UNIVERSITI SAINS MALAYSIA

PEJABAT PENGURUSAN & KREATIVITI PENYELIDIKAN
RESEARCH CREATIVITY AND MANAGEMENT OFFICE [RCMO]

LAPORAN AKHIR PROJEK PENYELIDIKAN JANGKA *PENDEK*
FINAL REPORT OF SHORT TERM RESEARCH PROJECTS

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1) **Nama Ketua Penyelidik** :
Name of Research Leader :

Ketua Penyelidik *Research Leader*	PTJ *School/Centre*
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Nama Penyelidik Bersama
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2) **Tajuk Projek** : Analysis on Structural Integrity and Stability of a High Rise Building Subjected to Hydraulic Loading from Rooftop Rainwater Harvesting (RRWH) Storage
Title of Project:

3) **Abstrak untuk penyelidikan anda**

(Perlu disediakan di antara 100 – 200 perkataan di dalam **Bahasa Malaysia dan Bahasa Inggeris.** Ini kemudiannya akan dimuatkan ke dalam Laporan Tahunan Bahagian Penyelidikan & Inovasi sebagai satu cara untuk menyampaikan dapatan projek tuan/puan kepada pihak Universiti & luar).

Abstract of Research

(Must be prepared in 100 – 200 words in Bahasa Malaysia as well as in English. This abstract will later be included in the Annual Report of the Research and Innovation Section as a means of presenting the project findings of the researcher/s to the university and the outside community)

Water is an essential element to life. With the arising amount of water demand and at risk of water pollution, water has changed from one of the relative abundance to one of the relative scarcity. Even though Malaysia receives plentiful rainfall every year, two extreme of acute water crisis such as flooding and water shortage is expected to be encountered. To pursue a sustainable development, rainwater harvesting has been proposed as the innovative solution. Two study sites are selected in two developed regions in Malaysia, namely Klang Valley and Penang. The RRWH tank is sized based on Swinburne Method and Supply Side Method by taking into consideration the requirements for water quantity control and water reuse. The integration of rooftop rainwater harvesting tank in the studied buildings are modeled and analysed by using EsteemPlus software. The structural responses resulted from the impact of the installation of rainwater harvesting tank are investigated.

4) Sila sediakan Laporan teknikal lengkap yang menerangkan keseluruhan projek ini. [Sila gunakan kertas berasingan]

Kindly prepare a comprehensive technical report explaining the project (Prepare report separately as attachment)

Senaraikan Kata Kunci yang boleh menggambarkan penyelidikan anda :

List a glosssary that explains or reflects your research:

Bahasa Malaysia	Bahasa Inggeris
Penggunaan Semula Air Hujan	Rainwater Harvesting
Bangunan Tinggi	High Rise Building
Lestari	Sustainable

5) **Output Dan Faedah Projek**

Output and Benefits of Project

(a) * Penerbitan *(termasuk laporan/kertas seminar)*

Publications (including reports/seminar papers)

(Sila nyatakan jenis, tajuk, pengarang, tahun terbitan dan di mana telah diterbit/dibentangkan).

(Kindly state each type, title, author/editor, publication year and journal/s containing publication)

Lau Tze Liang, Taksiah A. Majid, Choong Kok Keong, Nor Azazi Zakaria, Aminuddin Ab. Ghani, (2005), "Study on a High Rise Building Incorporated with Rainwater Harvesting Storage Tank towards Building a Sustainable Urban Environment in Malaysia", The 2005 World Sustainable Building Conference in Tokyo (SB05Tokyo), pp 3312-3319, 27-29 September 2005, Tokyo, Japan

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(b) **Faedah-Faedah Lain Seperti Perkembangan Produk, Prospek Komersialisasi Dan Pendaftaran Paten atau impak kepada dasar dan masyakarat.**

Other benefits such as product development, product commercialisation/patent registration or impact on source and society

* Sila berikan salinan

* *Kindly provide copies*

7. **Untuk Kegunaan Jawatankuasa Penyelidikan Universiti**

:

PROF. MADYA DR. WAN HASHIM WAN IBRAHIM
Dekan
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T/TANGAN PENGERUSI
J/K PENYELIDIKAN PUSAT PENGAJIAN

Pulau Pinang.

CHAPTER 1
INTRODUCTION

1.1 Research Background

Water is an essential element to life. Water covers approximately three quarter of the earth's surface. The growth in water need is outstripping available supply resulting in the rapid pace of urbanization and industrialization. High populations have the effects of reducing the water quality of rivers due to humanity pollutes.

The study published by United Nations in 1997 stated that:

(i) Two thirds of the world's population is likely to live in countries with moderate or severe water shortages by 2025,

(ii) Half of the world's population lives in urban areas today with 18,000 additional urban dwellers in the world everyday. It is expected by 2008, the figure will exceed more than 50 % of the world population.

These issues need to be addressed urgently since water scarcity will cause negative impact to the socio-economic, stability and harmony of the community of the world.

During World Day for Water 2002, the Secretary-General of United Nations, Kofi Annan, has expressed his concern regarding the world's water problems and worry on the new violent conflict prompted by water issues in his message as follows (United Nation, 2002):

(i) An estimated 1.1 billion people lack access to safe drinking water,

(ii) 2.5 billion people have no access to proper sanitation, and

(iii) More than 5 million people die each year from water-related diseases, which is 10 times the number killed in wars, on average, each year.

In Malaysian context, we are moving towards achieving a developed nation status by the year 2020 following the rapid socio-economic growth in the last two decades. With a present estimated total of 21 million people, the Malaysian population is expected to escalate to 30 million in 2020 and, cities and towns may reach 55-60 % of the total population. Malaysia is blessed with plentiful water resources with an average annual rainfall of 3000 mm or 990 billion m^3 over the Malaysian land mass amounts, of which 566 billion m^3 becomes surface runoff, 64 billion m^3 recharges the aquifers and 360 billion m^3 returns to the atmosphere (Abdullah & Mohamed, 1998). 97 % of the raw water supply originates from surface water sources.

The overall water demand is growing at the rate of 4 % annually, and projected to be about 20 billion m^3 by 2020. Even though this volume is less than 2 % of annual runoff, due to the variation of rainfall both in time and space and the development of resources could not meet the rapid pace of urbanization and industrialization. It has indicated that by 2025, a country that has abundance of water such as Malaysia is not spared from this impending water crisis (Abdullah & Mohamed, 1998).

Even though Malaysia is rich in water resources, but who would have imagined water fluctuations due to uneven distribution of rainfall do happen in Malaysia. Some urban regions of high water demand such as Klang Valley has encountered water scarcity over the past few years culminating in the water crisis in early 1998. Conversely, due to excess water from too much rainfall, Malaysia is experiencing frequent flash flood which is grown with the development. As a result, the urbanization has become a cause of tension to the sustainable development.

The crisis driven development of water resources is not cost effective and should not be a strategy to overcome the frequent occurrences of water stress. The management of water resources to cater for current and future needs and for emergencies should be carried out under properly developed policies and strategies. The management of water resources should be an important component of long-term water crisis rather than to cope with the immediate effects of water shortage under a crisis situation.

On 7th May 1998, the Minister of Housing and Local Government has expressed the Government's interest for buildings/houses to be designed for collecting rainwater following this Water Crisis (Abdullah, Mohamed, 1998). In 1999, the Ministry of Housing and Local Government has produced a Guideline on Installing a Rainwater Collection and Utilization System.

Rainwater harvesting has been a traditional practice in some cultures for centuries and as such many technologies are available as a result of a long evolutionary process. Even the current resurgence of interest in rainwater harvesting as a source of water supply has been in existence for over twenty-five years.

Domestic rainwater harvesting is a solution to the problems of overexploitation of water resources and has been working apace to implement user-friendly, reliable and high quality systems in a cost-effective manner. The average annual rainfall over Malaysian land mass amounts to 990 billion m^3, 58% becomes surface runoff. Therefore, as an appreciation for this precious given resource, the development of inexpensive and sustainable water supply

technologies such as Rooftop Rainwater Harvesting (RRWH) system is suitable to be addressed in Malaysia.

It is worth bearing in mind that RRWH is a viable method to conserve water. It can be introduced as part of a wider drinking or portable use water supply program as the user realizes the benefits of a clean, reliable water source. In many cases RRWH has been introduced as part of an integrated water supply system, where the town supply is unreliable or where local water sources dry up for a certain part of a year. Apart from this, it is also often used as the sole water source for a community or household. It is a technology which is flexible and adaptable to a very wide variety of conditions.

However, installation of a RRWH system on a structure must also be considered from a structural point of view. Water load from large RRWH tanks on the top roof of an existing high rise building would certainly impose a huge additional weight that is not catered for, in the original design. Designers, engineers and general public are still doubtful and argue on the extra hydraulic load on building from the application of rainwater harvesting especially on the roof and other related members until today. Generally, if entire building has to be designed to cater for such extra loading of rainwater harvesting storage, large scale of structure is required and the project will become very costly. However, there is very limited published information describing the structural impact of this issue. Hence, this project is initiated in order to assess the integrity of a building with/without storage tank in term of bending moment and shear force distributions, deflection and displacement of members in the entire building.

1.2 Research Objectives

The main objective of this research is to formulate relationship and criteria for rainwater storage for water reuse and flood control purposes. To meet the general objective, the following specific objectives are carried out as follows:

I. To study the impact of urbanization on the stormwater management and the development of RRWH technique,
II. To study and evaluate the impact of rooftop rainwater storage in a high rise building on its structural integrity and stability,
III. To formulate a relationship and criteria to minimize this impact., and
IV. To formulate a criteria to optimize the rainwater storage in a high rise building.

CHAPTER 2
LITERATURE REVIEW

2.1 Water Scenario in Malaysia

In Malaysia, the two most significant natural hazards in terms of economic losses are water related, they are floods and drought. These phenomena are due to the extremes of water, whereby floods are due to excess water from too much rainfall, whilst drought is associated with a lack of water from too little rainfall.

The acute water shortages which occurred in many parts of our country during the first half of 1998s highlighted the contribution of water towards sustaining the ecosystems, healthy living and the successes of commercial and industrial activities.

Over the past few decades, the water situation for our country has changed from one of relative abundance to one of relative scarcity (Abdullah & Mohamed, 1998). This is because population growth, rapid urbanization and industrialization are imposing rapidly growing demands and pressure on the water resources, apart from contributing to the rising problem of water pollution. The problem is not generally associated with inadequacy of water resources, but more on water use, water management, water quantity, water quality, water treatment, distribution facilities and capacity building.

2.1.3 Floods

Flash floods in Malaysia are subjected to intense short duration rainfall. They are the effects of rainfall resulting in excess water running into streams and rivers. Uncontrollable development activities along river corridors can increase the rate of sedimentation in the rivers.

It is estimated that 29,000 km^2 or 9 % of the total land area in Malaysia is flood prone, affecting 2.7 million people (Abdullah & Mohamed, 1998). Incidences of flash floods in urban areas are on the rise. This is due to the landuse changes from pervious areas originally into impervious areas as urbanisation and industrialisation take place. A study has revealed that an increase in area imperviousness from zero to 10 % would cut time to peak flow discharge by about 50% and increase the discharge magnitude by about 90 % (Abdullah & Mohamed, 1998). The allocation for flood mitigation project has exceeded RM6000 million for the 8th Malaysia Plan. In the year 2000, Department of Irrigation and Drainage, Malaysia has published the new urban drainage guideline namely Urban Stormwater Management Manual

for Malaysia (USMM) to preserve the urbanized areas in a sustainable urban environment and achieve the aim of "Zero Flash Flood" by 2010.

2.1.1 Water Shortages

This refers to the interruption of treated water supply. The main reasons for the recent water crisis in the Klang valley were due to 3 main factors. The first factor is the development of the resource and treatment facilities could not meet the rapid pace of urbanization and industrialization. Second, a prolonged drought causing the reduction of flows in the rivers, these resulted in shortfalls in water supply. Lastly, river pollution levels exceeded the threshold of treatment resulting in the frequent closures of water treatment plants which obtained raw water from the run-of-the-river intakes; and unaccounted for water losses due to leakages in the distribution systems and old pilferages and inefficient leak-detection and repairs.

The severe drought in 1998, in particular affected 1.8 million residents in southern Kuala Lumpur City, Bangi and Kajang, bringing in its wake some periods of disruption water supply (Shaaban & Low, 2003). The drought also hit other areas in Malaysia such as Penang, Kedah, Kelantan, Sarawak and Sabah. A guideline for installing a rainwater collection and utilization system is then published by the Ministry of Housing and Local Government (KPKT).

The recent study on water resources for Selangor and Kuala Lumpur shows that the present water resources for Selangor and Kuala Lumpur are adequate to meet the water demand up to the year 2007 and the quality of water supplied is in full compliance with World Health Organisation International Standards for Drinking Water as outlined in Figure 2.1. The demand for Selangor and Kuala Lumpur grows at an average rate of 6% per year. Beyond 2007, the State Government, together with the Federal Government, is planning to source water from a neighbouring state (Subramaniam, 2004).

2.1.2 Water Pollution

It is a known fact that humanity pollutes much of the available fresh water resources. High population and rapid urbanization and industrialization have the effects of reducing the water quality of rivers due to indiscriminate dumping of wastes by all water user sectors into the rivers. This has increased the rate of erosion as a result of land development which causes the siltation of rivers.

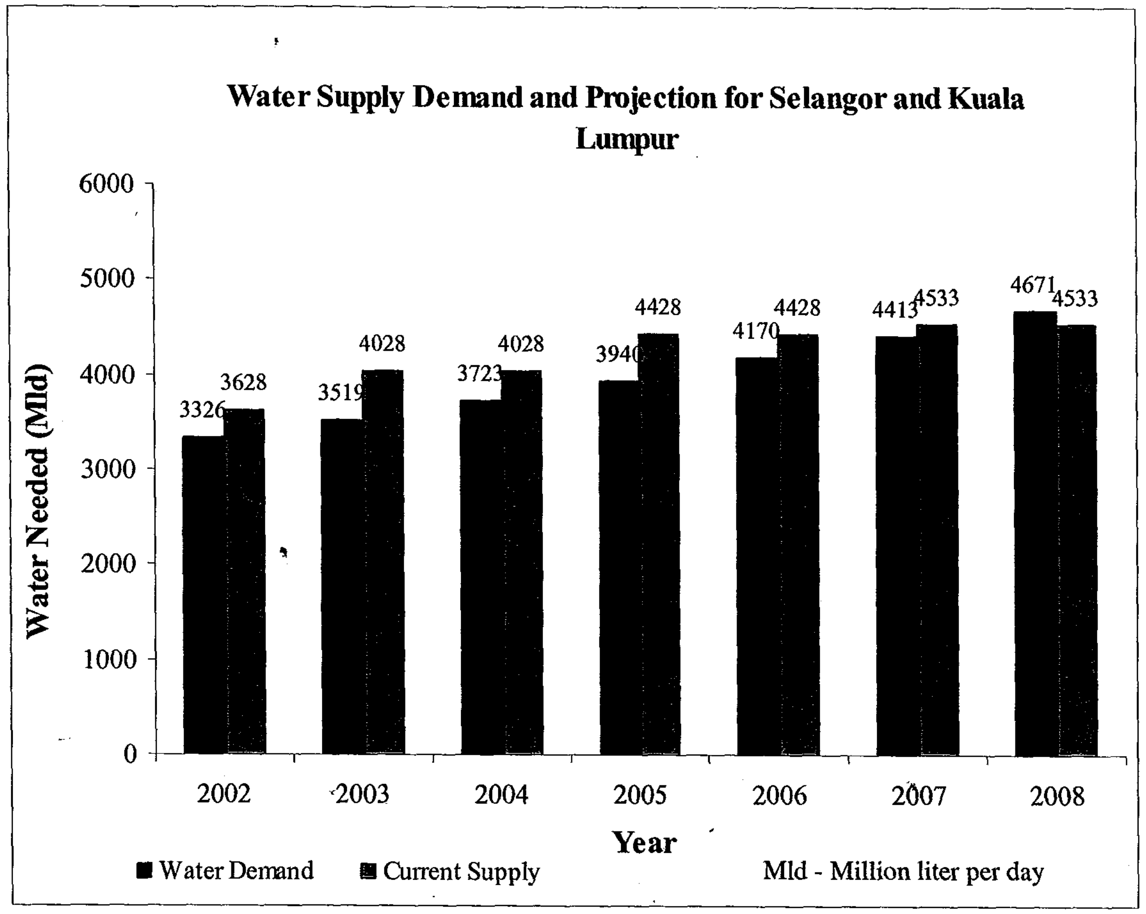

Figure 2.1: Water Supply Demand and Projection for Selangor and Kuala Lumpur (Subramaniam, 2004)

As water pollution increases, it generally leads to three effects namely increase in water 'quantity scarcity', increase in water treatment costs and erosion of the ecological health of the water bodies and the surrounding eco-systems which will affect the aquatic habitat and the safety of recreational activities.

2.1.4 Water Management

Water management is becoming increasingly comprehensive and complicated due to larger concentrations of population. Commercial activities and industries around the cities and towns have increased the water consumption, water pollution, land use conflicts and also climate changes.

There are two methods to solving the problem which are, a *supply management*, whereby new supply sources are tapped to meet increasing demand; or a *demand management*, whereby efforts are directed towards managing the demand to keep it within available supply sources.

Rainwater harvesting system is an adoptable solution for supply management where it provides a relatively clean water supply source and it is easily accessibly throughout the whole year in Malaysia.

2.2 Rooftop Rainwater Harvesting System

Water is the most precious natural resource. It is always treated as an infinite free resource and taken for granted by the people. With hastily increased population all over the world, the people would compete over clean water supply for survival in the future. With its limited supply, the rainwater harvesting technique is one of the other alternatives to manage and conserve water for a secure and sustainable future.

