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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.

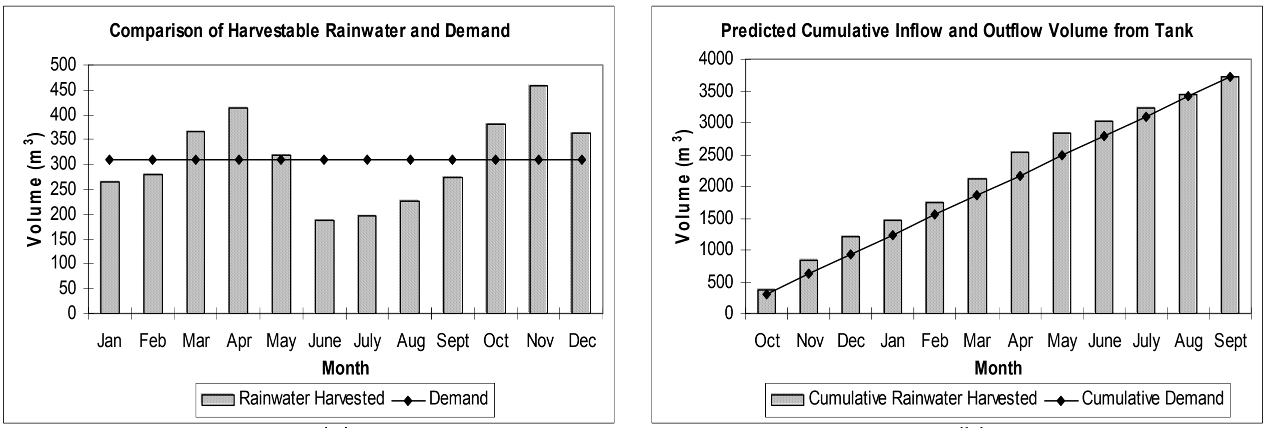
The hydrological data and calculation sheets for storage tank sizing are tabulated in Tables 4 and 5. Figure 1(a) shows the comparison of harvestable water while the demand and the predicted cumulative inflow and outflow from the tank is illustrated in Figure 1(b).

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

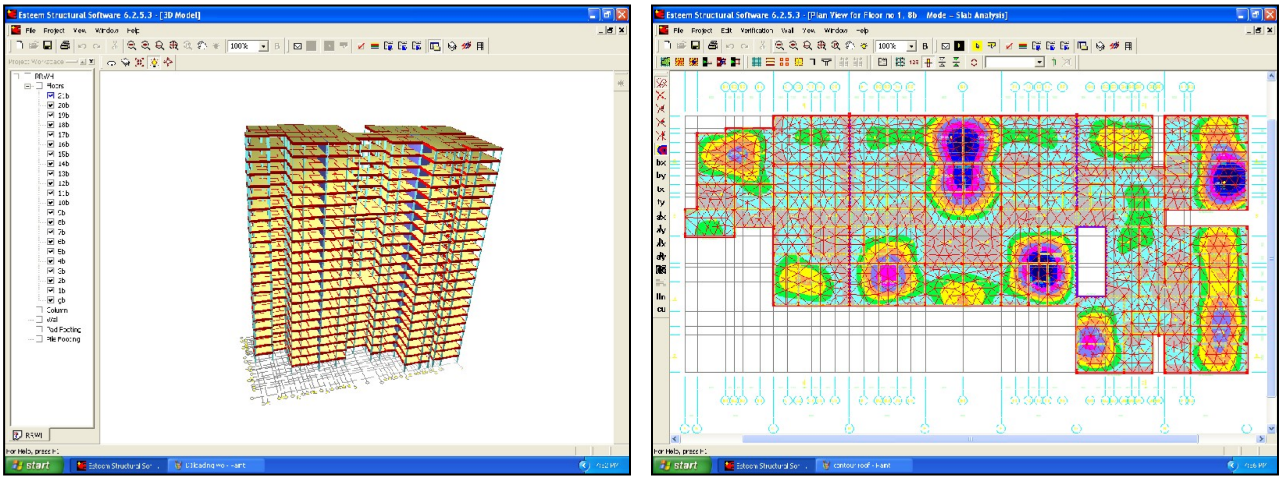
4.1 Computer Modelling

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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