm²
	Tensile Strength	50kg/mm²	52kg/mm²
	Modulud of Section	3.70kg/mm²	3.83kg/mm²
	Protection of Rust	Zinc Galvanised	Zinc Galvanised

We hereby certify the materials herein has been made and tested in accordance with above specifications and the results of the test are acceptable.

Chief of Safety Certification Center, KISCO

원본대조필

Figure A.4.2 (d) Inspection Certificate of tube

A.4.3 Test Certificate of Catwalk

UniQuest

DEPARTMENT OF CIVIL ENGINEERING
THE UNIVERSITY OF QUEENSLAND
ST LUCIA, QLD. 4072

Page 1 of 3

TEST REPORT : Nº 3036704

REPORT ON	:	Tests on prefabricated platform units
FOR	:	Professor S Kitipornchai, Department of Building & Construction, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong.
REFERENCE	:	Professor S Kitipornchai
SPECIFICATION	:	AS/NZS 1576.3 - 1995, Appendix E

CHECKED BY : ....

APPROVED SIGNATORY : ....

HEAD OF DEPARTMENT : .... DATE : 21/6/01

N.B. A laboratory certificate, statement, or report may not be published except in full, unless permission for publication of an approved abstract has been obtained, in writing, from the Head of Department.

A.4.3(a) Test Report of Catwalk

DEPARTMENT OF CIVIL ENGINEERING
THE UNIVERSITY OF QUEENSLAND
ST LUCIA, QLD. 4072

Page 2 of 3

REPORT Nº 3036704

Two prefabricated platform units were submitted to this department. They were tested to give the following results :-

Test 1 - Point load 100 x 100mm at centre of unit

Loading	Deflection (mm)	
	Platform 1	Platform 2
Apply 2 kN load	5.30	4.90
2 kN for 15 mins	5.32	4.90
Remove load - permanent deformation	0.06	0.06

Test 2 - Point load 100 x 100mm at edge of unit (mid span)

Loading	Deflection (mm)	
	Platform 1	Platform 2
Apply 2 kN load	11.06	12.80
2 kN for 15 mins	11.05	13.35
Remove load - permanent deformation	0.08	0.45

Test 3 - Uniformly distributed load over middle 1/3

Loading	Deflection (mm)	
	Platform 1	Platform 2
Apply 4 kN load	8.15	5.50
4 kN for 15 mins	8.17	5.58
Remove load - permanent deformation	0.00	0.10

Tests conform with AS/NZS 1576.3 - 1995, Clause 4.2.5 - Prefabricated platform units

A.4.3(b) Test Report of Catwalk

DEPARTMENT OF CIVIL ENGINEERING
THE UNIVERSITY OF QUEENSLAND
ST LUCIA, QLD. 4072

REPORT Nº 3036704

Load-deflection tests were carried out to destruction on both platforms, Centre Test - Test 4 and Edge Test - Test 5. Loading was applied through a 100 x 100mm loading pad as for Tests 1 & 2.

Note : Test 4 failure mode was buckling through centre beams.
Test 5 failure mode was splitting of edge beam.

Pictures were sent to S.Kitipornchai@cityu.edu.hk.
The results are shown in the accompanying graph.

A.4.3(c) Test Report of Catwalk

A.5.1(a) Copy of Grant of Patent for United Kingdom

PATENTS • DESIGNS • The Patent Office • COPYRIGHT • TRADE MARKS

Certificate of Grant of Patent

Patent Number: GB2355752

Proprietor(s): Wui Loong Scaffolding Works Co Ltd

Inventor(s): Yu S So

This is to Certify that, in accordance with the Patents Act 1977,

a Patent has been granted to the proprietor(s) for an invention entitled "**Scaffolding**" disclosed in an application filed **28 July 2000**.

Dated 4 July 2001

THE PATENT OFFICE

DIEU ET MON DROIT

Alison Brimelow
Comptroller General of Patents,
Designs and Trade Marks
UNITED KINGDOM PATENT OFFICE

The attention of the proprietors(s) is drawn to the important notes overleaf.