The rainwater harvesting is not a new technique to collect and store water for later use. It has been adopted thousands of years ago by our ancestors when the piped water system is not in existence. It is still in practice for certain areas where water supplies are scare, expensive or of poor quality or in island nations as the sole domestic water source. The harvesting of rainwater involves the collection of rainwater from catchment, conveying this water to storage tank and subsequent delivery.

The current resurgence of rainwater harvesting as a source of water supply has been applied for over twenty-five year or more over the world. There are numerous innovative systems to satisfy the identified needs and achieve high reliability. Various design methods and models have been established based on localized water balance.

In 1998, drought which is due to lack of rainfall had invaded Klang Valley. It was unpredictable for a humid tropical country such as Malaysia where rainfall is abundant (annual rainfall 2400mm for Peninsular Malaysia). Such water fluctuations which brought unpleasant water supply disruptions for Klang Valley folks. Due to this water crisis, the Minister of Housing and Local Government has stressed on the Government's interest for building/houses to be designed for collecting rainwater.

2.2.1 History of Rooftop Rainwater Harvesting System

A sufficient, clean drinking water supply is essential to life and yet millions of people throughout the world continue to work hard on this effort but are still insufficient to access to this basic necessity.

Rooftop Rainwater Harvesting (RRWH) is an option which has been adopted in many areas of the world where conventional water supply systems have failed to meet the needs of the people due to pollution of water supplies either through industrial or human wastes or by intrusion of minerals such as arsenic or fluoride. The growth in water need is outstripping available supply resulting in rapid urbanization and industrialization (Appan, 1999).

RRWH system is a technique which has been used since antiquity and examples of RRWH system can be found in all the great civilizations throughout history. The technology can be as simple or complex depending on its requirement. Traditionally, in Uganda and in Sri Lanka rainwater is collected from trees, using banana leaves or stems as temporary gutters up to 200 liters may be collected from a large tree in a single storm (Appan et. al., 1987). With the growth in corrugated iron roofing in many developing countries, people often place a small container under their eaves to collect falling water during a storm one 20 liter container of clean water captured from the roof can save a walk of many kilometers to the nearest clean water source. In the industrialized countries of the world, sophisticated RRWH systems have been developed with the aim of reducing water bills or meeting the needs of remote communities or individual households in arid regions. Many individuals and groups have taken the initiative and developed a wide variety of different RRWH systems throughout the world.

2.2.2 RRWH System

Rooftop rainwater harvesting are mainly used in low and medium rise building, if there are high rise building, the storage tank normally located on the ground (basement) or underground. This is probably because there are still some doubts about whether the structure can or can not withstand the extra water load on top of the high rise building.

In some cultures, rainwater harvesting has been a traditional practice for centuries and many technologies are developed from the long evolutionary process. The techniques usually found in Asia and Africa arise from practices employed by ancient civilizations within these regions and still serve as a major source of drinking water supply in rural areas. As a result a number of technologies have become accepted in rainwater harvesting practice. Some of these are modifications of designs that go back into antiquity while others have been developed more recently. Rainwater harvesting systems can roughly be broken down into 4 primary processes and 3 treatment processes as shown in Figure 2.2.

In the most basic form of rainwater harvesting system, rainwater is collected in simple vessels at the edge of the roof, or collection of rainwater in gutters which drain to the collection vessel through down-pipes constructed for this purpose (Figure 2.3). The amount and quality of rainwater collected depends on the area and type of roofing material. Most losses are through infiltration, although some water will also bounce off the edge of the surface in heavy rain and usually some water will be lost in wetting the surface. The loss is usually represented by a "run-off coefficient" C_R which is a number between zero and one: (1- C_R) expresses the loss fraction averaged over a year (Warwick, 2004). This means that the higher the value of C_R the lesser water lost from the harvesting system. Table 2.1 gives the characteristics of various types of roof and their associated runoff coefficients.

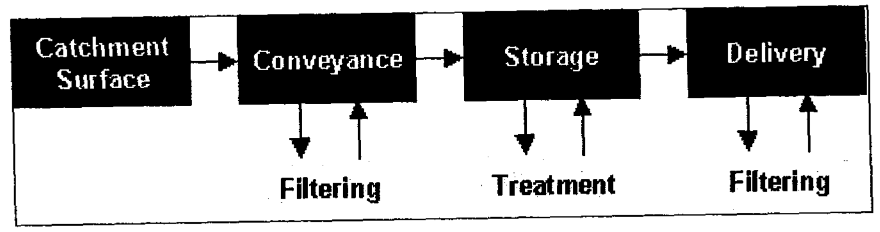

Figure 2.2: Process Diagram of Domestic Rainwater Harvesting Systems (University of Warwick, 2004)

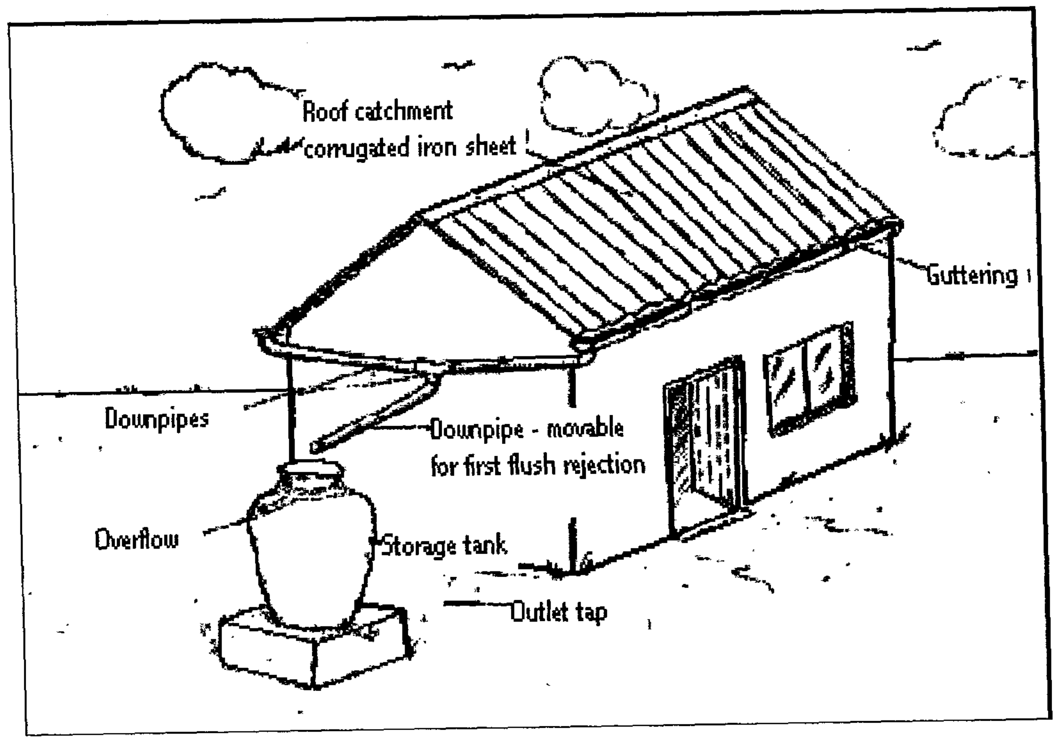

Figure 2.3: Typical Very Low Cost Roofwater Harvesting System In a Developing Country (University of Warwick, 2004)

Pure rainwater can be collected from roofs constructed with galvanized corrugated iron, aluminium or asbestos cement sheets, tiles and slates. Roofs with metallic paint or other coatings are not recommended as they may cause tastes or colour to the collected water. Roof catchments should also be cleaned regularly to remove dust, leaves and bird droppings so as to maintain the quality of the product water.

Usually, the main calculation when designing a RWH system will be to size the water tank correctly to give adequate storage capacity. The storage requirement will be determined by a number of interrelated factors. They include:

- local rainfall data and weather patterns
- roof (or other) collection area
- runoff coefficient (this varies between 0.5 and 0.9 depending on roof material and slope)
- user numbers and consumption rates

Table 2.1: Characteristics of Roof Types (University of Warwick, 2004)

Type	Runoff Coefficient	Notes
GI Sheets	>0.9	• Excellent quality water. Surface is smooth and high temperatures help to sterilise bacteria
Tile (glazed)	0.6 - 0.9	• Good quality water from glazed tiles. • Unglazed can harbour mould • Contamination can exist in tile joins
Asbestos Sheets	0.8 - 0.9	• New sheets give good quality water • No evidence of carcinogenic effects by ingestion • Slightly porous so reduced runoff coefficient and older roofs harbour moulds and even moss
Organic (Thatch, Cadjan)	0.2	• Poor quality water (>200 FC/100 ml) • Little first flush effect • High turbidity due to dissolved organic material which does not settle

In support on Government's interest in rainwater collection for potable use later, National Hydraulic Research Institute of Malaysia (NAHRIM), a division of the Ministry of Natural Resources And Environment is currently pursuing research and development on rainwater

harvesting together with the collaborative arrangement between Department of Irrigation and Drainage and local universities. Various subsystem of this rainwater harvesting system is shown in Figure 2.4.The main components of RRWH system are as follows:

- Catchment subsystem (normally the rooftop).
- Conveyance subsystem – Used to convey the rainwater from the catchments subsystem to the storage tanks).
- Filtration – Used to filter out dirt, bird droppings, leaves and other materials in the rainwater
- Storage tank – A reservoir used to store all the rainwater after undergoing filtration.
- Booster pump – Used to pump water from the storage tanks to the roof tank and roof tank
- An additional tank to the existing domestic roof tank – Provided separate rainwater supply for non-potable household use.

Table 2.2 shows the quality comparison of the samples of the rainwater collected in the storage tank with World Health Organization (WHO) Drinking Water Quality Guidelines (NAHRIM, 2002). The results show that the pH which ranges from 6.26 to 6.62 is reasonable. The hardness in between 8.6 to 32.6 is considered as low. The manganese and iron contents are low as well. Toxic metals such as cadmium at less than 0.001 mg/l is below the WHO Guideline while lead at < 0.05 mg/l is above the WHO Guideline. The Faecal Coliform at 20 counts per 100 ml shows contamination from some animals. This has proven that the rainwater been collected is safe for non-potable use. It can therefore be used for, washing clothes, car washing, plant watering, and general cleaning around the house.

2.2.3 Water Demand

The amount of rainwater to be used for non-portable purposes should be estimated as in order to find out the required rainwater storage volume. The demand depends on the type and usage of the entire building and the number of occupancy.

The guideline published by the Ministry of Housing and Local Government (KPKT, 1999) recommends minimum rainwater harvesting storage capacity as given in Table 2.3. The minimum storage capacity is based on usage for toilet flushing, watering plants, washing vehicles and general cleanings. It is based on the location having rain once every 4 days on the average.

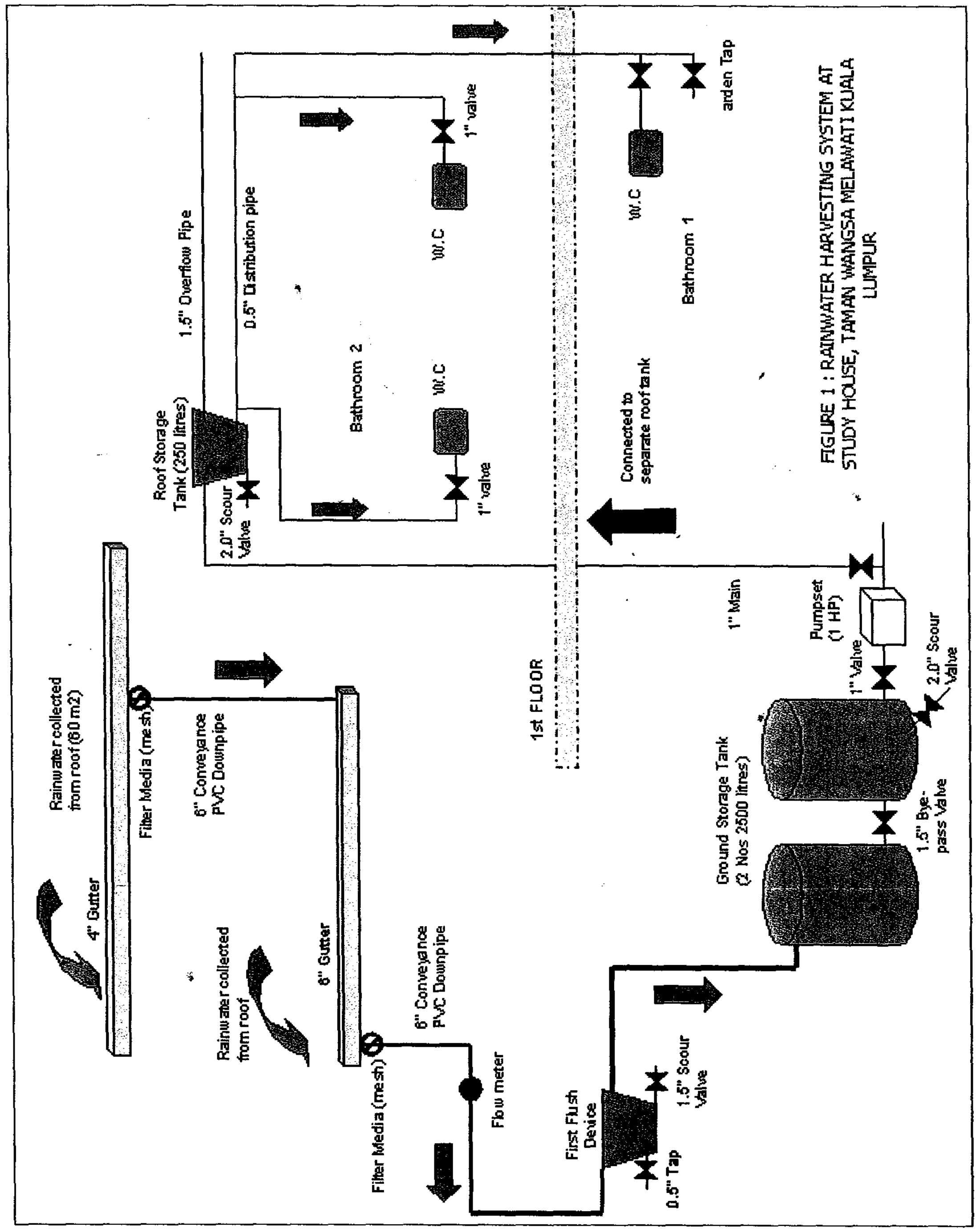

Figure 2.4: Rainwater Harvesting System at NAHRIM Study House (NAHRIM, 2002)

Table 2.2: Table of Rainwater Quality in Storage Tank (NAHRIM, 2002)

Test Parameters	Units	Storage tank	WHO Drinking Water Guidelines
pH	-	6.26 – 6.62	6.5 – 8.5
Magnesium	mg/l	0.2 – 0.27	
Calcium	mg/l	3.2 – 12.6	
Sulfate	mg/l	1.4 – 6.8	250
Chloride	mg/l	< 1	250
Silica as SiO_2	mg/l	1.2 – 4.2	
Iron	mg/l	0.01 – 0.02	0.3
Manganese	mg/l	0.01 – 0.04	0.1 – 0.5
Sodium	mg/l	0.1 – 1.1	
Hardness as $CaCO_3$	mg/l	8.6 – 32.6	
Turbidity	NTU	0.44 – 2.56	
Bicarbonate	mg/l	4 – 10.6	
Nitrate as N	mg/l	0.36 – 1.52	50
Cadmium	mg/l	< 0.001	< 0.003
Lead	mg/l	< 0.05	< 0.01
Potassium	mg/l	0.3 – 2.6	
Total Dissolved Solids	mg/l	14 – 126	1000
Dissolved Oxygen	mg/l	2.1 – 4.2	
Ammonia as N	mg/l	0.02 – 0.18	
Total Alkalinity as $CaCO_3$	mg/l	4 – 18	
Coliform Count	cfu/100 ml	0 – 230	0
E. Coli Count	cfu/100 ml	0 – 50	
Faecal Coliform Count	cfu/100 ml	0 – 20	0

A study has been carried out by Shabaan et al. (2002) for a typical double storey terrace house of a family of two adults and four school going children. The amount of untreated rainwater used was monitored manually for twelve months period using mechanical water meter installed at each facilities. The result (Table 2.4) indicates that household use for non-portable purpose using rainwater constitutes 34 % of the total monthly household water use.

In Malaysia, the majority of the people rely on the sole water source, treated water. Embi (2002) believes that more than 50 % of daily water requirements in Malaysia do not required treated water such as flushing toilets, washing clothes, watering garden, washing cars, pavements and drains. As a consequence, high cost associated with treating water at centralised plant, pumping and distributing (reticulation) can be saved.

Table 2.3: Recommended Minimum Storage Capacity (KPKT, 1999)

Building Type	Storage (Litres)
1. Terrace house	1120
2. Bungalow	1800
3. Multi-storey building	Depends on type of building

* Base on 5 person/household
* An average person uses 36 litres/day for toilet flushing

Table 2.4: Rainwater Use for Various Facilities (Shabaan et al., 2002)

Item	Average Daily Use (liters)	Average Monthly Use (liters)	%
Washing Clothes	300	9000	66
Toilet Flushing (3 W.Cs)	90	2700	20
General Cleaning (including car and motorcycles washing)	65	1950	14
TOTAL	**455**	**13650**	

Monthly Rainwater Use = 13,650 liters
Monthly Water Use (from public water supply) = 27,000 liters
Total Monthly Household Water Use = 40,650 liters

2.2.4 Rainwater Storage Tank Sizing

University of Warwick, UK (Warwick, 2004) has outlined 3 different methods with examples for sizing RRWH system components; the methods are: Demand Side Approach, Supply Side Approach and Computer Model.

