A STRUCTURAL ANALYSIS ON THE IMPACT OF WATER LOAD FROM ROOFTOP RAINWATER HARVESTING TANK ON A 13 STOREY BUILDING.

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ABSTRACT: Rain Water Harvesting System (RWHS), collects rainwater systematically from the rooftop and stores it in tanks for potable or non-potable purposes. These water-filled tanks impose massive load to the high-rise structure, which is usually not catered for, in the original design. This research studies the response of a 13-storey high building under wind and the RWHS water loads. The result shows that the structure steadfastly sustained the loads. It is concluded that, RWHS may be safely installed to the 13-storey high building under investigation, although the same cannot be said to other similar high-rise buildings.

Keywords: Rainwater harvesting, high-rise building, structural analysis,

1 INTRODUCTION

United Nation study, published in 1997 has indicated that by 2025, as much as two-thirds of the world's population will be affected by moderate-to-severe water shortages (Appan, 1999). Even a country that has abundant of water such as Malaysia is not spared from this impending water crisis. Who would have imagined that a tropical country such as Malaysia would have to face water shortages as it had occurred around Klang valley area, back in 1998. Even more perplexing, at one time, a litre of gasoline cost half as much as a bottled water.

Increasing water demand as a result of population growth and industrialization has called for the need to manage the finite water resources efficiently and effectively. To add gravity to the problem is the growing trend towards urbanisation. Highly populated areas are putting tremendous toll on the water supply capacity. A proactive step must be taken in order to avoid acute water shortages in the future.

One of the solutions, which has been given due consideration by the Malaysian government, is the implementation of Rainwater Harvesting System (RWHS). It is basically a system of collecting rainwater from mainly rooftops, and storing it for later uses. The beauty of this system lies, perhaps, in its simplicity. Rainwater is relatively clean, free of charge, easily accessible and Malaysia receives huge volumes of it all year long. Unfortunately, 58% of this pristine, naturally recycled water ends up as runoff water especially in urban areas (Abdullah, 1998). RHWS can be a viable method to harness this water for better use such as washing, gardening and toilet flushing. This alleviates some flood problems due to surface runoff and at the same time saves valuable treated water for potable purpose such as drinking and cooking.

Rapid urbanisation will dwindle building space and make high-rise building structures, the trend of dwellings in the future. Nonetheless, installing a RWHS on such structures must be considered also from the structural point of view. Water load from large RHWS tanks on the rooftop of an existing high-rise building, would certainly impose huge additional weight that is not catered for, in the original design. Not much research has been done to study the effect of this loading to the structural integrity and its behaviour under the influence of wind. This research is aimed at addressing such issues.

2 THE STRUCTURE AND METHODS

The objective of this research is to determine whether the structural changes of a 13-storey building under the additional water load from the installation of the RWHS storage tanks are within the allowable limits.

2.1 Methodology

The 13 storey building is located at Jalan Ghazali Jawi, Ipoh. The building height is 35.4 m and the plan dimension is 67.8 m by 18 m. It accomodates 204 households. The building is choosen because it is a typical low cost flat. The research methodology can be summarised as follows:

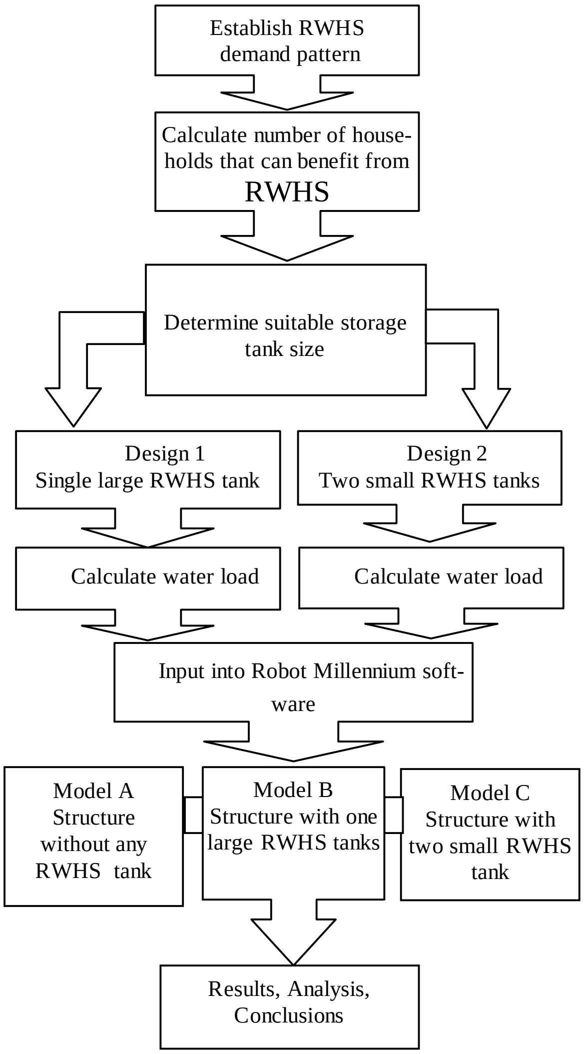

Figure 1. Methodology flowchart

2.2 RWHS tank sizing

The first step in the analysis is to determine the size of the RHWS tanks based on the water supply and demand pattern. The monthly rainwater supply that can be captured from the roof is 214.5m^3. The demand is determined based on the water use for toilet flushing of a six-person household per month. The demand matches the supply when the number of household is limited to 59 units or about 30% of the total flat households.

However it is uneconomical to design a tank to hold this huge amount as the water demand will be continuously depleting the supply. What needs to be stored is only the excess of water due to the uneven distribution of monthly rainfall. In other words, during the raining season, the supply exceeds the demand because more water is available. On the other hand, during dry season, the rainwater supply might be reduced to none and a huge but empty RWHS water tank is definitely a waste. The best size is the one that can strike a balance between the two. A spreadsheet calculation for sizing the tank is adapted from the University of Warwick, UK, RWHS tank sizing method. This calculation takes into consideration the accumulated supply and demand of the rainwater.

Table 1. Spreadsheet calculation for sizing the storage tank

Month	Cumulative rainfall harvested A (m^3)	Cumulative rainfall demand B (m^3)	Excess Rain A – B (m^3)
Sept	217.22	215.11	2.11
Oct	532.04	430.11	101.93
Nov	827.97	645.11	182.86
Dec	1078.78	860.11	**218.67**
Jan	1239.34	1075.11	164.23
Feb	1392.55	1290.11	102.44
Mac	1589.84	1505.11	84.73
Apr	1864.78	1720.11	144.67
May	2094.60	1935.11	159.49
Jun	2243.61	2150.11	93.50
Jul	2409.42	2365.11	44.31
Aug	2576.27	2580.11	-3.84

From Table 1, it’s evident that the maximum water volume that needs to be stored is 218.67m^3.

2.3 RWHS proposed design

Two designs of RWHS storage tanks, as shown in Figure 2 and 3, are proposed. Design 1 is single large tank and Design 2 is two tanks each having half the size of Design 1. The locations of the proposed RWHS water tanks on the rooftop are chosen as such, due to the presence of several additional beams there. For example, the proposed location of Design 1 has extra two 6 m long, rectangular BR 150 x 600 mm and three 6.6 m long, rectangular BR 450 x 500 mm beams beneath it.

Consequently, the tank base dimensions are fixed to be 6 m by 6.6 m. The height of the water level can then be determined which are 5.52 m for Design 1 and 2.76 m for Design 2. These figures are rounded up to 6 m and 3 m respectively because tanks are sold in incremental heights of one meter. Assuming that the tanks are filled with rainwater up to the brim, the water pressure can easily be calculated and converted to dead load. The water load for design 1 is 58.86 kN/m^2 and Design 2 is 29.43 kN/m^2.

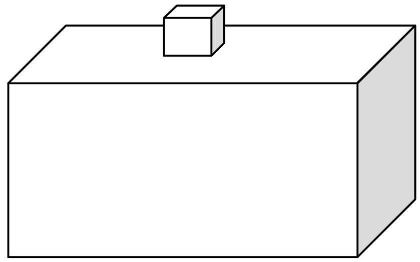

Figure 2. Water tank arrangement of Design 1

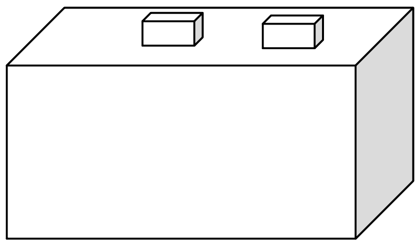

Figure 3. Water tank arrangement of Design 2

2.4 Structural analysis

Modelling of the structure is done using the Robot Millennium version 13.0.575 software. Robot Millennium is an integrated graphic programme for modeling, analysing and designing various types of structures. Three types of models are prepared:

Model A: Existing building with no RWHS water load
Model B: Building with single large water load (RWHS tank design 1)
Model C: Building with two smaller water loads (RWHS tank design 2)

These models are then applied loadings as explained in the next section.

