ANALYSIS OF THE RECTANGULAR AND CIRCULAR CYLINDRICAL RC ELEVATED WATER TANK DESIGN ACCORDING TO EUROCODE

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DESIGN OF RC WATER TANK ACCORDING TO EUROCODE

by

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ABSTRAK

Tangki simpanan adalah bekas yang menampung cecair, gas termampat, atau medium yang digunakan untuk penyimpanan haba atau sejuk jangka pendek atau jangka panjang. Tangki tersebut boleh dibina secara menegak dan mendatar, di atas tanah, semi bawah tanah, dan di bawah tanah, membawa beban statik dan dinamik, di bawah vakum atau tekanan berlebihan, pengaruh angin, seismik, dan suhu. Untuk projek ini, tangka yang dibina di aras tinggi direkabentuk sebagai bentuk silinder bulat dan bentuk empat segi. Perbezaan anatar tetulang besi and isipadu konkrit akan dilakukan untuk kedua-dua rekabentuk. Parameter rekabentuk dipertimbangkan sebagaimana dalam Standard Eurocode. Beberapa pembolehubah yang dipertimbangkan untuk rekabentuk tangka pada aras tinggi adalah ketebalan dinding, ketebalan asas dan bumbung, kedalaman tangki, dan ketinggian menara penyokong. Beban angin telah diperolehi melelui kaedah berangka. Untuk membantu rekabentuk, perisian ETABS telah digunakan untuk rekabentuk kedua-dua tangki aras tinggi ini. Didapati bahawa bentuk silider bulat ini adalah lebih stabil berbanding dengan bentuk empat segi, dengan beban dan tanpa beban angin. Walau bagaimanapun, kos untuk tangka bentuk silinder bulat ini lebih 39.47% daripada tangki bentuk empat segi.

ABSTRACT

Storage tanks are containers that hold liquids, compressed gases, or mediums used for the short or long-term storage of heat or cold. The tanks can be constructed vertically and horizontally, above ground, semi-underground, and underground, carry static and dynamic loads, under vacuum or overpressure, wind, seismic, and temperature influences. In this project, the elevated tank is designed as a circular cylindrical shape elevated water tank and a rectangular shape. The differences between the reinforcement steel and the volume of concrete will be compared between the two designs. The design parameters considered are as described in the Eurocodes. some variables were considered in the design of an elevated water tank which are the thickness of the wall, the thickness of the base and roof, the depth of the tank, the height of the supporting tower. The wind loads are determined using finite element methods. To assist in design, the ETABS software is applied to design the two elevated water tanks. It was found that the circular cylindrical shape is more stable than the rectangular shape by modelling the model in Etabs with and without wind condition. However, the cost of circular cylindrical shape is 39.47 % more than the rectangular shape tanks..

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LIST OF ABBREVIATION

USM	University Sains Malaysia
ASCE	American Society of Civil Engineers
WP	Water Pressure

NOMENCLATURES

F_c	Compressive strength of concrete
F_s	Stress in steel reinforcement
T	Axial tension
A_e	Equivalent area of uncracked composite section
A_s	Area of steel uniformly distributed in the section
A_c	Concrete area in the section
F_{ct}	Direct tension in concrete
S	Strouhal number

CHAPTER 1

INTRODUCTION

1.1 Background

In the USM engineering campus, since 2001 there is no water tank constructed even though there is a need for one. There are a lot of users such as in the academic schools, administration offices, facilities and student accommodation which the water in supplied direct from the PBA water pipeline straight into the storage tanks at each building.

In order to avoid disruption in the Engineering campus, a water tank is needed to provide the storage requirements for the needs of the users in the campus, which would then provide a standby quantity of water if water supply is disrupted due to unforeseen circumstances.

1.2 Problem Statement

Storage tanks are containers that hold fluid and liquids, can be vertical and horizontal and above ground, semi-underground, and underground, carry static and dynamic loads, and work under vacuum or over pressure, upon the wind, seismic, and temperature influences.