A.5.1(b) Copy of Grant of Patent for Hong Kong

CERTIFICATE OF GRANT OF PATENT
批予專利證明書
Patents Ordinance (Chapter 514)
專利條例 **(第 514 章)**
STANDARD PATENT 標準專利

I hereby certify that a standard patent with the following particulars has this day been granted 茲證明下述標準專利在今日批予:

Name and Address of Proprietor 專利所有人姓名或名稱及地址:
Wui Loong Scaffolding Works Co Ltd
Rooms 601-6, 6th Floor
Pacific Link Tower, Southmark
11 Yip Hing Street
Wong Chuk Hang, Aberdeen
HONG KONG

Patent No.專利編號 **: HK1045721** **Application No.**申請編號 **: 02107303.5**

Title of Invention 發明名稱 **:**
SCAFFOLDING
棚架

Term of Standard Patent 標準專利有效期 **:**
Twenty years commencing on 28.07.2000
由 28.07.2000 年起計 20 年

Please see the important notes overleaf 請細閱背頁的專利所有人須知
IP 336

A.5.1(b) Copy of Grant of Patent for Hong Kong

Continuation Sheet for the Certificate of Grant of Patent No. 1045721
標準專利號 **1045721** 的專利批予證明書續頁

Dated this 20th March, 2008
二零零八年三月二十日

Stephen Selby
Registrar of Patents
專利註冊處處長謝肅方

Patents Registry
Intellectual Property Department
The Hong Kong Special Administrative Region
香港特別行政區知識產權署專利註冊處

Please see the important notes overleaf 請細閱背頁的專利所有人須知

IP 336

A.5.1(c) Copy of Grant of Patent for People's Republic of China

证书号第267374号

北京市海淀区地方税务局 印花税代扣专用章 国家知识产权局

发明专利证书

发明名称：脚手架及其建造方法

发明人：苏汝成

专利号：ZL 00 8 00169.3

专利申请日：2000年7月28日

专利权人：汇隆棚业有限公司

授权公告日：2006年6月7日

本发明经过本局依照中华人民共和国专利法进行审查，决定授予专利权，颁发本证书并在专利登记簿上予以登记。专利权自授权公告之日起生效。

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局长 田力普

中华人民共和国国家知识产权局

2006年6月7日

第1页(共1页)

A.6.1 Summary of Maximum Gust Peak Speeds and Maximum Hourly Mean Winds of Kammuri on 6 August 2008 (Hong Kong Observatory)

Station	Maximum Gust				Maximum Hourly Wind			
	Direction	Speed (km/h)	Date/Month	Time	Direction	Speed (km/h)	Date/Month	Time
Bluff Head (Stanley)	NNE	113	6/8	03:41	ENE	62	6/8	09:00
Central Pier	E	96	6/8	08:28	E	56	6/8	08:00
Cheung Chau	NE	124	6/8	09:13	ENE	83	6/8	10:00
Cheung Sha Wan	NE	96	6/8	08:14	NE	31	6/8	05:00
					NE	31	6/8	06:00
Green Island	ENE	126	6/8	06:56	ENE	56	6/8	08:00
Hong Kong International Airport	E	90	6/8	08:44	E	58	6/8	12:00
Kai Tak	NE	101	6/8	05:26	E	47	6/8	11:00
King's Park	ESE	85	6/8	10:32	E	36	6/8	10:00
Lau Fau Shan	E	92	6/8	10:25	E	47	6/8	12:00
	E	92	6/8	11:43				
Ngong Ping	ENE	227	6/8	10:09	E	166	6/8	11:00
North Point	E	101	6/8	08:03	E	52	6/8	09:00
Peng Chau	NE	112	6/8	07:12	ENE	75	6/8	09:00
Ping Chau	ENE	75	6/8	05:59	E	25	6/8	06:00
Sai Kung	NE	104	6/8	07:23	ENE	58	6/8	08:00
Sha Chau	E	83	6/8	12:12	E	54	6/8	13:00
Sha Lo Wan	E	103	6/8	08:27	E	54	6/8	12:00
Sha Tin	NE	77	6/8	08:41	NE	30	6/8	09:00
Shek Kong	E	92	6/8	10:29	E	40	6/8	10:00
					E	40	6/8	12:00
Star Ferry (Kowloon)	ESE	90	6/8	10:24	E	54	6/8	10:00
Ta Kwu Ling	ENE	85	6/8	09:12	ENE	31	6/8	08:00
Tai Mo Shan	E	146	6/8	08:56	E	96	6/8	11:00
Tate's Cairn	E	142	6/8	06:25	E	96	6/8	11:00
	E	142	6/8	10:08				
Tsak Yue Wu	ENE	65	6/8	07:35	NE	20	5/8	23:00
Tseung Kwan O	NE	85	6/8	05:26	NE	27	6/8	03:00
Tsing Yi Shell Oil Depot	ESE	85	6/8	10:13	ESE	31	6/8	11:00
Tuen Mun Government Offices	SE	79	6/8	19:59	SE	31	6/8	22:00
Waglan Island	E	140	6/8	06:44	E	96	6/8	07:00
Wetland Park	E	75	6/8	11:19	ENE	34	6/8	08:00
Wong Chuk Hang	ESE	101	6/8	10:17	ESE	45	6/8	12:00