Method 1 - Demand Side Approach
This is a very simple method is to calculate the largest storage requirement based on the consumption rates and occupancy of the building. This simple method assumes sufficient rainfall and catchment area which is adequate, and is therefore only applicable in areas where this is the situation. It is a method for acquiring rough estimates of tank size.

Method 2 – Supply Side Approach
In low rainfall areas or areas where the rainfall is of uneven distribution, more care has to be taken to size the storage properly. During some months of the year there may be an excess of water, while at other times there will be a deficit. If there is sufficient water throughout the year to meet the demand, then sufficient storage will be required to bridge the periods of

scarcity. This method takes into consideration of water fluctuation and the storage tank sizing would be more accurate.

Method 3 – Computer Model
There are several computer-based programmes for calculating tank size quite accurately such as SimTanka. The idea of a computer simulation is to predict the performance of a rainwater harvesting system based on the mathematical model of the actual system. In particular SimTanka simulates the fluctuating rainfall on which the rainwater harvesting system is dependent.

2.2.5 Benefits of Rooftop Rainwater Harvesting

The benefits of rainwater harvesting are discussed as below:

i. Environmental Benefits

Independence, self sufficiency and also help to develop an appreciation for this pristine given resource are represented by rainwater harvesting. It is relatively clean, free of charge and it is easily accessible in Malaysia since our country receives huge volume of it all year long. This activity conserves water resource efficiently and effectively.

Intercepting and storing some of the rain as rainwater harvesting help to reduce local erosion and flooding due to runoff from impervious areas such as pavement and roofs.
Stormwater run-off which picks up contaminants and degrades the drains, streams, rivers and seas is tamed and harnessed for human uses. Consequently, it can prevent cities from being plagued with thermal pollution and water shortage. It also helps to improve the urban environment and consumption of good tasting groundwater through enabling the groundwater recharge. Rainwater harvesting utilization leads to the integrity solution of water resources and environmental problems in urban areas.

ii. Domestic and Industrial Benefits

Rainwater quality often exceeds that of ground or surface water as it does not come into contact with soil, dissolving salts and minerals in the process. Its hardness advancing nearly zero thereby reducing significantly the quantity of detergents needed for cleaning process, as compared to typical piped water. Soap scum and hardness deposits disappear, and the need for a water softener in piped water, often an expensive requirement for well clean hardness water supply, is now, eliminated. Water heaters and pipes that will deposit caused by hard water can be dwindled and this should make the life spend of pipes last even longer.

The exceptional quality of rainwater have prompted many people to choose rainwater as their primary water source, or for other non-potable uses such as toilet flushing, washing clothes and garden watering. The purity of rainwater also makes it attractive for certain industries for which pure water is a requirement such as computer microchip manufacturing and photographic processing.

2.3 Stormwater Quantity Control

Landuse changes from undeveloped to developed areas not only cause local runoff impacts on receiving water flow but also cause degradation of water quality and ecology. Apart from erosion and sedimentation problems associated with development, it has become increasingly apparent that stormwater runoff contributes to receiving waters a significant part of total loads of such pollutants as nutrients (including phosphorus and nitrogen), heavy metals, oil and grease, bacteria, etc. Over the years, flood damage and adverse impacts on water quality, fisheries, scenic river areas, and wildlife habitats have been recognized as shortcomings of long-accepted approaches to the planning, design and management of storm drainage facilities in urban areas.

As a result rivers, lakes, ponds, reservoirs, and estuarine and coastal waters, have become sensitive to increased rates and volumes of runoff and pollutant discharges. These discharges have posed major issues to many urban and residential centers, particularly in the western states of the Peninsular Malaysia. The problems have become even more aggravated by frequent intense rainfalls, the physiological nature of the basins, and the pattern of urbanization with relatively poor urban services.

Conventional storm drainage has long been in practice in Malaysia which adopts the rapid disposal, localized, reactive, and mono-functional drainage concepts. These approaches are not likely to solve the above-mentioned problems. Therefore, there is an immediate need to accept the new concept and challenging roles of not only designing satisfactory flood protection facilities but also of controlling and reducing stormwater pollution in urban catchments and receiving water bodies. These are the core effort to implement Manual Saliran Mesra Alam (MSMA) which emphasising the minimization and control of flooding and pollution risks with maximizing wildlife habitats and enhancing landscape values or minimizing the long term effects of development on the ecological of the area.

It has been the Malaysian Government's commitment to ensure a balanced approach in its efforts in promoting socio-economic development and the management of natural resources and environmental quality. Emphasis has been stressed on the necessity of the use of new Urban Drainage Stormwater Management Manual (Manual Saliran Mesra Alam) in all drainage design and implementation in order to protect the environmental of the surrounding areas. In this regard, the Department of Irrigation And Drainage (DID) of Malaysia has decided to replace the 1975 manual with the new "Manual Saliran Mesra Alam (2000)". Therefore all planning and design in the project associated with the drainage and water bodies shall be in accordance to the new manual.

2.3.1 Control At-Source Concept

The new stormwater management approach is a storage-oriented to provide for the temporary storage of stormwater runoff at or near its point of origin with subsequent slow release to the downstream stormwater system or receiving water (detention), or infiltration into the surrounding soil (retention). Detention and retention facilities are designed with the purpose to meet the aim of zero peak contribution discharge by reducing the post-development peak flow equal to or less than the pre-development peak flow rate from the development site as shown in Figure 2.5.

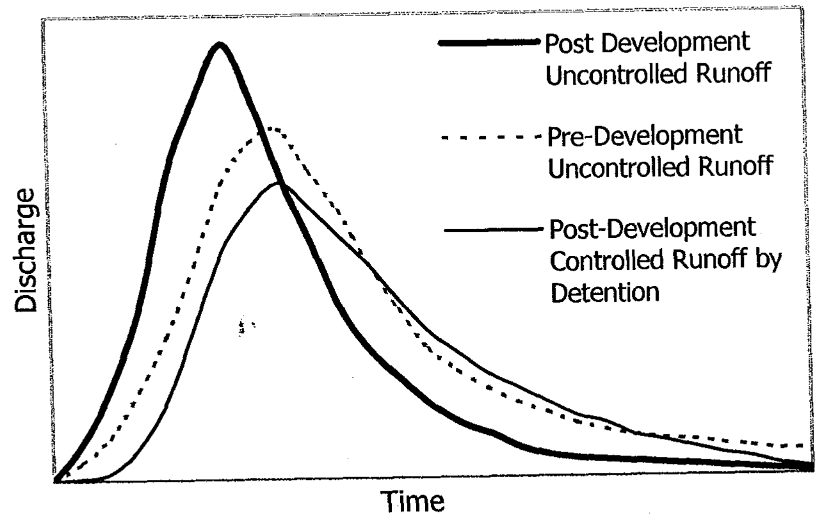

Figure 2.5: Hydrograph Schematics (DID, 2000)

2.3.2 Swinburne Method

The recommended method in USMM (2000) for sizing on-site detention (OSD) storage tank is the Swinburne Method, developed at the Swinburne University of Technology in Melbourne, Australia. This method is essentially site-based, some allowance is made for the position of the site within the catchment. The Permissible Site Discharge (PSD) which is defined as the maximum allowable post-development discharge from a site for the selected discharge design storm is set as pre-development minor storm discharge calculated from Rational Method:

$$PSD = Q_p = C_p I_p A \quad (1)$$

where Q_p = pre-development discharge,

C_p = runoff coefficient for pre-development condition,

I_p = rainfall intensity for pre-development condition, and

A = catchment area.

The Site Storage Requirement (SSR) is the total amount of storage required to ensure that the required PSD is not exceeded and the OSD detention facility does not overflow during the storage design storm ARI which is 10 year ARI. The method uses the Rational Method to calculate site flows and utilises a non-dimensional triangular site hydrograph based on the triangular design storm method. Typically, the critical storm duration that produces the largest required storage volume is different from the time of the concentration used for peak flow estimation. Therefore, storage volumes must be determined for a range of storm duration to find the maximum storage required.

$$SSR = 0.06 t_d (Q_d - c - d) \quad (2)$$

For above-ground storage:

$$c = 0.875 PSD \left(1 - 0.459 \frac{PSD}{Q_d}\right) \quad (3)$$

$$d = 0.214 \frac{PSD^2}{Q_d} \quad (4)$$

For below-ground storage:

$$c = 0.675 PSD \left(1 - 0.392 \frac{PSD}{Q_d}\right) \quad (5)$$

$$d = 0.117 \frac{PSD^2}{Q_d} \quad (6)$$

where t_d = selected storm duration (minutes), and

Q_d = the peak post-development flow from the site for a storm duration equal to t_d (l/s).

2.4 High Rise Building

From the definition of the Council on Tall Buildings and Urban Habitat (CTBUH), a "building" is considered to be a structure that is designed for residential, business, or manufacturing purposes. Other categories of buildings include institutional, public assembly, special purpose and multi use structures. An essential characteristic of a building is that it has floors.

A "high rise building" is not strictly defined by the number of stories or its height. The important criterion is whether or not the design, use, or operation of the building is influenced by some aspect of "tallness". The Council solicits information on buildings of ten or more stories. Other definition of high rise building is given in Figure 2.6.

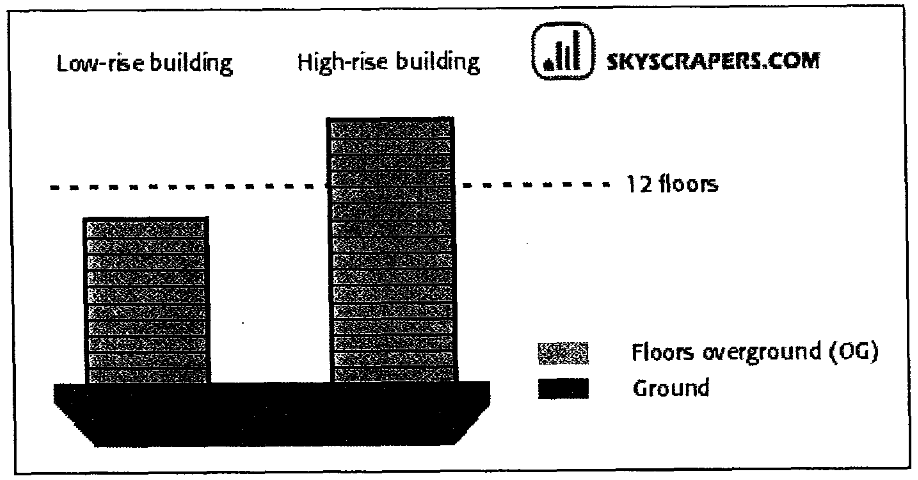

Figure 2.6: General Definition of High Rise Building (SKYCRAPERS, 2004)

The tallness of building is a matter of a person's or community's circumstance and their consequent perception. From the structural engineer's point of view, a high rise building may be defined as one that, because of its height, is affected by lateral forces due to wind or earthquake actions to an extent that they play an important role in the structural design.

High rise buildings have fascinated mankind from the beginning of civilization, their construction being initially for defense and subsequently for ecclesiastical purposes. The growth in modern tall building construction which began in the 1880s has been largely for commercial and residential purposes.

The reasons for many parts of the world to build high are:

i) response to the demand by business activities, logic and commercial prestige,

ii) increasing mobility of the business and tourist community,

iii) rapid growth of urban population and the consequent pressure on limited space and high cost of land,

iv) local topographical restrictions, and

v) ever-increasing technological capability architectural idealism.

2.4.1 Design Criteria

Tall buildings are designed primary to serve the needs of an intended occupancy, whether residential, commercial or a combination of the two. The main design criteria are architectural because the dominant design requirement is the provision of an appropriate internal layout of the building and at the same time to satisfy the client's expectations concerning the aesthetic qualities of the building's exterior.

The basic layout of a tall building must be

i) minimally obtrusive to the functional requirements, and

ii) an integration with the various service systems which are expensive and complex – heating, ventilating, air-conditioning, water supply and waşte disposal, electrical supply and vertical transportation.

The engineer is usually constrained to fit his structural system into the established functional layout that will satisfy design criteria efficiently and economically. The vital structural criteria are an adequate reserve of strength against failure, adequate lateral stiffness, and an efficient performance during service life of the building.

2.4.2 Design Philosophy

The radical changes in the structural form of tall building have caused a major shift occurred in design philosophy from the earlier working stress or ultimate strength deterministic bases to probability-based approaches. The probabilistic approach for both structural properties and loading conditions has led to the limit states design philosophy. The aim of the probabilistic approach is to ensure that all the structures and their constituent components are designed to resists with reasonable safety the worst loads and deformations that are liable to occur during construction and service, and to have adequate durability during their lifetime.

Two fundamental types of limit state must be considered for tall building design are:

i) Ultimate Limit States (ULS) – corresponding to the loads to cause failure including instability (permitted probability of failure must be very low)

ii) Serviceability Limit State (SLS) – involve the criteria governing the service life of the building (much higher of permitted probability of occurrence)

2.4.3 Loading

The structure must be designed to resist the gravitational (gravity loading) and lateral forces (wind and earthquake loadings), both permanent and transient, to sustain during its construction and subsequent service life. These forces will depend on the size and shape of the building as well as on its geographic location, and maximum probable values must be established before the design can proceed.

2.4.4 Strength and Stability

For ULS, the prime design requirement is that the building structure should have adequate strength to resist, and to remain stable under, the worst probable load actions that may occur during the lifetime of the building including the period of construction. An analysis of the forces and stresses is required for the most critical possible load combinations including the augmented moments that may arise from second-order additional deflections (P-Delta effects). An adequate reserve of strength must be presented.

In addition, a check must be made on the most fundamental condition of equilibrium, to establish that the applied lateral forces will not cause the entire building to topple as a rigid body about one edge of the base.

2.4.5 Stiffness and Drift Limitations

The provision of adequate stiffness, particularly lateral stiffness, is a major consideration in the design of a tall building for several important reasons:

a. For ULS, the lateral deflections must be limited to prevent second-order P-Delta effects.

b. For SLS, deflections must be maintained at a sufficiently low level:

i) to allow the proper functioning of non-structural components such as elevators and doors,

ii) to avoid distress in the structure, to prevent excessive cracking and consequent loss of stiffness, and to avoid any redistribution of load to non-load-bearing partitions, infills, cladding or glazing, and

iii) to prevent dynamic motions becoming large enough to cause discomfort to occupants, prevent delicate work being undertaken, or affect sensitive equipment.

One simply parameter that affords an estimate of the lateral stiffness of a building is the drift index.

$$\text{Drift Index} = \frac{\text{maximum deflection at the top of the building}}{\text{total height}}$$

The corresponding value for a single storey height:

$$\text{Intersorey Drift Index} = \frac{\text{maximum deflection at a particular storey of the building}}{\text{storey height}}$$

Design drift index limits are different in various countries. The traditional accepted limit of the drift index is 1/500. The preferred acceptable range is 0.0015 to 0.003 (1/650 to 1/350) for conventional structures.

The drift of a structure can be reduced by:

i) changing the geometric configuration to alter the mode of lateral load resistance
ii) increasing the bending stiffness of the horizontal members,
iii) adding additional stiffness by the inclusion of stiffer wall or core members,
iv) achieving stiffer connections,
v) sloping the exterior columns, and
vi) adding dampers (active or passive types).

2.5 Sustainable Building Concept

The concept of sustainability in building and construction has evolved over many years. The initial focus was on how to deal with the issue of limited resources, especially energy, and on how to reduce impacts on the natural environment. Emphasis was placed on technical issues such as materials, building components, construction technologies and energy related design concepts (Watermeyer, 2002). More recently, an appreciation of the significance of non-technical issues has grown. It is now recognized that economic and social sustainability are important, as are the cultural heritage aspects of the built environment.

Sustainable building involves considering the entire life cycle of buildings, taking environmental quality, functional quality and future values into account (Shaeffer, 1980). In the past, attention has been primarily focused on the size of the building stock in many countries. Quality issues have hardly played a significant role. However, in strict quantity terms, the building and housing market is now saturated in most countries, and the demand

for quality is growing in importance. Accordingly, policies that contribute to the sustainability of building practices should be implemented, with recognition of the importance of existing market conditions. Both the environmental initiatives of the construction sector and the demands of users are key factors in the market. Governments will be able to give a considerable impulse to sustainable buildings by encouraging these developments.

One of the priorities in planning and design of sustainable buildings which has been given due consideration by Malaysia government is the implementation of Rooftop Rain Water Harvesting System. It is basically a system of collecting rainwater from mainly rooftops and storing it for portable or non-portable use later. After all, rainwater is clean and a reliable source throughout Malaysia the whole year. This also helps to alleviate some local erosion and flooding due to excess runoff from impervious areas. Further more, RRWH system can prevent cities from being plagued with thermal pollution and water shortage, yet help to improve urban environment. Rapid urbanization is dwindling building space and increase the number of high rise buildings. Therefore, installing a RRWH system on a high rise building is a way to achieve sustainable building concept.

CHAPTER 3
METHODOLOGY

3.1 Site Selection

The structural analysis are carried out for two high-rise buildings located in two main developed regions in Malaysia, namely Klang Valley and Penang. The existing building in Klang Valley which being considered in this research is a 20 storey building and it consists of 270 unit of service apartment. It is located at Bukit Lanjan, Mukim Sungai Buloh, Daerah Petaling, Selangor Darul Ehsan. The height of the building is 54.6 m and the plan dimension is 56.0 m by 27.27 m. The second building is a 20 storey residential building and consists of 150 unit of service apartment. The building is located in Gelugor, Penang with 65.6 m height and 68.672 m x 25.415 m in plan. These buildings are selected because they represent a common high-rise building which normally appears in the urban area in Malaysia. A RRWH system is applied to a particular floor of this building throughout the installation of the RRWH storage tanks.