2.4.1 Loadings

The loads are assigned attributes such as dead, live and wind loads. The dead loads in the analysis are the water load, empty water tank, brick wall, slab, partition and finishes. Self-weight of the structure is automatically accounted for by Robot Millennium. The live load is the imposed floor load obtained from Table 1, BS 6399: Part 1, 1999. The wind load, which is basically the wind pressure is based on the specification of British Standard. The wind velocity, v and wind load q, values are 32.0 m/s and 0.746 kN/m^2 respectively (Jamaluddin, 2002)

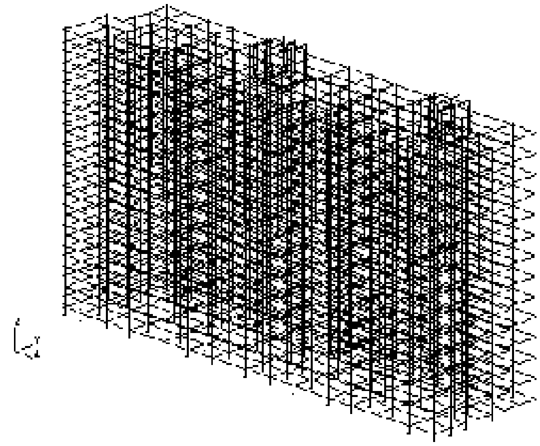

Figure 4. Structural representation of the 13-storey flat with the two water load at the top

2.4.2 Assumptions

The assumptions made in modeling the high-rise structure in Ipoh are as follows:

- The material of the structure and structural components are linearly elastic.
- Only the primary structural components participate in the overall behaviour.
- Floor slabs are assumed to be rigid in plane.
- Negligible small-scale stiffness and deformations.
- Members and joints are essentially cast as a unit and behave as rigidly connected.
- All the beams are uniform rectangular beam sections (BR 230 x 450 mm) except the five beams underneath the water tank which are BR 150 x 600 mm and BR 450 x 500 mm.
- All the columns are uniform rectangular column sections (CR 300 x 600 mm).
- The magnitude of axial loading from the panels are estimated from the slab tributary areas and transferred to the beams.
- All the columns have uniform length except for the studs underground.

3 . RESULTS AND DISCUSSIONS

The critical beam and column are analysed using the Robot Millennium linear statics analysis. The critical beam is the one having the largest deflection and the critical column is the one having the biggest displacement under the extreme loading. The results from the deflection, sway and shear and bending moment values are analysed.

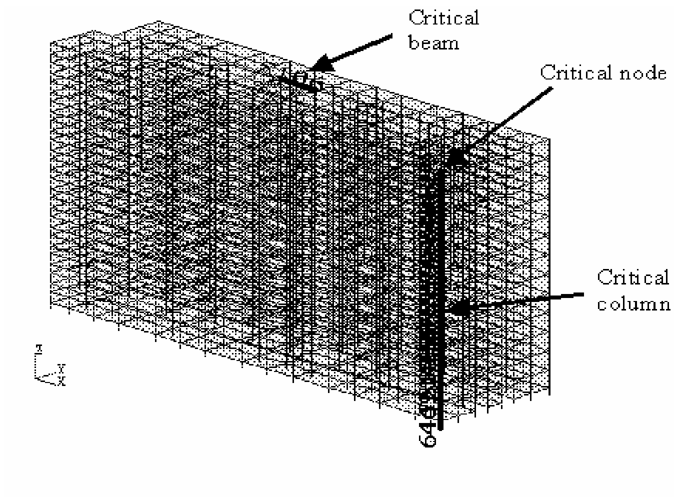

Figure 5. Positions of various critical members

3.1 Deflection

Under extreme load of Model B, the critical beam deflection is 1.07 cm. This is far less than the Serviceability Limit State in section 3.2.1.1 BS 8110 Part 2: 1985 of 2.4 cm.