Several issues must be tackled by the designer when designing an elevated water tank. If a water tank is to be designed, therefore the designer needs to consider the needs analysis, design parameters, design codes and design software. The tanks are then designed to meet the design parameters and then checked whether the design is appropriate to meet the purposes and requirements.

1.3 Objective

The objectives of the study are:

1. To compare the bending moment and deflection between the rectangular and circular cylindrical designed water tanks.
2. To compare the steel reinforcement, concrete volume and cost of construction material between the rectangular and circular cylindrical designed water tanks.
3. To compare the steel reinforcement, concrete volume and cost of construction material between the presence and absence of wind condition.

1.4 Scope of Work

For this FYP, the factors that affect the design of elevated water tank will be studied. Besides, the elevated water tank with different type of supporting structure will also be investigated. ETABS software will be used for the analysis the model. The design code is based on Eurocode 0, Eurocode 1, Eurocode 2, and Eurocode 8 .

The other notional loads such hydraulic pressure and wind load, the loading will be generated in the ETABS 2018 software. From ETABS also, we need to evaluate the deflection of the elevated water tank and the material cost after designing the elevated water tank.

1.5 Significance of Study

From this study, the expected outcome is to be able to design the RC water tank in different condition. Besides, we are able to understand the parameter that may influence the design of RC water tank. Not only that, we are able to fully understand the analysis and design of elevated water tank.

1.6 Dissertation Outline

The dissertation contains 5 chapters and the description for every chapter is as below.

Chapter 1: Introduction

This chapter describes the reasons behind the study and the objectives of doing the research. Besides, it shows the scope of work and significant of study.

Chapter 2: Literature Review

This chapter shows the purposes, the important design variables and aspects, and design requirements of elevated water tank. Shear and bending theories which are the important theories applied during the design process of elevated water tank. Discussion are made about the characteristics of the different types of elevated water tank supporting structure and the effect of wind towards the elevated water tank are included in this chapter.

Chapter 3: Methodology

This chapter describes about the research methodology conducted for this study to achieve the research objectives. The steps involved in validation exercise and parametric study by using ETABS 2018 software are discussed in detail.

Chapter 4: Result and Discussion

This chapter presents the numerical results of the validation process and the parametric study in term of concrete volume and total steel reinforcement by using ETABS 2018 software.

Chapter 5: Conclusion

This chapter summarizes the important findings of this research based on the objectives of the study before the conclusion can be made. To further appreciate the study using Eurocode 0, Eurocode 1, Eurocode 2, and Eurocode 8 for the design of buildings and similar structures, recommendations for future work are given.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

It is very common that reinforced concrete is applied as the building material for water retaining structures. Concrete is generally the most economical material of construction which will provide long life and low maintenance cost when it is designed correctly (Anchor, 1981). A structure should be design in the way that it will achieve its intended structure function in safety and within the estimated cost. Especially for water retaining structure such as elevated water tank, water tightness and durability are required. These structures must be designed for serviceability, stability and settlement.

Cracking of concrete on its water face should be avoided and considered during design. Cracking due to external loads, and early thermal and shrinkage effects must be assumed as the major design criterion. The other causes of deterioration including weather and aging begin to act after the completion of structure. Thus, it is the responsibility of designer to ensure the continued serviceability of the designed structure for its designed life time (Anchor, 1981).

During the design process, the balance between initial and maintenance cost should be considered . Costly maintenance might occur due to improper original design and these could be avoided or gently reduced at a little or no increase in initial cost of a structure. For a water retaining structure, the inappropriate choice of type or location of movement joints and inadequate allowance for tolerances on reinforcement cover responsible for the most frequent of such maintenance problems. (Water Storage Tank Maintenance of Pittsburg Tank & Tower Group, n.d.)

2.2 Purposes of a Water Tank

The purpose of a water tank is to store water, liquid petroleum or petroleum products. To prevent leakage, all tanks are built as crack-free constructions. The retaining slab and walls for water or raw petroleum can be reinforced concrete with suitable reinforcing cover. Because water and petroleum react with concrete, there is no need to treat the surface in any way. With a few exceptions, industrial wastes can also be collected and handled in concrete tanks. Petroleum products, such as gasoline and diesel oil, are prone to leaking through concrete walls, necessitating the use of specific membranes to prevent leakage. Reservoir is a phrase used to describe a liquid storage facility that can be either below or above ground level (Sahoo, 2008).