Figure 3.1 shows the flow chart of RRWH system designing steps taken in order to accomplish the objectives of this research.

3.2 Design of Storage Tank

According to the Guidelines for Installing A Rainwater Collection and Utilization System prepared by the Kementerian Perumahan dan Kerajaan Tempatan, the rainwater tank should include the following features to achieve its minimum requirement:

i. A solid secure cover.
ii. A overflow pipe larger in diameter than the incoming rainwater supply pipe.
iii. A scour pipe and valve for drainage.
iv. An extraction system e.g. taps or pumps.
v. A device to indicate the water level in the tank (optional).

Tank material can be hot dipped galvanized steel, stainless steel, glassfibre reinforced plastic, reinforced concrete and polyethylene.

The storage tank is installed under the roof. This is the simple purpose of collecting and utilizing rainwater. It allows the rainwater to be supply to the lower level of the building by gravity.

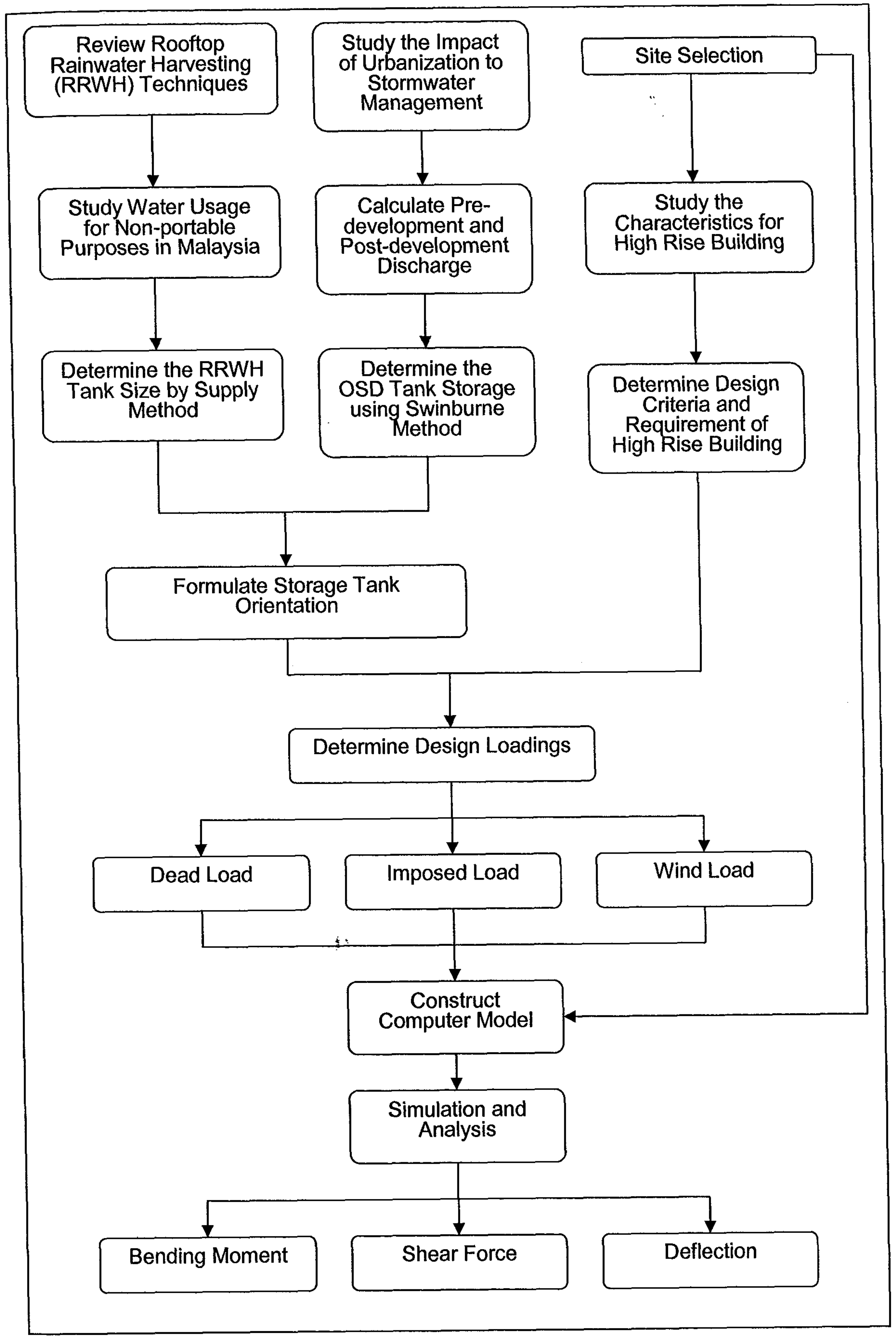

Figure 3.1: Flow Chart of Methodology

3.3 Rainwater Storage Tank Sizing

Two approaches for rainwater harvesting storage tank sizing which suit the local conditions and requirements have been adopted in this study. The quantity of rainwater to be stored for water reuse purposes is determined based on Supply Side Approach as recommended by University of Warwick while the quantity of rainwater for flood control purposes is calculated based on the determination of OSD storage tank sizing using Swinburne Method as recommended in Urban Stormwater Management Manual for Malaysia (DID, 2000).

3.4 Storage Tank Orientation

The storage tank can be installed in a few arrangements. The tank could be a single large tank or a few smaller tanks which are located on rooftop, at particular floor level of the building or on ground. Pumping is required for on ground storage compared to other above-mentioned storages where water can flow due to gravity effect. On ground storage requires more tanks, pipes, plumbing fittings and pumps in general. During operation, higher energy consumption and maintenance is needed.

The critical element of the structure is then identified. The results on bending moment, shear, deflection and sway are analysed subsequently. The main objective of the computer modeling is to study the impact of rainwater harvesting storage tank on the structural behaviour of the building. The potential for storage tank integration on the existing building is evaluated and the minimum impact subjected to storage tank installation to the existing building is then formulated.

3.4.1 Case Study I

Three models, namely Model A, Model B and Model C, are constructed to represent different tank installation at rooftop and landscape deck at Level 8 and Level 15 of the building with specific tank dimension as delineated in Table 3.5. These models are applied with dead, live and wind loads accordingly.

3.4.2 Case Study II

Three models of rainwater harvesting system storage tanks are proposed in this analysis. Model B has two large storage tanks; Model C has four storage tanks, while Model D has five storage tanks. The calculations of storage tank are shown in Table 3.6.

Table 3.5: Dimension and Location of Storage Tank

	Description	Dimension (Width × Length x Height)
Model A	Without Storage Tank	-
Model B	Singe Large Tank at Rooftop	8.5 m × 12 m × 3.55 m
Model C	Storage Volume Equally Distributed at Rooftop, Landscape Deck at Level 8 and Level 15	8.5 m × 12 m × 1.2 m at Rooftop, 4 m × 8 m × 2.4 m and 3 m × 6 m × 2.4 m at Level 8 and Level 15

Table 3.6: Dimension and Location of Storage Tank

	Description	Dimension (Width × Length x Height)
Model A	Without Storage Tank	-
Model B	Two Large Tank at Rooftop	5 m × 16.5 m × 3 m
Model C(i)	One Large Tank and Three Small Tank at Rooftop	5 m × 17 m × 3 m 5 m × 6 m × 3 m (2 units) 4 m × 5 m × 3 m (1 unit)
Model C(ii)	One Large Tank at Rooftop and Three Small Tank at Level 10	5 m × 17 m × 3 m at Rooftop, 5 m × 6 m × 3 m (2 units) and 4 m × 5 m × 3 m (1 unit) at Level 10
Model D	Five Tanks at Rooftop	2.5 m × 6 m × 3 m (3 units) 6 m × 10 m × 3 m (2 units)

3.5 Modeling of Structure

The general design flow chart of EsteemPlus is shown in Figure 3.6.

3.6 Loads

Loads are one of the major considerations in analyzing a structural integrity of the high rise building. The loads on structure are divided into two types: 'dead' loads, and 'live' (or imposed) loads. Dead loads are those which are normally permanent and constant during the structure's life. Live loads, on the other hand, are transient and are variable in magnitude, as for example those due to wind or human occupants.

3.6.1 Dead loads

Dead loads in the analysis include the weight of the structure itself, all architectural components such as exterior cladding, partitions and ceiling and also the RRWH system

components which are water load and empty storage tank load. Self weight of the structure is automatically accounted by the EsteemPlus once the common design parameters for beams, columns, slabs and piles are input.

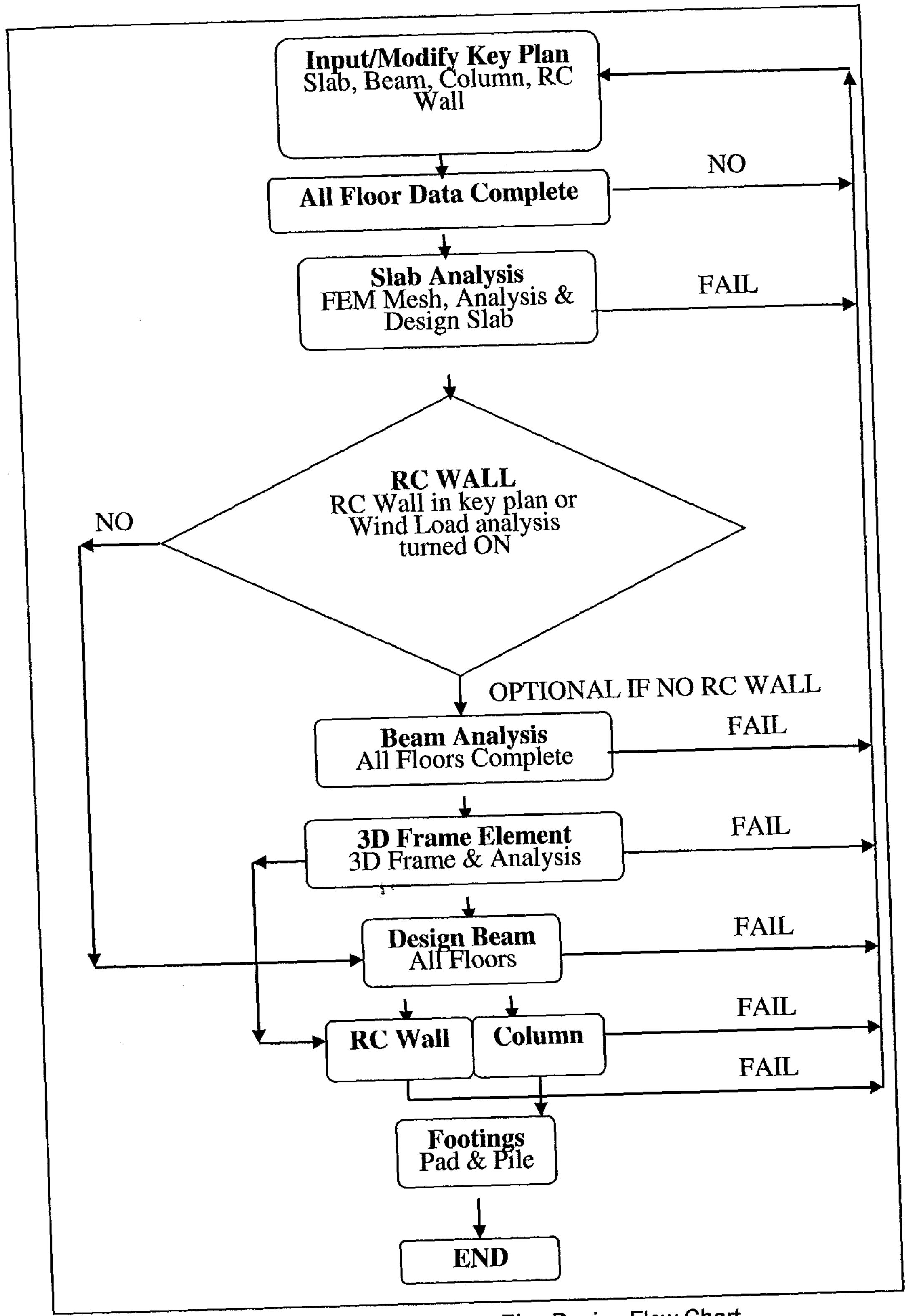

Figure 3.6: EsteemPlus Design Flow Chart

3.6.1.1 Water load

For this research, the main loading will be the water load imposed by the RRWH storage tanks. The pressure imposed by the water load is affected by these three main elements which are water density, ρ, gravity, g, and the height of water level, h. The equation of water pressure is shown as:

$$\text{Water pressure} = \rho gh$$

Since the water density and the gravity are the constant values upon earth, quantity of pressure imposed are simply related directly to the height of the water in the storage tanks. The highest load takes place when the storage tank is filled up to the rim of tank. Therefore the water pressures for proposed RRWH storage tanks in all models and their converted uniform distributed loadings.

3.6.1.2 Empty water storage tank

The choices of choosing storage tanks are optional from Water Tanks Company, USA, tank's catalogue.

Specification:

Type	: Field erected corrugated galvanized steel tank
Maximum Capacity	: 53550 gallons (equivalent to 243652.5 litres)
Weights	: 8000 lbs = 3636 kg = 36.36 kN

This weight is distributed uniformly to all plinths under the storage tank. The largest storage tank among all models is 12 m x 9 m x 4 m in size, which in Model B, is supported by 12 plinths. Hence, the empty water storage tank's load is:

$$36.36 \text{ kN}/ 12 \times 9 \text{ m} = 0.34 \text{ kN/m}$$

This value is negligible compared to the load imposed by the water. Therefore it is excluded from this analysis.

3.6.1.3 Brickwall, Slab and Others

The following specifications have been used for modeling the structure without any storage tank:

Concrete characteristic strength	= 25 kN/m^2
Reinforcement bar	= 460 kN/m^2
Finishes	= 1.2 kN/m^2

3.6.2 Imposed loads

These loads are more difficult to determine to determine accurately. For many of them, it is only possible to make conservative estimates based on standard codes of practice or past experience. Examples of imposed loads on a building are: the weight of its occupants, furniture, or machinery; the pressure of wind, the weight of snow and of retained earth or water; and the forces caused by thermal expansion or shrinkage of concrete. The imposed load being considered in this research is referred to BS 6399, Part 1: 1996. The imposed loads used in this research are the minimum values stated in Table 1: Minimum imposed floor loads, in BS6399 as summerised in Table 3.7.

Although the wind load is an imposed load, it is kept in a separate category when its partial factors of safety are specified, and when the load combinations on the structure are being considered. The wind load is basically the pressure of wind applying on the vertical surfaces of the building. It depends on its speed, the condition of exposure and the size or the surface area of the building (Morgan and Buckle, 1978). However, the wind load is not being taken into consideration in this research.

Table 3.7: Minimum Imposed Floor Loads (BS 6399: Part 1: 1996, Table 1)

Type of activity/occupancy for part of the building or structure	Examples of specific use	Uniformity distributed load kN/m^2
A) Domestic and residential activities	Bedrooms in hotels and motels	2.0
	Toilet areas	2.0
	Balconies	1.5
E) Warehouse and storage areas. Areas subject to accumulation of goods. Areas for equipment and plant.	Cold storage	5.0
	Plant rooms, boiler rooms, fan rooms, etc., including weight of machinery.	7.5
F) Vehicle and traffic areas	Parking for cars, light vans, etc. not exceeding 2500 kg gross mass, including garages, driveways and ramps	2.5

3.6.3 Wind Loads

The lateral loading due to wind is the major factor that causes the design of high-rise building to differ from those of low- to medium-rise buildings. For buildings up to about 10 stories and of typical proportions, the design is rarely affected by wind loads. Above this height, however, the increase in size of the structural members, and the possible rearrangement of the structure to account for wind loading, incurs a cost premium that increases progressively with height.

The design criteria of wind loading on building structures are given in MS 1553, 2002. It sets out procedures to for determining the wind speeds and resulting wind actions to be used in the structural design for structures subjected to wind action other than those caused by tornadoes and typhoons. The standard covers structures within the following criteria:

- (i) Building less than 200 m high;
- (ii) Structures with roof spans less than 100 m; and
- (iii) Structures other than off-shore structures, bridges and transmission towers.

For buildings higher than 25m and for frames, design wind speeds for other levels up to roof height may need to be considered. The wind speeds are established for each particular region and are related to standard exposure, peak gust, annual probability of exceedence (or return period) and wind direction. The wind speed is based on 50 years return period (MS1553: 2002). Figure 3.7 shows that the basic winds speed in Peninsular Malaysia.

The acceleration of building due to wind-induced motion shall not exceed 1.0 % for residential structures and 1.5 % for other structures of the acceleration due to gravity. The totals drift and inter story drift of wind force resisting system shall not exceed h/500 and h_i/750 respectively, where h is the overall height of the structure and h_i is the floor to floor height of the structure (MS1553: 2002).

BS 8110: Part 2: 1985 also stated that excessive accelerations under wind loads that may cause discomfort or alarm to occupant should be avoided in Section 3.2.2.1. The wind load applied is calculated by referring to MS 1553:2002 Code of Practice on Wind Loading for Building Structure. In the analysis, the wind action is exerted onto building face in weak axis.