3.2 Sway

The building experiences a slight sway under the influence of wind. This sway is observed from the displacement of the critical column node. The sway of the critical column also falls within the acceptable limit of a high-rise structure as proposed by Smith and Coull (1991). Under the wind and gravity loadings, the highest node of the critical column displaces to 2.15 cm. This is only about half the sway limit of 5.3 cm.

3.3 Shear and Bending Moment

The results for shear and bending moment can be seen in Table 2 and 3:

Table 2. Results for shear

	Beam	Column
Model A	0.75 kN	880 kN
Model B	700 kN	880 kN
Model C	350 kN	883 kN

Table 3.Results for bending moment

	Beam	Column
Model A	-1.30 kNm	37.5 kNm
Model B	640 kNm	37.2 kNm
Model C	320 kNm	37.5 kNm

The shear and bending moments of the critical beam under single large water tank, which is the extreme loading (Model B), are 700 kN and 640 kNm respectively. These values are 933 (shear) and 492 (bending moment) times greater than the values of the model without any water load. These large values are expected, as the critical beam is located right beneath the water tank. The beam has to carry most of the imposed water load.

For the model that has two smaller water tanks (Model C), the results reveal that the shear force and bending moment are half of that of Model B. This is again, expected, since the water load of Model C is also half of that of Model B. Hence, the findings support the assumption that the materials behave in a linearly elastic manner.

The results also demonstrate that the RWHS water load has virtually nominal effect on the shear force and bending moment of the critical column. The values for the shear force and bending moments for all three cases are remarkably within 1% difference from one another. This may be due to both the loading distribution and position of the tanks with regard to the critical column. Although Model B has a huge concentrated load in the middle, it is situated at quite a distance (33 metres) from the critical column. On the other hand, one of the Model C tanks is near (7 metres) to the column, but the water load is only half as much. Consequently, these factors cancel out each other and in the end; the RWHS water load has little effect on the shear and bending moment of the column.

4 . CONCLUSIONS

It is evident from the results of the structural analysis that the inclusion of RWHS tanks has minimal effect on the structural integrity of the 13-storey building in Jalan Ghazali Jawi, Ipoh. The high-rise structure has steadfastly sustained the additional load imposed by the RWHS water tank even for the worst case (Model B). This conclusion is drawn up based on the compliance under permissible deflection of Serviceability Limit State (SLS) design in section 3.2.1.1, BS 8110: Part 2: 1985 of the critical beam. The beam deflection under extreme RWHS water load is only 1.07 cm. This is way below the beam SLS design limit of 2.4 cm. The sway of the building is only 40% of the permissible limit.

It is also found that the maximum shear force and bending moment for all three models occur at the base of the column. These values taper off as they move upwards, reaching the minimum at the top of the column. This conforms to the expected behaviour of a high-rise structure under the influence of wind.

In essence, RWHS tanks can be installed to the 13-storey building without needing for any additional reinforcement. The system can comprise of either single large tank in the middle or two separate half-sized tanks at the proposed locations. The choice, however, depends on other factors such as economic, which is beyond the scope of this research.

It should be realised though that the proposed locations of the tanks already have certain reinforcement beams. For example, the proposed site for Model C has two additional 150 x 600 mm rectangular beams and three 450 x 500 mm rectangular beams. The designer of the building may have arranged that for future installation of additional regular water tank, but this, cannot be confirmed. The results, nonetheless, verify that the presence of these beams do bolster the strength of the structure in sustaining the RWHS water load.

That raises another question: Could the building have withstood the additional RWHS water load without the presence of the five beams mentioned above? Further studies have to be carried out in order to answer the question, but as far as the analysed structure is concerned, it can be concluded that such reinforcement arrangement is sufficient.

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RWHS has a promising role to play in helping to alleviate the water shortages and other water related problems in Malaysia. It can be applied safely to the 13-storey building in Jalan Ghazali Jawi, Ipoh, although the same cannot be said to other similar high-rise buildings. Each structure has to be analysed separately. Proper investigation on the loading capacity of the beams and columns must be carried out prior to installing the system to avoid any catastrophic structural failure.

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