According to Calderón et al. (2009), a tank housing water for human consumption is a structure that must perform two basic duties in addition to holding a particular volume of water as following :

(a) It regulates the supply or water pressure in the supply lines.

(b) It acts as a reserve water supply in emergency situations, as for example, in the case of fire.

2.3 Elevated Water Tanks

Due to the reason of hydraulic efficiency and economy, the best placement for these installations is the centre of the supply zone with at a little higher height. As a result, they are frequently positioned near the supply zone on the slope of a hill or on top of specially constructed towers in flat zones. Being at a greater height than the area to which it provides water can mean that any structural failure could have a disastrous effect and catastrophic. (Calderón et al., 2009).

Normally, a water tower tank is constructed for the following purposes (Calderón et al., 2009);

(a) Water flow from the tap is sufficiently high

(b) Water can be supplied to the upper floors of building

(c) As a backup to supply water during power outage or cut-off of water supply

(d) Serves as a reservoir to supply water during the peak usage hours

(e) Eliminate negative pressures of the gravity flow in water distribution systems in hilly areas

2.4 Variables of Design

From Pluto (2018), it states the variables which influence the design of water tower

(a) Design capacity of the water tank

(b) Loading and Pressure

(c) The purposes of the water will be used for

(d) Wind load

(e) Seismic Load

(f) Local temperature outside the water tank (concern for freezing in country with winter)

2.5 Design Criteria

In the absence of accurate method for calculating maximum widths of tensile cracks, the design procedure can be based on elastic theory and modular ratio (Zingoni, 2015). Though the method is not very sound and tends to give the section larger in size with higher margin of safety, but it has been found to give satisfactory performance in the field.

2.5.1 Design Code

The used design standards and references for this elevated water tank are :

(a) Eurocode 0 (BS EN 1990, 2002) – Basic of structural design

(b) Eurocode 1 (BS EN 1991-1-1, 2002) – Action on structure (dead load and imposed load)

(c) Eurocode 2: (BS EN 1992-3, 2006) – Design of concrete structure

(d) MS 1553 : 2002 – Code of practice on wind loading for building structure

2.5.2 Section Subjected to Axial Tension

The first consideration is to provide enough reinforcement to resist all the tensile force. Secondly, for the uncracked composite section, the tensile stress in concrete should not exceed the permissible stress under service load conditions. These conditions can be expressed as (Water Tank Design, n.d.)

The area of concrete required to carry the tension without cracking of concrete is given by,

$$A_e > \frac{T}{f_{ct}} \qquad \text{Eqn 1}$$

And, the area of steel required to carry to tension is given by,

$$A_s > \frac{T}{f_s} \qquad \text{Eqn 2}$$

Where

T = Axial tension

A_e = Equivalent area of uncracked composite section

= A_c + (m-1)A_s

A_s = Area of steel uniformly distributed in the section

A_c = Concrete area in the section

f_{ct} = Direct tension in concrete

f_s = Tension in steel

For 1.0 m length of wall, b = 1000 , thickness t can be obtained by the formula,

$$t \geq \frac{T}{(1000 f_{ct})}\left[1-(m-1)(\frac{f_{ct}}{f_s})\right] \qquad \text{Eqn 3}$$

Thus, the procedure adopted for the design of reinforced concrete section subjected to direct tension is:

1. Based on the exposure condition and grade of reinforcement to be used to determine f_s and calculate the area of steel,

   $A_s = \frac{T}{f_s} \geq$ 0.35 or 0.50% depending upon the type of steel.

2. Select size of the bar, and determine its spacing with clear distance between the bars $\leq$ 300mm to limit the crack width.
3. Determine the thickness of the section from the relation:

$$t \geq \frac{T}{(1000 f_{ct})}\left[1-(m-1)(\frac{f_{ct}}{f_s})\right] \quad \text{Eqn 4}$$

4. Compute the minimum secondary steel to be provided in the section,

A_{sd} = 0.0035A_c for deformed bars Eqn 6

= 0.005A_c for plain bars Eqn 6a

5. Determine size and spacing of bars, S $\leq$ 300 mm
6. Depending upon the exposure conditions select the nominal or clear cover to the reinforcement.