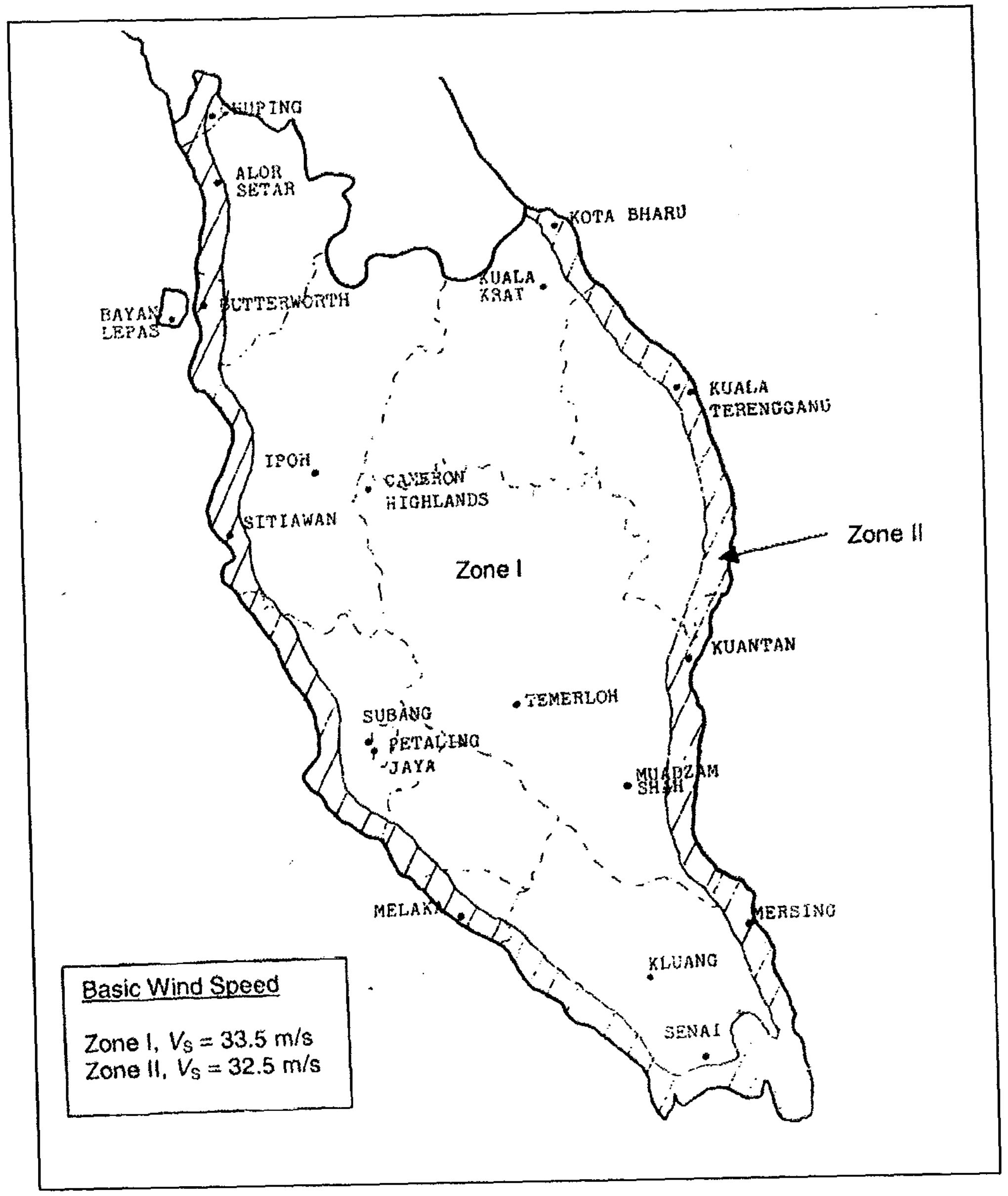

Figure 3.7: Basic Wind Speed at Peninsular Malaysia (MS 1553: 2002)

The wind pressure calculation is site dependent and backgrounds of this project are important to be considered in calculating wind pressure as follow:

(i) Case Study I:

Location	: Petaling Jaya
Topography	: Homogeneueous
Terrain	: Urban
Dimensions	: 77.0 m height, 59.35 m x 22.75 m in plan

(a) Site Wind speed

The site wind speeds, V_{sit} is defined at the level of the average roof height above ground by the expression:

$$V_{sit} = V_s(M_d)(M_{z,cat})(M_s)(M_h) \quad (3.1)$$

Basic wind speed, V_s = 33.5 m/s (Zone I) (MS1553:Figure 3.1)

Wind directional multiplier, M_d = 1.0 (MS1553:Clause 2.2)

Shielding multiplier, M_s = 1.0 (MS1553:Clause 4.3.1)

Hill shape multiplier, M_h = 1.0 (MS1553:Clause 4.4)

Terrain/height multiplier, $M_{z,cat}$: vary with height, z (MS1553:Table 4.1)

$$\therefore V_{sit} = 33.5\, M_{z,cat}$$

(b) Design wind speeds

The building design wind speeds, V_{des} is taken as the maximum site wind speed, V_{sit} multiplied by the importance factor, I.

$$V_{des} = V_{sit} \times I \quad (3.2)$$

Importance factor, I = 1.15 (Category of structures; III) (MS1553:Table 3.2)

(c) Design wind pressure

The design wind pressures, in Pascal, is determined for structures and parts of structures using the following equation:

$$P = (0.5\rho_{air})(V_{des})^2\, C_{fig}\, C_{dyn} \quad \text{N/m}^2 \quad (3.3)$$

ρ_{air} = density of air which can be taken as 1.225 kg/m^3

$0.5\rho_{air}$ = 0.613 (This value is based on standard air conditions and typical ground level atmospheric pressure).

C_{fig} = aerodynamic shape factor

Dynamic response factor, C_{dyn} = 1.0 (shall be taken as 1.0 unless the structure is wind sensitive)

(i) For external pressure

$$C_{fig} = C_{p,e}\, K_a\, K_c\, K_l\, K_p \quad (3.4)$$

(ii) For internal pressure

$$C_{fig} = C_{p,i}\, K_c \quad (3.5)$$

Internal pressure coefficient, $C_{p,i}$

$C_{p,i}$ = -0.3 or 0.0 whichever with the more severe for combined forces (MS 1553:Table 5.1(a)

External pressure coefficient, $C_{p,e}$ (MS 1553: Table 5.2)

$C_{p,e}$ = 0.8 (windward wall)

$C_{p,e}$ = -0.27 (Wind acting perpendicular to the 59.35 m face with d/b = 2.61) (leeward wall)

$C_{p,e}$ = -0.65 (side walls)

Area reduction factor, K_a (MS 1553: Table 5.4)

K_a = 1.0 (windward wall and leeward wall)

K_a = 0.8 (sidewalls)

Combination factor, K_c (MS 1553: Table 5.5)

K_c = 1.0

Local pressure factor, K_l (MS 1553: Table 5.6)

K_l = 1.0

Porous cladding reduction factor, K_p (MS 1553: Clause 5.4.5)

K_p = 1.0

(d) Summary of calculation

(i) External Pressure

The calculation for external wind pressure on windward walls and side walls are tabulated in Table 3.8 and Table 3.9 respectively. But, MS 1553 Clause 2.4.2 stated that the minimum design wind load = 0.65 kN/m^2. Therefore, $P_{e,ww}$ for Ground Floor to 13th Floor is taken as 0.65 kN/m^2.

The external wind pressure on leeward wall is given as

$$P_{e,lw} = -0.261 \text{ kN/m}^2$$

(ii) Internal Pressure

The internal pressure for all the walls is

$$P_i = -0.206 \text{ kN/m}^2$$

(ii) Case Study II:

Location: Bayan Lepas

Topography: Homogeneous

Terrain: Urban

Dimensions: 65.6 m height, 68.672 m x 25.415 m in plan

Based from Table 5.1 (a) (MS1553, 2002), $C_{p,i}$ = -0.3 or 0.0 whichever with the more severe for combined forces

Table 3.8: Calculation Sheet of External Wind Pressure on Windward Walls, $P_{e,ww}$.

Floor	Height (m)	$M_{z,cat}$	V_{des} (m/s)	windward wall	
				$C_{p,e}$	$P_{e,ww}$ (kN/m^2)
plant room	77.0	1.03	39.681	0.8	0.772
20	73.5	0.98	37.755	0.8	0.699
19	70.0	0.98	37.755	0.8	0.699
18	66.5	0.98	37.755	0.8	0.699
17	63.0	0.98	37.755	0.8	0.699
16	59.5	0.98	37.755	0.8	0.699
15	56.0	0.98	37.755	0.8	0.699
14	52.5	0.98	37.755	0.8	0.699
13	49.0	0.90	34.673	0.8	0.590
12	45.5	0.90	34.673	0.8	0.590
11	42.0	0.90	34.673	0.8	0.590
10	38.5	0.85	32.746	0.8	0.526
9	35.0	0.85	32.746	0.8	0.526
8	31.5	0.85	32.746	0.8	0.526
7	28.0	0.80	30.820	0.8	0.466
6	24.5	0.80	30.820	0.8	0.466
5	21.0	0.80	30.820	0.8	0.466
4	17.5	0.75	28.894	0.8	0.409
3	14.0	0.75	28.894	0.8	0.409
2	10.5	0.75	28.894	0.8	0.409
1	7.0	0.75	28.894	0.8	0.409
ground floor	3.5	0.75	28.894	0.8	0.409

Table 3.9: External Wind Pressure on Side Walls, $P_{e,sw}$.

Horizontal dist. from windward edge. (m)							
0 to 77.0		77.0 to 154.0		154.0 to 231.0		> 231.0	
$C_{p,e}$	$P_{e,sw}$ (kN/m^2)	$C_{p,e}$	$P_{e,sw}$ (kN/m^2)	$C_{p,e}$	$P_{e,sw}$ (kN/m^2)	$C_{p,e}$	$P_{e,sw}$ (kN/m^2)
-0.65	-0.502	-0.5	-0.386	-0.3	-0.232	-0.2	-0.154

Based on Table 5.2 (MS1553, 2002), External pressure coefficient, $C_{p,e}$ are:

$C_{p,e}$= 0.8 (windward wall)

$C_{p,e}$= -0.27 (Wind acting perpendicular to the 68.672 m face with d/b= 2.70)(Leeward wall)

$C_{p,e}$= -0.65 (sidewalls)

Based on Table 5.4 (MS1553, 2002), Area reduction factor are:

K_a= 1.0 (windward wall and leeward wall)

K_a= 0.8 (sidewalls)

Based on Table 5.5 (MS1553, 2002), Combination factor, K_c

K_c= 1.0

Based on Table 5.6 (MS1553, 2002), Local pressure factor, K_1

K_1= 1.0

Based on Clause 5.4.5 (MS1553, 2002), Porous cladding reduction factor, K_p

K_p = 1.0

From equation 2.6, $C_{fig} = C_{p,e}K_aK_cK_1K_p$

$= 0.8$

(i) External pressure

The calculation for external pressure on windward walls and side walls are tabulated in Table 3.10 and Table 3.11 respectively. However, MS 1553 Clause 2.4.2 stated that the minimum design wind pressure is 0.65 kN/m^2. Therefore, $P_{e,ww}$ for Ground floor to 6th Floor is taken as 0.65 kN/m^2.

The external wind pressure on leeward wall is given as

$$P_{e,sw} = 0.613 \times (V_{des})^2 C_{fig}$$
$$= 0.613 \times (41.113)^2 \times -0.27$$
$$= -0.280 \text{ kN/m}^2$$

(ii) Internal Pressure

The internal pressure for all the walls is

$$P_i = 0.613 \times (V_{des})^2 C_{fig}$$
$$= 0.613 \times (41.113)^2 \times -0.3$$
$$= -0.311 \text{ kN/m}^2$$

Table 3.10: Calculation Sheet of External Wind Pressure on Windward Walls, $P_{e,ww}$

Floor	Height (m)	$M_{z,cat}$	V_{des} (m/s)	Windward wall	
				$C_{p,e}$	$P_{e,ww}$ (kN/m^2)
19	65.6	1.10	41.113	0.8	0.829
18	62.4	1.09	40.739	0.8	0.814
17	59.2	1.09	40.739	0.8	0.814
16	56.0	1.08	40.365	0.8	0.799
15	52.8	1.07	39.991	0.8	0.784
14	49.6	1.07	39.991	0.8	0.784
13	46.4	1.06	39.618	0.8	0.770
12	43.2	1.05	39.244	0.8	0.755
11	40.0	1.04	38.870	0.8	0.741
10	36.8	1.02	38.123	0.8	0.713
9	32.8	1.01	37.749	0.8	0.699
8	29.6	1.00	37.375	0.8	0.685
7	26.4	0.98	36.628	0.8	0.658
6	23.2	0.96	35.880	0.8	0.631
5	20.0	0.94	35.133	0.8	0.605
4	16.8	0.90	33.638	0.8	0.555
3	13.6	0.87	32.516	0.8	0.518
2	10.4	0.83	31.021	0.8	0.472
1	7.2	0.79	29.526	0.8	0.428
Ground floor	4.0	0.75	28.031	0.8	0.385

Table 3.11: External Wind Pressure on Side Walls, $P_{e,sw}$

	Horizontal distance from windward edge. (m)			
	0 to77.0	77.0 to 154.0	154.0 to 231.0	> 231.0
$C_{p,e}$	-0.65	-0.5	-0.3	-0.2
$P_{e,sw}$ (kN/m^2)	-0.579	-0.445	-0.267	-0.178

3.6.4 Load combinations

Various combinations of the characteristic values of the dead load, Gk, imposed load, Qk, wind load, Wk, and their partial factors of safety must be considered for the loading of the structure. The partial factors of safety specified by BS 8110 are being provided in EsteemPlus, and for the ultimate limit state the loading combinations to be considered are as follows:

1. Dead and imposed load
   1.4Gk + 1.6Qk
2. Dead and wind load
   1.0Gk + 1.4Wk
3. Dead, imposed and wind load
   1.2Gk + 1.2Qk + 1.2Wk

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Rainwater Storage Tank Sizing

Two approaches for rainwater harvesting storage tank sizing which suit the local conditions and requirements have been adopted in this study.

4.1.1 Supply Side Approach

For the case of high rise building, the demand of water based on consumption rates and occupancy of the building is no longer governing the storage requirement. Furthermore, the distribution of rainfall varies throughout a year in Malaysia.

Roof collection areas, monthly average rainfall of the area and runoff coefficient are the 3 governing factors for the supply of the rainwater. The roof of this service apartment is the main resource of rainwater catchment. Rainwater collected from roof during heavy rain is being stored in tank and awaiting to be supplied to the place of use. The hydrological data and calculation sheets for storage tank sizing are tabulated in Tables 3.1 to 3.3. Figures 3.2 and 3.3 show the comparison of harvestable water while the demand and the predicted cumulative inflow and outflow from the tank is illustrated in Figures 3.4 and 3.5. The average rainfall for Petaling Jaya and Penang are derived for 35 years data from Jabatan Kajicuaca Malaysia (1971 – 2005).

From the calculation by using supply-side approach, the required storage tank volumes are 362 m^3 and 484 m^3 for the study site in Klang Valley and Penang, respectively. This is the maximum harvestable volume of rainwater that can be used for non-portable purposes for these particular sites.