A.6.2 Summary of Maximum Gust Peak Speeds and Maximum Hourly Mean Winds of Nuri on 22 August 2008 (Hong Kong Observatory)

Station	Maximum Gust				Maximum Hourly Wind			
	Direction	Speed (km/h)	Date/Month	Time	Direction	Speed (km/h)	Date/Month	Time
Bluff Head (Stanley)	SSW	118	22/8	19:54	SSW	75	22/8	20:00
Central Pier	WNW	90	22/8	11:44	NW	43	22/8	12:00
Cheung Chau	SSW	126	22/8	22:18	SSW	88	22/8	23:00
Cheung Sha Wan	SW	96	23/8	00:10	SW	54	22/8	21:00
Green Island	SSW	144	22/8	23:06	SW	110	22/8	21:00
Hong Kong International Airport	SSW	112	23/8	01:11	SSW	76	23/8	01:00
Kai Tak	N	118	22/8	13:08	N	47	22/8	13:00
King’s Park	NNE	118	22/8	10:51	SSW	49	22/8	21:00
Lau Fau Shan	N	92	22/8	08:28	N	49	22/8	09:00
Ngong Ping	SW	196	22/8	23:31	SW	128	23/8	01:00
North Point	NNE	110	22/8	12:02	NNE	54	22/8	14:00
Peng Chau	N	112	22/8	10:32	NNW	62	22/8	12:00
					NNW	62	22/8	14:00
Ping Chau	ENE	108	22/8	13:32	E	34	22/8	15:00
Sai Kung	NNE	148	22/8	13:33	NNE	87	22/8	14:00
Sha Chau	NNW	128	22/8	12:36	N	94	22/8	15:00
	SSW	128	23/8	01:12				
Sha Lo Wan	SW	135	23/8	01:10	SW	65	23/8	02:00
Sha Tin	SW	101	22/8	21:27	SSW	45	22/8	21:00
Shek Kong	NNE	76	22/8	14:10	N	38	22/8	15:00
Star Ferry (Kowloon)	WSW	104	22/8	20:00	S	34	22/8	21:00
	SW	104	22/8	21:12				
Ta Kwu Ling	NNE	87	22/8	13:26	N	40	22/8	14:00
Tai Mei Tuk	SW	144	22/8	20:25	NE	79	22/8	14:00
Tai Mo Shan	SSW	144	22/8	20:53	N	96	22/8	13:00
Tap Mun	NE	121	22/8	13:33	NE	62	22/8	14:00
Tate’s Cairn	N	193	22/8	13:45	N	122	22/8	14:00
Tsak Yue Wu	NNE	106	22/8	11:48	NNE	45	22/8	12:00
Tseung Kwan O	N	90	22/8	12:08	N	31	22/8	13:00
Tsing Yi Shell Oil Depot	NNW	101	22/8	10:06	NNW	56	22/8	13:00
Tuen Mun Government Offices	SSW	96	23/8	02:39	S	36	23/8	01:00
					S	36	23/8	02:00
Waglan Island	SSW	157	22/8	19:32	SSW	115	22/8	20:00
Wetland Park	N	94	22/8	12:08	N	41	22/8	14:00
Wong Chuk Hang	N	88	22/8	11:32	NNW	31	22/8	13:00