2.5.3 Section Subjected to Bending

For the tension face in contact with water or for the member of thickness less than 225 mm, the flexure design procdure for singly (or doubly reinforced) beam with constants k, j and Q for working stress design hold good (Water Tank Design, n.d.). However, the constants are to be modified as per reduced permissible stresses. The permissible compressive stress in concrete on the water face is the same as recommended in ordinary cases. The expressions for working stress design constant are :

$$k = \frac{1}{1+[f_{st}/(m f_c)]} \quad \text{Eqn 7}$$

$$j = 1 - \frac{k}{3} \text{ and } Q = \frac{f_c k j}{2} \quad \text{Eqn 7a}$$

$$P_{t,bal} = \frac{100Q}{f_{st} j} = \frac{50\, k\, f_c}{f_{st}} \quad \text{Eqn 7b}$$

Different grade concrete and steel got different value of the abbreciation. For example, steel of grade Fe415 have the f_{st} of 150MPa and M 25 grade concrete have f_c of 25 MPa. The design criteria for bending can be expressed as :

$$A_{st} > \frac{M}{f_{st} j d} \qquad \text{Eqn 8}$$

2.6 Movement Joints

According to Sahoo (2008), there are three types of movement joints.

a. Contraction Joint.

It is a movement joint with deliberate discontinuity without initial gap between the concrete on either side of the joint. The purpose of this joint is to accommodate contraction of the concrete, as shown in Figure 2-1.

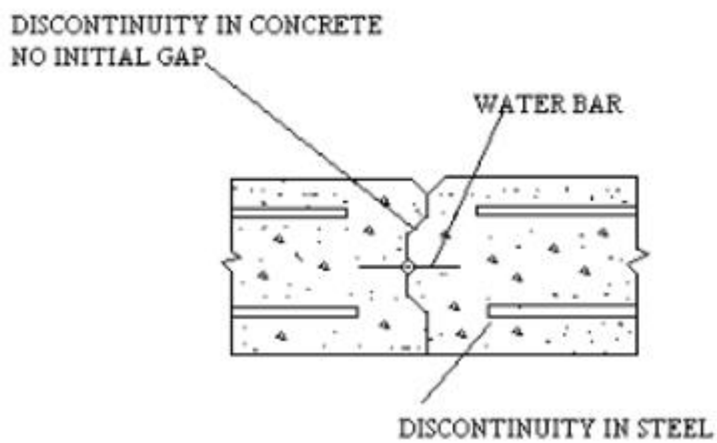

Figure 2-1 : Contraction Joints from Sahoo (2008).

b. Expansion Joint

It is a joint with complete discontinuity in both steel reinforcement and concrete and it is to accommodate either expansion or contraction of the structure. A typical expansion joint is shown in Figure 2-2. This type of joint requires the provision of an initial gap between the adjoining parts of a structure which by closing or opening accommodates the expansion or contraction of the structure.

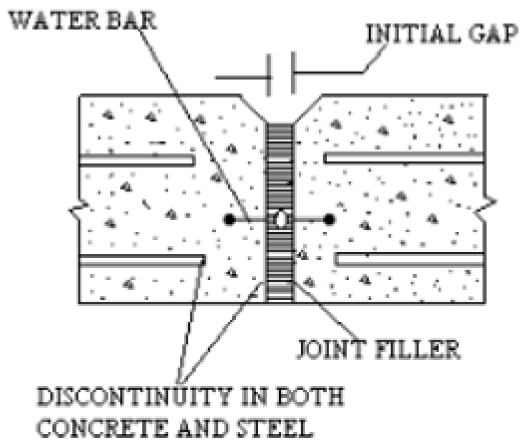

Figure 2-2 : Expansion Joints from Sahoo (2008).

c. Sliding Joint

It is a joint with complete discontinuity in both steel reinforcement and concrete with special provision to facilitate movement in plane of the joint shown in below. This type of joint is provided between wall and floor in some cylindrical tank designs.