Table 3.1: Site Characteristic and Hydrological Data

Description	Klang Valley	Penang
Catchment Area (m^2)	1500	1339.5
Runoff Coefficient	0.9	0.9
Average Annual Rainfall (MMS,2005) (mm/year)	2759.1	2429
Annual Available Water to be Harvested (Assume 100%) (m^3)	3725	2928.3
Daily Available Water (m^3/day)	10.2	8.1
Monthly Available Water (m^3/month)	310.4	244

Table 3.2: Storage Tank Sizing Calculation for Case Study I

Month	Rainfall (mm)	Rainwater Harvested (m^3)	Cumulative Rainwater Harvested (m^3)	Demand (m^3)	Cumulative Demand (m^3)	Difference between Columns 4 & 6 (m^3)
Oct	281.9	380.57	380.57	310	310	70.56
Nov	339.3	458.06	838.62	310	620	218.62
Dec	268.1	361.94	1200.56	310	930	270.56
Jan	195.8	264.33	1464.89	310	1240	224.89
Feb	208	280.80	1745.69	310	1550	195.69
Mar	271.5	366.53	2112.21	310	1860	252.21
April	305.6	412.56	2524.77	310	2170	354.77
May	235.1	317.39	2842.16	310	2480	**362.16**
June	138.9	187.52	3029.67	310	2790	239.67
July	145.9	196.97	3226.64	310	3100	126.64
Aug	167	225.45	3452.09	310	3410	42.08
Sept	202	272.70	3724.79	310	3720	4.78
	2759.1			**3720**		

Table 3.3: Storage Tank Sizing Calculation for Case Study II

Month	Rainfall (mm)	Rainwater Harvested (m^3)	Cumulative Rainwater Harvested (m^3)	Demand (m^3)	Cumulative Demand (m^3)	Difference between Columns 4 & 6 (m^3)
April	209.8	252.92	252.92	244	244	8.92
May	235.2	283.55	536.47	244	488	48.47
June	172.7	208.20	744.67	244	732	12.67
July	200.3	241.47	986.14	244	976	10.14
Aug	247.5	298.37	1284.51	244	1220	64.51
Sept	339.9	409.77	1694.28	244	1464	230.28
Oct	378.9	456.78	2151.06	244	1708	443.06
Nov	236.5	285.11	2436.17	244	1952	**484.17**
Dec	106.7	128.63	2564.80	244	2196	368.80
Jan	67.3	81.13	2645.93	244	2440	205.93
Feb	92.4	111.39	2757.32	244	2684	73.32
Mar	141.8	170.95	2928.27	244	2928	0.27
	2429			**2928.3**		

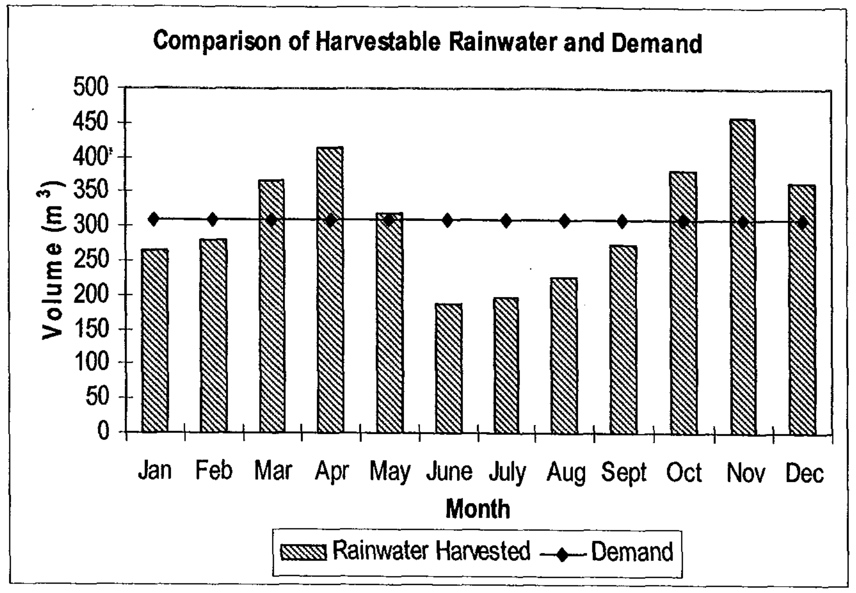

Figure 3.2: Comparison of Harvestable Rainwater and Demand for Case Study I

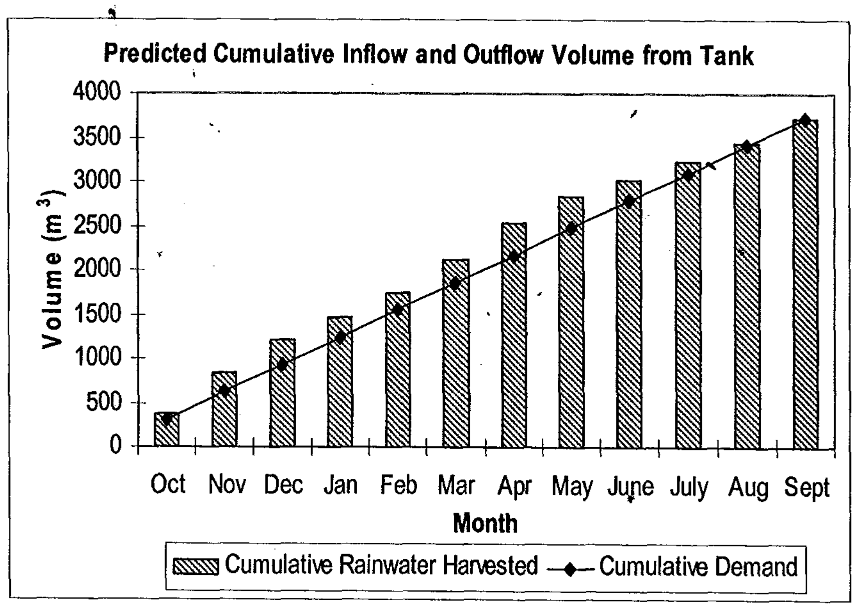

Figure 3.3: Predicted Cumulative Inflow and Outflow Volume from Tank for Case Study I

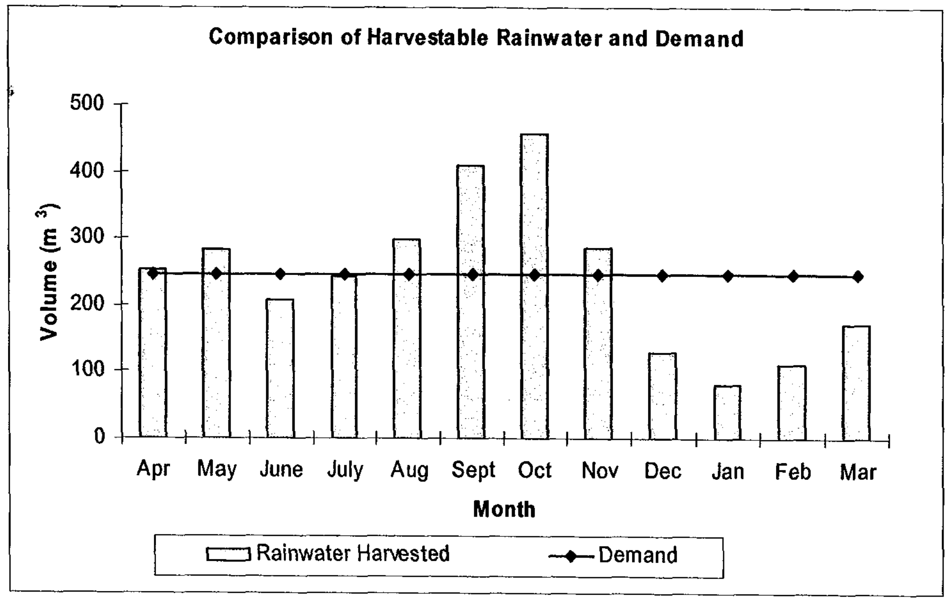

Figure 3.4: Comparison of Harvestable Rainwater and Demand for Case Study II

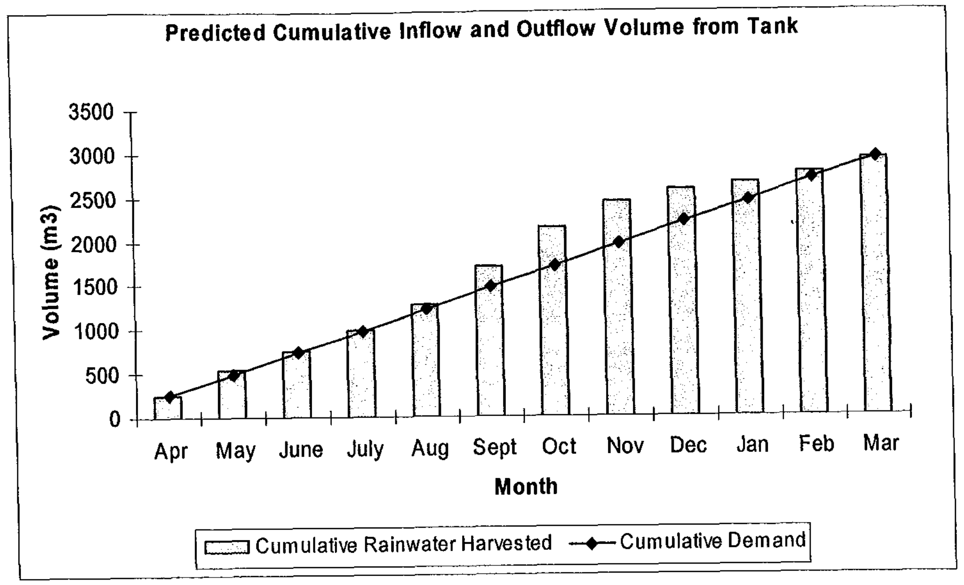

Figure 3.5: Predicted Cumulative Inflow and Outflow Volume from Tank for Case Study II

4.1.2 Swinburne Method

The determination of OSD storage tank sizing is summarized in Table 3.4 for both above-ground and below-ground storage for both locations. From the result, the minimum storage tank requirements for above-ground and below-ground storage facilities to meet the requirement of USMM to limit the post-development site discharge to pre-development site discharge are 43.22 m^3 and 53.09 m^3 (Klang Valley) and 31.11 m^3 and 42.60 m^3 (Penang),

4.1.3 Discussions

The study sites are multistorey service apartment in Klang Valley, Selangor and Penang. The buildings accommodate 270 households and 160 households in total, respectively. The water demand of rainwater for the study site is assumed to be 50 % of the water usage data collected by Shabaan et al. (2002) after considering the variation of the building type. The monthly non-portable water demand for toilet flushing and general cleaning is 628 (Klang Valley) and 697.5 m^3/month (Penang). The water demand exceeds the harvestable rainwater from the catchment. The calculated rainwater supply is able to serve 49 % and 35% of the demand for apartment in Klang Valley and Penang. This is basically caused by smaller catchment area compared to the total number of household for high rise building.

In terms of stormwater quantity control, the SSR for above-ground facility is higher than below-ground facilities because of the storage geometry and outflow characteristics. These two values of storage amount are much smaller compared to the amount determined by using supply side approach. The SSR is adopted as the minimum storage required for rainwater harvesting storage tank in order to regulate the peak flow discharge to the PSD.

Table 3.4: Summary of OSD Storage Tank Calculation

Description	Case Study I		Case Study II	
	Above-ground	Below-ground	Above-ground	Below-ground
Catchemnt Area, A (m^2)	1500		1339.5	
Pre-development:				
t_c (minutes)	18.5		20.0	
Intensity, I (mm/hr)	133.62		143.88	
Runoff coefficient, C	0.71		0.72	
PSD = Q_p (l/s)	39.53		38.55	
Post-development:				
t_c (minutes)	5		5	
Intensity, I (mm/hr)	212.46		208.14	
Runoff coefficient, C	0.91		0.91	
Q_a (l/s)	80.56		70.47	
t_d	20	20	20	20
Coefficient c	23.14	20.56	21.43	14.41
Coefficient d	4.28	2.71	5.14	3.14
Q_d (l/s)	63.43	67.51	52.50	37.84
SSR (m^3)	43.22	53.09	31.11	42.60

4.2 Computer Modelling

The buildings are modeled using EsteemPlus, as illustrated in Figure 4.1. EsteemPlus is an integrated total solution computer program that offers a complete package in reinforced concrete design. With EsteemPlus, user can create and edit a model, perform analysis, design, produce calculations and drawings through a graphic driver interface within Microsoft windows platform.

4.2 Results and Discussions

4.2.1 Case Study 1: Klang Valley

(a) Effect of Storage Tank Provision

The structural integrity and stability of the service apartment are assessed and the results in term of deflection, sway, shear and bending moment for critical element are analysed as shown in Figures 4.2 to 4.5. The result is summarized in Table 4.1. Generally, Model B has

the highest value for shear force and bending moment. The single large storage tank imposes significant additional load at specific area on rooftop. Critical shear force and bending moment are increased approximately 3.3 and 2.5 times, respectively. If the same amount of storage volume is equally distributed at three different floor levels as indicated by Model C, it has virtually nominal effect on the building compared to Model B. The increments of structural responses are not greater than 50 % (shear force) and 20 % (bending moment). Deflections for all the models are under the permissible limit referred to BS8110. In terms of sway, the three models experience a slight sway under the wind action.

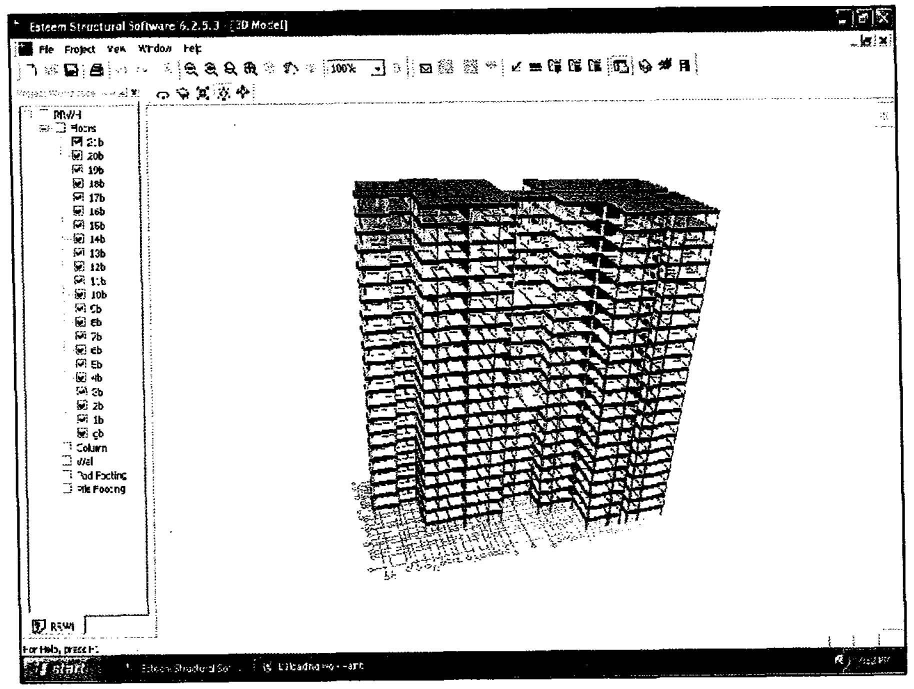

Figure 4.1: Structural Representation of the 20-Storey Service Apartment in Klang Valley, Selangor

Table 4.1: Summary of Results for Critical Element at Rooftop

Description	Shear Force (kN)	Bending Moment (kN.m)	Deflection	Sway (mm)
Model A	136.5	127.2	acceptable	20.23
Model B	447.4	311.7	acceptable	20.13
Model C	204.9	152.7	acceptable	20.26

Note: Acceptable denotes the value is under the limit allowed by design code.

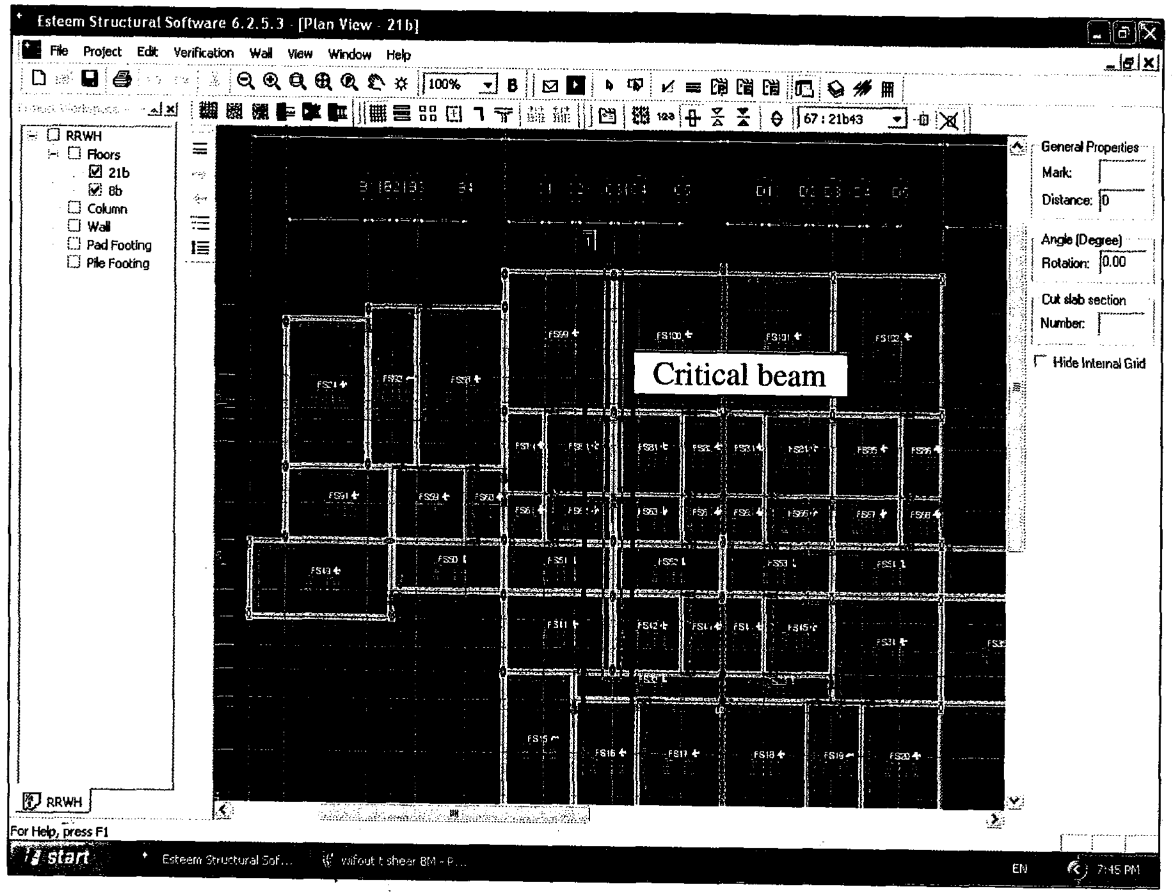

Figure 4.2: Critical Beam at Rooftop

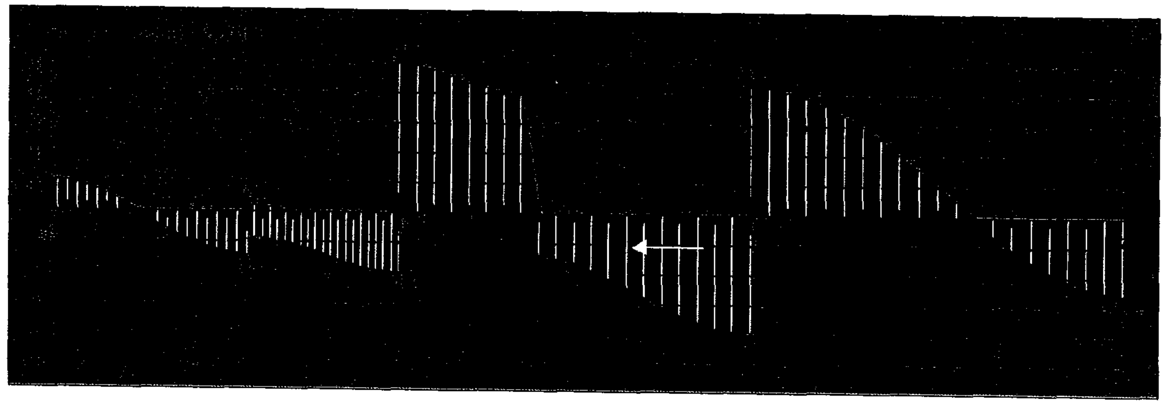

Figure 4.3: Shear Force Diagram

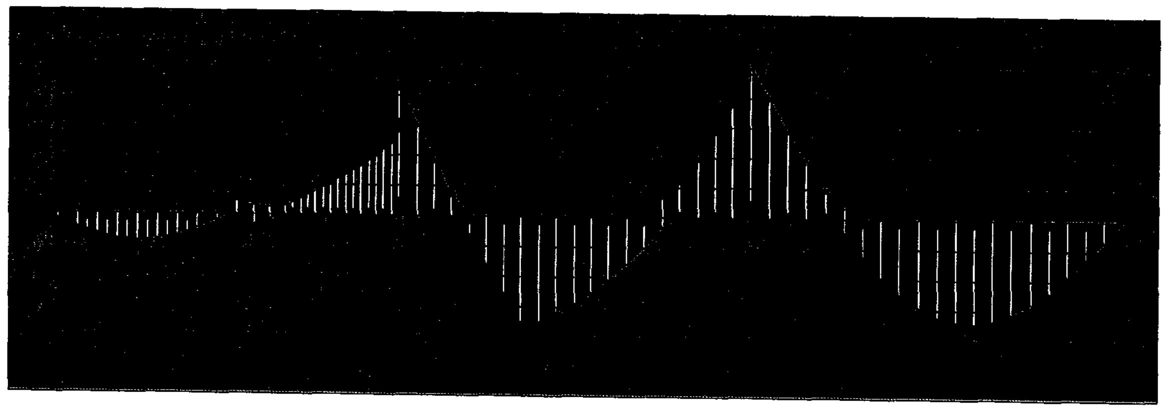

Figure 4.4: Bending Moment Diagram

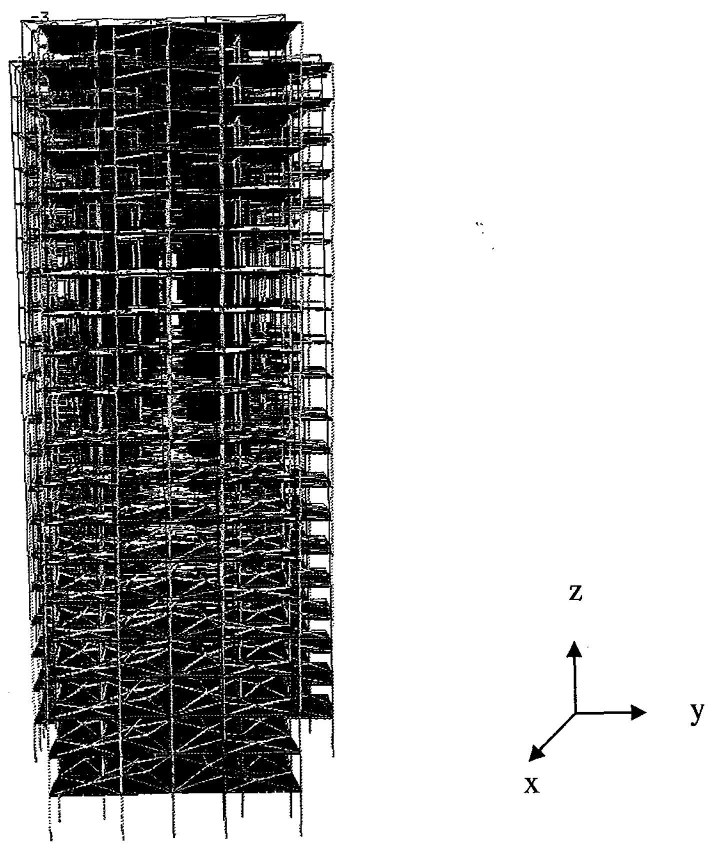

Figure 4.5: Deflection

(b) Effect of Storage Tank Located at Different Stress Zone

Table 4.2 presents the results gathered from the analysis for storage tank installation at different stress zones. Stress zone in a plane is defined from displacement contour produced as shown in Figure 4.6. Two landscape decks are utilised for rainwater harvesting storage tank installation and each of them are categorised into two distinctive stress zones. Storage tank which located at high stress zone induces larger magnitude of shear force and bending moment in general. The volume for storage tank at large landscape deck and high stress zone is reduced as a result of the instability of the structure.

Table 4.2: Summary of Results for Critical Element at Landscape Deck

Landscape Deck	Stress Zoning Description	Shear Force (kN)	Bending Moment (kN.m)	Deflection Status
Large	High	265.5*	695.3*	acceptable
Large	Low	255.3	585.2	acceptable
Small	High	159.4	454.0	acceptable
Small	Low	153.0	360.3	acceptable

Note: *The storage volume has been reduced to 60 % of the original volume.
Acceptable denotes the value is under the limit allowed by design code.

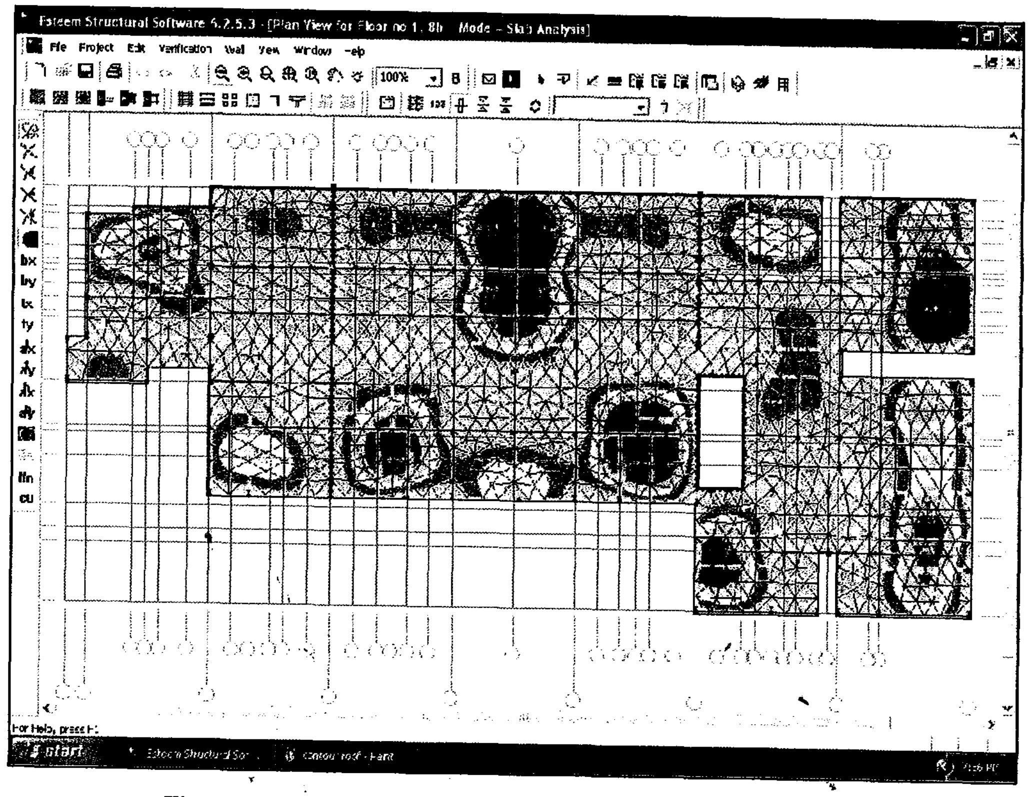

Figure 4.6: Typical Floor Plan with Displacement Contour

4.2.2 Case Study II: Penang

For Case Study II in Penang, there are five models are constructed namely, Model A, Model B, Model C(i), Model C(ii) and Model D. The structural responses of these models are compared in terms of deflection in two principle axes. The results are summarised in Table 4.3.

Table 4.3: Summary of Results for Critical Element for Maximum Deflection

Model	Deflection x-direction (mm)	Deflection y-direction (mm)	Deflection Status
Model A	3.818	30.78	Acceptable
Model B	3.562	31.25	Acceptable
Model C(i)	3.678	30.59	Acceptable
Model C(ii)	3.769	30.54	Acceptable
Model D	3.842	30.88	Acceptable

Based on the results, it is clearly shown that the appropriate arrangement of RRWH tanks will improve the building in resisting lateral loading. The simulated deflection in x-direction for all the models except Model D decreases about 0.024 mm to 0.256 mm or 0.6 % to 6.7 %

compared to Model A. For deflection in y-direction, Models C(i) and C(ii) show drop from 0.19 mm to 0.24 mm which is about 0.6 % to 0.8 %.

The improvement in y-direction is not significant as compared to x-direction because wind load has been exerted in y-direction. Considering the deflection in x-direction only, Model B exhibits the good orientation if RRWH tank is intended to e installed at this building. If only deflection in y-direction is considered, Model C(ii) gives the good recommendation. As the whole, Models C(i) and C(ii) show the best solution of the installation of RRWH tank in terms of deflection in both principle directions. The installation of RRWH tank for Model D has increased its structural response in terms of deflection in both principle axes.

Based on the overall results of the analysis, it shows that different location of RRWH tank installed on the building has caused different structure behaviour to the building under the action of lateral loading. It also shows that the effect of lateral load on high rise building with rooftop rainwater harvesting system is small due to the structural form of this high rise building, i.e. core and shear wall structure. The core and shear wall are continuous vertical wall which have high stiffness in resisting lateral loading. All the deflection recorded has fell within in the allowable limit recommended by MS1553, 2002 which is h/500, where h is the total height of the building.

CHAPTER 5
CONCLUSION AND RECOMMENTATIONS

5.1 Conclusion

To achieve a developed country for a better living, the most precious environment is scarified for urbanisation and industrialisation. Unfortunately, development has generated adverse impact to the environment, economy and social. People aware of this counter effect and the importance of sustainability. The Bruntland Commission has provided the necessary objective for sustainable development as *"to meet the needs of the present without compromising the ability of future generations to meet their needs"*.

Due to development, the change in surface impermeability has caused abrupt increment up to 50% in surface runoff. This has been clearly shown in the calculation of OSD storage tank sizing for both case studies. To reduce such impact to the receiving waterbodies after development, this increased surface runoff needs to be temporarily stored at onsite detention level. The amount of this runoff quantity is determined by Swinburne Method as given in USMM (DID, 2000).

The quantity required for OSD is related to the quantity needed for water reuse in this research in accordance to the local requirement. The quantity of harvested rainwater is determined by adopting Supply Side Method suggested by University of Warwick after considering local condition.

Rainwater harvesting is an approach to preserve the valuable natural resource. Harvestable rainwater is estimated through probabilistic analysis. Two feasible methods of storage tank sizing are highlighted to obtain the required volume for non-portable use and peak discharge attenuation.

The impact of storage tank in term of structural stability and integrity are analysed and the responses are evaluated. From the outcome, it shows that the structural impact can be kept to a minimum if the required storage is installed in an appropriate position as discussed in Chapter 4. The application of rainwater harvesting technique for high rise building is a viable approach to realise the aspiration of sustainable urban environment for Malaysia in future.

5.2 Recommendation for Future Works

This research can be extended to study the effectiveness of the adopted Supply Method for RRWH tank sizing if the real model is installed with the proposed system. These methods outlined above can be further refined where necessary to use daily rainfall data. The quantity for the collected rainwater and water usage for non-portable purposes can be recorded and compared with the analytical results.

The lateral load considered in this research is mainly from wind effect. However, this type of loading can be contributed by earthquake action as well. The action of seismic load can be determined by using UBC Equivalent Static Analysis and exerted to the building as a part of lateral loading. The impact of seismic and wind loading to high rise building can be determined by referring to the appropriate load combination proposed in design code. This can be done in elastic analysis using most common computer software such as EsteemPlus. The further analysis of water impact loading due to sloshing (if the RRWH tank is not fully stored) on to the structure can be considered if higher capability software if available or computer model is developed.

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KERTAS KERJA

STUDY ON A HIGH RISE BUILDING INCORPORATED WITH RAINWATER HARVESTING STORAGE TANK TOWARDS BUILDING A SUSTAINABLE URBAN ENVIRONMENT IN MALAYSIA

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Summary

Water is an essential element to life. With the arising amount of water demand and at risk of water pollution, water has changed from one of the relative abundance to one of the relative scarcity. Malaysia as a nation in humid tropics regions which received plentiful rainfall every year is expected to encounter acute water crisis such as flooding and water shortage in particularly. The current scenario of water in Malaysia is discussed. To pursue a sustainable development, rainwater harvesting has been recognised as one of the innovative solution. As high rise building is expected to be the trend of future dwelling and office development in Malaysia, the installation of rainwater harvesting facility in a high rise building in Klang Valley is studied in line with the goal of the government to solve water related issues. The criteria of storage tank sizing are highlighted in details by taking into consideration the requirements for water quantity control and water reuse. The integration of rooftop rainwater harvesting tank in the studied building is modeled and analysed in order to investigate the impact of the installation of rainwater harvesting tank on the structural stability and integrity of this building.

1. Introduction

Water covers approximately three quarter of the earth's surface. The study published by United Nations in 1997 stated that two thirds of the world's population is likely to live in countries with moderate or severe water shortages by 2025. Half of the world's population lives in urban areas today with 18,000 additional urban dwellers in the world everyday. It is expected by 2008, the figure will exceed more than 50 % of the world population. During World Day for Water 2002, the Secretary-General of United Nations, Kofi Annan, has expressed his concern regarding world's water problems and worry on the new violent conflict prompted by water issues in his message. An estimated 1.1 billion people lack access to safe drinking water, 2.5 billion people have no access to proper sanitation, and more than 5 million people die each year from water-related diseases, which is 10 times the number killed in wars, on average, each year (United Nation, 2002).

Malaysia is moving towards achieving a developed nation status by the year 2020 following the rapid socio-economic growth in the last two decades. With a present estimated total of 21 million people, the Malaysian population is expected to escalate to 30 million in 2020 and, cities and towns may reach 55-60 % of the total population. Malaysia is blessed with plentiful water resources with an average annual rainfall of 3000 mm or 990 billion m^3 over the Malaysian land mass amounts, of which 566 billion m^3 becomes surface runoff, 64 billion m^3 recharges the aquifers and 360 billion m^3 returns to the atmosphere (Abdullah & Mohamed, 1998). 97 % of the raw water supply originates from surface water sources.

The overall water demand is growing at the rate of 4 % annually, and projected to be about 20 billion m^3 by 2020. Even though this volume is less than 2 % of annual runoff, due to the variation of rainfall both in time and space and the development of resources could not meet the rapid pace of urbanization and industrialization, some urban regions of high water demand such as Klang Valley, the hub of Malaysia, has encountered water scarcity over the past few years culminating in the water crisis in early 1998. Conversely, due to excess water from too much rainfall, Malaysia is experiencing frequent flash flood which is grown with the development. As a result, the urbanization has become a cause of tension to the sustainable development.

2. Water Scenario in Malaysia

Floods and droughts are two most significant natural hazards in terms of water related socio-economic losses in Malaysia. These phenomena are related to two extreme cases of water quantity aspect. The former incidence is triggered by excess of stormwater from too much rainfall whereby the latter issue is due to too little rainfall.

2.1 Floods

Flash flood in Malaysia is subjected to intense short duration rainfall. It is estimated that 29,000 km^2 or 9 % of the total land area in Malaysia is flood prone, affecting 2.7 million people (Abdullah & Mohamed, 1998). Incidences of flash floods in urban areas are on the rise. This is due to the landuse changes from pervious areas originally into impervious areas as urbanisation and industrialisation take place. A study has revealed that an increase in area imperviousness from zero to 10 % would cut time to peak flow discharge by about 50% and increase the discharge magnitude by about 90 % (Abdullah & Mohamed, 1998). The allocation for flood mitigation project has exceeded RM6000 million for the 8th Malaysia Plan. In the year 2000, Department of Irrigation and Drainage, Malaysia has published the new urban drainage guideline namely Urban Stormwater Management Manual for Malaysia (USMM) to preserve the urbanized areas in a sustainable urban environment and achieve the aim of "Zero Flash Flood" by 2010.

2.2 Droughts

The severe drought in 1998, in particular affected 1.8 million residents in southern Kuala Lumpur City, Bangi and Kajang, bringing in its wake some periods of disruption water supply (Shaaban & Low, 2003). The drought also hit other areas in Malaysia such as Penang, Kedah, Kelantan, Sarawak and Sabah. A guideline for installing a rainwater collection and utilization system is then published by the Ministry of Housing and Local Government (KPKT).

The recent study on water resources for Selangor and Kuala Lumpur shows that the present water resources for Selangor and Kuala Lumpur are adequate to meet the water demand up to the year 2007 and the quality of water supplied is in full compliance with World Health Organisation International Standards for Drinking Water as outlined in Table 1. The demand for Selangor and Kuala Lumpur grows at an average rate of 6% per year. Beyond 2007, the State Government, together with the Federal Government, is planning to source water from a neighbouring state (Subramaniam, 2004).