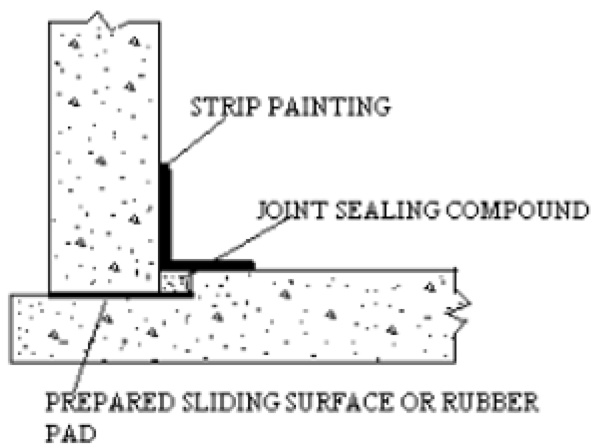

Figure 2-3 : Sliding Joints from Sahoo (2008).

2.7 Water Tightness of RC Water Tank

Water tightness is an important consideration during the design of reinforced concrete water tank. During the design process of reinforced concrete structure, it is assumed that tensile capacity of concrete does not contribute to the strength of the structure, and steel reinforcement is the only component which resists the developes internal tensile forces. Since steel reinforcement can develop the resisting tensile forces only when extension occurs, and hence cause cracks to form in the surrounding concrete, thus it is difficult to avoid cracks in reinforces concrete structures (Li et al., 2018). However, it is found that cracks of limited width do not allow water to leak and therefore it is essential to design a structure so that the surface crack widths are limited to a predetermined size (Anchor 1981.). In the design of water retaining structure, the maximum design surface crack widths in BS 8007 for direct tension and flexure or restrained temperature and moisture effects are as follows (Li et al., 2018).

W = 0.2 mm for severe or very severe exposure

W = 0.1mm for critical aesthetic apperance

Besides preventing leakage, imperviousness of concrete also provide adequate durability, resistane to frost damage, and protection against corrosion of reinforcement and other embedded steel. The minimum thickness of concrete slab for satisfactory performance in most structures is 200mm and thinner slabs should only be used for structural members of very limited dimensions or under very low liquid pressures (Anchor,1981).

Table 2-1 : Classification of tightness from Eurocode.

Table 7.105 — Classification of tightness

Tightness Class	Requirements for leakage
0	Some degree of leakage acceptable, or leakage of liquids irrelevant.
1	Leakage to be limited to a small amount. Some surface staining or damp patches acceptable.
2	Leakage to be minimal. Appearance not to be impaired by staining.
3	No leakage permitted

Tightness Class 0. — the provisions in 7.3.1 of EN 1992-1-1 may be adopted.

Tightness Class 1. — any cracks which can be expected to pass through the full thickness of the section should be limited to w_{k1}. The provisions in 7.3.1 of EN 1992-1-1 apply where the full thickness of the section is not cracked and where the conditions in (112) and (113) below are fulfilled.

Tightness Class 2. — cracks which may be expected to pass through the full thickness of the section should generally be avoided unless appropriate measures (e.g. liners or water bars) have been incorporated.

Tightness Class 3. — generally, special measures (e.g. liners or prestress) will be required to ensure watertightness.

As stated previously, cracking should be the major concern during the design process in order to ensure the water tightness of water tank, thus it is important to identify the factors of cracking and according to Sahoo (2008) and Anchor (1981)and they can be summarized as follows.

- Plastic shrinkage and settlement in very immature concrete due to moisture loss
- Early thermal contraction in the immature concrete
- Long-term drying shrinkage and thermal movement
- Flexural, direct tension or shear stresses in the mature concrete
- Volume changes due to physical or chemical attack
- Inadequate reinforcement and poor construction techniques

Ways to minimize the risk of cracking include:

- Correct placing of reinforcements
- Limiting changes in moisture content and temperature
- Avoiding the use of thick shuttering which prevent the easy escape of heat of hydration
- Reducing the restraints on the expansion or contraction of the structure
- Limiting the restraint from adjacent sections of the work by applying a planned sequence of construction or temporary open section
- Rate of first filing should not greater 2m in 24 hours (Section 9.2, BS 8007)

In addition, segregration and honey-combing should be avoided and all joints of the water tank should be free from leakage (Ibrahim et al., 2021)

Impermeability of concrete is influence by the water-cement ratio of the concrete mix (Krishna Raju, 2005). Higher impermeability will be achieved by reducing the water-cement ratio, but very much reduced water-cement ratio will cause difficulties in compaction and prove to be harmful. Selection of a richness of mix compatible with available aggregates is essential since the particle shape and grading have an important bearing on workability. Cement content used should be sufficiently high to ensure that thorough compaction can be achieved while maintaining low water-cement ratio. The quantity of cement should be within the range of 330 kg/m^3 of concrete to 530 kg/m^3 of concrete. As for thicker parts, temperature as a result of cement hydration. It is usual to use rich mix of M20 to M30 grade in most of the water tank (Krishna Raju, 2005). Impermeability can also be improved by introducing a pozzolanic admixture such as fly ash (Anchor, 1981).

2.8 Settlement

Settlement is one of the aspects which should also be considered during the design of water retaining structure. Serious differential settlement, subsidence and movement might occur in foundations which subject to mining, ground movement, geological faults and subsoils of varying compressibility. Thus, movement results from these must be allowed. The structure can be divided into smaller units and provide additional joints which help to reduce and to accommodate the anticipated differential movement between units. Where subsidence is likely to be severe, flexibility for the anticipated movements should be incorporated in the design (Anchor, 1981).

2.9 Wind Effects

Generally, the wind condition of concern for building design is primarily that of a wind storm, specifically high-velocity, ground-level winds (Ambrose & Veroun, 1990). The winds exerts windward forces and also cause vibration of elevated water tank due to fluctuating forces. Thus, the constructed elevated water tank should have high flexural strength to overcome these windward forces and wind-induced vibration.

According to (Liu, 1991),wind-induced structural vibration largely depends on the characteristics of structures. The most important characteristics are shape, stiffness, and damping. Different shape will cause different amount of vortex shedding forces as wind flow around the object, thus the amplitude of vibration will be. Damping of a structure to reduce the vibration is affected by mechanical friction in used materials or between structural parts, interaction between the structure and foundation, and the mass of the entire structure. Besides, wind-induced structural vibration also depends on the wind characteristics.

Turbulence with domino frequency which almost matches the natural frequency of the structure will cause serious buffeting of that structure.

2.9.1 Windward Forces

Windward forces consist of forces due to positive pressure, negative pressure and aerodynamic drag which tend to move the elevated water tank along the wind direction. Positive pressure occurs when wind energy creates lateral loads onto the surfaces of elevated water tank that are facing the wind direction. Besides, there will be a suction that consists of pressure outward on the surfaces of elevated water tank on the leeward side. This pressure is known as negative pressure as it is in the opposite direction of pressure on the windward side. Since the wind will flow around the elevated water tank after striking the elevated water tank, Ambrose & Veroun (1990) stated that there will be a drag effect on surfaces that are parallel to the direction of the wind. These surfaces may have inward or outward pressure exerted on them. This drag effect adds some force in the windward direction.

2.9.2 Wind-induced Structural Vibration

According to Anchor (1981), wind-induced structural vibration can be classified into few categories, and only few most relevant types of vibration will be discussed here.