Table 1 Water Supply Demand and Projection for Selangor and Kuala Lumpur (Subramaniam, 2004)

Year	Demand (Mld)	Supply (Mld)
2002	3,326	3,628
2003	3,519	4,028
2004	3,723	4,028
2005	3,940	4,428
2006	4,170	4,428
2007	4,413	4,533
2008	4,671	4,533

3. Rainwater Harvesting

Water is the most precious natural resource. It is always treated as an infinite free resource and taken for granted by the people. With hastily increased population all over the world, the people would compete over clean water supply for survival in the future. With its limited supply, the rainwater harvesting technique is one of the other alternatives to manage and conserve water for a secure and sustainable future.

The rainwater harvesting is not a new technique to collect and store water for later use. It has been adopted thousands of years ago by our ancestors when the piped water system is not in existence. It is still in practice for certain areas where water supplies are scare, expensive or of poor quality or in island nations as the sole domestic water source. The harvesting of rainwater involves the collection of rainwater from catchment, conveying this water to storage tank and subsequent delivery.

The current resurgence of rainwater harvesting as a source of water supply has been applied for over twenty-five year or more over the world. There are numerous innovative systems to satisfy the identified needs and achieve high reliability. Various design methods and models have been established based on localized water balance.

3.1 Water Demand

The amount of rainwater to be used for non-portable purposes should be estimated as in order to find out the required rainwater storage volume. The demand depends on the type and usage of the entire building and the number of occupancy.

The guideline published by the Ministry of Housing and Local Government (KPKT, 1999) recommends minimum rainwater harvesting storage capacity as given in Table 2. The minimum storage capacity is based on usage for toilet flushing, watering plants, washing vehicles and general cleanings. It is based on the location having rain once every 4 days on the average.

A study has been carried out by Shabaan et al. (2002) for a typical double storey terrace house of a family of two adults and four school going children. The amount of untreated rainwater used was monitored manually for twelve months period using mechanical water meter installed at each facilities. The result (Table 3) indicates that household use for non-portable purpose using rainwater constitutes 34 % of the total monthly household water use.

In Malaysia, the majority of the people rely on the sole water source, treated water. Embi (2002) believes that more than 50 % of daily water requirements in Malaysia do not required treated water such as flushing toilets, washing clothes, watering garden, washing cars, pavements and drains. As a consequence, high cost associated with treating water at centralised plant, pumping and distributing (reticulation) can be saved.

Table 2 Recommended Minimum Storage Capacity (KPKT, 1999)

Building Type	Storage (Litres)
1. Terrace house	1120
2. Bungalow	1800
3. Multi-storey building	Depends on type of building

* Base on 5 person/household
* An average person uses 36 litres/day for toilet flushing

Table 3 Rainwater Use for Various Facilities (Shabaan et al., 2002)

Item	Average Daily Use (liters)	Average Monthly Use (liters)	%
Washing Clothes	300	9000	66
Toilet Flushing (3 W.Cs)	90	2700	20
General Cleaning (including car and motorcycles washing)	65	1950	14
TOTAL	**455**	**13650**	

Monthly Rainwater Use = 13,650 liters
Monthly Water Use (from public water supply) = 27,000 liters
Total Monthly Household Water Use = 40,650 liters

3.2 Rainwater Storage Tank Sizing

Two approaches for rainwater harvesting storage tank sizing which suit the local conditions and requirements have been adopted in this study.

3.2.1 Supply Side Approach

This approach is established by University of Warwick, United Kingdom. It is suggested that this approach is used to size the storage tank for low rainfall areas or areas where the rainfall is of uneven distribution. For the case of high rise building, the demand of water based on consumption rates and occupancy of the building is no longer governing the storage requirement. Furthermore, the distribution of rainfall varies throughout a year in Malaysia.

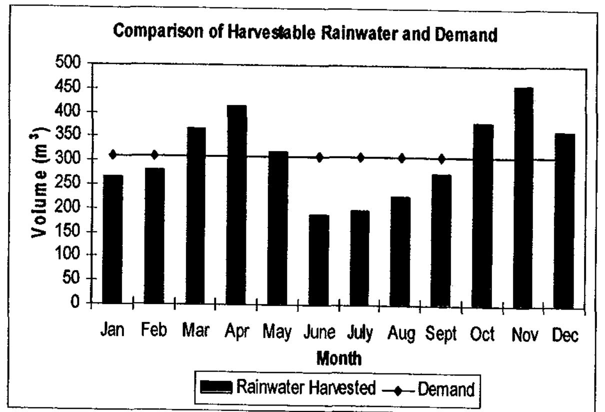
The hydrological data and calculation sheets for storage tank sizing are tabulated in Tables 4 and 5. Figure 1(a) shows the comparison of harvestable water while the demand and the predicted cumulative inflow and outflow from the tank is illustrated in Figure 1(b).

Table 4 Site Characteristic and Hydrological Data

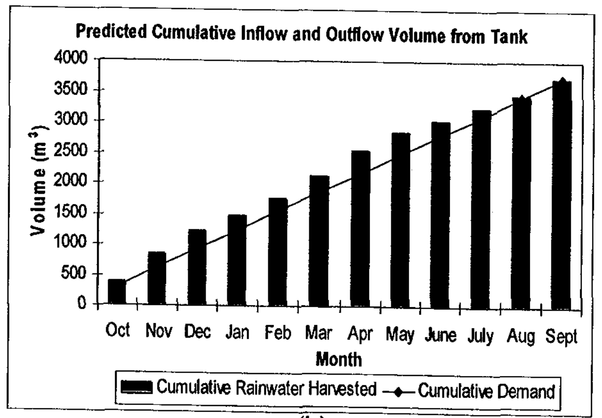
Description	
Catchment Area (m^2)	1500
Runoff Coefficient	0.9
Average Annual Rainfall (MMS,2005) (mm/year)	2759.1
Annual Available Water to be Harvested (Assume 100%) (m^3)	3725
Daily Available Water (m^3/day)	10.2
Monthly Available Water (m^3/month)	310.4

Table 5 Storage Tank Sizing Calculation

Month	Rainfall (mm)	Rainwater Harvested (m^3)	Cumulative Rainwater Harvested (m^3)	Demand (m^3)	Cumulative Demand (m^3)	Difference between Columns 4 & 6 (m^3)
Oct	281.9	380.57	380.57	310	310	70.56
Nov	339.3	458.06	838.62	310	620	218.62
Dec	268.1	361.94	1200.56	310	930	270.56
Jan	195.8	264.33	1464.89	310	1240	224.89
Feb	208	280.80	1745.69	310	1550	195.69
Mar	271.5	366.53	2112.21	310	1860	252.21
April	305.6	412.56	2524.77	310	2170	354.77
May	235.1	317.39	2842.16	310	2480	362.16
June	138.9	187.52	3029.67	310	2790	239.67
July	145.9	196.97	3226.64	310	3100	126.64
Aug	167	225.45	3452.09	310	3410	42.08
Sept	202	272.70	3724.79	310	3720	4.78
	2759.1			**3720**		



(a)



(b)

Figure 1 (a) Comparison of harvestable rainwater and demand, (b) Predicted cumulative inflow and outflow volume from tank.

From the calculation by using supply-side approach, the required storage tank volume is 362 m^3 for the study site. This is the maximum harvestable volume of rainwater that can be used for non-portable purposes for this particular site.

3.2.2 Swinburne Method

The new design approach for urban drainage in Malaysia emphasize the minimization and control of flooding and pollution risks with maximizing wildlife habitats and enhancing landscape values or minimizing long term effects of development on the ecological of urban area. In order to achieve zero peak contribution discharge after development, source control is the vital measure. Runoff will be collected and temporary stored at or near its point of origin with subsequent slow release to the downstream receiving water body. The recommended method in USMM (2000) for sizing on-site detention (OSD) storage tank is the Swinburne Method, developed at the Swinburne University of Technology in Melbourne, Australia. This method is essentially site-based, some allowance is made for the position of the site within the catchment. The Permissible Site Discharge (PSD) which is defined as the maximum allowable post-development discharge from a site for the selected discharge design storm is set as pre-development minor storm discharge calculated from Rational Method.

$$PSD = Q_p = C_p I_p A \tag{1}$$

where Q_p = pre-development discharge, C_p = runoff coefficient for pre-development condition, I_p = rainfall intensity for pre-development condition and A = catchment area.

The Site Storage Requirement (SSR) is the total amount of storage required to ensure that the required PSD is not exceeded and the OSD detention facility does not overflow during the storage design storm ARI which is 10 year ARI. The method uses the Rational Method to calculate site flows and utilises a non-dimensional triangular site hydrograph based on the triangular design storm method. Typically, the critical storm duration that produces the largest required storage volume is different from the time of the concentration used for peak flow estimation. Therefore, storage volumes must be determined for a range of storm duration to find the maximum storage required.

$$SSR = 0.06 t_d (Q_d - c - d) \tag{2}$$

For above-ground storage:

$$c = 0.875 PSD\left(1 - 0.459\frac{PSD}{Q_d}\right) \tag{3}$$

$$d = 0.214\frac{PSD^2}{Q_d} \tag{4}$$

For below-ground storage:

$$c = 0.675 PSD\left(1 - 0.392\frac{PSD}{Q_d}\right) \tag{5}$$

$$d = 0.117\frac{PSD^2}{Q_d} \tag{6}$$

where t_d = selected storm duration (minutes) and Q_d = the peak post-development flow from the site for a storm duration equal to t_d (l/s).

The determination of OSD storage tank sizing is summarized in Table 6 for both above-ground and below-ground storage. From the result, the minimum storage tank requirements for above-ground and below-ground storage facilities to meet the requirement of USMM to limit the post-development site discharge to pre-development site discharge are 43.22 m^3 and 53.09 m^3.

3.3 Discussions

The study site is a 20 storey service apartment in Klang Valley, Selangor. The building is in 56 m length by 27 m width and 63 m height which accommodate 270 households in total. The water demand of rainwater for the study site is assumed to be 50 % of the water usage data collected by Shabaan et al. (2002) after considering the variation of the building type. The monthly non-portable water demand for toilet flushing and general cleaning is 628 m^3/month. The water demand exceeds the harvestable rainwater from the catchment. The calculated rainwater supply is able to serve 49 % of the demand. This is basically caused by smaller catchment area compared to the total number of household for high rise building.

Table 6 Summary of OSD Storage Tank Calculation

Description	Above-ground	Below-ground
Catchemnt Area, A (m^2)	1500	
Pre-development:		
t_c (minutes)	18.5	
Intensity, I (mm/hr)	133.62	
Runoff coefficient, C	0.71	
PSD = Q_p (l/s)	39.53	
Post-development:		
t_c (minutes)	5	
Intensity, I (mm/hr)	212.46	
Runoff coefficient, C	0.91	
Q_a (l/s)	80.56	
t_d	20	20
C	23.14	20.56
D	4.28	2.71
Q_d (l/s)	63.43	67.51
SSR (m^3)	43.22	53.09

In terms of stormwater quantity control, the SSR for above-ground facility is higher than below-ground facilities because of the storage geometry and outflow characteristics. These two values of storage amount are much smaller compared to the amount determined by using supply side approach. The SSR is adopted as the minimum storage required for rainwater harvesting storage tank in order to regulate the peak flow discharge to the PSD.

The storage tank can be installed in a few arrangements. The tank could be a single large tank or a few smaller tanks which are located on rooftop, at particular floor level of the building or on ground. Pumping is required for on ground storage compared to other above-mentioned storages where water can flow due to gravity effect. On ground storage requires more tanks, pipes, plumbing fittings and pumps in general. During operation, higher energy consumption and maintenance is needed.

4. Structural Analysis

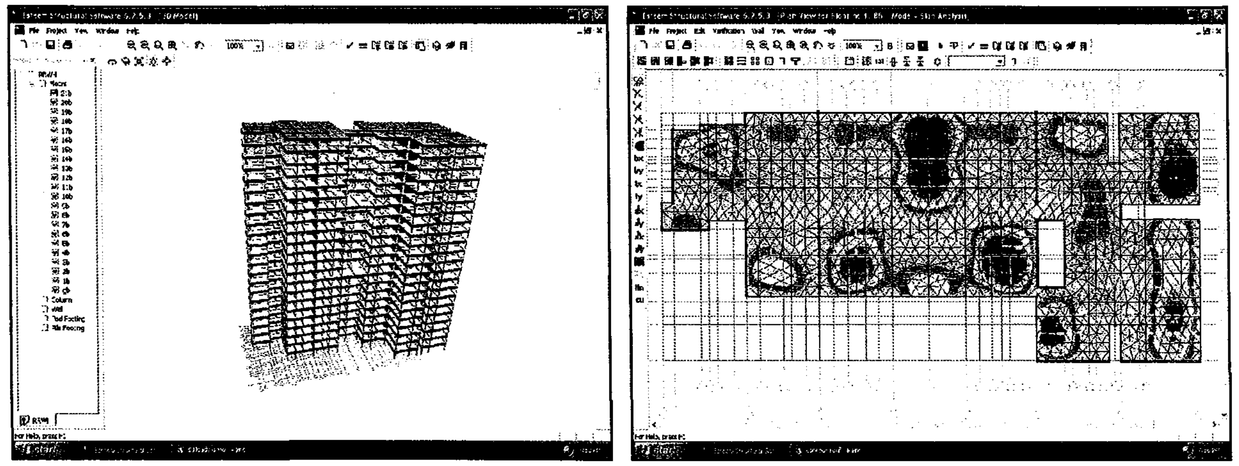
4.1 Computer Modelling

The building is modeled using EsteemPlus 6.2, as illustrated in Figure 2. Three models, namely Model A, Model B and Model C, are constructed to represent different tank installation at rooftop and landscape deck at Level 8 and Level 15 of the building with specific tank dimension as delineated in Table 7. These models are applied with dead, live and wind loads accordingly.

Table 7 Dimension and Location of Storage Tank

	Description	Dimension (Width × Length x Height)
Model A	Without Storage Tank	-
Model B	Singe Large Tank at Rooftop	8.5 m ? 12 m ? 3.55 m
Model C	Storage Volume Equally Distributed at Rooftop, Landscape Deck at Level 8 and Level 15	8.5 m ? 12 m ? 1.2 m at Rooftop, 4 m ? 8 m ? 2.4 m and 3 m ? 6 m ? 2.4 m at Level 8 and Level 15

The critical element of the structure is then identified. The results on bending moment, shear, deflection and sway are analysed subsequently. The main objective of the computer modeling is to study the impact of rainwater harvesting storage tank on the structural behaviour of the building. The potential for storage tank integration on the existing building is evaluated and the minimum impact subjected to storage tank installation to the existing building is then formulated.



(a) (b)

Figure 2 (a) Structural representation of the 20-storey service apartment in Klang Valley, Selangor, and (b) Typical floor plan with displacement contour

4.2 Results and Discussions

4.2.1 Effect of Storage Tank Provision

The structural integrity and stability of the service apartment are assessed and the results in term of deflection, sway, shear and bending moment for critical element are analysed as highlighted in Table 8. Generally, Model B has the highest value for shear force and bending moment. The single large storage tank imposes significant additional load at specific area on rooftop. Critical shear force and bending moment are increased approximately 3.3 and 2.5 times, respectively. If the same amount of storage volume is equally distributed at three different floor levels as indicated by Model C, it has virtually nominal effect on the building compared to Model B. The increments of structural responses are 50 % (shear force) and 20 % (bending moment). Deflections for all the models are under the permissible limit referred to BS8110. In terms of sway, all the models experience a slight sway under the wind action.

Table 8 Summary of Results for Critical Element at Rooftop

Description	Shear Force (kN)	Bending Moment (kN.m)	Deflection	Sway (mm)
Model A	136.5	127.2	acceptable	20.23
Model B	447.4	311.7	acceptable	20.13
Model C	204.9	152.7	acceptable	20.26

Note: Acceptable denotes the value is under the limit allowed by design code.

4.2.2 Effect of Storage Tank Located at Different Stress Zone

Table 9 presents the results gathered from the analysis for storage tank installation at different stress zones. Stress zone in a plane is defined from displacement contour produced as shown in Figure 2. Two landscape decks are utilised for rainwater harvesting storage tank installation and each of them are categorised into two distinctive stress zones. Storage tank which located at high stress zone induces larger magnitude of shear force and bending moment in general. The volume for storage tank at large landscape deck and high stress zone is reduced as a result of the instability of the structure.

Table 9 Summary of Results for Critical Element at Landscape Deck

Landscape Deck	Stress Zoning Description	Shear Force (kN)	Bending Moment (kN.m)	Deflection
Large	High	265.5*	695.3*	acceptable
Large	Low	255.3	585.2	acceptable
Small	High	159.4	454.0	acceptable
Small	Low	153.0	360.3	acceptable

Note: *The storage volume has been reduced to 60 % of the original volume.
Acceptable denotes the value is under the limit allowed by design code.

5. Conclusion

To achieve a developed country for a better living, the most precious environment is scarified for urbanisation and industrialisation. Unfortunately, development has generated adverse impact to the environment, economy and social. People aware of this counter effect and the importance of sustainability. The Bruntland Commission has provided the necessary objective for sustainable development as "*to meet the needs of the present without compromising the ability of future generations to meet their needs*".

Rainwater harvesting is an approach to preserve the valuable natural resource. Harvestable rainwater is estimated through probabilistic analysis. Two feasible methods of storage tank sizing are highlighted to obtain the required volume for non-portable use and peak discharge attenuation. This study is an initial effort to assess the potential of utilising rainwater harvesting technique for high rise building in Malaysia. It is hope that the finding will put an end to the queries of stakeholder at large on the additional load on the building due to rainwater harvesting storage tank integration.

The impact of storage tank in term of structural stability and integrity are analysed and the responses are evaluated. From the outcome, it shows that the structural impact can be kept to a minimum if the required storage is installed in an appropriate position. The application of rainwater harvesting technique for high rise building is a viable approach to realise the aspiration of sustainable urban environment for Malaysia in future.

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