2.9.2.1 Buffeting Vibration

Wind velocity and direction of turbulence are random. The pressure and forces variation on the elevated water tank will tend to follow the variation of velocity, if the dimension of the elevated water tank is small as compared to the length scales if the turbulence. Thus, this will cause the tank in the wind path to buffet and rock. This buffeting vibration is caused by free-stream turbulence or disturbances of the flow by other upwind neighboring structure instead the vibrating structure itself. The latter type is known as wake buffeting or interference. (Liu, 1991)

2.9.2.2Vortex Shedding Vibration

Unsteady flow will be generated by the vortex shedding when the wind strikes the elevated water tank. This flow is perpendicular to the wind direction and causes periodic lateral forces which result in vibration or elevated water tank. Vortex shedding is most noticeable for circular cylinder structure. Strouhal number (S) is the parameter used to study the vortex shedding frequency.

$$S = nD/V \qquad \text{Eqn 9}$$

Where n = shedding frequency (Hz)

D = characteristic length

V= wind speed relative to object

The frequency n shows the number of vortices shed from each side of the object per second besides showing the frequency of structural vibration since two vortices shed from both sides are required to complete one cycle of vibration.

According to (Liu, 1991)vortex shedding vibration occurs when the wind speed is such that the vortex shedding frequency is approximately equal to the natural frequency of the elevated water tank. The vortex shedding frequency can be predicted using Equation 10 to 12. The velocity V in Equation 9 represents the hourly mean velocity at the top of elevated water tank.

$n = \frac{V}{6D}$ if $nD^2 < 0.5\ m^2/s$ Eqn 10

$n = \frac{1}{3D}(V - \frac{1.5}{D})$ if $0.5m^2 < nD^2 < 0.75m^2/s$ Eqn 11

$n = \frac{V}{6D}$ if $nD^2 > 0.75m^2/s$ Eqn 12

where D is in meter and V is in meters per second

2.9.2.3 Wake Galloping

Vibration of a structure may occur due to wake of another structure. If an elevated water tank is located at a few diameters away from another structure, the water tank will tend to oscillate in clockwise direction if it is located in the upper half of the wake of that structure (Liu, 1991).

2.9.3 Wind-induced Structural Vibration Reduction Methods

The wind speed of the relevant location should be studied and the elevated water tank should be designed in such a way that its natural frequency is different from the frequency of wind flow to avoid resonance. (Liu, 1991)state that since the energy of turbulence is concentrated in the low-frequency range of the spectrum, structural vibration caused by turbulence is significant when the elevated water tower has low natural frequency and light damping. According to Varghese (2005), the natural frequency of irregular structure like elevated water tank is to be calculated by dynamic analysis.

For a frame type staging, lateral bracing can be used to increase the stiffness of the elevated wated tank, thus reduce the vibration. `Also a helical stair can be provided around the elevated water tank to reduce vortex shedding vibration by breaking up regular pattern of vortices shed from cylinder of elevated water tank.

2.10 Types of Water Tank Supporting Structure

Generally, there are three types of supporting structure used for elevated water tanks, which including pedestal, multi-column or framed staging, and fluted column. Concrete pedestal and multi-column are commonly being used as supporting structure of water tank in our country as compared to steel fluted column since fluted column need higher construction cist and has more steel to be repainted from time to time as steel tend to corrode under the acceleration of hot and humid climate in Malaysia. Thus, only pedestal and multi-column supporting structures will be discussed here. The material normally being used for pedestal and multi-column are concrete or steel. Wind and seismic effect should be considered in the design criteria as they may cause failure of elevated water tank due to failure of supporting structure when stresses cause by lateral forces are large enough to cause large deformation. Since different type of supporting structures has different ductility and energy-absorbing capacities, thus different location with different wind and seismic pattern will affect the decision of type of supporting structure to be use. Besides, construction and maintenance cost, local needs, construction schedule, and aesthetic are among the factors the need to be considered when choosing the type of support.

2.10.1 Pedestal Elevated Water Tank

This type of water tank has only one central support which normally consists of reinforced concrete circular hollow shaft, like an inverted pendulum. The riser pipe, control system and access ladder are contained inside the circular hollow shaft and can be accessed only through a lockable door. This type of tank has an attractive simplistic appearance. Since climbing this type of water tower would be very difficult as there is no cross bracing, this would avoid graffito on the tank which deface the appearance. Pedestal water tank is easier and less expensive to be maintained, but it is costly to be constructed.

The gravity force and lateral forces resulting from winds or seismic are resisted by the axial strength, and flexural strength and stiffness of the circular shaft respectively. The diameter of circular hollow shaft increases with the capacity of the elevated water tank. According to Rai (2003), the thickness of the staging section is usually kept between 150 and 200mm. As compare to multi-column, circular hollow shaft type staging has lower redundancy and toughness. The lateral stability of the entire structure of elevated water tank is depending on this single shaft. Besides, the circular hollow shaft which consists of thin shell has lower ductility to dissipate the seismic and wind energy thus required higher design forces. As stated by Rai (2003), circular thin reinforced concrete sections with high axial load behave in brittle manner at the flexural strength and should be avoid. Therefore, more detail design is required as compare to multi-column water tank to withstand the lateral load, especially seismic load.

Figure 2-4 : Pedestal Elevated Water Tank.

2.10.2 Multi-Column Elevated Water Tank

Multi-column or framed staging elevated water tank is usually supported by structural system of legs which may consists of reinforced concrete or steel columns with bracing. Water is pumped to or released from the tank through an insulated riser pipe located in the central support of elevated water tank. The design of this type of water tank normally includes a balcony with handrail around the water tank and access ladders attached to columns. Larger area is required by multi-column water tank as compare to pedestal water tank since it has larger foot print. However, this make multi-column elevated water tank since it has larger foot print. However, this make multi-column elevated water tank more stable to resist overturning caused by lateral loads. Multi-column water tank offers the most economical mean to provide elevated water storage since the construction cost is less/ However, it is more difficult to be maintained due to irregular surfaces, multi-column, support rods, and removal of graffito at the difficult to-access locations, thus high in maintenance cost. Security and safety should be included in the design consideration as this type of water may be climbed or vandalized. Multi-column elevated water tank is more preferred for installation of cellular antennas since there is more available space to isolate its respective components.

According to Rai (2003), braced frame type staging is generally regarded superior to shaft type staging in aspect of lateral load resistance due to their large redundancy and greater capacity to absorb seismic or wind energy through inelastic actions. Lateral loads are resisted by flexural members such as braces and columns, and failure of a few members will not cause a sudden collapse of entire structure as the load will be transferred to other members. Moreover, reinforced concrete framed staging can also be designed to increase its ductility by design the beam ends to sustain inelastic deformation and dissipate seismic or wind energy.

As for steel frame staging, it is recommended by American Society of Civil Engineers (ASCE) that it should be designed in such a way that yielding can develop in the bracing system before failure of the entire structure when subjected to seismic loads. The yielding members able to absorb the seismic energy thus reduce the seismic impact towards the structure. Rods with upset threads are recommended to be used for bracing. Large deformable washers under retaining nuts can be used to absorb the seismic energy. One advantage of steel frame staging over reinforced concrete frame staging is less construction time is required.

Figure 2-5 : Multi-column Elevated Water Tank.

2.11 Location of Elevated Water Tank

Area must be sufficient for construction of elevated water tank and it includes the setback of 9 m from boundary. The elevated water tank shall be located closer to the road for ease operation, maintenance and safety of the equipment and elevated water tank itself from vandalism.

2.12 Size of Elevated Water Tank

This elevated water tank is designed as water storage tank and supply water for domestic use. It is predicted that the capacity of this water tank is able to serve the population until 20 to 25 years. Normally, the capacity of water tank is designed to serve the population up to at least 15 years.

2.13 Pressure Required in Delivery of Water to consumer

Hydraulic pressure head shall be ascertained as it is important in the determination of elevated water tank height. Pressure testing is carried out during preliminary stage to ensure the water can be delivered to the supplied areas. Thus, the level of the elevated water tank should be higher than the supplied area to ensure the gravitational force can applied.

Figure 2-6 : The work of elevated water tank. (How Water Towers Work - YouTube, n.d.)

2.14 Hydraulic Pressure

The effects of tying the floors and walls together and the method of supporting the tank can, however, have a significant effect upon the resulting moments and forces within the structure. The liquid pressure on plane walls may be resisted by a combination of horizontal and vertical bending moments. An assessment should be made of the proportions of the pressure to be resisted by bending moments in the vertical and horizontal planes (Batty & Westbrook, 1991).

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